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Universidad del País Vasco
Euskal Herriko Unibertsitatea

ANÁLISIS DE LA ESTRATEGIA DEL RITMO EN MARATÓN DESDE EL NIVEL RECREACIONAL HASTA LOS RÉCORDS DEL MUNDO: INFLUENCIA DEL NIVEL ATLÉTICO, SEXO Y PERFIL DEL CIRCUITO

ANALYSIS OF MARATHON PACING STRATEGIES FROM RECREATIONAL TO WORLD RECORD LEVEL: INFLUENCE OF ATHLETIC ABILITY, SEX AND RACE PROFILE

José Joaquín Díaz Martín

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Vitoria-Gasteiz, 2020

"No te rindas que la vida es eso,

continuar el viaje,

perseguir tus sueños,

destrabar el tiempo,

correr los escombros y destapar el cielo."

(Mario Benedetti).

AGRADECIMIENTOS

Y cuando menos te lo esperas, estás cruzando la meta de uno de los mejores "maratones" de tu vida. Es el momento de poner punto y final a la Tesis Doctoral. No sin antes recordar que, al igual que cuando se bate un récord mundial todo el sacrificio, esfuerzo y dedicación requerido en cada entrenamiento quedan compensados, la presente Tesis es el resultado de todo el trabajo empleado durante estos años.

Indudablemente, hubiera sido imposible correr este "maratón" sin la contribución y el esfuerzo incondicional de muchas personas. Honestamente, la culpa principal reside en el Dr. Jordan Santos-Concejero. No podría haber tenido otro director mejor que él. Agradezco enormemente su trabajo, apoyo y comprensión durante todo el recorrido. Contigo, se logran muchos "récords mundiales".

Mención especial, a mi compañero y amigo de batallas durante estos años, el Dr. Eduardo Fernández-Ozcorta. Gracias por tu implicación y dedicación desinteresada en esta ardua "carrera". Los obstáculos fueron más fáciles con tu ayuda. Siempre estaré en deuda contigo.

Al Dr. Miguel Torres García, por todos sus consejos y aportación científica en este proyecto.

I am also very grateful to Dr. Renfree, thank you for your help and scientific contribution. Thank you very much his colleagues from School of sport & Exercise Sciense (University of Worcester, UK) for hosting me during my visit and share your knowledge.

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A Fran, Raquel y Araceli por vuestro cariño y aliento incansable en esta carrera de fondo. A veces, habéis confiado más en mí que yo mismo.

A mis amigos y a mi grupo de “Ineftos”, por todo el tiempo compartido, por vuestros consejos diario y afecto. Por alegraros de cada “km” conquistado. Es un placer que cada día sea un aprendizaje mutuo.

Finalmente, y no menos importante, gracias Papá y Mamá, gracias Mª Carmen por vuestra infinita paciencia, sacrificio y amor. Siempre habéis sido mi inspiración y parte esencial en cada unos de mis pasos. Y a toda mi familia por compartir este camino junto a mi, apoyándome en los momentos más difíciles y más agradables.

“No hay secretos para el éxito. Éste se alcanza preparándose, trabajando arduamente y aprendiendo del fracaso” (Colin Powell).

ÍNDICE

1.- Resumen

“En tiempos de cambio, quienes estén abiertos al aprendizaje se adueñarán del futuro, mientras que aquellos que creen saberlo todo estarán bien equipados para un mundo que ya no existe” (Eric Hoffer).

1.1. RESUMEN

Introducción:

La estrategia de ritmo adoptada por los corredores se considera uno de los factores claves en el rendimiento del maratón. Determinar cuál es la estrategia más adecuada favorecerá que los atletas mejoren de forma significativa sus tiempos finales.

Propósito:

Esta tesis tiene como objetivo principal, el analizar y comparar la influencia del nivel atlético, sexo y tipo de circuito sobre los ritmos adoptados por corredores de maratón. Esto permitirá establecer no sólo la mejor estrategia de ritmo para correr un maratón, sino también determinar qué circuito de maratón ofrece un mayor potencial para futuros récords mundiales.

Métodos:

Estudio 1: Se analizó la estrategia de ritmo de 14.420 atletas (13.386 hombres *vs.* 1034 mujeres). Se analizaron los resultados de tres maratones disputadas en Sevilla, en los años 2013 y 2014, y en Castellón en el año 2013. Analizamos las diferencias entre grupos de rendimiento en función del ritmo adoptado y del sexo.

Estudio 2: Se analizó la estrategia de ritmo adoptada por un total de 76 atletas masculinos, ganadores de las 6 "*World Marathon Majors*" entre los años 2006 y 2018 (Boston, Nueva York, Chicago, Tokio, Londres y Berlín).

Estudio 3: Se analizaron las estrategias de ritmo empleadas por los todos los plusmarquistas mundiales masculinos de maratón desde 1967 hasta 2014 (15 atletas). Los atletas se dividieron en dos grupos: grupo de atletas *clásicos* (poseedores de récords

entre 1967 y 1988) y grupo de atletas *contemporáneos* (poseedores de registros desde 1988 hasta 2014).

Estudio 4: Se analizaron las estrategias de ritmo empleadas por los plusmarquistas mundiales masculinos y femeninos desde 1998 hasta 2018 (un total de 18 récords). Las plusmarquistas femeninas fueron divididas en 2 subgrupos: registros de mujeres logrados con liebres masculinas (1998-2003) y registros femeninos logrado sin liebres masculinas (2005-2017).

<u>Resultados:</u>

Estudio 1: Se observaron diferencias entre sexos en todos los tramos, aunque estás fueron pequeñas o triviales (t > 3.78, $p < .05$, TE < 0.31). Los hombres lograron velocidades superiores en todos los tramos, exceptuando en el último, donde las mujeres alcanzaron una mayor velocidad. Por lo general, la estrategia más utilizada durante la competición por hombres y mujeres fue *positiva* (segunda mitad más lenta que la primera). Sin embargo, en las mujeres se observó una mayor utilización de las estrategias *constante* (primera y segunda mitad al mismo ritmo) y *negativa* (segunda mitad más rápida que la primera) en comparación con los hombres (X2 = 11.19, df = 2, $p < .01$). Se encontraron diferencias en la distribución de las estrategias empleadas entre los grupos de rendimiento analizados (X2 > 171, df = 6, $p < .01$).

Estudio 2: El análisis del tiempo de los atletas ganadores en las últimas 13 ediciones de cada *World Marathon Majors,* arrojan diferencias entre Nueva York y Londres (ES = 1.46, efecto moderado, $p = 0.0030$), Nueva York y Berlín (ES = 0.95, efecto pequeño, $p = 0.0001$), Londres y Boston (ES = 0.08, efecto pequeño, $p = 0.0001$), Boston y Berlín (ES = 0.10, efecto pequeño, $p = 0.0001$), Boston y Chicago (ES = 0.16, efecto pequeño ,

p = 0.0361), Berlín y Tokio (ES = 0.20, efecto pequeño, p = 0.0034), Berlín y Chicago (ES = 0.27, efecto pequeño, p = 0.0162).

Estudio 3: En general, al batir un récord del mundo, los atletas son ligeramente más rápidos en la primera media maratón que en la segunda, donde disminuyeron su velocidad progresivamente (ES = 0.28, efecto pequeño). Sin embargo, al comparar atletas clásicos *vs.* atletas contemporáneos, observamos que los atletas clásicos comenzaron significativamente más rápidos ($p < .05$, ES = 1.16, efecto moderado), aunque después de 25 km, su velocidad disminuyó drásticamente y fue significativamente más lenta que los atletas contemporáneos (ES = 2,41, efecto muy grande).

Estudio 4: Las plusmarquistas mundiales femeninas mantuvieron velocidades similares en la primera y segunda mitad del maratón (ES = 0.22, efecto pequeño, p = 0.705), mientras que los plusmarquistas masculinos aumentaron su velocidad a medida que avanzaba el maratón (ES = 1.18, efecto moderado, p = 0.011). Sin embargo, no se observaron diferencias entre hombres y mujeres en la primera (ES = 0.56, efecto pequeño, p = 0.290), o en la segunda mitad del maratón (ES = 0.60, efecto moderado, p = 0.266). Al comparar los récords mundiales de las mujeres (1998–2003) *vs.* hombres (1998–2018) por tramos de 5-km, observamos diferencias al inicio de la carrera (segundo tramo, ES = 0.89, efecto moderado) y al final (último tramo, ES = 0.87, efecto moderado). Las variaciones del ritmo durante la competición fueron similares entre hombres y las mujeres con liebres masculinas (1.53% ± 0.60 vs. 1.68% ± 0.84, respectivamente). Sin embargo, se observó una tendencia hacia mayores variaciones de ritmo durante la carrera en los récords femeninos con liebres femeninas (2.28% ± 0.95).

Conclusiones:

Estudio 1: Los atletas, independientemente del sexo y del nivel de rendimiento adoptan, en su gran mayoría, una estrategia positiva (segunda mitad más lenta) para completar el maratón.

Estudio 2: En términos de posibles lugares para futuros intentos de récord mundial, los datos históricos sugieren que Berlín, que posee las 7 mejores actuaciones de todos los tiempos en esta distancia en hombres, es el escenario más posible, mientras que es poco probable en Nueva York o Boston.

Estudio 3: La estrategia de ritmo de los mejores atletas de maratón del mundo ha cambiado en los últimos 50 años. Aunque se ha propuesto la estrategia negativa como opción más eficiente, una estrategia caracterizada por muy pocos cambios en la velocidad durante la carrera puede ser el camino a seguir en el futuro.

Estudio 4: Hombres y mujeres han utilizado diferentes estrategias en los récords mundiales de maratón en los últimos 20 años. Mientras que los atletas masculinos aumentaron la velocidad a medida que avanzaba la carrera (estrategia negativa), las atletas femeninas usaron un ritmo menos uniforme durante toda la competición.

1.2. ABSTRACT

Introduction:

Pacing strategy is in one of the limiting factors in competitive performance in long-term sports such as the marathon. Determining which is the most appropriate strategy may help athletes to improve their final race times.

Purpose:

This thesis aimed to analyse and compare the influence of performance status, sex and race profile on the pacing strategies adopted by marathon runners. This will help to determine the best pacing strategy for marathon performance as well as the most suitable location for future world record attempts.

Methods:

Study 1: This study analysed the pacing strategies employed by 14.420 athletes, (13.386 men *vs.* 1.034 women) in different three marathons held in Seville (2013 and 2014) and in Castellon (2013). We analysed the differences between performance groups according to the pacing strategy adopted and sex.

Study 2: This study analysed the pacing strategies adopated by each winner of every World Marathon Major (Boston, New York, Chicago, Tokyo, London y Berlin) since 2006 to 2018 (A total of 76 male athletes).

Study 3: This study analysed the pacing strategies adopted by the marathon world record holders in every world record since 1967 to 2014 (a total of 15 world records). Worl record holders were divided into two groups: *classic* athletes (record holders

between 1967 and 1988) and *contemporaneous* athletes (record holders from 1988 to 2014).

Study 4: This study analysed the pacing strategies employed by every world record holder (men and women) since 1998 to 2018 (a total of 18 marathon world records). We sub-divided the women's records into two sub-groups: women's records achieved with male pacemakers (1998–2003) and female records achieved without male pacemakers (2005–2017).

Results:

Study 1: Sex differences were observed in all sections, although they were small or trivial (t> 3.78, p <.05, TE <0.31). Men achieved higher speeds in all sections except the last where women reached a higher speed. In general, the most successful strategy during competition for men and women was the *positive* one (second half slower than the first half). Although women tended to use *constant* (first and second half marathons at similar pace) and *negative* strategies (second half faster than the first half) when compared to men (X2 = 11.19, df = 2, p <.01). We found that the pacing strategies used differed between athletes of different performance levels (X2> 171, df = 6, p <.01).

Study 2: When we analyzed the mean winning time in the last 13 editions of each of the World Marathon Majors, we observed differences between New York and London (ES = 1.46, moderate effect, p = 0.0030), New York and Berlin (ES = 0.95, small effect, p = 0.0001), London and Boston (ES = 0.08, small effect, p = 0.0001), Boston and Berlin (ES = 0.10, small effect, p = 0.0001), Boston and Chicago (ES = 0.16, small effect, p = 0.0361), Berlin and Tokyo (ES = 0.20, small effect, p = 0.0034), Berlin and Chicago (ES = 0.27, small effect, p = 0.0162).

Study 3: Overall, world record holders in the last 50 years were slightly faster in the first half-marathon than in the second one, where they slowed down progressively (ES = 0.28, small effect). However, when comparing *classic* vs. *contemporaneous* athletes, we observed that *classic* athletes started significantly faster (p < .05, ES = 1.16, moderate effect), although after 25 km, their speed dropped dramatically and was significantly slower than in their *contemporaneous* counterparts (ES = 2.41, very large effect).

Study 4: Female world record holders in the last 20 years kept similar speeds in the first and second half of the marathon (ES = 0.22, small effect, $p = 0.705$), whereas male world record holders increased their speed as the marathon progressed (ES = 1.18, moderate effect, $p = 0.011$). However, no differences were observed between men and women in either the first (ES = 0.56, small effect, $p = 0.290$), or in the second half of the marathon (ES = 0.60, moderate effect, $p = 0.266$). When comparing the women's world records (1998–2003) vs. men's records (1998–2018) by sections, we observed differences at the beginning of the race (second section, ES = 0.89, moderate effect) and at the end (last section, ES = 0.87, moderate effect). The pace variations during the race were similar between male athletes and that of women with male pacemakers (1.53% ± 0.60 vs. 1.68% ± 0.84, respectively). However, a trend towards higher pace variations during the race in the female records with female pacemakers was observed (2.28% ± 0.95).

<u>**Conclusions:**</u>

Study 1: Most athletes, regardless of sex and performance level, adopt a positive pacing strategy (second half slower than the first one) to complete a marathon.

Study 2: In terms of potential venues for future world record attempts, historical data suggests that Berlin, which owns the 7 best performances of all time over this distance in men, is the most likely candidate whilst such a performance is unlikely in New York or Boston.

Study 3: The pacing strategies of the best marathon runners in the world have changed over the last 50 years. Although a negative pace distribution has been proposed as the most efficient option, a pacing strategy characterised by very little speed changes across the whole race may be the way to go in the future.

Study 4: Men and women have used different strategies when breaking world marathon records in the last 20 years. While male athletes increased speed as the race progressed (*negative* strategy), female athletes used a less uniform pacing throughout the competition.

2.- CONTRIBUCIONES

"Utiliza en la vida los talentos que poseas: el bosque estaría muy silencioso si sólo cantasen los pájaros que mejor cantan" (Henry Van Dyke).

2. CONTRIBUCIONES

2.1. Artículos científicos

1º Estudio: Publicado. Díaz, J. J., Fernández, E. J., Floría, P., & Santos-Concejero, J. (2019). Analysis of the pacing strategies used by Marathon runners. *Retos, 35,* 156-159.

Indicadores de Calidad: *Scimago Journal Rank* 0.260. Factor de impacto IN-RECS = 0.127. Posición 29/142 (primer lugar de índice H en Ciencias del Deporte). Indexada en Web of Science de Thomson Reuters y Scopus. ISSN 1579-1726

2º Estudio: Publicado. Díaz, J. J., Renfree, A., Fernández, E. J., Torres, M., & Santos-Concejero, J. (2019). Pacing and Performance in the 6 World Marathon Majors. *Frontiers in Sports & Active Living.* DOI: 10.3389/fspor.2019.00054.

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3º Estudio: Publicado. Díaz, J. J., Fernández, E. J., & Santos-Concejero, J. (2018). The influence of pacing strategy on marathon world records. *European Journal of Sports Science*, *18*(6), 781-786. DOI: 10.1080/17461391.2018.1450899.

Indicadores de Calidad: ISI-JCR Factor de impacto: 2.376. 29/83 SPORT SCIENCES 2018 (Q2, T1). ISSN: 1746-1391

4º Estudio: Publicado. Díaz, J. J., Fernández, E. J., & Santos-Concejero, J. (2019). Men Vs. Women World Marathon Records' Pacing Strategies From 1998 To 2018. *European Journal of Sports Science, 19*(10), 1297-1302. DOI: 10.1080/17461391.2019.1596165.

Indicadores de Calidad: ISI-JCR Factor de impacto: 2.376. 29/83 SPORT SCIENCES 2018 (Q2, T1). ISSN: 1746-1391

2.2. Comunicaciones en congresos

Presentación oral. Santos-Concejero, J., Fernández, E. J., & Díaz, J. J. "The influence of pacing strategy on marathon world records". 23rd Annual Congress of the European College of Sport Science. Dublín, Irlanda, 2018.

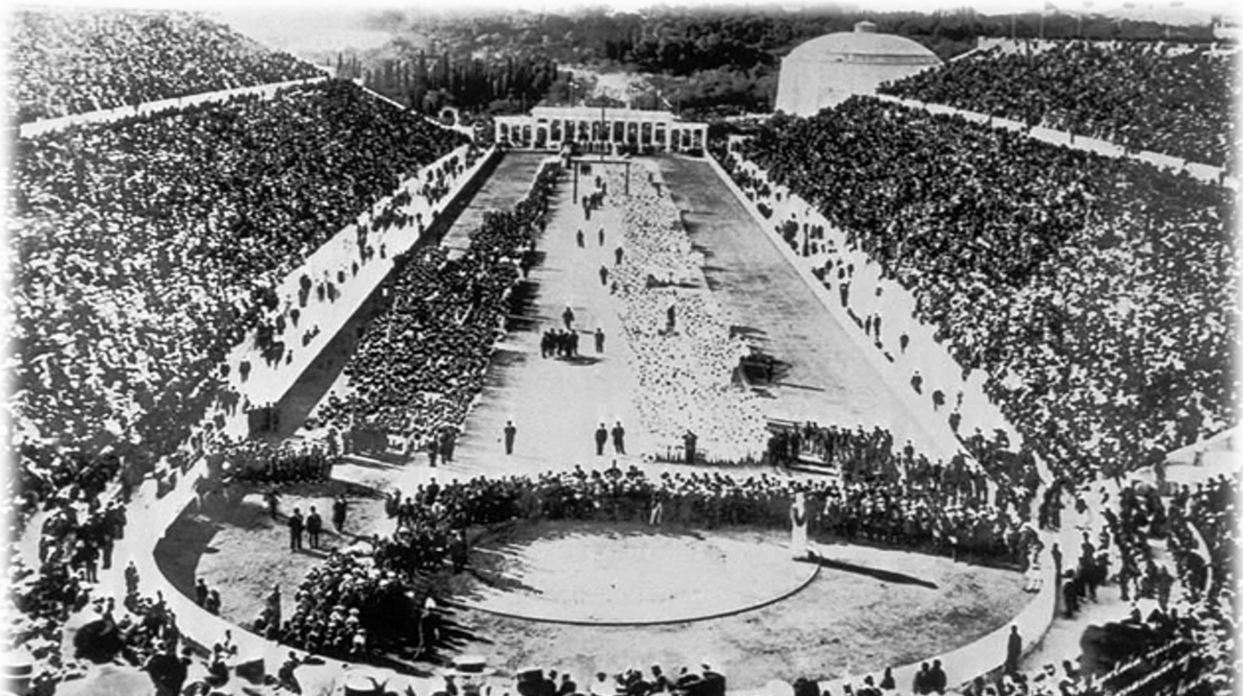
Publicado como *abstract* en la página 375 del libro "*Book of Abstracts 23th annual Congress of the European College of Sport Science*". Editores Murphy M, Boreham C, De Vito G, Tsolakidis E. Editorial SporTools GmbH, Feldblumenweg (Alemania). ISBN: 978-3-9818414-1-1.

2.3. Colaboración Internacional

Estancia internacional (del 14 de enero al 15 de abril de 2019). School of Sport & Exercise Science, University of Worcester. Worcester, UK. Tutela: Dr Andrew Renfree.

3.- Introducción

"Quien no haya experimentado la irresistible atracción de la ciencia no podrá comprender su tiranía. En la investigación científica siempre existe materia para nuevos descubrimientos y nuevas maravillas" (Mary Shelly).



3.1. ANTECEDENTES

Uno de los eventos más clásicos e importantes de las competiciones atléticas es el maratón, introducido en los Juegos Olímpicos desde Atenas de 1896 (Polley, 2009). La distancia total a cubrir fue alrededor de 40 km, comenzando en Maratón (Grecia) y con llegada en el Estadio Panathinaiko (Quercetani, 1992). Se conmemoró la leyenda de Filípides (Φιλιππίδης), mensajero que recorrió dicha distancia para anunciar la victoria griega sobre los persas en la Batalla de Maratón en el año 490 a. c. (Polley, 2009). No fue hasta 1908, en los Juegos Olímpicos de Londres, cuando se adoptó la distancia oficial de 42 km y 195 m, ampliada para poder acercar la salida de la prueba al castillo Windsor, ya que la línea de meta debía estar fijada frente al palco real en el estadio olímpico White City (Polley, 2009; Wilcock, 2008). Jonny Hayes fue el ganador de la carrera con un tiempo de 2:55:18 (24 de julio de 1908), en detrimento de Dorando Pietri descalificado por la ayuda que le facilitó los comisarios para cruzar la línea de meta tras varios desfallecimientos (Polley, 2009). Finalmente, en el congreso de la IAAF celebrado en Ginebra en 1921, se estableció esta distancia como la definitiva de la carrera de resistencia por antonomasia.

Aunque en un principio la participación en carreras de maratón era exclusivamente masculina, en marzo de 1896, Stamata Revithi se convirtió en la primera mujer en correr un maratón al completar el recorrido olímpico entre Maratón y Atenas (Lovett, 1997). Sin embargo, no fue hasta el 3 de octubre de 1926 cuando se cronometro a una mujer por primera vez. La británica, Violet Piercy, completó el maratón en 3:40:32.

Antes de 1972, las mujeres habían sido excluidas del maratón más famoso del mundo, Boston. A pesar de esa regla, en 1966, Roberta Gibb escondida tras un arbusto al comienzo de la carrera, se convirtió en la primera mujer en completar con éxito el maratón. Un año más tarde, Kathrine Switzer (inscrita como KV Switzer) consiguió finalizar el maratón de Boston a pesar del frustrado intento de expulsión y su posterior descalificación (Lovett, 1997). Su gesta tuvo tal repercusión social y política que tanto el maratón de New York en 1970 y el maratón de Boston de 1972 admitirían desde ese instante a mujeres en sus respectivas competiciones (Jones, 2003). Aunque, no fue hasta los Juegos Olímpicos de Los Ángeles en 1984, cuando se introdujo por primera vez el maratón femenino. La ganadora fue Joan Benoit con un tiempo de 2:24:52 (5 de agosto de 1984).

Desde la inclusión de la mujer en los Juegos Olímpicos, hemos observado un incremento considerable en la participación femenina durante las últimas décadas (Sousa, Sales, Nikolaidis, Rosemann, & Knechtle, 2018), desde un 1.9% en 1990 a un 42.3% en 2008 (Marc et al., 2014). En la actualidad, por ejemplo, de 52.706 atletas que completaron el maratón de New York (2018), el 41.97% fueron mujeres (New York City Marathon, 2018). Asimismo, el aumento significativo del número de participantes en el maratón en los últimos años (Ahmadyar, Rosemann, Rüst, & Knechtle, 2016; Marc et al., 2014; Knechtle, Nikolaidis, Zingg, Rosemann, & Rüst, 2016) coincide con un crecimiento considerable en el número de competiciones oficiales celebradas, desde 664 maratones en 1990 a las 2820 competiciones en 2011 (Marc et al., 2014). Jones (2003) atribuye este incremente al atractivo popular del maratón frente a otras disciplinas.

Paralelamente, al interés social de la prueba, han surgido grandes avances científicos en el mundo del deporte, traducido estos en mejoras sustanciales de los registros temporales en el maratón (Joyner, Ruíz, & Lucia, 2011; Weiss, Newman, Whitmore, & Weiss, 2016). En concreto, estas mejoras se han cuantificado en más de 50 minutos en casi un siglo (Ahmadyar et al., 2016). De hecho, se especula que los tiempos límites en el maratón no se han alcanzado en la actualidad e incluso podrían aún mejorarse (Ahmadyar et al., 2016). En este sentido, Joyner et al. (2011) afirmaron que, en torno al año 2021, se finalizará un maratón homologado por debajo de las 2 horas, mientras que Sousa et al., (2018) estimaron en torno al 2025-2028. Asimismo, se ha propuesto un límite potencial entre 1:57:58 y 2:01:52 (Denny, 2008; Joyner, 1991) casi 3 minutos más rápidos que el actual récord mundial de Eliud Kipchoge (2:01:39, maratón de Berlín, disputada el 16 de septiembre de 2018). En cambio, no existía un consenso sobre cuando se batiría el récord mundial de Paula Radcliffe (2:15:25 en el maratón de Londres disputada el 13 de abril de 2003). Hunter, Joyner, & Jones (2015) sugirieron que el tiempo de Radcliffe era ya el equivalente al maratón masculino de las sub 2 horas, aunque esto fue rebatido por Tucker & Santos-Concejero (2017). En cualquier caso, recientemente Brigid Kosgei en el maratón de Chicago el 13 de octubre de 2019, logró rebajar el récord mundial femenino en más de 1 minuto y 21 segundos parando el cronómetro en 2:14:04 y afirmando que "*se veía capaz de luchar por correr en 2.10*". Péronnet y Thibault (1989) por su parte estimaron que el récord femenino será de 2:11:41 en el 2033.

Recientemente, Eliud Kipchogue consiguió para el cronómetro por debajo de las 2 horas en un maratón no homologado (1:59:40 establecido en Viena, 12 de octubre de 2019) tras un primer intento fallido en Monzan (2:00:25, 5 de mayo de 2017). A pesar de ello, existe una gran controversia alrededor de este logro por las numerosas ventajas con las que contó la prueba.

El circuito de Viena no estaba oficialmente homologado por la Federación Internacional de Atletismo (IAAF) y se incumplía el actual reglamento. Kipchogue corrió solo (excluyendo liebres) en contraposición de un maratón oficial en el que al menos deben participar tres corredores. Además, una de las principales ventajas fueron las 41 liebres en turnos de 7 (cinco delante de Kipchogue y dos detrás, formando una flecha invertida) y la cercanía del coche que le marcaba el ritmo y proporcionaba protección contra la resistencia al viento. Se determinó que el uso de liebres coordinadas para proteger a los atletas del aire, puede llegar a reducir en un 93% la resistencia al mismo y mejorar la economía de carrera en 2.7% (Hoogkamer, Kram & Arellano, 2017). En términos de tiempo, un atleta capaz de correr un maratón en 2:03:00 lograría bajar de dos horas en maratón (Hoogkamer et al., 2017).

En el reto INEOS celebrado en Viena, Kipchogue uso un prototipo de zapatillas *AlphaFly* de Nike consideradas por muchos como “doping tecnológico” por su amortiguación y propulsión exagerada (Moya, 2019). Hoogkamer et al., (2018) establecieron que la tecnología del calzado puede mejorar la economía de carrera en más de un 4%. En consecuencia, los mejores atletas podrían correr sustancialmente más rápidos y lograr el primer maratón por debajo de las 2 horas. Asimismo, los avituallamientos durante el maratón de Viena fueron a la carta, desde una bicicleta, con el objetivo de evitar los pequeños parones que realizan los maratonianos.

En definitiva, los límites del rendimiento humano siguen debatiéndose (Sousa et al., 2018). Posiblemente, romper la barrera de las 2 horas en un maratón homologado depende de una combinación de factores que estudiaremos a continuación y, que incluyen un gran atleta con cualidades biomecánicas y fisiológicas únicas, compitiendo un buen día, con condiciones ambientales y de carrera favorables (Coyle, 1995; Hoogkamer et al., 2017; Joyner & Coyle, 2008; Joyner et al., 2011; Smith, 2003; Sousa et al., 2018).

3.2. FACTORES IMPLICADOS EN EL RENDIMIENTO DEL MARATÓN

Es necesario realizar un análisis de los diferentes factores extrínsecos (temperatura ambiental, humedad, etc.) e intrínsecos (fisiología, biomecánicas, etc.) implicados en el rendimiento del maratón con el objetivo de determinar cuáles son los parámetros necesarios para superar los actuales récords mundiales o romper la barrera de las 2 horas en maratón homologado (Sousa et al., 2018).

Dentro de los factores intrínsecos, existen pioneros trabajos que estudiaron el rendimiento aeróbico desde la perspectiva del maratón desde diferentes prismas. Desde trabajos orientados a los requisitos fisiológicos y energéticos (e.g. Di Prampero, 2003; Di Prampero, Atchou, Brückner, & Moia, 1986; Sjodin & Svedenhag, 1985), como modelos matemáticos de rendimiento y sus limitaciones teóricas (e.g. Péronnet &

Thibault, 1989; Ward-Smith, 1985). Si nos centramos en los últimos avances, dentro de los factores fisiológicos y energéticos que influyen en el rendimiento del maratón, se han determinado tres aspectos fundamentales por encima del resto como son: la capacidad aeróbica o consumo máximo de oxígeno ($VO_{2máx.}$), la economía de carrera y la velocidad de carrera obtenida en el umbral de lactato (e.g. Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001; Joyner & Coyle, 2008; Joyner et al., 2011; Sousa et al., 2018; Tjelta & Shalfawi, 2016). Asimismo, se determinan que existen factores adicionales en hombres, como la morfología del corazón y la cinética del lactato durante el esfuerzo; y en mujeres, los niveles de adiposidad y hierro en la sangre (Arrese, Izquierdo, & Galindo, 2006).

El $VO_{2máx.}$ es un factor clave en el rendimiento del maratón ya que puede determinar la máxima cantidad de energía que se obtiene a través del metabolismo aeróbico (Joyner & Coyle, 2008). Los atletas que consiguen los mejores resultados en deportes de resistencia tienen valores de $VO_{2máx.}$ cercanos o superiores a 70-85 mL/kg/min (Joyner & Coyle, 2008), aunque lo realmente destacable es que puedan mantener ritmos de carrera superiores durante la competición (Joyner, 1993; Joyner & Coyle, 2008). En este sentido, Sousa et al. (2018) se aventura a indicar que el atleta que romperá la barrera de las 2 horas en un maratón homologado, será masculino, con una edad aproximada a 27 años, posiblemente etíope, con un ritmo de carrera superior del 85 % de su $VO_{2máx.}$ Sin embargo, existen científicos contrarios a estas afirmaciones y, creen que bajar de las 2 horas es imposible fisiológicamente (Hill, 1925; Liu & Schutz, 1998; Weiss et al., 2016).

Además del $VO_{2máx.}$, es fundamental la economía de carrera (Lucia et al., 2006), definida como una baja demanda de energía para correr a una determinada velocidad (Foster & Lucia, 2007), lo que implica que un atleta eficiente, necesite un menor porcentaje del $VO_{2máx}$ para mantener una determinada velocidad de carrera (Lucia et al, 2006). Lucia et al. (2006) determinaron que la superioridad de los atletas africanos respecto a los españoles se debe a la economía de carrera, ya que los valores de $VO_{2máx.}$ no representaron diferencias significativas. Esto demuestra que la economía de carrera en atletas con valores similares de $VO_{2máx.}$ será el factor más importante para definir el rendimiento en maratón (Lucia et al., 2008). El último parámetro fisiológico que favorece el rendimiento de los atletas de maratón y, a su vez, mejora la economía de carrera, es la velocidad de carrera a la que se obtiene el umbral de lactato (Sousa et al., 2018). El umbral de lactato se define como la intensidad del ejercicio en la que la concentración de lactato en sangre comienza a acumularse, de manera exponencial, por encima de los niveles de reposo durante el ejercicio de intensidad creciente (Allen et al., 1985). Para mejorar la velocidad carrera en el umbral de lactato y, consecuentemente, el rendimiento en maratón se ha determinado que el entrenamiento de carrera por encima del umbral de lactato es el más efectivo (Billat, Sirvent, Lepretre, & Koralsztein, 2004; Tanaka et al., 1986).

Sin embargo, la velocidad de carrera a la que se obtiene el umbral de lactato no es el único factor que beneficia una mejor economía de carrera. Hoogkamer et al. (2017), han observado que se podría obtener una mejora de la economía de carrera al modificar diferentes aspectos de la biomecánica de carrera. Más del 80 % del gasto metabólico se ha relacionado con el soporte del peso del cuerpo humano y la propulsión hacia delante

(Arellano & Kram, 2014). Un atleta podría reducir el gasto metabólico al correr cerca del ecuador, menor gravedad, y a través de una deshidratación estratégica del peso corporal en un 2 % (Hoogkamer et al., 2017). Se observó que la deshidratación previa al maratón podría mejorar la economía de carrera en 1.5 %, lo que se traduce en un tiempo de 108 segundo más rápido durante la competición (Hoogkamer et al., 2017). Además, aunque la regla 260.21b de la IAAF hace imposible correr un maratón completo con viento a favor, un diseño óptimo durante los primeros 21.1 km y, un posterior aprovechamiento del viento a favor durante los últimos 21.1 km, podría reducir el gasto de la propulsión hacia adelante del atleta (Hoogkamer et al., 2017).

Con respecto a los factores ambientales, se ha demostrado que el maratón es la disciplina que más se ve afectada por las condiciones climáticas (Saunders, Telford, Pyne, Hahn, & Gore, 2004). En efecto, el aumento de la temperatura ambiental, la humedad relativa y la radiación solar intensa durante el maratón provoca un descenso progresivo en el rendimiento de los atletas independientemente del sexo y de la categoría e incluso se incrementa el porcentaje de atletas que no finalizan la competición (El Helou et al., 2012; Ely, Martin, Cheuvront, & Montain, 2008). De hecho, un clima más cálido tiene un mayor efecto negativo en el rendimiento de los corredores más lentos (Ely, Cheuvront, Roberts, & Montain, 2007b; Ely et at., 2008). Vihma (2009), observó que el aumento de temperatura de 10 a 25 º C en corredores de élite produjo un aumento del tiempo final en 5 minutos, mientras que para los corredores más lentos el incremento fue de 23 minutos. Sin embargo, un clima más frío, entre 5-10 º C, se asocia con una mejor capacidad para mantener el ritmo de carrera en comparación con un clima cálido, principalmente por los corredores más rápidos (Ely et al., 2008).

Por último, uno de los factores claves en el rendimiento del atleta es la estrategia de ritmo (conocida como *pacing strategy* en inglés) adoptada durante la competición (Abbiss & Laurse, 2008; Ely et al., 2008; March et al., 2011; Renfree & Gibson, 2013). Continuamente, los atletas deben decidir cómo y cuándo invertir sus recursos energéticos limitados a lo largo del tiempo para ganar la carrera (Edwards & Polman, 2013; Smits, Pepping, & Hettinga, 2014) no solo cuando compiten solos, sino también cuando compiten contra otros (Hettinga, de Koning, Meijer, Teunissen, & Foster, 2017). Por esta razón, a continuación, realizaremos un análisis más profundo y exhaustivo del *pacing strategy.*

3.3. *PACING STRATEGY*

La estrategia de ritmo adoptada por los corredores o *pacing strategy* se ha descrito como la capacidad para utilizar y distribuir eficientemente los recursos energéticos durante la competición (Foster, Schrager, Snyder, & Thompson, 1994), con el objetivo de utilizar todas las reservas energéticas antes de finalizar la carrera, evitando la fatiga prematura (Skorski & Abbiss, 2017) y, con ello, una desaceleración significativa de la velocidad lejos de la línea de meta (Foster, Koning, & Hettinga, 2003; Hettinga et al., 2007; Tucker & Noakes, 2009).

Posteriormente, se han asociado otras variables al *pacing strategy* como los cambios en el terreno o la altitud (Hanley & Mercey, 2011) y la influencia de las temperaturas ambientales y la temperatura corporal (Marino, Lambert, & Noakes; 2004). Se observó que a medida que aumentó la temperatura, la capacidad para mantener un ritmo constante se vio afectada, provocando una desaceleración significativa de la velocidad de carrera (Ely, Cheuvront, & Montain, 2007a; Ely et al., 2008). Aunque en la actualidad no existe un consenso sobre los diferentes mecanismos involucrados en la regulación efectiva del ritmo (Renfree, Crivoi do Carmo, Martin, & Peters, 2015), aspectos como la valoración del esfuerzo percibido (Tucker, 2009), la toma de decisiones (Smits et al., 2014), el factor de riesgo (de Koning et al., 2011), la emoción (Baron, Moullan, Deruelle, & Noakes, 2011) y la pasión (Schiphof-Godart & Hettinga, 2017) se han considerado como factores que influyentes.

Foster et al. (1993), indicaron que uno de los factores limitantes en el rendimiento de los deportes de resistencia es el ritmo utilizado durante la competición. Aunque pueda haber poca diferencia fisiológica entre los atletas, pueden conseguir la victoria o derrota dependiendo de la capacidad para gastar energía adecuadamente y prevenir la fatiga prematura antes del final del evento (Garland, 2005, Hanley, 2014, Skorski & Abbis, 2017). En este sentido, Hanley (2014), afirmó que el éxito de las carreras depende fundamentalmente del ritmo impuesto por el atleta durante el maratón, independientemente de su capacidad y de haber entrenado o preparado adecuadamente con antelación la competición. Por esta razón, es importante entender cómo distribuir el ritmo, ya que puede conducir a una mejor comprensión de los factores que influyen en el rendimiento y, en este sentido, ayudar a los corredores a completar un maratón con éxito o mejorar su rendimiento en carrera (Abbiss & Laursen, 2008).

En la actualidad, se han identificado diferentes estrategias de ritmo en eventos de larga distancia (Abbiss & Laursen, 2008). La primera que encontramos es la estrategia *positiva*. Esta es entendida como aquella en la que la velocidad de carrera de un atleta disminuye gradualmente a lo largo de la duración del evento (Abbis & Laursen, 2008). Esta reducción progresiva de la velocidad puede deberse al aumento de la depleción del glucógeno (Coley & Coggan, 1984; Rauch, St Clair Gibson, Lambert, & Noakes, 2005) asociado a la fatiga neuromuscular (O'Toole, Douglas & Hiller, 1998; Laursen & Rhodes, 2001) y a factores psicológicos (Abbiss & Laursen, 2005; St Clair Gibson et al., 2003). Asimismo, la adopción de esta estrategia provocó un aumento del $VO_{2máx.}$, una mayor concentración de lactato en sangre y, un aumento en la percepción del esfuerzo percibido (Thompson, MacLaren, Lees, & Atkinson, 2004; Sandals, Wood, Draper, & James, 2006).

Por otro lado, se encuentra la estrategia *constante*. Dicha estrategia se basa en la distribución de un ritmo uniforme a lo largo de la competición (Abbiss & Laursen, 2008). Se ha sugerido que el empleo de un ritmo constante durante la competición produjo un rendimiento general más rápido (Abbiss & Laursen, 2008; Ely et al., 2008; Lambert, Dugas, Kirkman, Mokone, & Waldeck, 2004; March et al., 2011) incluso se observó que era la estrategia más efectiva durante carreras de larga distancia como el maratón en temperaturas tanto cálidas como frías (Ely et al., 2008).

Por último, podemos hablar de la estrategia *negativa*. Ésta se produce cuando durante una competición se observa un aumento significativo en la velocidad de carrera (Abbis & Laursen, 2008). Desde la literatura se sugiere que el ritmo negativo es el más adecuado para un ejercicio prolongado como es el caso del maratón, debido a la menor reducción del agotamiento de los hidratos de carbono (Abbiss & Laursen, 2005), menor consumo excesivo de oxígeno (Sandals et al., 2006) y limitar la concentración de lactato en sangre (Abbiss & Laursen, 2005, 2008; Mattern, Kenefick, Kertzer, & Quinn, 2001; Robinson, Robinson, Mountjoy, & Bullard, 1958) pero este perfil de ritmo no siempre es adoptado en la práctica (Hanley, 2013).

Los diferentes cambios que se producen en la estrategia adoptada por los atletas de maratón, ha sido un tema gran interés para los científicos del deporte debido a su gran influencia en el rendimiento (Díaz, Fernández, & Santos-Concejero, 2018; Díaz, Fernández, Torres, & Santos-Concejero, 2019; Foster, et al., 1993). Asimismo, la reciente disponibilidad de datos sobre esta competición ha permitido estudiar el *pacing strategy* en atletas de élite (Abbis & Laurse, 2008; Díaz et al., 2018; Díaz et al., 2019, Ely et al., 2008; Mauhlbauer, Panzer & Schindler, 2010; Vleck, Bentley, Millet, & Burgi, 2008) determinando que una estrategia adecuada puede favorecer que los atletas de élite sean más económicos, adquiriendo mejoras significativas en su rendimiento y, por consiguiente, mejoras a nivel de récord mundial (Angus, 2014).

3.4. CONOCIMIENTO CIENTÍFICO SOBRE EL *PACING STRATEGY*

Entre las evidencias más recientes se ha observado cómo los corredores de élite generalmente hacen muy pocos cambios de velocidad durante un maratón, mientras que los de menor rendimiento reducen el ritmo a medida que avanza la carrera, especialmente después de 20-25 kilómetros (Ely et al., 2008). Por ejemplo, los primeros atletas clasificados en el maratón del Campeonato Mundial en Berlín 2009 mostraron una estrategia de ritmo más uniforme que los atletas más lentos, que seleccionaron velocidades iniciales insostenibles con el resultado de una pérdida significativa de velocidad (Renfree & Gibson, 2013). En esta misma línea, March et al., (2011) mostraron que los maratonianos más rápidos mantienen una velocidad de carrera más constante durante toda la competición a diferencia de los atletas más lentos. Este fenómeno también se ha observado en los ultramaratones, donde los atletas que terminaron en el top-10 mostraron menos cambios de velocidad de carrera que el resto de corredores (Lambert et al., 2014).

En un reciente estudio, Santos-Lozano, Collado, Foster, Lucia, & Garatachea (2014) analizaron todos los finalistas en dos ediciones del maratón de Nueva York. Los autores observaron que la gran mayoría de los corredores desarrollaron un perfil de ritmo positivo, aunque los mejores atletas tenían una menor variabilidad de la velocidad inicial de la carrera en comparación con los atletas menos exitosos. Asimismo, tanto hombres como mujeres tratan de mantener un perfil de ritmo a lo largo del maratón, en parte, porque comenzar la competición excesivamente rápido podría dar lugar a una disminución pronunciada de la velocidad en la segunda parte de la carrera (Santos-Lozano et al., 2014).

Por otro lado, las diferencias observadas en el ritmo adoptado durante la prueba de maratón no sólo se han observado en corredores con diferentes capacidades, sino también al comparar hombres versus mujeres (Deaner, Carter, Joyner, & Hunter, 2015). Por ejemplo, se ha observado que las mujeres usan velocidades de carrera más estables durante la competición (March et al., 2011; Trubee, Vanderburgh, Diestelkamp, & Jackson, 2014), a diferencia de los hombres, que generalmente disminuyeron su ritmo en la última parte de la carrera (Deaner et al., 2015; Trubee et al., 2014). Esto contrasta, sin embargo, con un estudio reciente de Nikolaidis & Knechtle (2018) que observaron cómo en el maratón de Nueva York tanto hombres como mujeres redujeron la velocidad durante la carrera y la aumentaron en el último tramo de la competición (40-42,2 km).

Estas diferencias en la estrategia de estimulación observadas entre hombres y mujeres pueden deberse a factores fisiológicos que incluyen la mayor susceptibilidad de los hombres al agotamiento del glucógeno muscular (Carter, Rennie, & Tarnopolsky, 2001; Roepstorff et al., 2002; Tarnopolsky, 2008) y la menor fatigabilidad del músculo esquelético en las mujeres (Hunter, 2014) o factores no fisiológicos, como las diferencias en la toma de decisiones (Allen & Dechow, 2013). Deaner et al., (2015) sugiere que es más probable que los hombres adopten estrategias agresivas de estimulación al comienzo de la carrera que no podrán mantener durante toda la competencia.

Las diferentes evidencias encontradas, nos plantean la cuestión de si la estrategia de ritmo adoptada por los poseedores de un récord mundial durante las últimas décadas y los últimos años ha sido ideal, además de estimar si hay margen de mejora. Asimismo, aunque se sabe que el sexo y el nivel de rendimiento influyen en el tipo de estrategia utilizada durante el maratón (Deaner et al., 2015; March et al., 2011), surge la cuestión de si los ritmo adoptados por los atletas poseedores de los récords mundiales femeninos y masculinos difieren.

4.- OBJETIVO

“La única manera de hacer un gran trabajo es amar lo que haces. Si todavía no lo has encontrado, sigue buscando. No te conformes” (Steve Jobs).

4. OBJETIVO

El objetivo principal de esta tesis doctoral fue analizar, comparar y determinar la influencia del nivel atlético y sexo sobre los ritmos de carrera adoptados por corredores de maratón. Asimismo, se establecieron objetivos más específicos como:

1) Analizar las estrategias utilizadas durante el maratón en hombres y mujeres *amateurs* de diferentes niveles de rendimiento. Nuestra hipótesis es que las diferencias entre hombres y mujeres serían más acusadas en los niveles de rendimiento más altos.

2) Analizar las estrategias de ritmos mostradas por los ganadores de los seis *World Marathon Majors* para determinar qué carrera ofrece el mayor potencial para futuros intentos de récord mundial. Nuestra hipótesis es que los récords mundiales de maratón se lograrán con perfiles más uniformes y que tendrá lugar en maratones con recorridos más estables como Berlín.

3) Analizar las diferentes estrategias de ritmos adoptados por los atletas poseedores de los récords mundiales de maratón en los últimos 50 años. Nuestra hipótesis fue que los récords mundiales de maratón se lograron con estrategias de ritmo relativamente más uniformes.

4) Analizar y comparar las estrategias de ritmos adoptadas por los corredores de maratón masculinos y femeninos de élite al establecer cada récord mundial en los últimos 20 años. Nuestra hipótesis era que los récords mundiales femeninos se lograron con patrones más uniformes que los récords masculinos.

5.- STUDIES

"Nunca consideres el estudio un deber, sino una oportunidad para penetrar en el maravilloso mundo del saber" (Albert Einstein).

5. ESTUDIOS

El trabajo realizado en esta tesis ha tenido como objetivo analizar, comparar y determinar la influencia del nivel atlético y sexo sobre los ritmos de carrera adoptados por corredores élite de maratón y no-élite, estructurándolos en cuatro estudios científicos.

Comenzamos analizando la influencia del nivel de atlético y sexo sobre los ritmos empleado por 14.420 atletas en tres maratones con perfiles muy similares en cuanto a recorrido y condiciones climáticas.

Con el fin de determinar que competición tiene un mayor potencial para intentar batir futuros récords mundiales, recopilamos los datos de los ganadores de las 6 "*Worl Marathon Majors*" desde que se creo esa categoría de maratones a nivel mundial y comparamos los ritmos empleados en relación con el perfil de cada maratón.

Posteriormente, analizamos los diferentes ritmos empleados por los récords mundiales de maratón en los últimos 50 años, con el fin de observar la evolución de las distintas estrategias adoptadas por los atletas y así valorar cuál sería el mejor patrón a utilizar para romper futuros récords.

Por último, comparamos los diferentes ritmos empleados por hombres y mujeres en los récords mundiales batidos en los últimos 20 años (desde 1998 hasta la actualidad).

5.1. STUDY 1: ANALYSIS OF THE PACING STRATEGIES USED BY MARATHON RUNNERS

5.1.1. Introduction

One of the most important aspects affecting marathon performance is the pacing strategy adopted during the competition (Renfree & Gibson, 2013). The success of a marathon runners depends not only on having trained and prepared properly, but also on the pacing strategy choosen during the competition, regardless of his ability (Hanley, 2014). Although there may be little physiological difference between competitors, athletes may win or lose depending on the ability to adequately expend energy to prevent premature fatigue before the end of the event (Garland, 2005; Hanley, 2014; Skorski & Abbis, 2017). In this regard, the pacing strategy used in the last world records is an efficient way of running from an energy point of view (Díaz, Fernández-Ozcorta & Santos-Concejero, 2018).

The influence of pacing strategy throughout the marathon if of great interest in the scientific literature. In particular, understanding how to distribute the pacing strategy can lead to a better understanding of the factors that influence performance and help runners successfully complete a marathon or improve their running performance (Abbiss & Laursen, 2008; Díaz, et al., 2018).

Different strategies have previously been identified in several endurance events: positive pacing (where the athlete slows down his speed during the course of the race), negative pacing (the athlete accelerates at the end) and constant pacing (a relatively constant speed is maintained) (Hanley, 2013). The adoption of one strategy or another will depend on the athlete's ability to maintain homeostasis (Abbiss & Laursen, 2008). If the wrong strategy is selected, symptoms such as fatigue could appear, slowing down the runner's speed and even causing him to abandon the race. Literature suggests that the negative pacing is the most appropriate for a prolonged exercise such as the marathon. This negative pacing leads to a lower depletion of carbohydrates, less excessive oxygen consumption and blood lactate concentration (Muñoz Pérez, Moreno Pérez, Cardona González, & Esteve-Lanao, 2012). However, this pacing profile is not always adopted in practice (Hanley, 2013).

Although the negative pacing may be the most appropriate, the pacing strategy most used by the vast majority of marathon runners is the positive one, slowing down the speed as the race progresses, especially after 20-25 km of race (Ely, Martin, Cheuvront & Montain, 2008; Santos-Lozano, et al., 2014). However, there are differences when comparing the strategies used between runners of different levels of performance and sex (Deaner, Carter, Joyner & Hunter, 2015; March, Vanderburgh, Titlebaum, & Hoops, 2011; Santos-Lozano, et al., 2014). Recent studies have reported that the best runners have less variability in their running speed compared to less successful athletes (Lamber, et al., 2004; Ely, et al., 2008; Renfree & Gibson, 2013; Santos-Lozano, et al., 2014). This difference of pacing strategy utilization is not only observed between groups of runners of different performance, but also between sexes. Women, relative to men, tend to use speeds that they can maintain throughout the race, unlike men, who usually perform one last part of the race at a lower speed than the first (Deaner, et al., 2014; Trubee, Vanderburgh, Diestelkamp & Jackson, 2014).

Although sex and performance level are known to influence the type of pacing strategy used during a marathon (Deaner, et al. 2014; March, et al., 2011), little is known about how each type of strategy is distributed among marathon runners based on sex and performance level. A deeper analysis of the types of strategies used by marathon runners could help increase knowledge about this test, so that coaches and athletes can choose strategies focused on improving performance.

From the above, despite the fact that marathon is a popular race that brings together thousands of runners, there are few studies that analyse the strategies adopted according to the level of performance of the runners. In addition, the differences observed between the sexes encourage the exploration of such differences in different performance groups. Therefore, the aim of this study was to analyse the distribution of pacing strategies used during the marathon in men and women at different levels of performance. According to previous studies, it was assumed that the differences between men and women were more pronounced at higher levels of performance.

5.1.2. Aim of the study

The aim of this study was to analyse the pacing strategy used during the marathon by men and women of different performance levels. According to previous studies, it was assumed that the differences between men and women were higher at higher performance levels.

5.1.3. Methods

Participants

We analysed 14420 athletes, of whom 92.8% (n=13386) were men and 7.8% (n=1034) were women. The results of three marathons held in Seville in 2013 and 2014 and in Castellon in 2013 were analysed. Although two marathons with different routes were studied, they both had very similar profiles and environmental conditions (temperature 4.0 ± 1.7 ºC, humidity 86 ± 5%, cumulative difference 242 ± 8 m).

Procedures

This study included the analysis of data available to the public; consequently the need for individual informed consent was not necessary. Outcomes were obtained by downloading the absolute overall ranking through the company *Cronochip.com.* Each data set includes at least: the data of position, category, official time and pacing times (10 km, 21.1 km and 30 km).

The total distance was divided into four sections of 10 km, 21.1 km, 30 km and 42.195 km respectively. The average total speed and the average speed of each section were individually computed. The pace was determined as a percentage of the variation in speed during each section with regards to the total average speed of each runner. The participants were divided into three groups as a function of the pacing strategy used: "*constant pacing strategy*" (keeping the same speed throughout the race), "*positive pacing strategy*" (the athlete slows down the speed in the course of the event) and "*negative pacing strategy*" (the athlete progressively increases the speed throughout the race). In order to differentiate each group, the speed ratio between the first and fourth sections was computed. When the data ranged between 1.05 and .95, a constant pacing strategy was assigned. Likewise, if the ratio exceeded 1.05 this was considered as a negative pacing strategy, while if the ratio was lower than .95 this was assumed as a positive pacing strategy.

The participants were divided into four performance groups depending on end time of the marathon: *Group 1* [very fast runners, time to end the race d>> 202 min. (men) and d>> 226 min. (women)], *Group 2* [fast runners, time to end the race 203 to 222 min. (men) and 227 to 247 min. (women)], *Group 3* [medium runners, time to end the race 223 to 243 min. (men) and 248 to 271 min. (women)], and group 4 [slow runners, time to end the race > 244 min. (men) and > 272 min. (women)]. In order to obtain homogeneous groups, the criteria used was to divide the sample into quartiles (first, second, third and fourth quartiles) 25% of the end net time of all finalists in each marathon.

Statistical analysis

Statistical analyses of data were performed using the Statistical Package for the Social Sciences 21.0 software package (StatSoft, Tulsa, OK, USA). Data were screened for normality of distribution and homogeneity of variances using a Kolmogorov-Smirnov Normality Test and a Levene test, respectively. One-way analysis of variance (ANOVA) was used for the comparison of the means of performance and pacing groups and the percentage of variance explained by the omega-square indicator (ù2) was calculated. The magnitude of differences or effect sizes (ES) were calculated according to Cohen’s d (1977). We used contingency tables with the Chi-square statistic to assess the performance level influence on the pacing strategy used. Significance for all analyses was set at $p < 0.05$.

5.1.4. Results

In order to evaluate the strategies employed by the participants, the timing in hours, minutes and seconds (hh:mm:ss) in the three races studied is depicted in Table 5.1.1.

Table 5.1.1. Descriptive analysis of times by sections (hh:mm:ss)

Marathon	**Year**	**Sex**	***n***	**Times by sections (M ± SD)**			
				10 km	21.1 km	30 km	42 km
Seville	2013	Men	5013	52:36 ± 07:36	1:48:29 ± 14:79	2:35:24 ± 22:05	3:45:38 ± 34:36
		Women	334	58:08 ± 07:46	2:01:09 ± 16:10	2:53:38 ± 23:53	4:09:31 ± 36:48
Castellon	2013	Men	1435	49:52 ± 06:26	1:44:51 ± 13:15	2:29:4 5± 19:31	3:36:33 ± 29:32
		Women	92	54:25 ± 05:31	1:53:34 ± 11:21	2:42:44 ± 16:53	3:53:01 ± 24:50
Seville	2014	Men	6938	51:46 ± 07:29	1:48:35 ± 14:44	2:34:19 ± 21:20	3:43:22 ± 33:46
		Women	608	57:30 ± 07:19	2:00:33 ± 14:13	2:52:33 ± 21:21	4:07:29 ± 33:21
Total		Men	13386	51:43 ± 07:25	1:48:10 ± 14:44	2:34:31 ± 21:19	3:43:08 ± 33:44
		Women	1034	57:11 ± 07: 37	2:00:22 ± 14:53	2:52:06 ± 22:60	4:07:04 ± 34:31

Notes: n= sample size; km= kilometres; M= mean; SD= Standard deviation

The standardised average speed on each section, considering the differences between men and women, is shown in Figure 5.1.2. Discrepancies between sexes were noted in all sections, although these were minor or trivial (t > 3.78, $p < .05$, TE < 0.31). Men achieved higher speeds un all sections except for the last one where women displayed higher speed.

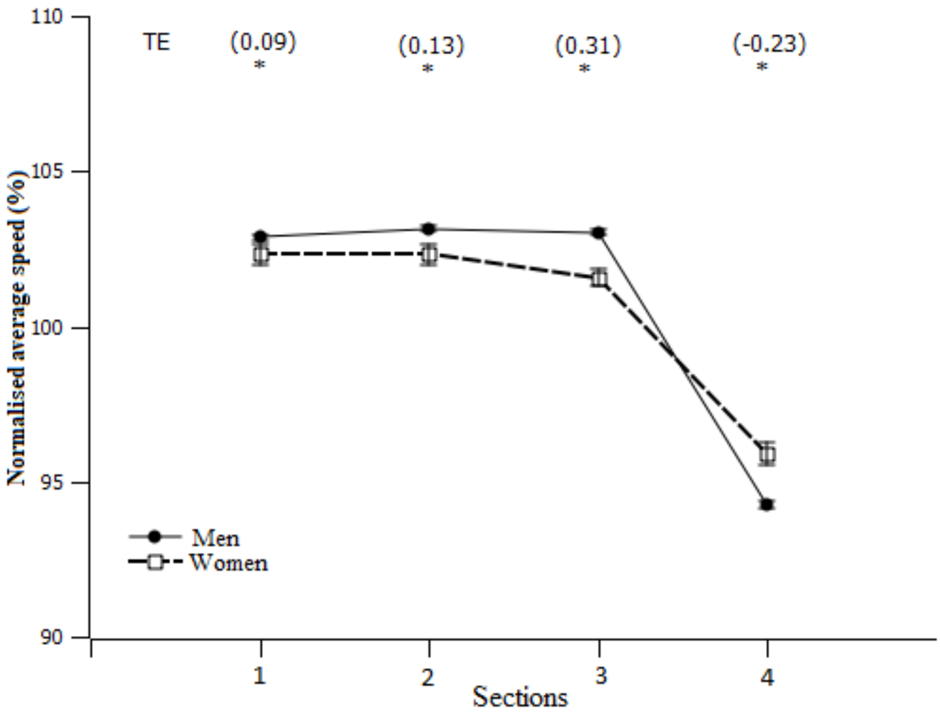


Figure 5.1.2. Normalised average speed in each section comparing men *vs.* women.

Generally, the most commonly used strategy during the competition between men and women was the positive one, a gradual decrease in speed over the course of the test (Table 5.1.3). Although women tended to use more constant and negative strategies when compared to men ($X^2 = 11.19$, df = 2, $p < .01$).

Table 5.1.3. Distribution of the pacing strategy used by sex.

Men			Women			*Differences X^2*
Positive	*Constant*	*Negative*	*Positive*	*Constant*	*Negative*	
54	36	10	50	38	12	11.19†

† Denotes distribution differences between sexes.

In both sexes (Table 5.1.4.), discrepancies were found in the distribution of the strategies used among the performance groups analysed ($X^2 > 171$, df = 6, $p < .01$). In particular, the constant strategy was most used, in men and women, in greater performers when compared to their slower counterparts. The strategy of increasing the speed throughout the race (*negative strategy*) was the least common of the analysed ones. This was more frequently used by fast athletes (Group 2) and medium athletes (Group 3). In both sexes, the performance group that most often adopted a positive strategy was the slow one (Group 4).

Table 5.1.4. Distribution of the pacing strategy used by performance groups and sexes.

Performance groups	**Men**			**Women**			**Differences between sexes** X^2
	Positive	*Constant*	*Negative*	*Positive*	*Constant*	*Negative*	
Very fast	47	48	5	35	51	14	287†
Fast	40	44	16	32	49	19	354†
Medium	52	34	14	50	36	14	57†
Slow	77	18	5	82	15	3	791†
X^2		1289*			171*		

* Denotes distribution differences between performance groups; † Denotes distribution differences between sexes.

5.1.5. Discussion

The aim of this paper was to analyse the pacing strategies used during the marathon in men and women of different levels of performance. According to our results, the differences between men and women were higher in the higher levels of performance.

We observed that men and women usually adopt high initial speeds that they fail to maintain through the entire race. These data indicate that they were generally using as positive pacing strategies (the second half of the race slower than the first one). This finding agrees with Santos-Lozano et al. (2014), who noticed how marathon runners adopted a positive pacing strategy, slowing down as the competition progresses, regardless of sex and performance level. According to Santos-Lozano et al. (2014), this decline in the fastest runners can be explained by several reasons. Firstly, because runners do not have energy reserves for the last kilometres. Secondly, because of the final outcome of the marathon, given that it is not generally defined in the last kilometres. And lastly, because the head group is usually gradually reduced in number, and only the best positioned seem to be capable of keeping up.

The analysis showed that men achieved higher speeds in all sections except the last one, where women achieved higher speed, although the magnitude of the differences was small. This somehow agrees with Trubee et al. (2014), who observed that women tend to exhibit a smaller race speed decline than men during the last stages of a marathon. March et al. (2011) suggests that non-elite women are consistently better at setting the pace relative to non-elite men, including when age, gender, and completion time are controlled. Several mechanisms may explain why women are faster than men in the last stage of the race. According to Speechly et al. (1996), women are capable of performing at a higher percentage of their maximum oxygen consumption ($VO_{2max.}$) than men in the last stages of an endurance test. Other studies (e.g., Carter, et al., 2001; Ruby & Roberts, 1994; Tarnopolsky, 2000) reveal that women have a lower rate of respiratory exchange ratio than men during submaximal endurance exercise, indicating a preference for fat oxidation in order to obtain energy while saving glycogen. This, in turn, may delay the runner's "wall", a phenomenon in which glycogen reserves in the body are depleted in the last quarter of the race (Coyle, 2007; Ruby & Roberts, 1994; Tarnopolsky, 2000), and thus contribute to the dramatic decrease in race speed.

The pacing strategy adopted by the runners in this study revealed that, regardless of gender and performance level, athletes generally slowed down progressively during the second half of the marathon by adopting a *positive* pacing strategy. The next most used strategy was the *constant* pacing strategy, followed by the *negative* pacing strategy. These results agree with those reported by Santos-Lozano et al. (2014), who observed in different editions of the New York Marathon (2006-2011) that all performance groups selected a positive pacing strategy. The results of Ely et al. (2008) were similar.

Although the data indicate that the *positive* pacing strategy was the most frequent in all performance groups, the distribution of percentages at each pace was different in each performance group. In the fastest groups of athletes, a higher percentage of athletes using a *constant* pacing strategy was observed when compared to the rest of performance groups. This agrees with Santos-Lozano et al. (2014), who reported that the best athletes have a lower variability in race speed compared to the least successful athletes. Similarly, Nikolaidis and Knetchtle (2017a, 2017b) and Nikolaidis, Onywera and Knetchtle (2018) observed that the fastest runners of the New York Marathon usually display a more even pace than lesser performers. On the other hand, Renfree et al. (2012) observed that first ranked runners in the 2009 World Championship marathon adopted a more constant pacing strategy throughout the competition, unlike the least successful runners, who opted for unsustainable speeds causing a significant loss of speed at the end.

The speed decrease in endurance sports is due to various factors including pace adjustment, which is largely dictated by the ability to resist fatigue (Abbiss & Laursen, 2008; Haney & Mercer, 2011), by a learning process (Lambert et al., 2004) and by temperature, as well as other variables such as experience or level of training (Knechtle, et al., 2015; Trubee, et al., 2014). According to the results of the present study, the group of fast athletes (Group 2) and Medium athletes (Group 3) had a higher percentage of athletes using a negative pacing than the other groups. The use of this type of pacing is described in literature as the most appropriate for a prolonged exercise such as marathon, due to the lower carbohydrates depletion, the lower oxygen consumption and lower concentration of blood lactate (Hanley, 2013). In contrast, in the slowest group of athletes, the percentage of athletes who used a positive pace was higher compared to the rest of the groups.

We also observed that, regardless of gender, the slowest runners showed greater differences with respect to the other performance groups. The slowest athletes adopted a faster pace than their average speed during the first 21.1 km, and then drastically slowed down their running speed, below the overall average speed. The greatest differences were observed in the last section. This information coincides with other studies such as Renfree and Gibson (2013) and Santos-Lozano et al. (2014) who found similar results, demonstrating that the slowest runners exhibited a greater decrease in running speed when compared to the best runners. In contrast, the faster runners (Group 1) experienced fewer speed changes and were able to keep the initial speed during a longer distance than the slower runners. This agrees with Lambert et al. (2004), who observed that faster ultra-marathon athletes adjusted their speed more effectively compared to the slowest athletes, who significantly decreased their speed in the second half of the competition.

According to Hanley (2013), one of the possible reasons why most athletes adopt unsustainable paces is because they try to follow the pace set by the leaders, with the aim of keeping that pace for the longest possible time in order to place themselves in a good position and improve their previous performance. Another possible explanation for the drastic reduction in running speed, which may be the result of an inadequate pattern or pace, underlies in glycogen depletion, hypoglycaemia or hyperthermia (Coley, 2007). From a physiological point of view, Joyner et al. (2011) indicated that a correlation between max $VO_{2max.}$ and the race economy could delay glycogen depletion and reduce metabolic heat production, thus reducing the risk of hyperthermia. Likewise, in the second part of the race, two important factors come into play and are crucial to explain the decrease in running speed and the adaptation of one pace or another. On the one hand, homeostasis, where the brain may subconsciously coordinate a regulatory response to ensure that the intensity of exercise does not exceed the physiological limits of the body (Abbis & Laursen, 2008; Edwards, et al., 2011; Faulkner, et al., 2008). On the other hand, a lower perception of effort in the fastest runners thanks to a greater experience to suffer symptoms associated with exercise (Faulkner, et al., 2008).

Overall, the current study reports important aspects for elite and non-elite marathon athletes and other sportspeople who take part in similar competitions, since the pace adopted has a great influence on the final outcome. If athletes, regardless of performance level, are able to adopt the right pace during competition and also understand the factors that influence performance, they will be able to achieve faster times or even finish ahead of other runners with higher physiological abilities who usedless effective paces.

Nevertheless, the present investigation has constraints that must be considered. The number of sections analysed were only four, being of a length of about 10 km each. Analysing shorter sections may be the way to go in the future, as it would allow for a deeper analysis and a more precise definition of the paces used by the runners.

In conclusion, we observed that regardless of gender and performance level, most athletes adopt a *positive* pacing strategy when running a marathon. This *positive* pacing strategy is characterised by running the last section at a slower pace than the preceding ones. The speed used in the last section was the one that determined to a greater extent the differences between performance groups. All groups showed a drop of speed in the last section, but this was more noticeable in the slower runners when compared to the other performance groups.

5.2. STUDY 2: PACING AND PERFORMANCE IN THE 6 WORLD MARATHON MAJORS

5.2.1. Introduction

The pacing strategy adopted during competition is crucial in determining marathon running performance (Abbiss and Laursen, 2008; Ely et al., 2008; March et al., 2011; Renfree and Gibson, 2013). Pacing, which has been described as the ability to use and distribute energy resources efficiently during athletic competition (Foster et al., 1993), aims to optimize the use of physiological reserves before the end of the race. This would help in avoiding premature fatigue (Skorski and Abbiss, 2017) and a subsequent reduction in speed before task completion (Foster et al., 2004; Hettinga et al., 2007; Tucker and Noakes, 2009).

Different studies have identified a number of factors that influence pacing during a maratón race, including changes in terrain or altitude (Haney and Mercer, 2011), as well as environmental and body temperature (Marino et al., 2004; El Helou et al., 2012; Hoogkamer et al., 2017). To date, there is no consensus about the mechanisms through which the regulation of pace is achieved (Renfree et al., 2015), although factors such as the assessment of perceived exertion (Tucker and Noakes, 2009), the Hazard score (de Koning et al., 2011), and emotion (Baron et al., 2011; Venhorst et al., 2018) have all been studied. Recently, it has been established that the pacing strategy adopted has a major influence on the performances achieved by world record breaking athletes (Díaz et al., 2018). In recent years, the world records have been achieved through progressively more consistent strategies than was the case in record performances of more than 25 years ago, which were typically characterized by a progressive reduction in speed (Díaz et al., 2018, 2019).

The present world record holder, Eliud Kipchoge of Kenya (2:01:39, Berlin Marathon, 16 September 2018) succeeded in lowering the previous record by 1min and 18 s. This performance has increased speculation regarding the possibility of a sub 2 h performance (Hoogkamer et al., 2017; Sousa et al., 2018). Some authors and scientists have suggested that such a performance is physiologically impossible (Liu and Schutz, 1998; Weiss et al., 2016), whereas others argue that the barriermay be broken in the near future (Boullosa et al., 2011; Joyner et al., 2011; Hoogkamer et al., 2017; Sousa et al., 2018).

With regards to any attempt to break the 2 h barrier, previous research proposed the use of several pacemakers that should be replaced with other athletes as soon as the first ones become fatigued on a loop circuit, as was the case in the Nike Breaking2 attempt (Hoogkamer et al., 2017). However, this strategy is not allowed by the IAAF rules (2015), so the only option is to compete in legitimate races. This is where the Marathon Majors take special importance as since 1998 all world records have been broken in these competitions.

Therefore, the main goal of this study was to analyse the pacing strategies displayed by the winners of the six World Marathon Majors in order to determine which race offers the greatest potential for future world record attempts. We hypothesize that world records are more likely to be achieved in marathons with more even profiles and taking place in stable favorable such as Berlin.

5.2.2. Aim of the study

The main goal of this study was to analyse the pacing strategies displayed by the winners of the six World Marathon Majors in order to determine which race offers the greatest potential for future world record attempts. We hypothesise that world records are more likely to be achieved in marathons with more even profiles and taking place in stable favourable such as Berlin.

5.2.3. Methods

Data were gathered from a publicly accessible website (Association of Road Running Statisticians' website, accessed 20 November 2018) providing the winners of the official World Marathon Majors for men between 2006 and 2018, which resulted in a sum of 76 winners. Each set of information included at least: the position, category, official final time, half-marathon time and time data every 5 km.

The total distance of the marathon was divided into eight sections of 5-km and one section of 2.195 km, and time needed to complete each section was calculated in seconds. Full marathon average speed and the average speed of each section were calculated individually. The relative speed of each section for every runner was then calculated and presented as a percentage of the average speed for the full race.

The athletes were divided into six groups: A) group of marathon Berlin (winners between 2006 and 2018), B) group of marathon Boston (winners between 2006 and

2018), C) group of marathon Chicago (winners between 2006 and 2018), D) group of marathon London (winners between 2006 and 2018), E) group of marathon New York (winners between 2006 and 2018, except the marathon of 2012 canceled by a hurricane), F) group of marathon Tokyo (winners between 2007 and 2018, as before 2007 Tokyo was not part of the Worlds Marathon Majors). The course information were retrieved through the official internet website for each city marathon, on marathon archive websites and from various media outlets.

Statistical analysis

SPSS for Windows version 25.0 (SPSS, Inc., Chicago, IL) was used to analyse the data. Each data set was screened for normality of distribution and homogeneity of variances using a Shapiro-Wilk normality test and a Levene test, respectively. One-way analysis of variance (ANOVA) was used to compare the mean winning time in the last 13 editions of each of the World Marathon Majors. Two-way analysis of variance (ANOVA) with repeated measures for time was used to compare the pacing strategies between the winners of the six world marathons majors. When differences were found, a Tukey's range test was used for post hoc comparisons. The magnitude of the differences or effect sizes (ES) were calculated according to Cohen's d (1998) and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2), large (≥1.2 and < 2.0) or very large (≥2.0 and <4) according to the scale proposed by Hopkins et al. (2009). Significance for all analyses was set at $p<0.05$.

We acknowledge that such a statistical approach has been criticised as it may induce a greater risk of type I error (Sainani, 2018) and may lead to flawed inference (Sainani et al., 2019). However, it has a practical use in sport science studies (Batterham and Hopkins, 2019).

5.2.4. Results

Mean winning time in the last 13 editions of each of the World Marathon Majors are presented in figure 5.2.1. We observed differences between New York and London (ES = 1.46, moderate effect, p = 0.0030), New York and Berlin (ES = 0.95, small effect, p = 0.0001), London and Boston (ES = 0.08, small effect, p = 0.0001), Boston and Berlin (ES = 0.10, small effect, p = 0.0001), Boston and Chicago (ES = 0.16, small effect, p = 0.0361), Berlin and Tokio (ES = 0.20, small effect, p = 0.0034), Berlin and Chicago (ES = 0.27, small effect, p = 0.0162).

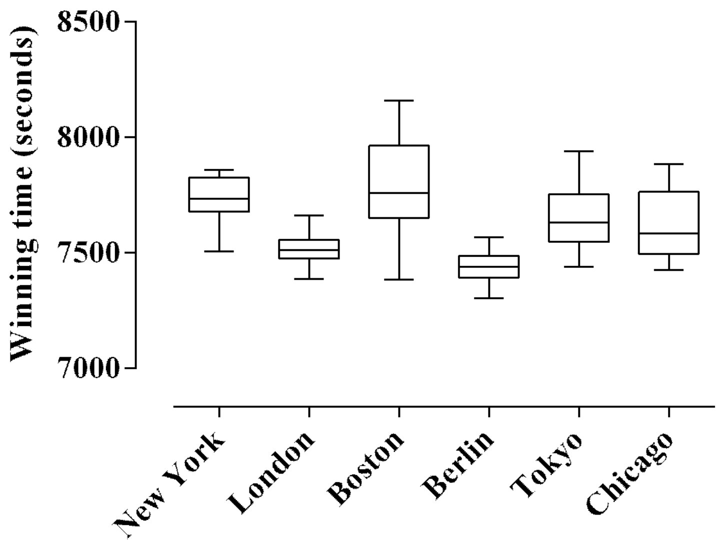


Figure 5.2.1. Winning times in the World Marathon Majors in the last 13 years.

When individual 5-km segments were analysed, differences were found in running speed relative to the whole race average. (Figure 5.2.2). In the first 5-km section, New York was slower than Berlin (ES = 2.77, very large effect, p = 0.0001), London (ES =

3.36, very large effect, p = 0.0001), Tokyo (ES = 3.12, very large effect, p = 0.0001), Boston (ES = 2.06, very large effect, p = 0.0001) and Chicago (ES = 1.83, large effect, p = 0.0133). On the other hand, London was faster than Chicago (ES = 2.00, very large effect, p = 0.028).

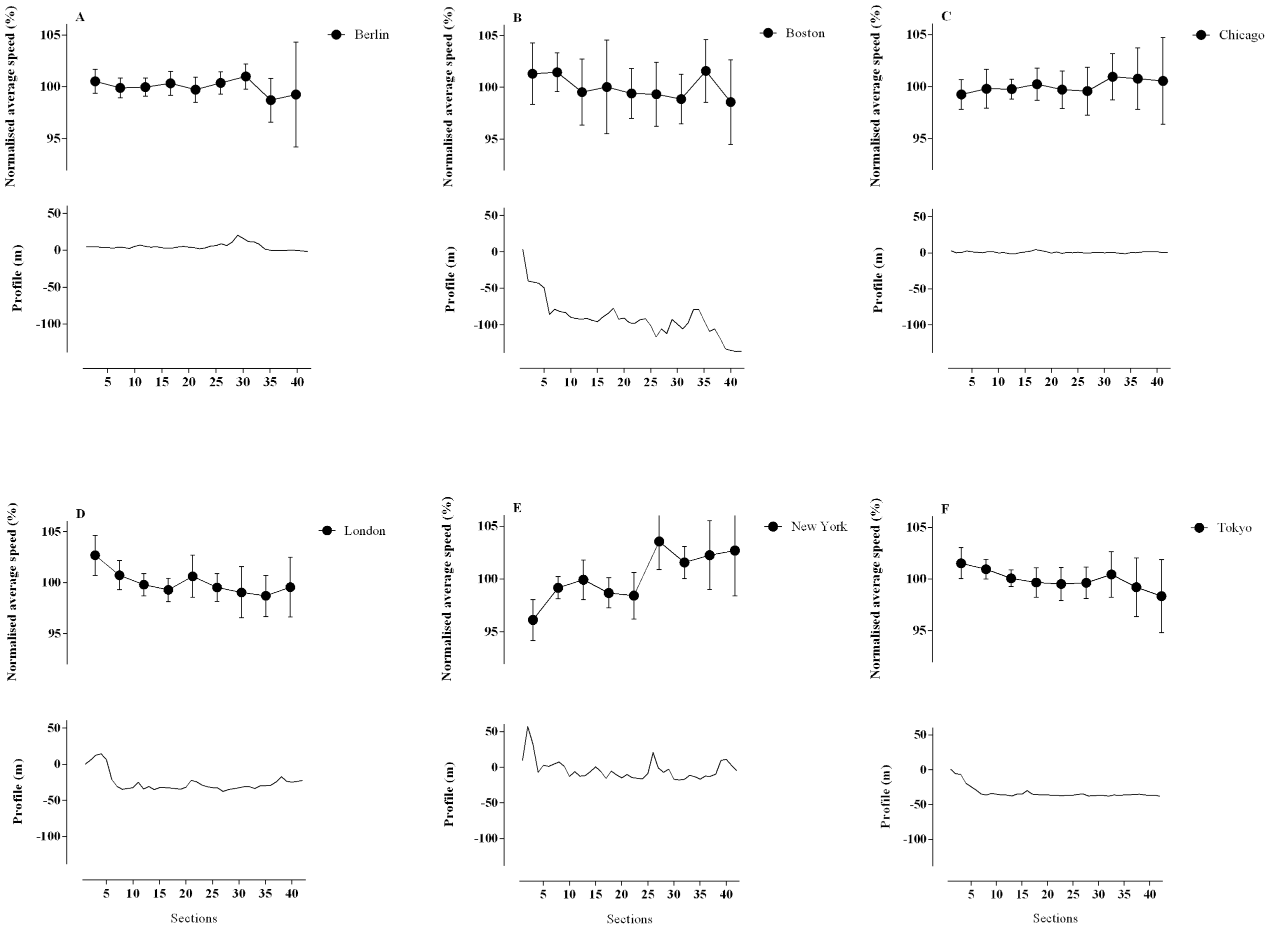


Figure 5.2.2. Course profile and normalised average speed of World Marathon Majors' winners by 5-km sections.

In section 6, New York again differed from other races, as it was faster than Berlin (ES = 1.55, large effect, p = 0.0133), London (ES = 1.89, large effect, p = 0.0003), Chicago (ES = 1.60, large effect, p = 0.0004), Boston (ES = 1.45, large effect, p = 0.0001) and Tokyo (ES = 1.79, large effect, p = 0.0008).

In section 8, we found the following differences: Berlin was slower than New York (ES = 0.55, small effect, p = 0.0029) and Boston (ES = 1.09, moderate effect, p = 0.0257), London was slower than New York (ES = 1.31, large effect, p = 0.0027), and Boston (ES = 1.11, moderate effect, p = 0.0240) and New York was faster than Tokyo (ES = 0.99, moderate effect, p = 0.0211).

In the final 2.2 km section, New York was faster than Berlin (ES = 0.73, moderate effect, p = 0.0043), London (ES = 0.85, moderate effect, p = 0.0126), Boston (ES = 0.98, moderate effect, p = 0.0002) and Tokyo (ES = 1.10, moderate effect, p = 0.0001).

5.2.5. Discussion

Analysis of winning times over a 13 year period indicates clear differences between the six World Marathon Majors (Figure 5.2.1.). Although there are probably numerous reasons for this, course topography is likely important, especially in terms of its influence on the pacing behaviours displayed. For example, the New York race, which is characterised by substantial undulations, differs from the other races in the initial and final individual 5-km sections. Similarly, New York marathon is the only one of the Majors that consistently allows for a second half marathon faster than the first (ES = 4.90, very large effect). In contrast Berlin, which has the fastest average winning time and is the sight of the current world best performance is relatively flat, starts at an elevation of 38m above sea level and never exceeds 53m, and has a net downhill profile over the final 15 km.

The Boston marathon is notable in that we found larger variability in the overall winning times than was the case for the other races. This is in line with a larger analysis performed by Maffetone et al., (2017) who found that the Boston Marathon is characterised by large variability in performances due to external factors such as weather and specifically, the wind direction.

In relation to climate, other aspect that may influence the performance of athletes is temperature (Helou et al., 2012). It is known that warm weather causes a major alteration of cardiovascular, metabolic, neuromuscular and thermoregulatory function (Maughan, Watson and Shirreffs, 2007). Consequently, it increases the risk of hyperthermia, directly affecting the central nervous system and contributing to the onset of fatigue during prolonged exercise (Marc, et al., 2014). In this sense, Helou et al., (2012) observed that, the higher the temperature increase, there is a drastic reduction in the running speed and significantly increases the percentage of athletes who retire. For example, in 2007 in the marathon in Chicago, 30.74% of the athletes withdrew, although the organisers tried to interrupt the competition with serious problems of dehydration and thermal shock syndromes (Roberts, 2010). Although we are unable to access data relating to climatic conditions at the time of every individual race, we speculate that variation between locations may at least partially account for the differences in performance we found. For example, with regards to the influence of temperature, Ely, Cheuvront and Montain (2007) indicated that the best historical times in the marathon have been achieved during the early morning, with cold ambient temperatures (10-15º C) and during the spring or autumn. In this regard, despite the high standard of competition during the summer in the Olympic Games, Continental or

International Championships no world records and few good annual performances are established possibly by the temperatures during this period of year (i.e. London Olympics 2012: 27ºC, Rio Olympics 2016: 21ºC, Doha World Championship 2019: 32ºC) (Marc et al., 2014).

One of the most important factors influencing marathon performance is the pacing adopted by athletes (Abbiss and Laursen, 2008, Díaz et al., 2018, Díaz et al., 2019). Athletes aim to efficiently use and distribute their energetic resources during athletic competition (Foster et al., 1994), with the aim of using all available reserves before reaching the finish, thereby avoiding premature fatigue (Skorski and Abbiss, 2017) and a significant deceleration before the end (Foster et al., 2003; Hettinga, de Koning and Meijer, 2007, Tucker and Noakes, 2009). We can observe that in the Tokyo and Boston races, race winners typically slow with increasing distance, and therefore, display positive pacing profiles, unlike Berlin where the athletes display a more uniform speed throughout the whole race (Figure 5.2.2.). Interestingly, the New York profile favours a fast end that never compensates for the slow pace of the first half, which reinforces the importance of a stable and constant intensity to perform optimally. There is evidence to suggest that, in a marathon, a pacing strategy characterised by very little speed changes across the race is optimal if the goal is to run as fast as posible (Angus, 2014). This observation is in line with that made by Díaz et al., 2018 who assessed the historical development of pacing strategies in world best marathon performances. This ability to achieve such a uniform pacing strategy may be enhanced through the use of designated ‘pacemakers’ who may reduce the psychological burden of regulating speed in competition, and thereby improve performance (Zouhal et al., 2015). During a 3000 m running time trial, presence of a pacemaker resulted in lower blood lactate concentrations and reduced RPE (Zouhal et al., 2015). Running with pacemakers also helps eliminate air resistance, thereby saving energy and reducing oxygen consumption by 8% at a speed of 21.5 kph (Pugh, 1970). Furthermore, Rauch et al., (2013) suggested that pacemakers can act as a placebo, increasing the motivation of the athletes to maintain or increase the pace in the final kilometers.

Finally, it is important to emphasise that organisational and traditional factors specific to the individual races may help explain some of the findings of this analysis. For example, the Boston race, and since 2007, the New York race, do not use pacemakers to assist athletes in achieving faster times. In explaining the reasons for this, organisers of the New York race say the presence of pacemakers makes the competitions lose their essence because the athletes do not "start running" until the pacemakers drop out (Mehaffey, 2009). Furthermore, the performances of elite runners may be influenced by the prize money (Maffetone et al., 2017). The winners of the World Marathon Majors receive a prize of $250,000 in addition to an event specific prize that differs between races as well as bonuses for breaking world records. Times set at Boston are ineligible for record purposes due to the distance of the start line from the finish line which could result in favourable prevailing winds. Given that economic reasons are a primary motivational factor for East African runners (Onywera et al., 2006), it would therefore seem unlikely that an athlete considered to have a realistic chance of achieving a world best performance would attempt to do so at Boston, regardless of the course profile.

5.3. STUDY 3: THE INFLUENCE OF PACING STRATEGY ON MARATHON WORLD RECORDS

5.3.1. Introduction

The limits of human performance in the marathon are still debated in the scientific literature, and several authors have proposed a potential limit that lays between 1:57:58 and 2:01:52 (Denny, 2008; Joyner, 1991), almost 5 minutes faster than the current world record (2:02:57 by Dennis Kimetto, Berlin Marathon, 28 September 2014). This suggests that substantial improvements in marathon are possible through the combination of the multitude of factors that influence performance, including physiology, training, professionalism, changes in economic and socio-cultural environments, technology and even doping practices (Tucker & Santos-Concejero, 2017).

One of the key factors to determine marathon performance is the pacing strategy adopted during the competition (Renfree & Gibson, 2013). Although there may be little physiological difference among competitors, athletes can win or lose depending on their ability to spend energy adequately and prevent premature fatigue before the end of the event (Garland, 2005; Hanley, 2014; Skorski & Abbiss, 2017). According to Foster et al. (1993), pacing strategy is in fact one of the limiting factors in competitive performance in long-term sports. Figuring out how to distribute the pace can lead to a better understanding of the factors that help runners to complete a maratón successfully (Abbiss & Laursen, 2008).

Pacing strategy can be influenced by several factors, including changes in terrain, environmental temperature, altitude or fatigue (Haney & Mercer, 2011). Previous research suggests that a negative pacing strategy (finishing the second half faster tan the first one) is the most appropriate one for endurance events such as the marathon, although it is not always adopted in practice (Hanley, 2014).

Elite runners usually make very little speed changes during a marathon, while the lesser performers slow the pace down as the race progresses, especially after 20–25 km (Ely, Martin, Cheuvront, & Montain, 2008). For example, the first classified athletes in the World Championships' marathon in Berlin 2009 showed a more uniform pacing strategy than the slower athletes, who selected unsustainable initial speeds with the result of a significant loss of speed (Renfree & Gibson, 2013). This phenomenon has also been observed in ultra-marathons, where top-ten finishers displayed fewer speed changes during the race than the lesser performers (Lambert, Dugas, Kirkman, Mokone, & Waldeck, 2004).

A recent study analysed the pacing strategy of the Haile Gebrselassie's (2:03:59) and Patrick Makau Musyoki's (2:03:38) world records, and concluded that a better pacing strategy could provide elite marathon runners with an economical pathway to significant performance improvements at world record level (Angus, 2014). The question arises whether the pacing strategy adopted by world record holders over the last decades and recent years has been ideal and whether there is margin for improvement.

Thus, this study aimed to explore the different pacing strategies adopted by marathon world record holders over the last 50 years. We hypothesised that world records were achieved with relatively uniform pacing strategies, with little difference between the first and second half of the race.

5.3.2. Aim of the study

This study aimed to explore the different pacing strategies adopted by marathon world record holders over the last 50 years. We hypothesised that world records were achieved with relatively uniform pacing strategies, with little difference between the first and second half of the race.

5.3.3. Methods

The Ethics Committee for Research on Human subjects of the University of the Basque Country UPV/EHU granted permission for this study. Data were gathered from a publicly accessible website (*Association of Road Running Statisticians'* website, accessed 10 January 2018) providing the official marathon world records for men between 1967 and 2014 (where the last world record was set), which resulted in a sum of 15 world records. Each set of information included at least: the position, category, official final time, half-marathon time and time data every 5 km.

The total distance of the marathon was divided into 8 sections of 5-km and 1 section of 2.195 km, and time needed to complete each section was calculated in seconds. Full marathon average speed and the average speed of each section were calculated individually. The relative speed of each section for every runner was then calculated and presented as a percentage of the average speed for the full race.

Athletes analysed were divided into two groups: group of *classic athletes* (record holders between 1967 and 1988) and group of *contemporaneous athletes* (record holders from 1988 to date). Lastly, we compared the pacing strategies of current world record holder Dennis Kimetto (2:02:57 set in Berlin Marathon, 28 September 2014) with previous record holder Wilson Kipsang (2:03:23 set in Berlin Marathon, 29 September 2013) and the first record holder of our analysis, Derek Clayton (2:09:36 set in Fukuoka Marathon, 3 December 1967).

Statistical analysis

Statistical analyses of data were performed using the Statistical Package for the Social Sciences 21.0 (StatSoft, Tulsa, OK, USA). Data were screened for normality of distribution and homogeneity of variances using a Shapiro-Wilk normality test and a Levene test, respectively. A student's t test was used to compare the first vs. the second half of the marathon world records. One-way analysis of variance (ANOVA) with repeated measures for time was used to compare the pacing strategies between groups (classic vs. contemporaneous). When differences were found, a Tukey's range test was used for *post hoc* comparisons. The historical variation in pace was assessed by the coefficients of variation (CV) of the average speed by 5-km splits and by first vs. second half-marathon as suggested by Foster, de Koning, & Thiel (2014). The magnitude of the differences or *effect sizes* (ES) were calculated according to Cohen's d (1998) and interpreted as small (<0.2 and <0.6), moderate (≥ 0.6 and <1.2), large $\geq$ or very large (≥2.0 and <4) according to the scale proposed by Hopkins and Cols. (2009). Significance for all analyses was set at $p<0.05$.

5.3.4. Results

The 15 world records analysed in this study, including the athlete's name, where and when the record was set, as well as the time (in seconds) for each section of the marathon are presented in Table 5.3.1.

Table 5.3.1. Times by sections of the 15 marathon world records between 1967 and 2014

		Final time	**Sections (s)**								
Athlete	*Date & Place*	*HH:mm:ss*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Kimetto	2014 - Berlín	2:02:57	882	882	886	866	872	870	849	882	388
Kipsang	2013 - Berlín	2:03:23	873	883	869	875	893	888	875	876	371
Makau	2011 - Berlín	2:03:38	877	880	875	878	888	860	878	899	383
Gebrelassie	2008 - Berlín	2:03:59	875	878	890	887	891	886	878	869	385
Gebrelassie	2007 - Berlín	2:04:26	884	883	890	894	895	891	883	870	376
Tergat	2003 - Berlín	2:04:55	901	897	890	897	898	882	875	878	377
Khannouchi	2002 - Londres	2:05:38	884	893	898	898	877	891	897	913	387
Khannouchi	1999 - Chicago	2:05:42	909	886	890	887	908	900	878	901	383
Da Costa	1998 - Berlín	2:06:05	921	917	925	914	881	876	881	880	370
Dinsamo	1988 - Rotterdam	2:06:50	905	900	901	894	912	901	909	898	390
Lopes	1985 - Rotterdam	2:07:12	898	906	920	886	887	904	911	922	398
Jones	1984 - Chicago	2:08:05	897	910	907	943	903	951	897	900	377
De Castella	1981 - Fukuoka	2:08:18	931	900	898	902	922	916	899	924	406
Clayton	1981 - Antwerpen	2:08:33	900	906	911	913	911	915	918	941	398
Clayton	1967 - Fukuoka	2:09:36	906	891	900	902	912	921	939	965	440

Figure 5.3.2. depicts the changes in the relative race speed of the world records. On average and analysing all world records together, athletes were slightly faster in the first

half marathon than in the second one, where they slowed down progressively (ES=0.28, small effect, Figure 5.3.2.A). However, when comparing the first half marathon to the second one in classic vs. contemporaneous athletes, we observed that classic athletes decreased their speed in the second half (ES=1.06, moderate effect, Figure 5.3.2.B), whereas contemporaneous athletes were faster in the second half of the race (ES=1.16, moderate effect, Figure 5.3.2.C).

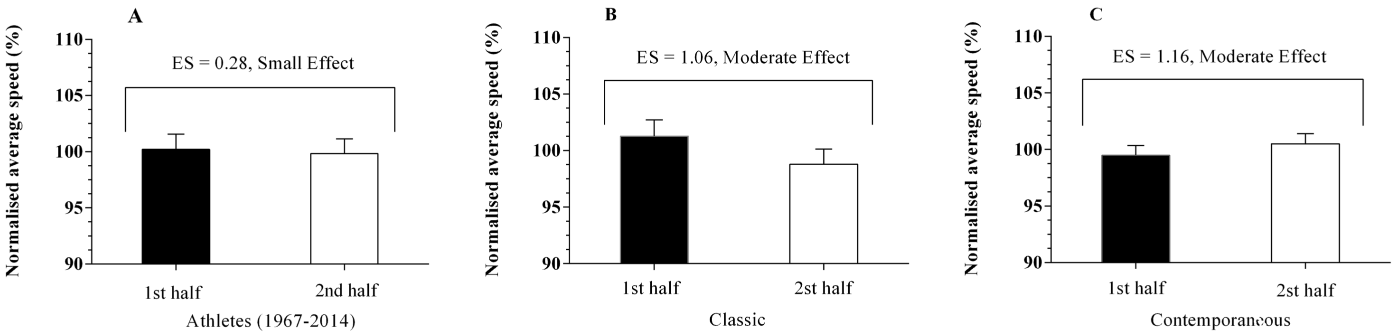


Figure 5.3.2. First half-marathon and second half-marathon normalised average speed comparison for the whole records analysed from 1967 to 2014 (A), for the Classic athletes (From 1967 to 1988) (B) and contemporaneous athletes (from 1988 to 2014) (C).

The normalised relative speed (%) by section of the classic world records (1967-1988) vs. contemporary records (1998-2014) is presented in Figure 5.3.3. Both groups used different pacing strategies during the marathon: the classic athletes started significantly faster than their contemporaneous counterparts (i.e. section 2: $p<0.03$, ES=1.16, moderate effect), although after 25 kilometres, the classic athletes' speed dropped dramatically, being meaningfully slower than in contemporaneous athletes (i.e. section 8, ES=2.41, very large effect).

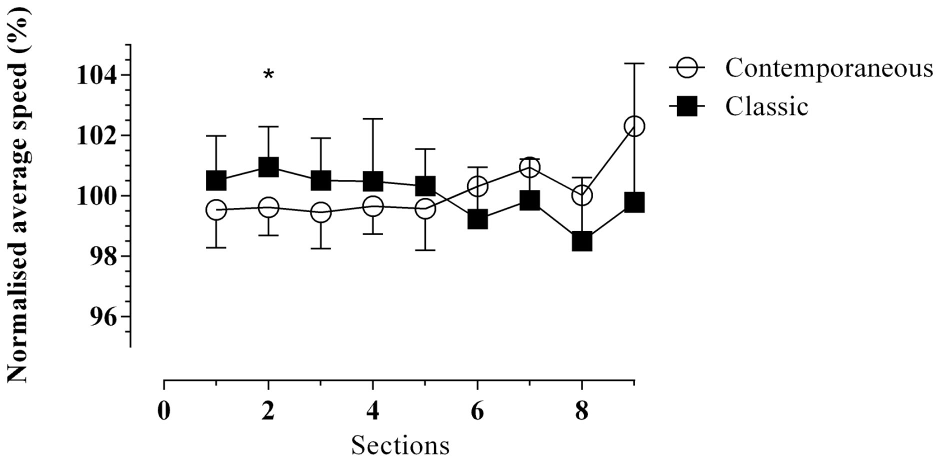


Figure 5.3.3. Normalised average speed in the different 5-km sections of the marathon for the classic and contemporaneous athletes.

The historical variation of pace according to the CV of the normalised average speed is depicted in Figure 5.3.4. A trend towards smaller pace variations during the race in recent years was observed when analysing the pacing strategies by 5-km splits (R=0.41; Figure 5.3.4.A) and by first vs. second half-marathon mean pace (R=0.40; Figure 5.3.4.B). The mean CV of the 5-km splits' speed when setting the classic world records was similar to that of the contemporaneous world records (1.45% vs. 1.40%); however, when analysing the mean CV in the first and second half-marathon, contemporaneous athletes had a lower speed variation than their classic counterparts (mean CV=0.88% vs. 1.39%).

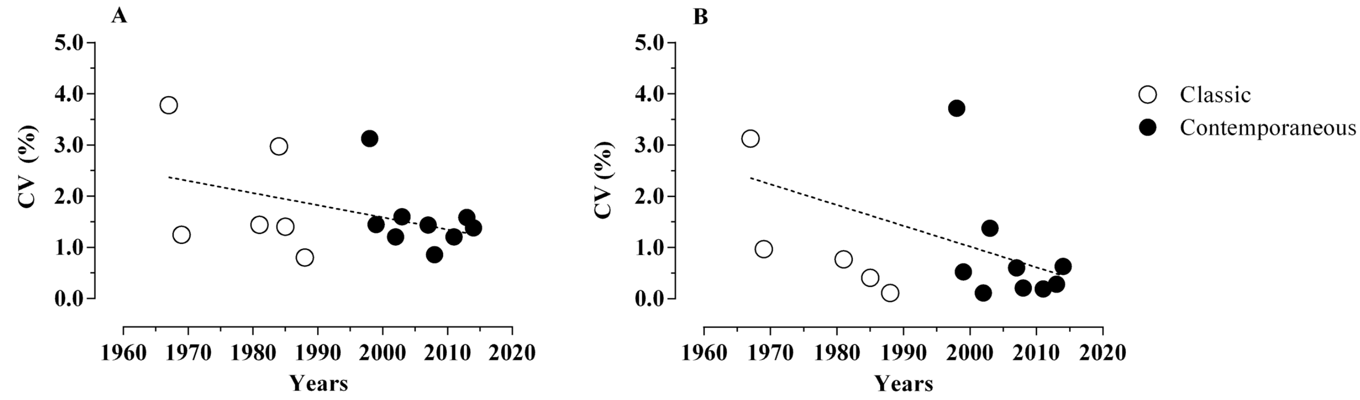


Figure 5.3.4. Historical evolution of the world records according to the coefficient of variation of the average speed by 5-km splits (A) and by first vs. second half-marathon (B).

The comparison between the current world record holder Dennis Kimetto's pacing strategy with Patrick Kipsang's and Derek Clayton's pacing is presented in Figure 5.3.5. Kimetto maintained more constant speeds in all 10-km sections of the race when comparing to Kipsang, who speeded up from section 3 to the end or the race ($p<0.02$, ES=6.18, very large effect) (Figure 5.3.5.A). In the case of the first record of our historical analysis, Derek Clayton started off the race significantly faster than Kimetto ($p<0.04$, ES = 4.03, very large effect), but slowed down dramatically at the end of the marathon (Figure 5.3.5B).

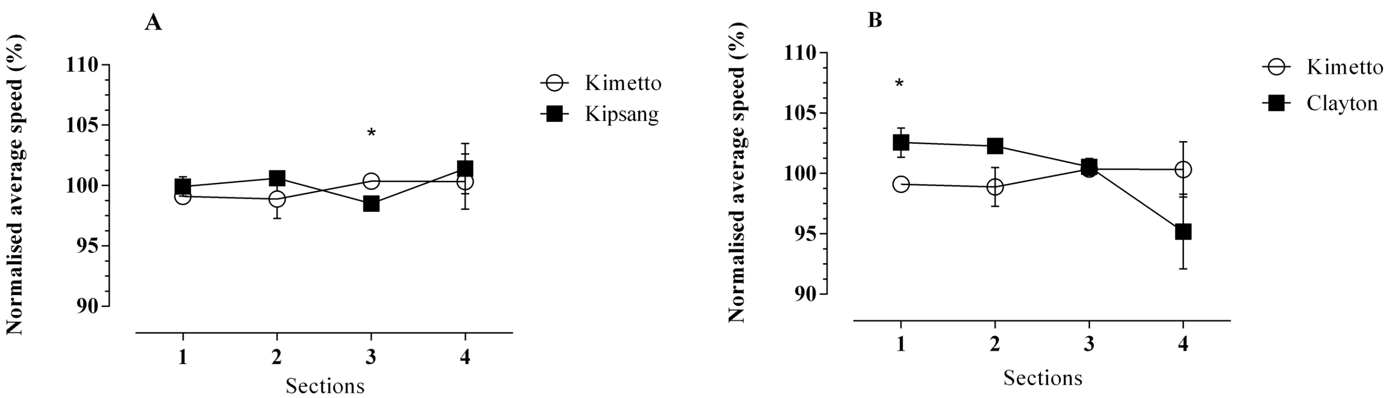


Figure 5.3.5. Normalised average speed in the different 10-km sections of the marathon for the last two world marathon records (Kimetto vs. Kipsang) (A) and the first and last word records of the last 50 years (Kimetto vs. Clayton) (B).

5.3.5. Discussion

The main finding of this study was that the pacing strategies of the best marathon runners in the world have changed over the last 50 years. From 1967 to 1988, athletes used to start off faster than the goal speed needed to break the world record, and due to these unsustainable initial speeds, they displayed significant speed losses in the last kilometres. However, since 1988, it seems that the pacing strategy has moved from a positive to a negative profile, with athletes completing the first kilometres of the marathon at a very stable pace (relatively slower than classic athletes), and speeding up from the 25th kilometre to the finish line.

A pacing strategy that allows athletes to distribute their energy, using all available energy resources, but not so early as to experience premature fatigue before the finish line is of paramount importance to achieve an optimum performance (Skorski & Abbiss, 2017; St. Clair Gibson et al., 2006). In this regard, although a negative pacing strategy (like the one used by contemporaneous athletes in this study) is suggested to be very efficient for a prolonged exercise, it is often not adopted in practice (Hanley, 2013).

Santos-Lozano, Collado, Foster, Lucia, and Garatachea (2014) and Nikolaidis and Knechtle (2017, 2018) found that a positive pacing (the second part of the race slower than the first one) was what the New York Marathon finishers used the most, regardless of gender and performance level. The prevalence of this suboptimal pacing strategy also in the best runners may be due to the race profile of the New York Marathon, which has a number of hills in the last kilometres, and because the leading group is gradually reduced in number, with only the best positioned able to keep the pace up. However, the common pacing drop observed in endurance events as a consequence of initial unsustainable speeds can be explained by other several reasons: 1) a glycogen depletion resulting in hypoglycaemia and hyperthermia (Coley, 2007); 2) a poor ability to resist fatigue (Abbiss & Laursen, 2008; Haney & Mercer, 2011,), 3) by peripheral fatigue caused by a failure of homeostasis in the exercised extremities (Hill & Lupton, 1923), 4) by the accumulation of lactate: if the pace is above the lactate threshold, it tends to accumulate in the muscles and in the blood, deactivating the enzymes for energy production (Pfitzinger & Douglas, 2001); 5) by a learning process (Lambert et al., 2004), 6) by the alteration of environmental conditions, affecting not only the supply of muscle oxygen and peripheral fatigue, but can also the central motor drive to the skeletal muscles (Davies et al., 2016; Ely et al., 2008; Trubee, Vanderburgh, Diestelkamp, & Jackson, 2014), and 7) by other variables such as experience or training status (Trubee et al., 2014).

Classic athletes in this study displayed positive pacing profiles, with large speed drops in the second part of the marathon (Figures 5.3.2. and 5.3.3.), while contemporaneous athletes showed negative pacing profiles, being the last 5-km sections of the race the fastest ones (from 30 to 35 km and from 35 to 40 km). The end-spurt in the last 2.195 km is present in both classic and contemporaneous athletes and may be due to the knowledge of the finish line, encouraging runners to mobilise the last energy reserves (Skorski & Abbiss, 2017). Interestingly, the key change in the pacing strategies used by world record holders (that is, a faster second half) coincides in time with the emergence of runners of African origin, mostly from Ethiopia and Kenya (Nikolaidis, Onywera, & Knechtle, 2017; Tucker, Onywera, & Santos-Concejero, 2015). Since the Ethiopian

Belayneh Densamo broke the world record in 1988, only one athlete not born in Africa has possessed the world record again, the Brazilian Ronaldo Da Costa from 1998 to 1999. A recent survey on Kenyan elite runners found that these athletes are able to maintain their cerebral oxygenation within a stable range during a maximum self-paced exercise (Santos-Concejero et al., 2015), in contrast to runners of European origin (Billaut, Davis, Smith, Marino, & Noakes, 2010). Santos-Concejero et al. (2015) suggested that this ability to avoid a drop in their brain oxygenation might be a contributing factor to the Kenyan dominance in long-distance running events. This also offers the intriguing possibility that the more efficient negative pacing strategy used by contemporaneous athletes may even have a physiological basis. Interestingly, prior to the period analysed in this study, an Ethiopian runner (Abebe Bikila), broke the world record and won two Olympic gold medals in Rome 1960 and Tokyo 1964. Bikila's pacing strategy was similar to that of contemporaneous runners analysed in this study: stay with the leaders during the first half-marathon and then slowly increase the pace until the end of the race. Whether the ability to break world records displaying negative pacing strategies is inherent to African runners certainly deserves further attention.

The question arises whether a negative pacing strategy is in fact the most efficient one. For example, when setting the current world record holder, Dennis Kimetto, adopted a very constant and uniform speed pattern throughout the competition (Figure 5.3.5.). This contrasts with the negative pacing strategy used by Kipsang (significantly faster second half) and the positive strategy used by Clayton (significantly faster first half) when they broke the world records in 2013 and 1967, respectively. Previous research has suggested that in the second half of a race, two important factors come into play 1) homeostasis, where the brain may subconsciously coordinate a regulation response to ensure that exercise intensity does not exceed the physiological limits of the body (Edwards, Bentley, Mann, & Seaholme, 2011; Faulkner, Parfitt, & Eston, 2008) and, 2) the index of the perceived effort; minor in the fastest runners due to a greater experience to suffer symptoms associated with exercise (Faulkner et al., 2008). Maybe, a completely stable pacing strategy, with an average speed every 5-km almost equal for the whole race should be the pacing goal for future world record seekers as our analysis of the historical variation of pace suggests (Figure 5.3.4.). The observed trend towards smaller pace variations during the marathon in recent world records suggests that more stable pacing strategies may be key for improved performance (Foster et al., 2014).

5.4. STUDY 4: MEN VS. WOMEN WORLD MARATHON RECORDS' PACING STRATEGIES FROM 1998 TO 2018.

5.4.1. Introduction

The pacing strategies used during athletic competitions is a topic that has been of great interest to sports scientists due to their influence on performance (Díaz, Fernández, & Santos-Concejero, 2018; Foster et al., 1993). Likewise, the availability of data on marathon events has allowed the pacing to be studied in elite athletes (Abbiss & Laursen, 2008; Díaz et al., 2018; Ely, Martin, Cheuvront, & Montain, 2008; Muehlbauer, Panzer, & Schindler, 2010; Vleck, Bentley, Millet, & Burgi, 2008), determining that an optimal pacing strategy may provide elite marathon runners with an economical pathway to significant performance improvements at world-record level (Angus, 2014).

Recent studies have reported that top runners display less variability in their running speed when compared to lesser performers (Ely et al., 2008; Renfree & Gibson, 2013; Santos-Lozano, Collado, Foster, Lucia, & Garatachea, 2014). These differences in the pacing strategies used have no only been observed in runners of different athletic ability but also when comparing men vs. women (Deaner, Carter, Joyner, & Hunter, 2015). For example, women have been reported to use more stable running speeds throughout the competition (March, Vanderburgh, Titlebaum, & Hoops, 2011; Trubee, Vanderburgh, Diestelkamp, & Jackson, 2014), in contrast with men, who usually decreased their pace in the last part of the race (Deaner et al., 2015; Trubee et al., 2014). This contrasts, however, with a recent study by Nikolaidis and Knechtle (2018) who observed how in the New York maratón both men and women reduced the speed during the race and increased it in the last stretch of the competition (40–42.2 km).

These pacing strategy differences observed between men and women may be due to physiological factors including the greater susceptibility of men to the depletion of muscle glycogen (Carter, Rennie, & Tarnopolsky, 2001; Roepstorff et al., 2002; Tarnopolsky, 2008) and the lower fatigability of skeletal muscle in women (Hunter, 2014) or non-physiological factors, such as differences in the decision making (Allen & Dechow, 2013). In this regard, previous research suggests that men are more likely to adopt aggressive pacing strategies at the beginning of the race that they cannot maintain during the entire competition (Deaner et al., 2015).

Although it is known that sex and performance level influence the type of strategy used during the marathon (Deaner et al., 2015; March et al., 2011), the question arises whether the pacing strategies used by female and male world record holders differ. Thus, the aim of this study was to analyse the pacing strategies adopted by elite male and female marathon runners when setting every world record in the last 20 years. We hypothesised that female world records were achieved with more uniform patterns than male records.

5.4.2. Aim of the study

The aim of this study was to analyse the pacing strategies adopted by elite male and female marathon runners when setting every world record in the last 20 years. We hypothesised that female world records were achieved with more uniform patterns than male records.

5.4.3. Methods

The Ethics Committee for Research on Human subjects of the University of the Basque Country UPV/EHU granted permission for this study. Data were gathered from a publicly accessible website (Association of Road Running Statisticians' website, accessed 10 December 2018) providing the official marathon world records for men and women between 1998 and 2018 (when the last world record was set), which resulted in a sum of 18 world records. Each set of information included at least: the position, category, official final time, half of the marathon time and time data every 5 km.

The total distance of the marathon was divided into eight sections of 5-km and one section of 2.195 km, and time needed to complete each section was calculated in seconds. Full marathon average speed and the average speed of each section were calculated individually. The relative speed of each section for every runner was then calculated and presented as a percentage of the average speed for the full race.

Athletes analysed were divided into two groups: group of men (record holders between 1998 and 2018) and group of women (record holders between 1998 and 2017). Lastly, we compared the pacing strategies of the current world record holder Eliud Kipchoge (2:01:39 established in the Berlin Marathon, September, 16th 2018) with the current holder of the women's record Paula Radcliffe (2:15:25 established in the London Marathon, April, 13th 2003) and the first male and female record holders of the time frame analysed in this study, Da Costa (2:06:05 established in the Berlin Marathon, 20th September 1998) and Tegla Loroupe (2:20:47 established in the Rotterdam Marathon, 19th April 1998). In addition, we divided the women's records into two sub-groups: women's records achieved with male pacemakers (1998-2003) and female records achieved without male pacemakers (2005-2017). Subsequently, we compared the coefficient of variation (CV) of all the women's world records *vs*. men's.

Statistical analysis

Statistical analyses of data were performed using the Statistical Package for the Social Sciences 21.0 (SPSS, Armonk, New York). Data were screened for normality of distribution and homogeneity of variances using a Shapiro-Wilk normality test and a Levene test, respectively. The Shapiro-Wilk test and Levene test determined that the variables were normally distributed with homogeneous variances (p-values > 0.05). An independent samples and a paired samples Student's t-test were used to compare the first *vs.* the second half of the marathon world records between and within sexes, respectively. Two-way analysis of variance (ANOVA) with repeated measures for time was used to compare the pacing strategies between groups (men *vs*. women). When differences were found, a Tukey’s range test was used for *post hoc* comparisons. The pacing differences between women and men were assessed by the coefficients of variation (CV) of the average speed in each of the world records as suggested by Foster, de Koning and Thiel (2014). The magnitude of the differences or *effect sizes* (ES) were calculated according to Cohen’s d (1998) and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2), large (≥1.2 and < 2.0) or very large (≥2.0 and <4) according to the scale proposed by Hopkins et al. (2009). Significance for all analyses was set at $p<0.05$.

5.4.4. Results

Table 5.4.1. shows the 8 world records of women's marathon (1998-2017) and the 10 world records achieved by men (1998-2018) in the last 20 years. Figure 5.4.2. shows the comparison of the mean first and second half of the marathon speed used by men and women when setting the world records. Female athletes maintained similar speeds in the first and second half of the marathon (ES=0.22, small effect, p=0.705), whereas male athletes increased their speed as the marathon progressed (ES=1.18, moderate effect, p=0.011). However, we found no differences during either the first half (ES=0.56, small effect, p=0.290,) or the second half of the race (ES=0.60, moderate effect, p=0.266, Figure 5.4.2.C) when comparing men and women (1998-2003).

Table 5.4.1. Times by sections of the 18 marathon world records from 1998 to 2018. "Women A" refers to female World records achieved with male pacemakers, and "Women B" to female World records achieved without male pacemakers.

			Final time	**Sections (s)**								
Gender	**Athlete**	*Date & Place*	*HH:mm:ss*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Women B	Keitany	2017 - London	2:17:01	15:31	15:46	15:58	16:11	16:17	16:22	16:34	16:59	07:23
	Radcliffe	2005 - London	2:17:42	15:47	16:30	16:17	16:21	16:08	16:24	16:40	16:19	07:16
Women A	Radcliffe	2003 - London	2:15:25	16:13	16:14	16:13	16:06	16:02	15:58	15:55	16:13	06:56
	Radcliffe	2002 - Chicago	2:17:18	16:27	16:20	16:18	16:21	16:08	16:06	16:05	16:23	07:10
	Ndereba	2001 - Chicago	2:18:47	17:41	16:28	16:31	16:05	16:04	16:15	16:17	16:24	07:02
	Takahashi	2001 - Berlin	2:19:46	16:45	16:25	16:27	16:34	16:18	16:33	16:27	16:41	07:36
	Loroupe	1999 - Berlin	2:20:43	16:20	16:12	16:40	16:52	17:11	17:23	16:29	16:26	07:10
	Loroupe	1998 - Rotterdam	2:20:47	16:35	16:34	16:31	16:45	16:58	16:36	16:34	16:57	07:17
Men	Kipchoge	2018 - Berlin	2:01:39	14:24	14:37	14:37	14:18	14:28	14:21	14:16	14:31	06:07
	Kimetto	2014 - Berlin	2:02:57	14:42	14:42	14:46	14:26	14:32	14:30	14:09	14:42	06:28
	Kipsang	2013 - Berlin	2:03:23	14:33	14:43	14:29	14:35	14:53	14:48	14:35	14:36	06:11
	Makau	2011 - Berlin	2:03:38	14:36	14:41	14:34	14:39	14:48	14:20	14:38	14:59	06:23
	Gebrselassie	2008 - Berlin	2:03:59	14:35	14:38	14:50	14:47	14:51	14:46	14:38	14:29	06:25
	Gebrselassie	2007 - Berlin	2:04:26	14:44	14:43	14:50	14:54	14:55	14:51	14:43	14:30	06:16
	Tergat	2003 - Berlin	2:04:55	15:01	14:57	14:50	14:57	14:58	14:42	14:35	14:38	06:17
	Khannouchi	2002 - London	2:05:38	14:44	14:53	14:58	14:58	14:37	14:51	14:57	15:13	06:27
	Khannouchi	1999 - Chicago	2:05:42	15:09	14:46	14:50	14:47	15:08	15:00	14:38	15:01	06:23
	Da Costa	1998 - Berlin	2:06:05	15:21	15:17	15:25	15:14	14:41	14:36	14:41	14:40	06:10

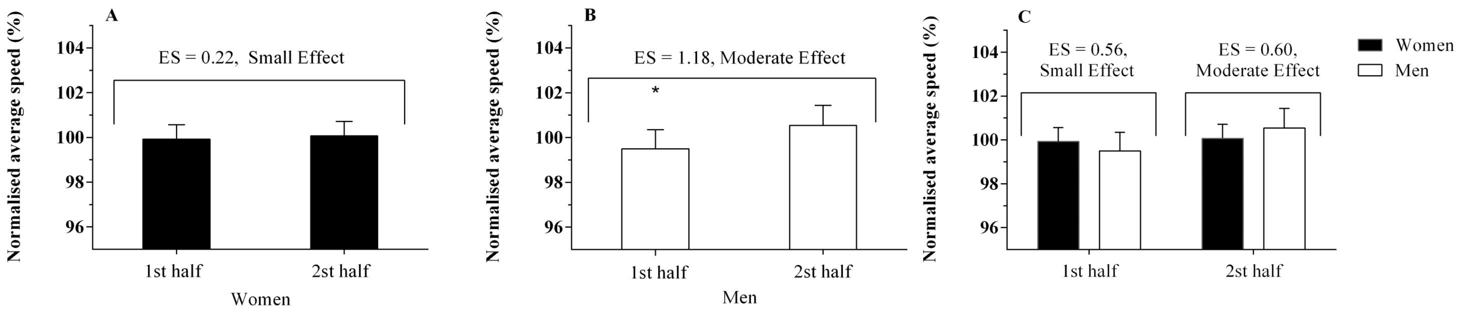


Figure 5.4.2. First half-marathon and second half-marathon normalised average speed comparison for women (A), men (B) and men *vs*. women (C).

The normalised average speed (%) of the women's world records (1998-2003) *vs*. men's records (1998-2018) by sections is depicted in Figure 5.4.3. There were no differences between men and women apart from the second section (ES=0.89, moderate effect) and the last section of the race (ES=0.87, moderate effect), where men meaningfully increased their speed as the finish line approached.

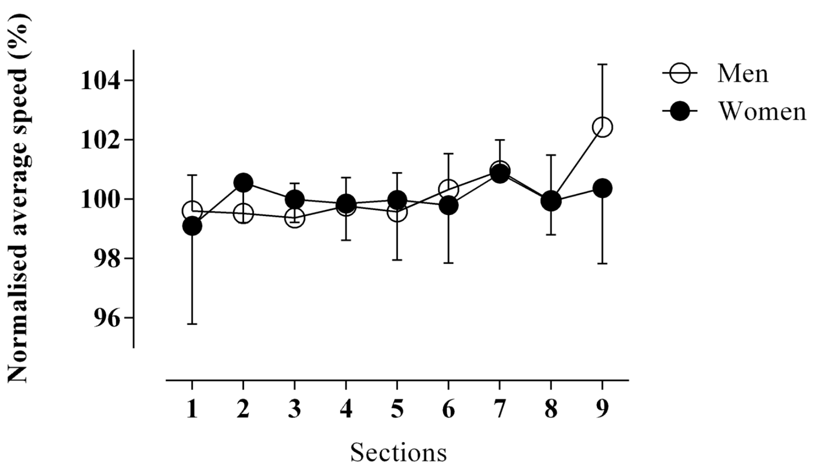


Figure 5.4.3. Normalised average speed by 5-km sections of the marathon for the female world records (1998-2003) *vs*. male records (1998-2018).

The variation of pace between women and men was calculated according to the CV of the normalised average speed. A trend towards smaller pace variations during the race in male athletes was observed (mean CV=1.53% ± 0.60, R=0.18) in contrasts with female world records, which presented higher pace variations (mean CV=2.28% ± 0.95, R=0.20), in part due to the influence of the records set after 2005 (with female pacemakers).

When comparing the normalised average speed (%) of the last 2 world records for women (with male pacemakers) and men (Paula Radcliffe 2003 and Eliud Kipchoge 2018, Figure 5.4.4.A), we observed a very similar pacing profile with a conservative first 5-km split and a progressive increment of the speed in the following sections. In the case of the first male and female records of the time frame analysed (Tegla Loroupe and Ronaldo Da Costa, both set in 1998 Figure 5.4.4.B), the pacing strategy used differed, as Da Costa employed a negative pacing strategy with a faster second half of the marathon and a dramatic *endspurt* in the last section, whereas Loroupe ran at a much more constant pace during the whole race.

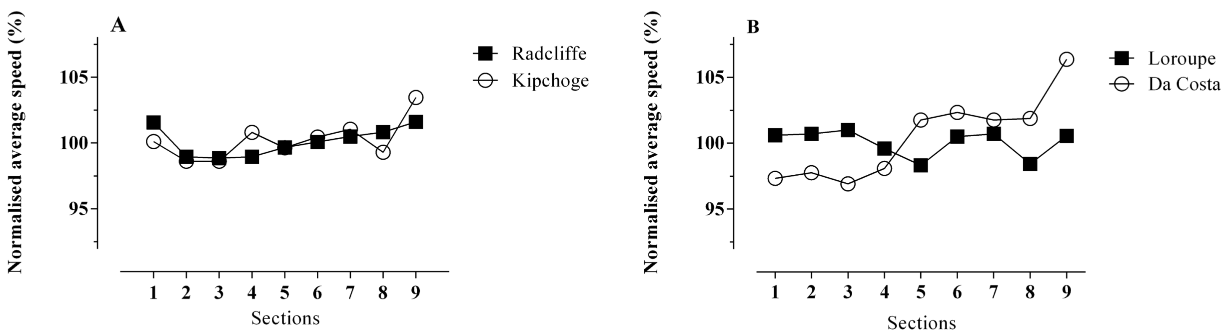


Figure 5.4.4. Normalised average speed by 5-km sections of the marathon for the last two world records for women and men (Paula Radcliffe 2003 *vs*. Eliud Kipchoge 2018) (A) and the first male and female records of the time frame analysed (Tegla Loroupe *vs*. Ronaldo Da Costa) (B).

5.4.5. Discussion

The main finding of this study was that men used pacing profiles characterised by a faster finishing when setting the marathon world records, whereas women ran less evenly than men, with no differences in the mean speed adopted in the first and second half of the marathon.

The negative pacing strategies (faster finishing) used by male athlete's world records (Figures 5.4.2. and 5.4.3.) has been reported as the most appropriate strategy for a prolonged exercise such as the marathon, mainly due to the lower reduction of carbohydrate depletion, lower oxygen consumption and lower concentration of blood lactate (Hanley, 2014). The speed drop in long-endurance sports is also influenced by factors including pacing regulation, the ability to resist fatigue (Abbiss & Laursen, 2008; Haney & Mercer, 2011), and other variables such as experience or training level (Knechtle, Rosemann, Zingg, Stiefel, & Rust, et al., 2015; Trubee et al., 2014).

When we analysed the average speed normalised by sections, we observed how male athletes completed the first kilometres of the race at a more stable pace, accelerating and achieving the highest percentages of race speed from kilometre 30. Although women used a less uniform pacing throughout the competition, in the last section of the marathon they also seem to increase their speed (Figure 5.4.3.). This may be due to their knowledge of the finish line, which encourages runners to mobilise their last energy reserves (Skorski & Abbiss, 2017).

This finding differs from those reported so far by the literature that holds that male athletes are more susceptible to the deceleration of speed during the marathon in relation to female athletes (Deaner, et al., 2015). We observed how the male world records are achieved with better pacemakers than female records. As such, during the last world record, Kipchoge ran with three pacemakers until approximately the 26th kilometre, and from the 30th kilometre onwards, they managed to go 53 seconds below the world record. Undoubtedly, the pacing used was adjusted to perfection to break the record. The use of one pace or another by athletes may have physiological consequences such as the increased risk of hyperthermia and glycogen depletion (Brooks, 2007; Coyle, 2007; Ely et al., 2008). Likewise, when the heart rate, the respiratory exchange ratio and the blood lactate concentration between male and female athletes have been compared, a greater physiological tension in women has been reported in the literature (Helgerud et al., 1990).

When we compared the current holders of the men's world record *vs*. women (Kipchoge *vs*. Radcliffe), we observed (Figure 5.4.4.) how both athletes adopted a more constant and uniform speed pattern during the whole competition in line with the study by Hanley (2016). Hanley (2016) observed how the elite runners competing in Olympic marathons and the IAAF World Championship showed a constant strategy from kilometre 10 onward. Similarly, Nikolaidis & Knetchtle (2017a, 2017b, 2018) discovered how the fastest runners in the New York Marathon adopt a more uniform pacing.

However, we observed how the first records of the timeframe analysed in this study used different strategies. While Da Costa (2:06:05 established in the Berlin Marathon, 20th September 1998) used a negative pacing, increasing speed from the second half of the test, Loroupe (2:20:47 established in the Rotterdam Marathon, 19th April 1998) (like Radcliffe) maintained more constant pacing. Possibly, the use of male pacemakers in the women's records between 1998 and 2003 helped to achieve more constant pacing strategies, and subsequently, better final times. Pacemakers can bear the psychological burden when it comes to setting the pace of competition and improving performance (Zouhal et al., 2015). On one hand, when the athletes had pacemakers, lower blood lactate concentrations are observed, and on the other hand, they reduce the rating of perceived exertion (Zouhal et al., 2015). In this sense, running with pacemakers helps eliminating air resistance, saving energy and reducing oxygen consumption by 8% (Pugh, 1970). In addition, Rauch, Schönbächler, and Noakes, (2013) indicated that pacemakers could act as a placebo effect, increasing athlete motivation to maintain the pace and even to increase it in the final kilometres.

Haney and Mercer (2011) determined that changes in the terrain, the elevation and the environmental temperature are factors that can influence the drastic reduction of the pace. In this regard, the historical best times in marathon have been achieved with cold environmental temperatures (10-15º C) during spring or fall (El Helou et al., 2012). It has been reported that Berlin and London are the fastest marathons of the World Marathon Majors in both men and women, showing the best end times and most of the world records (Maffetone, Malcata, Rivera, & Laursen, 2017). As such, every male world record since 2003 (Paul Tergat) to 2018 (Eliud Kipchoge) has been broken in

Berlin, considered an ideal race for records due to several factors: it is flat with few corners, starting at 38 m above sea level, never reaches more than 53 m or less than 37 m and the last 15 km are slightly downhill. In addition, the average temperature by the end of September is 15°C. In contrast, in London, where the latest women's world records have been broken, the race profile is more variable (-1 m lower altitude at 55 m maximum altitude), there are turns more frequently and the first part of the race is downhill. This suggests that in the future is more likely to see a world record or even a sub 2-h marathon in Berlin than in any other location.

6.- CONCLUSIONS

"La ciencia, muchacho, está hecha de errores, pero de errores útiles de cometer, pues poco a poco, conducen a la verdad" (Julio Verne).

6. CONCLUSIONS

(1) Athletes, regardless of sex and performance level, who are able to adopt the right pacing strategy during the competition (that is, a negative or a constant pacing strategy), will be able to achieve faster times, and even finish ahead of other runners with higher physiological abilities using less efficient pacing.

(2) In terms of potential venues for future world record attempts, historical data suggests that Berlin, which owns the 7 best performances of all time over this distance in men, is the most likely candidate whilst such a performance is unlikely in New York or Boston.

(3) The pacing strategies of the best marathon runners in the world have changed over the last 50 years. *Classic* athletes used to start off relatively faster than their contemporary counterparts, and consequently, they used to slow down dramatically in the second half of the race. Although a negative pace distribution has been proposed as the most efficient option, a pacing strategy characterised by very little speed changes across the whole race may be the way to go in the future.

(4) Men and women have used different strategies when breaking world marathon records in the last 20 years. While male athletes increased speed as the race progressed (*negative* strategy), female athletes used a less uniform pacing throughout the competition.

7.- Bibliografía

"Nací con una lista de lectura que nunca terminaré" (Maud Casey).

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7.2. FUENTES DE LAS FIGURAS

Figura 1, página 2. https://www.gettyimages.es/

Figura 2, página 9. https://www.gettyimages.es/

Figura 3, página 19. https://www.gettyimages.es/

Figura 4, página 23. https://www.gettyimages.es/

Figura 5, página 40. https://www.gettyimages.es/

Figura 6, página 43. https://pictures.reuters.com/

Figura 7, página 94. https://www.gettyimages.es/

Figura 8, página 97. Propia elaboración.

Figura 9, página 147. https://www.gettyimages.es/

ANEXO 5

COMUNICACIONES EN CONGRESOS

23rd annual Congress of the
EUROPEAN COLLEGE OF SPORT SCIENCE
SPORT SCIENCE AT THE CUTTING EDGE
4 - 7 July 2018, Dublin - Ireland
Hosted by University College Dublin & Ulster University

ECSS DUBLIN 2018

EUROPEAN COLLEGE OF SPORT SCIENCE

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GERMANY

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Dublin, 09.07.2018 - 12:04:30

Confirmation of Presentation

This is to certify that the following title has been presented at the 23rd Annual Congress of the European College of Sport Science between 4 - 7 July 2018 in Dublin - Ireland:

Jordan Santos-Concejero

University of The Basque Country UPV/EHU
Portal de Lasarte 71
01007 Vitoria-Gasteiz, Spain

Abstr.-ID: 674, Presentation format: Oral , Session name: OP-PM64 - Pacing 2
Title: THE INFLUENCE OF PACING STRATEGY ON MARATHON WORLD RECORDS
Authors: Santos-Concejero, J., Fernández, E.J., Díaz, J.J.
Institution: University of The Basque Country UPV/EHU
Presentation date: 05.07.2018, 18:00, Lecture room: Wicklow Meeting Room 1, No: 6

Institute for Sport and Health, UCD & Ulster University School of Sport

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was offset by being significantly faster in the second race section (d = 0.27 – 0.66) and the penultimate race section compared to all groups (d = 0.23).
Participants who had previously completed between 4 and 9 races were quickest (~22.81 ± 3.3 km/h) to complete the course (d = 0.26 – 0.5), followed by those who had previously participated on 2-3 occasions (~21.9 ± 3.6 km/h; d = 0.2 – 0.26). Those that had completed 4-9 races exhibited a lower relative speed than all other groups in the final race section (d = 0.21 – 0.34), which was offset by having a higher relative speed across each race section compared to other groups.
CONCLUSION: Pacing and performance in cross-country marathon mountain biking is related to age, sex and race experience. Specifically, better performance was observed in younger age groups, males, and those that had previously performed 4-9 races. These groups typically adopted a greater relative speed in climbing race sections and lower relative speed during later descents.
References: Abbiss CR. Megan L. Garvican L. Ross N. Pottgiesser J. Martin D. (2013) J Sports Sci, 7, 787-794.

THE INFLUENCE OF PACING STRATEGY ON MARATHON WORLD RECORDS

SANTOS-CONCEJERO, J., FERNÁNDEZ, E.J., DÍAZ, J.J.
UNIVERSITY OF THE BASQUE COUNTRY UPV/EHU

INTRODUCTION: The limits of human performance in the marathon are still debated although several authors have proposed a potential limit that lays between 1:57:58 and 2:01:52 (Joyner et al, 1991; Denny, 2008). The pacing strategy adopted during the competition is one of the key factors in determining marathon performance as athletes can win or lose depending on their ability to spend energy adequately and prevent premature fatigue before the end of the event. The question arises whether the pacing strategies adopted by world record holders over the last decades and recent years has been ideal and whether there is still margin for improvement. Thus, the aim of this study was to analyse the influence of the pacing strategies used by marathon world record holders when setting every world record in the last 50 years.
METHODS: We divided former marathon record holders into two groups: classic runners (record holders between 1967 and 1988) and contemporaneous runners (record holders between 1988 and 2018). The total distance of the marathon was divided into eight sections of 5 km and one last section of 2.195 km, and the relative average speed of each section was calculated individually.
RESULTS: On average and analysing all world records together, athletes were slightly faster in the first half marathon than in the second one, where they slowed down progressively (ES=0.28, small effect). However, when comparing the first half marathon to the second one in classic vs. contemporaneous athletes, we observed that classic athletes decreased their speed in the second half (ES=1.06, moderate effect), whereas contemporaneous athletes were faster in the second half of the race (ES=1.16, moderate effect). When analysing the normalised relative speed (%) by section of the classic world records vs. contemporary records, we observed that both groups used different pacing strategies: the classic athletes started significantly faster than their contemporaneous counterparts (p=0.03, ES=1.16, moderate effect), although after 25 kilometres, the classic athletes' speed dropped dramatically, being meaningfully slower than in contemporaneous athletes (ES=2.41, very large effect).
CONCLUSION: This study shows that the pacing strategies of the best marathon runners in the world have changed over the last 50 years. Classic athletes used to start off relatively faster, and consequently, they used to slow down dramatically in the second half of the race. Although a negative pace distribution has been proposed as the most efficient option, a pacing strategy characterised by very little speed changes across the whole race may be the way to go in the future.

Oral presentations

OP-PM50 Ageing and age related disease

ENTROPY IN POSTURAL AND CARDIAC-AUTONOMIC CONTROL AS A MARKER OF ADAPTABILITY TO A MENTAL TASK IN YOUNG VS. MIDDLE-AGED HEALTHY MALES

BLONS, E.1, GILFRICHE, P.1,2, ARSAC, L.M.1, DESCHODT-ARSAC, V.1
UNIV. BORDEAUX

INTRODUCTION: A number of studies have shown that the time series generated by diverse free-running healthy physiologic dynamics demonstrate complex fluctuations that are not simply due to uncorrelated random errors. This is true for physiological systems whose main purpose seems to be reducing variability and maintaining a steady state, as for example, postural control and cardiac autonomic control (1). Complexity is closely linked to coordination between systems components so that a too a regular (metronomic) or a too an erratic (random) signal output, has been associated with abnormal control, pointing to a lack flexibility to adapt to everyday life demands. Complexity indices such as signal entropy are believed to be greater markers of neurophysiological control than temporal and frequency markers (2). Here we aimed at assessing signal complexity/regularity (entropy) in both postural and cardiac control when young and middle-aged healthy subjects are challenged by a mental task.
METHODS: Twelve young and eleven middle-aged healthy males participated to the present study. Heart inter-beat (RR) time series and center of pressure (CoP) oscillations were obtained in quite conditions (Control), and again when performing a prefrontal cortex activating task (Cognitive task). RR intervals were recorded (Polar belt) during 10min and CoP displacement (Winposturo platform) during 51.2s at 40Hz. Multiscale Entropy (MSE) was computed between scales 1-4 for RR series and 1-10 for CoP series. The entropy index EI was derived by calculating the area under the curve produced by the calculation of sample entropy at each time scale.
RESULTS: In control situations, the entropy index (EI) in heart and postural control showed no difference between young and middle-aged. In contrast, differences due to age appeared when confronted to a cognitive load both in postural and in heart control. In heart control, EI increased in young (Control: 5.4 ± 0.2 vs Cognitive task: 5.9 ± 0.1, $p<0.05$) but not in middle-aged during mental task (Control: 5.3 ± 0.2 vs Cognitive Task: 5.2 ± 0.3). In CoP signal, EI increased dramatically in young (Control: 5.2 ± 0.4 vs Cognitive task: 7.5 ± 0.4, $p<0.01$) but moderately in middle-aged (Control: 5.8 ± 0.6 vs Cognitive task: 7.5 ± 0.8, $p<0.05$).
CONCLUSION: In young people, prefrontal cortical arousals associated with a cognitive task increased entropy in cardiac and postural signal output, which is interpreted as an improved multiscale coordination in neurophysiological control. No such positive response was observed in middle-aged. This might rely on a disrupted interconnectivity between central and peripheral systems components when constrained by a cognitive task. The present results point to MSE as a sensitive, and thus promising tool, to evaluate early stages in impairments in neurophysiological control associated with ageing.

ANEXO 6

CERTIFICADO ESTANCIA INTERNACIONAL

University of Worcester

School of Sport & Exercise Science
Direct Line: 01905 55376
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15th April 2019

Dear Mr Jose Joaquin Diaz Martin

We wish to thank you for your visit to the University of Worcester from 14th of the January to the 15th of April 2019. During this time you participated in our MSc Applied Sports Science programme, and contributed to classes in exercise physiology and the limits to human performance. You also collaborated with myself on the writing of a paper analysing pacing and performance in the 6 World Marathon Majors.

We hope that this visit results in further collaborative projects and we would like to produce further outputs on this topic in future.

Yours faithfully,

Dr Andy Renfree
Principal Lecturer in Sport and exercise Science
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KIPCHOGE