Programa de doctorado en Deporte y Salud

EJERCICIO FÍSICO Y FUNCIÓN COGNITIVA EN ADULTOS MAYORES

Tesis Doctoral

Presentada por

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INFORMA:

Que Dña. *Laura Carbonell Hernández ha* realizado bajo nuestra supervisión el trabajo titulado *"Ejercicio físico y función cognitiva en adultos mayores"* conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo con el Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmo para los efectos oportunos,

En Elche a ……. de …………………….. de 202….

Director de la tesis

Dr. Diego Pastor Campos

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El Dr. D. *Francisco Javier Moreno Hernández*, Coordinador/a del Programa de Doctorado en **Deporte y Salud**

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Que Dña. *Laura Carbonell Hernández* ha realizado bajo la supervisión de nuestro Programa de Doctorado el trabajo titulado *"Ejercicio físico y función cognitiva en adultos mayores"* conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo con el Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

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RESUMEN

Se ha demostrado que las habilidades cognitivas se consolidan durante la adolescencia y alcanzan su máxima eficiencia durante la juventud. Por desgracia, cuando empezamos a envejecer comienza su deterioro. Esta disminución tiene un efecto directo en la vida diaria de las personas mayores, afectando a su calidad de vida y funcionalidad. Es por ello por lo que resulta importante buscar fórmulas para detener o lentificar este proceso. La evidencia científica muestra el ejercicio físico como una herramienta útil para reducir el deterioro cognitivo e incluso mejorarlo durante el envejecimiento. Además, la literatura científica lleva tiempo intentando explicar las variables de prescripción de ejercicio de podrían influir en esas mejoras de la función cognitiva en el envejecimiento. Por tanto, el objetivo de la presente tesis fue ayudar a incrementar el conocimiento de la relación de dichas variables para una correcta prescripción de ejercicio físico en beneficio de la función cognitiva de las personas mayores.

El presente documento presenta una serie de investigaciones para analizar el efecto del ejercicio físico en la función cognitiva de las personas mayores en relación con el tipo y la intensidad del ejercicio físico, tanto de forma aguda como crónica. En un estudio previo realizado se comprobó el efecto crónico del ejercicio físico en la respuesta cognitiva de las personas mayores al participar en un programa de ejercicio físico durante 6 meses. El resultado de dicho estudio implicó una mejora en algunas variables de la condición física, pero no una mejora en la función cognitiva. Al analizar los posibles motivos por los que no se había logrado una mejora de la función cognitiva, se observó que la baja adherencia, la falta de mejora de la condición física aeróbica, y la falta de control de la intensidad, podían haber sido la consecuencia de estos resultados. En consecuencia, se planteó en esta tesis un primer estudio para determinar la forma más eficaz de valorar la intensidad del ejercicio, comprobando la ineficacia de la acelerometría con el fin de valorar

las sesiones de ejercicio físico, especialmente aquellas que no estaban centradas en desplazamientos constantes. En un segundo estudio se observó de forma aguda si diferentes tipos de ejercicios producían diferente impacto en la función cognitiva y si éste era dependiente del SNP de BDNF. Dicho estudio mostró que no parece haber diferencias en los beneficios en la función cognitiva según el tipo de actividad, sino que es la intensidad la que podría ser el elemento diferenciador.

Con el fin de poder generar transferencia a la sociedad, se participó en dos proyectos europeos cuya finalidad fue la creación de dos manuales de ejercicio que permitieran aplicar en diferentes entornos de la Comunidad Europea el conocimiento adquirido. Como resultado de la aplicación de los manuales creados a nivel europeo, se pudo observar que el entrenamiento físico es la estrategia determinante para mantener la función cognitiva y que, mejorar la condición física de las personas mayores, independientemente de su edad, produce mejoras en su bienestar subjetivo que ayuda a aumentar su calidad de vida. Por último, se elaboró una recopilación de lo aprendido y las perspectivas futuras de la investigación y se publicó una editorial en una revista científica.

En conclusión, los hallazgos obtenidos muestran la capacidad del ejercicio físico para producir respuestas tanto físicas como cognitivas, así como agudas y crónicas, también se evidencia la necesidad de controlar de forma individualizada las variables que determinan los programas de ejercicio físico.

ABSTRACT

Cognitive abilities are known to consolidate during adolescence and reach their peak efficiency during young adulthood. Unfortunately, they begin to deteriorate as we age. This decline has a direct impact on the daily lives of older adults, affecting their quality of life and functionality. Therefore, it is important to find ways to stop or slow down this process. Scientific evidence suggests that physical exercise is a useful tool for reducing cognitive decline and even improving it during aging. Furthermore, the scientific literature has been trying to explain the exercise prescription variables that could influence these improvements in cognitive function in the elderly.

The present doctoral thesis aimed to contribute to the knowledge of the relationship between these variables for a correct prescription of physical exercise to benefit the cognitive function of older adults. This document presents a series of investigations to analyze the effect of physical exercise on cognitive function in older adults in relation to the type and intensity of exercise, both acutely and chronically.

The a previous study investigated the chronic effect of physical exercise on the cognitive response of older adults by participating in an exercise program for 6 months. The result of this previous study showed an improvement in some physical fitness variables, but no improvement in cognitive function. When analyzing the possible reasons why no improvement in cognitive function had been achieved, it was observed that low adherence, lack of improvement in aerobic fitness, and lack of intensity control could have been the consequence of these results.

Consequently, a first study from this thesis was designed to determine the most effective way to assess exercise intensity, verifying the inefficiency of accelerometry to assess exercise sessions, especially those that were not focused on constant displacement. A second study observed acutely whether different types of exercises produced different impacts on cognitive function and whether this was dependent on the BDNF SNP. This second study showed

that there does not seem to be any difference in the benefits to cognitive function according to the type of activity, but that intensity could be the differentiating element.

In order to generate transfer to society, two European projects were participated in, the aim of which was to create two exercise manuals that would allow the knowledge acquired to be applied in different settings within the European Community. As a result of the application of the manuals created at a European level, it was observed that physical training is the determining strategy for maintaining cognitive function and that improving the physical condition of older adults, regardless of their age, produces improvements in their subjective well-being that helps to increase their quality of life. Finally, a compilation of the lessons learned and future research perspectives was developed, and an editorial was published in a scientific journal.

CAPÍTULO 1. INTRODUCCIÓN GENERAL

ENVEJECIMIENTO Y DETERIORO FÍSICO

A lo largo de la vida, resulta inevitable experimentar ciertos cambios fisiológicos en el cuerpo humano, que determinarán nuestra vejez (Park & Yeo, 2013). El envejecimiento constituye un fenómeno natural intrínseco a la vida, siendo una manifestación del transcurso del tiempo en los sistemas biológicos. En los seres humanos, este proceso conlleva una disminución progresiva de funciones, una reducción de adaptabilidad y, en última instancia, la muerte (Park & Yeo, 2013).

En el último siglo, se ha experimentado un incremento significativo en la esperanza de vida humana, como consecuencia de algunos cambios de carácter conductual y/o ambiental entre los que se encuentra el ejercicio físico (Jones, Scheuerlein, Salguero-Gómez, et al., 2014).

A pesar de ello, ocurren cambios fisiológicos producidos por el envejecimiento que nos llevaran a padecer una considerable disminución del rendimiento físico (Park & Yeo, 2013). Podemos clasificar los diferentes cambios físicos en tres áreas principales: disminución de fuerza, disminución de capacidad cardiorrespiratoria y disminución de movilidad y coordinación (Cruz-Jentoft, Bahat, Bauer, Boirie, Bruyère, et al., 2019).

En cuanto a la fuerza, diversos procesos fisiológicos subyacen en esta disminución, siendo la sarcopenia la consecuencia más evidente, principalmente por la pérdida de masa muscular. El consenso europeo respecto a la definición y diagnóstico de la sarcopenia incorpora tres criterios para su identificación: baja fuerza muscular, reducción en la cantidad o calidad muscular y bajo rendimiento físico (Cruz-Jentoft, Bahat, Bauer, Boirie, Bruyère, et al., 2019). Algunos procesos fisiológicos son los causantes de esta pérdida de cantidad y calidad de masa muscular.

A nivel estructural, encontramos que existe un proceso de cambio de fibra rápida a lenta asociado a un cambio en las neuronas motoras (Lim & Frontera, 2023; Miljkovic et al., 2015); En la fibra muscular, se reduce el acoplamiento excitación-contracción, disminuyendo el flujo de calcio y afectando así a la calidad muscular (Miljkovic et al., 2015). La disminución en el contenido mitocondrial de la fibra muscular durante el proceso de envejecimiento es otra de las causantes de una pérdida de la funcionalidad del músculo. Además, podemos observar también un crecimiento de tejido adiposo intermuscular que nos conduce a una reducción en la fuerza y funcionalidad en las personas mayores (Addison et al., 2014).

A nivel molecular, también ocurren diversos cambios que nos explican la reducción de cantidad y calidad de masa muscular en la vejez. La reducción de testosterona y hormona de crecimiento desciende la posibilidad de hipertrofiar y regeneración muscular (Ryall et al., 2008). Además, también hay una reducción en los factores de crecimiento similares a la insulina relacionados con la proliferación, diferenciación y fusión de las células satélite musculares, que son las células precursoras de la masa muscular. Además, los factores reguladores miogénicos (MRF), involucrados en el crecimiento y desarrollo de las células musculares, no responden al ejercicio en las personas mayores como lo hacen en los jóvenes.

Por consiguiente, de estos cambios estructurales y moleculares también obtenemos cambios a nivel neural, que están muy relacionados con la funcionalidad muscular (Aagaard, Suetta, Caserotti, Magnusson,

& Kjær, 2010). Un ejemplo de ello es la disminución en el diámetro del axón de las neuronas motoras con el envejecimiento. Esto conlleva una disminución en la velocidad de disparo y una reducción en la excitabilidad de las fibras musculares. La disminución axonal se asocia con una reducción considerable en el número de neuronas motoras y, como consecuencia, una disminución en las unidades motoras, provocando la atrofia de las fibras musculares denervadas (Aagaard, Suetta, Caserotti, Magnusson, & Kjær, 2010).

Por lo que respecta a la capacidad cardiorrespiratoria, existe una evidente reducción de captación de oxígeno con el incremento de la edad (Edvardsen et al., 2013). Esto puede ser explicado por la disminución de la frecuencia cardíaca máxima con el envejecimiento (Tanaka et al., 2001a); cambios en la función diastólica del ventrículo derecho durante el ejercicio (Murat Celik et al., 2015), y menor número de capilares que perfunden los pulmones (Mendonca et al., 2017). El incremento en la rigidez del sistema vascular eleva tanto la presión sistólica como la diastólica durante el ejercicio, resultando en un aumento de la poscarga cardíaca y una disminución del volumen sistólico durante la actividad física (Mendonca et al., 2017). Además, la disminución de las mitocondrias asociada al envejecimiento implica una reducción en la capacidad de las fibras musculares para emplear oxígeno en la producción de ATP (Peterson et al., 2012). Desenlazando en una reducción en la diferencia arteriovenosa de 02 y la disminución del consumo de oxígeno.

El envejecimiento afecta también a la coordinación, aumentando la variabilidad de los movimientos si los comparamos con población más joven, provocando lentitud en sus movimientos y problemas con el equilibrio y la marcha (Seidler et al., 2010). Siendo, por ejemplo, la explicación al incremento de caídas por pérdida de control y equilibrio de la población adulta mayor.

Afortunadamente, el envejecimiento puede regularse, al menos parcialmente, mediante la actividad física y un estilo de vida saludable. Existen numerosos artículos científicos que muestran las mejoras obtenidas mediante el ejercicio físico, mejoras en la fuerza (Peterson et al., 2010) (Peterson, Rhea, Sen, & Gordon, 2010), resistencia (Vigorito & Giallauria, 2014) (Vigorito & Giallauria, 2014) o reducción del riesgo de caídas (Greenwood-Hickman et al., 2015) (Greenwood-Hickman, Rosenberg, Phelan, & Fitzpatrick, 2015).

ENVEJECIMIENTO Y DETERIORO COGNITIVO

El sistema nervioso central es uno de los más afectados durante el proceso de envejecimiento (Raz & Rodrigue, 2006). El deterioro de éste se manifiesta a través de varios mecanismos moleculares, neuronales y conductuales, como pueden ser el declive en la actividad mitocondrial que contribuye significativamente al deterioro de los circuitos neuronales relacionados con la edad; además las neuronas envejecidas pueden modular las respuestas conductuales derivadas del sistema nervioso, como el aprendizaje, la memoria y el estado emocional (Alcedo et al., 2013). La velocidad de procesamiento de la información o la memoria de trabajo se deterioran (Bherer et al., 2013); hay una pérdida de tejido nervioso, con pérdida tanto de materia gris (Erickson et al., 2014) como de materia blanca (Hayes et al., 2015). Este deterioro morfológico se asocia con una disminución en la capacidad cognitiva.

Por un lado, el volumen cerebral se reduce en regiones que incluyen los lóbulos frontal, parietal y temporal, y posiblemente está vinculado a las reducciones observadas en el flujo sanguíneo cerebral (Kirk-Sanchez & McGough, 2014), probablemente explicado por la reducción en la producción de VEGF (Factor de Crecimiento Endotelial Vascular), un potente factor angiogénico, que interrumpe la creación de nuevos vasos sanguíneos (Ladoux & Frelin, 1993). También se ha observado una disminución en el volumen del hipocampo que se ha relacionado con el declive cognitivo durante el envejecimiento (Bettio et al., 2017). El hipocampo es una estructura cerebral que desempeña un papel central en los procesos asociados con la memoria declarativa y visoespacial (Squire, 1992b).

Por otro lado, los cambios moleculares también pueden acelerar el declive cognitivo. Estas modificaciones comprenden la reducción de los niveles de factores neurotróficos, como el BDNF (Factor Neurotrófico Derivado del Cerebro) y el IGF-1 (Factor de Crecimiento Similar a la Insulina-1), ambos asociados con una supervivencia neuronal disminuida y un declive sináptico (Kowiański et al., 2018).

La consecuente disminución cognitiva afecta a las actividades de la vida diaria en las personas mayores. Sin embargo, es esencial saber que la tasa de declive es diferente entre individuos y está influenciada por muchos factores (Lövdén et al., 2020). Es de vital importancia reconocer los elementos que pueden explicar la ralentización en la disminución cognitiva. En este aspecto, se ha evidenciado que tanto la actividad como el ejercicio físico pueden mitigar este proceso (Blondell et al., 2014). La evidencia muestra la capacidad del ejercicio físico para reducir el deterioro cognitivo e incluso mejorar la función cognitiva durante el envejecimiento (Izquierdo et al., 2021). Durante años, la investigación científica ha estudiado las variables de prescripción de ejercicio como la frecuencia, intensidad, tiempo y tipo (FITT), que modulan el impacto sobre la cognición (Sáez de Asteasu et al., 2017). Por ello, comprender los mecanismos que subyacen a esta protección cognitiva mediante la actividad física resulta esencial.

ACTIVIDAD FISICA Y EJERCICIO FÍSICO

Es importante diferenciar entre la actividad y el ejercicio físico, ambos relacionados con la salud a lo largo de toda la vida. Por un lado, la actividad física se refiere a cualquier movimiento producido por el sistema muscular que implica un aumento en el consumo de energía; actividades como ir de compras, jardinería, limpieza de la casa, etc., aumentan la actividad física de las personas. Por otro lado, el ejercicio físico es una actividad física planificada, estructurada y repetitiva con el objetivo de mejorar uno o más componentes de la condición física de una persona (Chodzko-Zajko et al., 2009). Dado el peligro asociado a la inactividad y los beneficios derivados de la actividad física, las directrices generales de actividad física del American College of Sports Medicine (ACSM) enfatizan la importancia de incrementar la actividad física a través de la realización regular de ejercicio físico cuidadosamente planificado.

En la actualidad, hay numerosas recomendaciones de ejercicio físico para promover la salud en adultos (ACSM, 2009; Garber, Blissmer, Deschenes, Franklin, Lamonte, Lee, Nieman, & Swain, 2011; O'Donovan et al., 2010), y específicamente para la población de personas mayores (Chodzko-Zajko et al., 2009). Estas diferentes modalidades de ejercicio implican diferentes actividades durante las sesiones de ejercicio físico, y con ello, diferencias en los beneficios asociados a dicha práctica.

EJERCICIO FÍSICO Y MEJORA DE LA CONDICIÓN FÍSICA

Para compensar los mecanismos de deterioro mencionados anteriormente, el ejercicio físico ha demostrado ser una herramienta eficiente (Chodzko-Zajko et al., 2009).

El entrenamiento de fuerza puede reducir la disminución de la fuerza con mejoras en la masa muscular; así como mejorar las tasas de disparo y reclutamiento de las unidades motoras de las fibras musculares (Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Müller, et al., 2011). Estas mejoras están vinculadas a la intensidad, observándose mayores beneficios a intensidades más elevadas (Mayer, et al., 2011), así como a la velocidad de contracción. En este sentido, los ejercicios de potencia demuestran notables mejoras en la fuerza y en condiciones relacionadas con la salud (Fragala et al., 2019). El entrenamiento de fuerza tiene un impacto positivo en la funcionalidad y otras variables de salud como la mejora de la composición corporal, ayudando a reducir la grasa corporal y aumentar la masa magra, obteniendo un metabolismo más saludable; reduce el riesgo de enfermedad cardíaca y mejora los perfiles de lípidos en sangre; mejora la sensibilidad a la insulina, el control glucémico y la salud metabólica en general, especialmente relevante en los adultos mayores en riesgo de diabetes tipo 2 y mejora la salud ósea, crucial para prevenir la osteoporosis y las fracturas relacionadas con la edad (Fragala et al., 2019).

El entrenamiento conocido como de resistencia o de corte aeróbico, también tiene múltiples beneficios sobre la salud de nuestros mayores. Este tipo de entrenamiento fortalece el corazón y los pulmones, mejorando la circulación sanguínea y reduciendo enfermedades como la hipertensión y enfermedades coronarias (Vigorito & Giallauria, 2014); mejora la capacidad pulmonar y eficiencia del sistema respiratorio; ayuda al control de peso corporal, disminuyendo problemas asociados con la obesidad; así como una mejora de la sensibilidad a la insulina y el control glucémico (Valenzuela, Castillo-García, et al., 2019).

El ejercicio físico permite mejorar la capacidad de realizar actividades diarias y mantener un estilo de vida saludable, contribuyendo significativamente a la calidad de vida de los adultos mayores. La realización de ejercicio de forma regular tiene un impacto muy positivo con el estado de ánimo y salud mental (D. K. Ehlers et al., 2018) . El ejercicio ayuda a reducir los niveles de estrés y ansiedad, mejorando de forma directa el bienestar emocional (Chodzko-Zajko et al., 2009); puede aumentar la producción de endorfinas (péptidos endógenos clasificados como neurotransmisores) contribuyendo al estado de ánimo y reduciendo la sensación de dolor; por otro lado, puede ayudar a reducir los síntomas de la depresión, si ya se padecen, o ayudar a prevenirla (Chodzko-Zajko et al., 2009). Mejora la autoestima y confianza en uno mismo, muchas veces deteriorada por la falta de funcionalidad experimentada con el paso del tiempo (McAuley et al., 2005). Y, sobre todo, el ejercicio ayuda a mejorar la función cognitiva, incluyendo en ella variables como la memoria de trabajo y la atención, entre muchas otras (McAuley et al., 2005).

EJERCICIO FÍSICO Y FUNCIÓN COGNITIVA

Es evidente que hay una conexión entre condición física y la función cognitiva (Colcombe & Kramer, 2003b). La condición física disminuye la pérdida de masa cerebral asociada al envejecimiento (Fletcher et al., 2016) y el ejercicio físico puede aumentar el volumen de materia gris (Erickson et al., 2014). En estudios realizados con ratas envejecidas se han observado mejoras en la densidad capilar del cerebelo, aumentando a la captación de colina de alta afinidad cortical y la densidad de receptores de dopamina, aumentando la expresión del Factor Neurotrófico Derivado del Cerebro (BDNF por sus siglas en inglés) e incluso incrementando la neurogénesis. Estos cambios moleculares y neuroquímicos observados en los estudios con roedores en respuesta a intervenciones de ejercicio físico pueden subyacer a las mejoras en los procesos cognitivos y motores de los adultos mayores humanos (Colcombe & Kramer, 2003b).

En particular, el BDNF parece ser un factor crítico en la función cognitiva. En los humanos, la secreción de BDNF está regulada por su correspondiente gen. Durante el desarrollo, las funciones de BDNF están relacionadas con el crecimiento, la supervivencia y diferenciación de las neuronas (Huang & Reichardt, 2001; Kowiański et al., 2018). Estas características, junto con el papel bien establecido de BDNF en la plasticidad sináptica, se traducen en cambios funcionales positivos, convirtiendo a BDNF en una proteína clave implicada en la formación y consolidación de memorias (Bramham & Messaoudi, 2005). Este gen presenta un polimorfismo de un solo nucleótido (SNP) conocido como rs6265 o polimorfismo genético BDNF Val66Met. Este SNP sustituye una valina (Val) por una metionina (Met) en el codón 66. Se ha descubierto que el SNP Met reduce la secreción de BDNF (Egan et al., 2003). Además, en los humanos, los portadores de Met han mostrado efectos reducidos de los beneficios del ejercicio en la memoria declarativa (Canivet et al., 2015).

Investigaciones recientes han demostrado en adultos mayores que el ejercicio, sobre todo aeróbico (Huang et al., 2014), puede aumentar la producción de BDNF en el cerebro y mejorar su expresión (Wang & Holsinger, 2018), lo que conduce a mejoras en el aprendizaje, la memoria y la función cognitiva (Cotman & Berchtold, 2002; Szuhany et al., 2015). Convirtiéndose en un aspecto clave para prever la pérdida de memoria y el deterioro cognitivo en enfermedades como el Alzheimer y demencias (Wang & Holsinger, 2018). Por lo que la relevancia de controlar el SNP de BDNF al estudiar el impacto del ejercicio en la función cognitiva resulta relevante.

La función cognitiva integra una gran cantidad de dominios cognitivos. Por ejemplo, en relación con el ejercicio físico, las funciones ejecutivas son un dominio común estudiado en la literatura e incluyen variables como la memoria de trabajo, la atención, la inhibición y la flexibilidad cognitiva (Diamond, 2013). El ejercicio físico ha demostrado tener efecto positivo en la atención, favoreciendo que los adultos mayores tengan mayor capacidad para enfocarse en tareas específicas y filtrar distracciones; también ha demostrado mejorar la velocidad de procesamiento cognitivo, otorgando mayor rapidez a la hora de desempeñar tareas cognitivas. A su vez, participar en programas de ejercicio ha incrementado la memoria tanto a corto plazo como la memoria episódica (Fabre, Chamari, Mucci, Massé-Biron, et al., 2002). E incluso, también se ha observado que la función ejecutiva, que incluye habilidades como la planificación, la toma de decisiones y el control inhibitorio, se han beneficiado de la práctica de ejercicio (Fabre, Chamari, Mucci, Massé-Biron, et al., 2002).

En definitiva, es de vital importancia para la salud cognitiva de esta población que participen en programas de ejercicio físico y que sean estudiadas todas las variables de prescripción física, así como, las herramientas óptimas para su control, que nos permitan desarrollar programas adecuados y efectivos para su desarrollo cognitivo y físico.

EJERCICIO FÍSICO Y SU PRESCRIPCIÓN

La Frecuencia de entrenamiento, Intensidad del ejercicio, el Tiempo y el Tipo de ejercicio (FITT) son las variables con las que comúnmente se prescribe el ejercicio físico para optimizar sus objetivos. En el caso del ejercicio físico para mejorar la función cognitiva de las personas mayores, todavía existen muchas lagunas de conocimiento respecto a cuáles son las variables FITT óptimas para los diversos colectivos.

La variable frecuencia de entrenamiento se refiere a la cantidad de sesiones de ejercicio que realiza un individuo en un período de tiempo específico, generalmente expresado en términos de días por semana. Es un componente importante del diseño de los programas de entrenamiento y denota la regularidad con la que persona participa en actividades planificadas. La frecuencia puede variar según los objetivos individuales, el nivel de condición física, la disponibilidad de tiempo y otros muchos factores (Gibson et al., 1983). Existen diferentes tipos de frecuencias de entrenamiento. Por un lado, tenemos las frecuencias de entrenamiento altas, de 5 a 7 días por semana. Este tipo de frecuencias se suele utilizar en programas de entrenamiento de fuerza donde el objetivo es aumentar la masa muscular o mejorar el rendimiento deportivo (Blonc et al., 2010). Por otro lado, tenemos frecuencias de entrenamiento moderadas, de 3 a 4 días por semana. Este tipo de frecuencias es adecuado para la mayoría de personas que buscan mejorar su salud y estado físico general (Birrer, 1985). Y, por último, frecuencias de entrenamiento bajas, de 1 a 2 días por semana. Este tipo de frecuencia puede ser adecuado para las personas mayores o con limitaciones físicas que buscan mantener su salud y movilidad (Izquierdo et al., 2021; Tse et al., 2015).

La variable intensidad de ejercicio, se refiere al nivel de esfuerzo o dificultad que se aplica durante una sesión de ejercicio físico. La intensidad del ejercicio se puede medir de diferentes maneras, utilizando la frecuencia cardíaca, la escala de percepción del esfuerzo o la velocidad de movimiento, entre otros métodos (Raffaelli et al., 2012). La intensidad moderada se define de forma cualitativa como un nivel de esfuerzo que aumenta la frecuencia cardíaca y la respiración, pero aún permite hablar con cierta dificultad. En términos de frecuencia cardíaca, la intensidad moderada se sitúa aproximadamente entre el 64% y el 76% de la frecuencia cardíaca máxima de una persona (Garber, Blissmer, Deschenes, Franklin, Lamonte, Lee, Nieman, & Swain, 2011). Algunos ejemplos de actividades de intensidad moderada incluyen caminar a paso ligero o andar en bicicleta a una velocidad moderada. La intensidad vigorosa, por otro lado, se define cualitativamente como un nivel de esfuerzo que hace que la respiración sea difícil y que no se pueda hablar fácilmente. En términos de frecuencia cardíaca, la intensidad vigorosa se sitúa aproximadamente entre el 77% y el 95% de la frecuencia cardíaca máxima de una persona (Garber et al., 2011). Algunos ejemplos de actividades de intensidad vigorosa incluyen correr, nadar a una velocidad rápida, o hacer ejercicios de alta intensidad como el entrenamiento de intervalos de alta intensidad (HIIT) (Ai et al., 2021).

Existen diferentes tipos de ejercicio que pueden formar parte de un programa de entrenamiento. Tenemos el entrenamiento de fuerza, centrado en vencer una carga para fortalecer y desarrollar la masa muscular. Se consideran ejercicios de fuerza el levantamiento de pesas o halteras, ejercicios con bandas elásticas que nos ofrecen una resistencia, o el uso de máquinas guiadas y/o poleas. Por otro lado, tenemos el entrenamiento aeróbico, cuyo enfoque es la mejora de la resistencia cardiovascular y la salud del corazón. Destacan como actividades de corte aeróbico las de correr, nadar, remar o ir en bicicleta. Además, existen actividades de equilibrio y flexibilidad cuyo objetivo principal es trabajar la estabilidad, equilibrio y flexibilidad del cuerpo. Destacan actividades de este tipo aquellas como el yoga, taichi, o ejercicios específicos para mejorar el equilibrio (Izquierdo et al., 2021).

Para población adulta mayor los programas más comunes y que pueden ser especialmente beneficiosos por la variedad de estímulos que presentan son los programas multicomponentes. Estos programas incorporan varios tipos de ejercicio para abordar diferentes aspectos de la salud y estado físico. Suelen incluir y combinar ejercicios de fuerza, aeróbicos, de equilibrio y flexibilidad. Además de intercalar diferentes niveles de intensidad en las actividades. Son programas especialmente diseñados para aumentar y mejorar la funcionalidad de nuestras personas mayores (Cordes et al., 2019; Linhares et al., 2022).

Finalmente es relevante que el ejercicio físico puede tener un impacto inmediato sobre las respuestas cognitivas, o puede modificar la función cognitiva a largo plazo mediante su repetición en periodos largos de tiempo. Este hecho abre la perspectiva del ejercicio de tipo agudo y crónico. La distinción de éstas en el campo de la fisiología se basa en la duración y regularidad del ejercicio. El ejercicio físico agudo se refiere a una sola sesión de ejercicio físico cuya atención se centra en los efectos inmediatos de una sola sesión de ejercicio. En cambio, el ejercicio físico crónico se refiere a un programa de ejercicio realizado de forma regular durante un período prolongado (semanas, meses o años) (Caspersen et al., 1985). Su atención se centra en los efectos a largo plazo del ejercicio regular en la función física de los sujetos. Normalmente, los efectos del ejercicio agudo en investigación son usados para estudiar respuestas fisiológicas específicas a diferentes tipos de ejercicios o intensidades. Por otro lado, los efectos del ejercicio crónico se usan para entender cómo el ejercicio regular afecta a la prevención y manejo de enfermedades crónicas, el envejecimiento y la salud en general (Izquierdo et al., 2021). En un estudio previo a esta tesis doctoral realizado por la doctoranda y su director se fracasó en el objetivo de conseguir una mejora cognitiva en un programa de ejercicio físico a largo plazo (Pastor, Carbonell-Hernández & Cervelló, 2017). Lo que orienta a esta tesis doctoral desarrollar un conocimiento previo de los efectos agudos del ejercicio físico para su posterior implementación en programas crónicos.

Existe mucha investigación sobre la intensidad del ejercicio, que puede modular significativamente la respuesta cognitiva después de un ejercicio agudo (Oberste et al., 2019), con la mayoría de las mejoras atribuibles al ejercicio de alta intensidad (Westerterp, 2003). En cuanto a la variable tiempo, hay algunas indicaciones de que las sesiones de baja duración son propicias para obtener la mayoría de los beneficios (Oberste et al., 2019). Con relación al tipo de ejercicio, la investigación en mayor medida ha analizado los efectos del ejercicio aeróbico en la cognición. Un conjunto grande de investigaciones ha demostrado que el ejercicio aeróbico agudo tiene un efecto positivo en la función ejecutiva (Chang et al., 2012; Lambourne & Tomporowski, 2010; McMorris et al., 2011), pero aún no está claro qué tiempo particular de ejercicio se necesita para lograr los máximos beneficios. Parece ser que al menos 20 min (Chang et al., 2012) y entre 20 y 60 min (Tomporowski, 2003) de trabajo aeróbico con intensidad moderada mejorará la función cognitiva, pero no están claras las dimensiones a las cuales se atribuyen dichas mejoras.

Por otra parte, hay un creciente interés por parte de la comunidad científica en estudiar el impacto del entrenamiento de fuerza en la respuesta cognitiva, con algunas evidencias que sugieren mejoras positivas de ejercicios de fuerza tanto de forma aguda como de forma crónica (Soga et al., 2018). Sin embargo, persiste una notable variabilidad tanto en los resultados de entrenamiento de fuerza como en los diseños de los protocolos (Landrigan et al., 2020), y se requiere de mayor investigación sobre los efectos dosis-respuesta del entrenamiento de la fuerza en la mejora cognitiva (Soga et al., 2018). Además, carecemos por completo de conocimientos acerca de la frecuencia.

En consecuencia, la presente tesis se planteó cómo abordar las variables de Intensidad y Tipo, dentro de las variables FITT, teniendo en cuenta el impacto del ejercicio físico sobre la función cognitiva. Partiendo de estudios agudos que nos permitan conocer las variables óptimas del ejercicio físico, con el fin de buscar posteriormente entornos reales donde llevar a cabo intervenciones prolongadas que nos muestren el efecto crónico.

CAPÍTULO 2. OBJETIVOS DE INVESTIGACIÓN E HIPÓTESIS

OBJETIVOS DE INVESTIGACIÓN E HIPÓTESIS

Con el fin de poder ayudar a incrementar el conocimiento sobre la relación de las variables FIIT estudiadas, para una correcta prescripción del ejercicio físico en beneficio de la función cognitiva de las personas mayores, se planteó una serie de investigaciones para analizar el efecto del ejercicio físico sobre la función cognitiva de las personas mayores en relación con el tipo y la intensidad del entrenamiento, primero de forma aguda y posteriormente de forma crónica.

Objetivo 1º

El primero objetivo fue determinar la forma más eficaz de valorar la intensidad de ejercicio, comprobando si la acelerometría, que nos permite valorar con precisión la actividad física, era igualmente interesante para valorar las sesiones de ejercicio físico.

Este objetivo presenta las siguientes hipótesis:

- H1: Existe una correlación positiva entre la acelerometría y la frecuencia cardíaca durante las sesiones de ejercicio físico.
- H2: La acelerometría permite valorar la intensidad de las sesiones de ejercicio físico.

Publicación: Carbonell-Hernández, L., Pastor, D., Jiménez-Loaisa, A., Ballester-Ferrer, J. A., Montero-Carretero, C., & Cervelló, E. (2020). Lack of Correlation between Accelerometers and Heart-Rate Monitorization during Exercise Session in Older Adults. *Int J Environ Res Public Health*, *17*(15). https://doi.org/10.3390/ijerph17155518

Objetivo 2º

El segundo objetivo tenía como finalidad comprobar, de forma aguda, cómo diferentes tipos de ejercicio podrían tener diferente impacto en la función cognitiva.

Este objetivo presenta las siguientes hipótesis:

- H3: Las sesiones de mayor intensidad, como las de fuerza y resistencia, tendrían mejoras más acentuadas que la de menor intensidad, como la de equilibrios.
- H4: La sesión de resistencia tendría mayor impacto que la de fuerza.
- H5: El SNP del BDNF debería modular la respuesta cognitiva después de una sesión aguda de ejercicio.
- H6: Los portadores del gen Met mostrarían efectos más reducidos de los beneficios de la actividad que los portadores del gen Val.

Publicación: Carbonell-Hernandez, L., Ballester-Ferrer, J. A., Sitges-Macia, E., Bonete-Lopez, B., Roldan, A., Cervello, E., & Pastor, D. (2022). Different Exercise Types Produce the Same Acute Inhibitory Control Improvements When the Subjective Intensity Is Equal. *Int J Environ Res Public Health*, *19*(15). https://doi.org/10.3390/ijerph19159748

Objetivo 3º

El tercer objetivo fue tratar de transferir el conocimiento adquirido a la sociedad a través de manuales y proyectos que pudieran presentar un impacto social relevante en base a lo aprendido. Fruto de estos proyectos se crearon dos manuales en el ámbito de la Unión Europea y sendas investigaciones científicas con los resultados de la aplicación de dichos manuales a diferentes entornos sociales de la UE.

- H7: La aplicación de los manuales de intervención creados para divulgación dará como resultado mejoras físicas y cognitivas en los participantes.

Publicación: Carbonell-Hernández, L., Cervelló, E., & Pastor, D. (2019). Two months of combined physical exercise and cognitive training, over cognitive function in older adults: the results of the memtrain project pilot program. *European Journal of Human Movement*, *42*, 59-75.

Publicación: Carbonell-Hernández, L., Ballester-Ferrer, J., Cervelló, E., & Pastor, D. (2020). Effect of six months ex ercise training in older adults. The results of the erasmus plus pace project. *The annals of the "stefan cel mare" university*, *xiii*(1).

Objetivo 4º

El último objetivo de la tesis fue elaborar una recopilación de lo aprendido y las perspectivas futuras de investigación mediante un editorial publicado en una revista científica.

Editorial: Pastor, D., Ballester-Ferrer, J. A., Carbonell-Hernández, L., Baladzhaeva, S., & Cervello, E. (2022). Physical Exercise and Cognitive Function. In *Int J Environ Res Public Health* (Vol. 19).

CAPÍTULO 3. RESUMEN DE LOS MÉTODOS

RESUMEN DE LOS MÉTODOS

En el siguiente capítulo se presenta de manera concisa y precisa el conjunto de métodos empleados a lo largo de tesis doctoral. Se expone la selección y caracterización de los participantes, así como la descripción de los diferentes diseños experimentales. Además, se detallará el proceso de preparación e intervención, y se explicarán las variables, instrumentos y herramientas utilizadas. Finalmente, se desarrollarán los análisis estadísticos empleados en función de la naturaleza de los datos y los objetivos de las diferentes investigaciones que conforman la tesis.

3.1. PARTICIPANTES

Todos los participantes incluidos en los estudios de esta tesis fueron adultos mayores de entre 60 y 80 años sin patologías a nivel cognitivo y lo suficientemente funcionales como para poder participar en programas de ejercicio físico de carácter multicomponente. Todos fueron debidamente informados sobre las características de la investigación y firmaron un consentimiento informado por escrito. Además, todas las investigaciones fueron diseñadas de acuerdo con la Declaración de Helsinki y aprobadas por el Comité de Ética de la universidad.

3.2. DISEÑO DE EXPERIMENTOS

Dado que en la presente tesis se ha llevado a cabo tanto estudios de carácter agudo como estudios de carácter crónico, los diseños experimentales son diferentes en cada caso.

En los estudios agudos, se planteó un diseño de medidas repetidas donde todos los sujetos pasaron por las mismas sesiones de intervención de ejercicio físico y condiciones de aplicación de manera contrabalanceada y aleatorizada. En (L. Carbonell-Hernández et al., 2020) fueron 2 días de experimento y en (Carbonell-Hernandez et al., 2022) fueron un total de 4 días, una vez a la semana, durante 2 y 4 semanas respectivamente.

En los estudios crónicos en (Carbonell-Hernández et al., 2019) se planteó un diseño cuasi-experimental de grupos no equivalentes con un grupo de tratamiento y un grupo control, pero sin asignación aleatoria de los participantes a estos grupos de medidas repetidas pre-post intervención de dos días durante 2 meses. Por último, en (L Carbonell-Hernández et al., 2020) se planteó un diseño cuasi-experimental de series temporales múltiples de medidas repetidas en múltiples grupos con variaciones en la implementación de la intervención sin contar con un grupo control. Los participantes en diferentes países siguieron el mismo programa general de ejercicio, pero con variaciones en la distribución del tiempo (dos períodos de tres meses con un intervalo, versus un programa continuo de seis meses). Esta variación permite comparar los efectos de diferentes esquemas de intervención.

3.3. PROCEDIMIENTOS

Los 2 experimentos agudos incluidos en esta tesis presentan estructuras muy similares. En todos se plantearon sesiones de ejercicio físico con una duración total en torno a los 60 minutos. Dichas sesiones se estructuraban de la siguiente manera: una primera fase de calentamiento de 10 minutos; una parte principal de entre 30 y 40 minutos, organizadas en tres bloques de trabajo continuo de entre 8 y 12 minutos; y una última fase de 10 minutos de vuelta a calma.

En Carbonell-Hernández et al., (2020) se contrabalancearon dos tipos de sesión, una de intensidad moderada y de carácter aeróbico, y otra de intensidad baja y de equilibrio. Ambas sesiones se controlaron con medición de frecuencia cardíaca y acelerometría. Y se usaron 10 minutos previos al inicio de sesión para instruir a los sujetos en la colocación de los dispositivos.

En Carbonell-Hernández et al., (2022) se contrabalancearon tres tipos de sesiones moderadas. Una fue de fuerza, otra de resistencia aeróbica y otra de equilibrio. Se empleó una sesión previa para aprender a manejar el software de la tarea cognitiva, que se evaluó 10 minutos después del final de cada sesión.

En los diseños experimentales agudos, las sesiones de resistencia o de carácter aeróbico se caracterizaron por ser actividades donde se combinaban momentos de caminar a un ritmo ligero y momentos de botar una pelota de baloncesto a una intensidad moderada (RPE 5-6). Las sesiones de fuerza fueron sesiones donde se realizaban ejercicios con autocargas tales como sentadillas, zancadas, etc., y ejercicios donde se empleaban bandas elásticas para vencer su resistencia en ejercicios como aperturas de brazos, empujes verticales, etc. Al igual que las anteriores, éstas también fueron de carácter moderado (RPE 5-6). En las sesiones de equilibrio, se realizaron tareas como caminar por líneas del suelo y/o cuerdas y tareas de coordinación, equilibrio y alcance limitando apoyo de las extremidades. En Carbonell-Hernández et al., (2020) esta sesión fue de intensidad baja, sin embargo, en Carbonell-Hernández et al., (2022) fue de carácter moderado (RPE 5-6). En cuanto a los descansos que se realizaron entre los bloques de ejercicio, destacar que en todas las ocasiones fueron descansos activos y los aprovecharon para hidratarse.

En los diseños experimentales crónicos los programas no tuvieron tantas similitudes. En Carbonell-Hernández et al., (2019) el grupo experimental realizó ejercicio aeróbico (baile, marcha nórdica, atletismo o ejercicios funcionales) durante 40 minutos y durante 20 minutos practicó juegos cognitivos (tareas coordinativas con movimientos bilaterales a diferentes ritmos, y juegos de memoria y matemáticas con palabras e imágenes). El grupo control realizó solo la actividad de 20 minutos de juegos cognitivos.

En Carbonell-Hernández et al., (2020) para el grupo más joven (50-65 años) se pautaron sesiones de unos 60 minutos de resistencia como correr, caminata nórdica y/o zumba. En cambio, para el grupo de mayores (65-75 años) se pautaron actividades de menor intensidad tales como gimnasia adaptada, ejercicios funcionales, estiramientos y caminata, también de unos 60 minutos. Las estructuras de las sesiones contemplaban unos 10-15 minutos de calentamiento, 20-30 de parte principal y 10-15 minutos de vuelta a la calma o enfriamiento.

3.4. MEDICIONES

En la investigación de Carbonell-Hernández et al., (2020), para asegurar el mantenimiento de la intensidad objetivo, se estimó la frecuencia cardíaca máxima (FCmax) de los sujetos utilizando la fórmula de Tanaka ((208 – 0.7) x EDAD) (Tanaka et al., 2001a), ajustando el esfuerzo para mantenerse dentro del 65-75% de la FCmáx durante ejercicios de intensidad moderada y por debajo del 65% para los de baja intensidad. La monitorización de la frecuencia cardíaca (FC) se realizó utilizando bandas pectorales H10 y el sistema Polar Team 2, que permite el registro de la FC directamente desde el pecho con una precisión de segundo a segundo. Estos datos detallados facilitaron el cálculo de las medias de FC tanto en intervalos minuto a minuto como de cinco minutos, proporcionando una medida precisa y continua de la respuesta cardíaca durante el período de estudio. Para medir la acelerometría, se emplearon dispositivos ActiGraph GT3X, registrando la magnitud del vector tridimensional en intervalos de un segundo. Esto permitió la recolección de datos detallados, incluyendo la frecuencia cardíaca, segundo a segundo. Los puntos de corte establecidos por Santos-Lozano et al. (2013) fueron utilizados para estimar el gasto energético, basados en estudios previos con dispositivos similares y poblaciones comparables. Los datos se analizaron tanto en intervalos segundo a segundo como en promedios de minuto a minuto y de cinco minutos.

En Carbonell-Hernandez et al., (2022) se utilizó la prueba de Stroop digital (Stroop test UMH-MEMTRAIN de Pastor et al., 2018), para medir el control inhibitorio antes y después de cada sesión. Además, se realizó un análisis genético para identificar el polimorfismo de un solo nucleótido de BDNF rs6265 mediante la recolección de muestras de saliva y análisis PCR cuantitativo en tiempo real en algunos participantes. La intensidad fisiológica se monitoreó mediante frecuencia cardíaca y el uso de bandas pectorales H10 y el sistema Polar Team 2.

El estudio Carbonell-Hernández et al., (2019) evaluó la agilidad y el equilibrio dinámico mediante el "8 foot Up and Go test", la aptitud aeróbica a través del "6 Minutes Walk Test", la función ejecutiva usando una aplicación digital del Test Stroop (Stroop test UMH-MEMTRAIN de Pastor et al., 2018), y la memoria verbal a corto y largo plazo con el Rey Auditory Verbal Learning Test (RAVLT). Estas mediciones permitieron analizar los efectos de un programa de entrenamiento físico y cognitivo de dos meses sobre la función física y cognitiva en adultos mayores.

Y, por último, en Carbonell-Hernández et al., (2020) se evaluó la fuerza de agarre y la fuerza de las piernas mediante pruebas específicas, la resistencia aeróbica a través del Rockport Walking Test para el grupo joven y el Six Minutes Walk Test para el grupo de mayor edad, y la agilidad y la marcha con el Timed Up and Go Test. Se midió el bienestar subjetivo utilizando el Cuestionario de Vitalidad Subjetiva y se registró el peso de los participantes al inicio y al final del programa.

3.5. ANÁLISIS ESTADÍSTICOS

En la investigación Carbonell-Hernández et al., (2020) se empleó la prueba t de Student para comparar las frecuencias cardíacas entre sesiones, y se incluyó correlaciones de Pearson para evaluar la relación entre variables, clasificando la fuerza de correlación según los criterios de Mukaka (Mukaka, 2012). Además, se realizaron análisis de regresión lineal para examinar la relación entre los datos de acelerometría y de frecuencia cardíaca. Estos análisis se utilizaron para determinar la precisión de los acelerómetros en comparación con la monitorización de la frecuencia cardíaca en sesiones de ejercicio de intensidad moderada y baja.

En Carbonell-Hernández et al., 2022) se emplearon ANOVAs repetidas para analizar los efectos del tipo de ejercicio en el control inhibitorio. Se compararon las mediciones de control inhibitorio pre y post ejercicio, y se examinó la interacción entre el tipo de ejercicio y el polimorfismo BDNF rs6265. Adicionalmente, se utilizó el análisis de varianza para determinar diferencias significativas en los cambios de la frecuencia cardíaca y en el rendimiento en el Test de Stroop entre los diferentes tipos de ejercicio.

En Carbonell-Hernández et al., (2019) los análisis estadísticos incluyeron ANOVAs de medidas repetidas para evaluar los cambios pre y post-intervención en las pruebas físicas y cognitivas. Se emplearon pruebas t para comparaciones pareadas y análisis de covarianza (ANCOVA) para ajustar por variables basales. Los efectos del tamaño se calcularon para determinar la magnitud de los cambios. Estos métodos proporcionaron una evaluación rigurosa del impacto del programa de entrenamiento en la función física y cognitiva de los participantes.

Y, por último, en Carbonell-Hernández et al., (2020) los análisis estadísticos empleados incluyeron pruebas t de Student para comparaciones independientes entre grupos, ANOVAs de medidas repetidas para evaluar los cambios pre y post-intervención, y análisis de varianza multivariante (MANOVA) para examinar los efectos combinados de las variables medidas. Estos métodos estadísticos facilitaron la evaluación rigurosa de los efectos del programa de entrenamiento en las capacidades físicas y el bienestar de los participantes, permitiendo la identificación de diferencias significativas y la magnitud de los cambios observados.

En todas las investigaciones realizadas en la presente tesis la significación se estableció en $p<0.05$. Las correlaciones se analizaron utilizando el coeficiente r de Pearson. Además, cuando se usaron ANOVAs de medidas repetidas se fijó significación bilateral de $p<0.05$; se realizó prueba de Mauchly para evaluar la esfericidad de los datos. Como medida de los tamaños del efecto en el análisis ANOVA RM, se utilizó eta-cuadrado parcial (η_p^2) y se agruparon como pequeño (≤ 0.01), mediano (≤ 0.06) y grande (≤ 0.14) (Cohen, 1992). Cuando se compararon los pares se usaron análisis post hoc de Bonferroni.

El software empleado para los análisis estadísticos en algunos casos fue SigmaPlot 12.0 (Versión para Windows, Systat Software Inc, USA) y en otros JASP 0.16 (Eric-Jan Wagenmakers, Departamento de Métodos Psicológicos de la Universidad de Ámsterdam, Nieuwe Achtergracht 129B, Ámsterdam, Países Bajos).

CAPÍTULO 4. RESUMEN DE LOS RESULTADOS

RESUMEN DE LOS RESULTADOS

Los estudios contemplados en la presente tesis abarcan desde la capacidad de diferentes tipos de ejercicio para mejorar el control inhibitorio, hasta la precisión de herramientas como los acelerómetros en la monitorización de ejercicio físico. Este apartado sintetiza los resultados clave de dichas investigaciones, destacando tanto las mejoras físicas y cognitivas observadas como las implicaciones prácticas para la promoción de un envejecimiento saludable y su prescripción.

En el primer estudio contemplado (Carbonell-Hernández et al., 2020) las correlaciones entre la frecuencia cardíaca y los datos de acelerometría durante sesiones de ejercicio en adultos mayores no fueron altas, indicando que la acelerometría podría no ser efectiva para evaluar ciertos tipos de ejercicio, especialmente aquellos que baja intensidad no basados en caminar. En sesiones de intensidad moderada, la correlación entre la frecuencia cardíaca y la acelerometría fue moderada ($r = 0.519$, $p < 0.001$) en intervalos de 5 minutos, pero no significativo en intervalos minuto a minuto ($r = 0.024$, $p = 0.297$). Estos resultados sugieren que los acelerómetros pueden no capturar adecuadamente la intensidad del ejercicio en actividades que no implican movimientos de caminar constante.

En el segundo estudio contemplando (Carbonell-Hernández et al., 2022) cuya finalidad era comprobar, de forma aguda, cómo diferentes tipos de ejercicio podrían tener diferente impacto en la función cognitiva, se mostraron mejoras significativas en el control inhibitorio tras todas las sesiones de ejercicio, sin diferencias entre tipos de ejercicio. La intensidad del ejercicio vario significativamente entre sesiones: aeróbica (67.69% ± 10.46% FCmáx), fuerza (62.4% ± 7.69% FCmáx), y equilibrio (57.8% ± 9.39% FCmáx) ($F(2, 53) = 5.21$, $p < 0.01$). En el Test Stroop, se observaron diferencias pre-post significativas en el tiempo de respuesta en todas las condiciones, pero sin diferencias entre tipos de ejercicio. La influencia del SNP BDNF no mostró resultados significativos en ninguna de las condiciones del Test de Stroop.

En el tercer y cuarto estudio planteado (Carbonell-Hernández et al., 2020; Carbonell-Hernández et al., 2019) cuyo interés era transferir nuestro conocimiento a la sociedad a través de manuales y proyectos que pudieran presentar un impacto social relevante en base a lo aprendido, en primer lugar se mostraron mejoras significativas post-intervención en el grupo tratado en tareas del Test de Stroop incongruentes, con un aumento medio en aciertos de 17.67 a 19.95 ($p = 0.002$, $\eta p^2 = 0.188$) y en el Índice de Interferencia de 3.15 a 4.75 ($p < 0.001$, $\eta p^2 = 0.344$). Pero no se observan diferencias significativas en las otras mediciones de cognición o memoria verbal. En cuanto a condición física, en el test "6 min walk" se mostró una mejora en la distancia recorrida del grupo tratado, indicando un aumento de la resistencia.

En segundo lugar, se mostró que, tras un programa de 6 meses de entrenamiento, hubo mejoras significativas en la fuerza de las piernas y el bienestar subjetivo tanto en el grupo de mayores jóvenes como en el de mayores viejos. Específicamente, el grupo joven experimentó una pequeña pero significativa pérdida de peso. En el grupo de mayor edad, se observaron mejoras en la fuerza (tanto de brazos como de piernas), agilidad, resistencia (medida con el "6 min walk") y bienestar subjetivo, sin cambios significativos en el peso. Los tamaños del efecto y las significaciones estadísticas indican la efectividad del programa de ejercicios en diferentes aspectos de la salud física y el bienestar en adultos mayores.

CAPÍTULO 5. RESUMEN DE LA DISCUSIÓN

RESUMEN DE LA DISCUSIÓN

El conjunto de los estudios que conforman esta tesis explora la relación entre ejercicio físico y función cognitiva en adultos mayores, enfocándose en distintos tipos e intensidades de ejercicio y su impacto tanto agudo como crónico.

En el estudio previo a esta tesis ya citado en la introducción (Pastor et al., 2017) se observó que, aunque el ejercicio físico incrementaba significativamente la fuerza y la agilidad en adultos mayores, no fue capaz de mejorar de manera significativa la función cognitiva tras seis meses de intervención. Esta discrepancia entre mejoras físicas y estancamiento cognitivo sugirió que la frecuencia o la intensidad del ejercicio podrían necesitar ajustes para impactar positivamente en la cognición. Además, la variabilidad en la asistencia resaltó la importancia de la adherencia al programa para lograr resultados óptimos, insinuando que futuras investigaciones deberían explorar estrategias para mejorar el impacto del ejercicio físico en la función cognitiva. Dentro de las variables que dieron lugar a los estudios de esta tesis, quedó patente que era necesario determinar la intensidad óptima de ejercicio y el tipo de ejercicio para poder organizar programas de ejercicio capaces de mejorar la función cognitiva.

Como consecuencia de los resultados negativos del dicho estudio (Pastor et al., 2017) estudio, se establecieron los dos primeros estudios agudos de esta tesis, con la finalidad de optimizar la evaluación de la intensidad física en esta población, y de determinar el tipo y la intensidad del ejercicio óptimos para la mejora de la función cognitiva.

Por un lado, con relación al análisis y monitorización de los estímulos de ejercicio físico en personas mayores, se subraya la moderada correlación entre la frecuencia cardíaca y la acelerometría en sesiones de ejercicio aeróbico de intensidad moderada, y la inexistente correlación en sesiones de baja intensidad. Determinando que los ejercicios de baja intensidad basados en el equilibrio se subestiman por completo con el uso de acelerómetros, así como otras modalidades de ejercicio físico recomendadas, como las sesiones de entrenamiento de fuerza, que también podrían estar subestimadas por este dispositivo. Además, tal y como destacaron (Schrack et al., 2018) es conveniente reconocer que actividades simples como caminar, presentan una mayor intensidad para individuos con menor capacidad funcional, y este hecho la acelerometría no siempre logra capturar adecuadamente. Esto se debe a que una reducida funcionalidad conlleva un esfuerzo y consumo energético más elevado al andar o realizar cualquier tipo de actividad física. Por tanto, sería conveniente establecer umbrales específicos para las personas mayores, basados en su nivel de funcionalidad, en lugar de hacerlo solo en función de su edad.

Por otro lado, al investigar sobre los efectos agudos de diferentes tipos de ejercicio en la función cognitiva de adultos mayores, se ha observado que todas las modalidades de ejercicio producían mejoras similares en el control inhibitorio, independientemente de la frecuencia cardíaca, siempre y cuando se mantenga la intensidad subjetiva del esfuerzo. En sesiones de fuerza y equilibrio, la frecuencia cardíaca puede no ser determinante para considerar la intensidad de la sesión. Se sugiere por tanto que la intensidad del ejercicio, más que el tipo, puede ser crucial para los beneficios cognitivos agudos. Sin embargo, la falta de diferencias significativas en la respuesta cognitiva entre los tipos de ejercicio desafía la necesidad de prescripciones de ejercicio altamente específicas basadas en el tipo para mejorar la cognición de los adultos mayores, ya que la intensidad subjetiva mantenida podría ser la razón por la cual el estudio no encontró diferencias entre los tres tipos de ejercicio en nuestra investigación. En relación con el efecto del genotipo de BDNF y el impacto del ejercicio físico en la cognición, el estudio de esta tesis no pudo corroborar la hipótesis de que el SNP del BDNF modula la respuesta cognitiva post-ejercicio.

En relación a lo aprendido, se decidió participar en actividades de transferencia del conocimiento, con el fin de observar el impacto de programas de ejercicio optimizados para la mejora de la función cognitiva.

En primer lugar, se presentó la posibilidad de participar en el proyecto Erasmus Plus KA2 MEMTRAIN, en el cual se planteó lo aprendido como programa de ejercicio y se evaluó los resultados obtenidos en el estudio de Carbonell-Hernández et al. (2019). Dicho estudio analizó los cambios producidos por la participación durante dos meses en un programa de ejercicio físico combinado con entrenamiento cognitivo respecto a un programa de solo entrenamiento cognitivo, y mostramos que existen mejoras significativas en el control inhibitorio y la función ejecutiva solo de aquellos que combinaron físico junto a las tareas cognitivas, sugiriendo la relevancia del ejercicio físico diseñado con la intensidad percibida correcta, para la salud cognitiva de las personas mayores.

Finalmente, en la otra participación en un proyecto Erasmus Plus KA2 (Carbonell-Hernández et al. 2020), en el cual se valoró el impacto del programa de ejercicio sobre el bienestar percibido, pudimos observar que los programas de ejercicio físico mejoran significativamente la fuerza y el bienestar en adultos mayores. Y aunque las mejoras físicas sean modestas, el aumento de la vitalidad subjetiva de forma moderada como consecuencia, destaca la importancia del ejercicio en el bienestar general de la vejez.

Por tanto, los hallazgos obtenidos en el desarrollo de esta tesis doctoral resaltan la capacidad del ejercicio físico para producir respuestas físicas y cognitivas tanto agudas como crónicas en personas mayores, al tiempo que muestran la necesidad de controlar de forma individualizada dichas intervenciones para poder obtener tales beneficios, y el riesgo de no obtener beneficios si la intervención no consigue las mejoras necesarias y/o no cuenta con el seguimiento adecuado por parte de los participantes.

CAPÍTULO 6. CONCLUSIONES DE LA TESIS

CONCLUSIONES DE LA TESIS

Las principales conclusiones que podemos extraer de la presente tesis son:

Respecto al primer objetivo, en relación a la eficacia de los acelerómetros para valorar la intensidad de las sesiones de ejercicio físico en personas mayores, se concluye que:

- Existe correlación moderada entre la frecuencia cardíaca y la acelerometría de intensidad moderada, pero no tan robusta como para afirmar correlación alta en todas las circunstancias (no se cumple H1).
- La acelerometría no permite valorar la intensidad de las sesiones de ejercicio físico en su conjunto (no se cumple H2).

Respecto al segundo objetivo que fue comprobar cómo diferentes tipos de ejercicio de forma aguda podrían tener diferente impacto en la función cognitiva, se establece que:

- Las sesiones de mayor intensidad como las de fuerza y resistencia no tuvieron mejoras más acentuadas que la de menor intensidad, como la de equilibrios (No se confirma H3).
- La sesión de resistencia no tuvo mayor impacto que la de fuerza (no se confirma H4).
- El SNP del BDNF no moduló la respuesta cognitiva después de una sesión aguda de ejercicio (no se confirma H5).

- Los portadores del gen Met no mostraron efectos más reducidos de los beneficios de la actividad que los portadores del gen Val (no se confirma H6).

Respecto al tercer objetivo, donde se quiso comprobar el impacto de lo aprendido en dos proyectos europeos de transferencia, se establece que:

- La aplicación de los manuales de intervención creados para divulgación produjo mejoras físicas y cognitivas en los participantes (se cumple H7).

LIMITACIONES DE LA TESIS

La presente tesis doctoral muestra diversas limitaciones propias de su diseño y de su elaboración. Por una parte, al tratar de abarcar múltiples dimensiones de un problema amplio y complejo como son las variables de determinan las relaciones dosis-respuesta entre el ejercicio físico y la función cognitiva, la presente tesis está limitada en profundizar preguntas relevantes que han sido resultado de algunas investigaciones. Así pues, la relevancia de la adherencia, o las variables de la condición física que es necesario mejorar de forma crónica para mejorar la función cognitiva, no han sido estudiadas, a pesar de emerger como preguntas de máxima relevancia tras el primer artículo publicado.

Al mismo tiempo, los estudios presentados tienen muestra suficiente para responder las principales preguntas planteadas, pero claramente se presentan muestras algo escasas para algunas dudas complejas, particularmente el impacto del SNP de BDNF.

Por otra parte, la propia voluntad de la tesis de trasladar lo aprendido por medio de proyectos Erasmus Plus KA2, a través de la creación de manuales y su aplicación en diversos entornos de la UE, dejan como resultado dos estudios científicos donde el rigor de los experimentadores es limitado, al haber tenido que entrenar en la recogida de datos a profesionales sin ningún conocimiento previo en metodología científica, lo que limita la relevancia de los estudios correspondientes.

Finalmente, en los estudios agudos, si bien el planteamiento de tratamiento contrabalanceado permite extraer conclusiones significativas a nivel metodológico usando un menor número de participantes. La presencia de grupos control, o incluso placebo, habría dado lugar a resultados más sólidos y relevantes.

CAPÍTULO 7. BIBLIOGRAFIA

BIBLIOGRAFIA

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CAPÍTULO 8. ANEXOS

8.1. Artículos indexados en JCR.

8.1.1. Artículo 1.

Lack of Correlation between Accelerometers and Heart-Rate Monitorization during Exercise Session in Older Adults

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Nota. Este estudio se encuentra publicado.

Carbonell-Hernández, L., Pastor, D., Jiménez-Loaisa, A., Ballester-Ferrer, J. A., Montero-Carretero, C., & Cervelló, E. (2020). Lack of Correlation between Accelerometers and Heart-Rate Monitorization during Exercise Session in Older Adults. *Int J Environ Res Public Health*, *17*(15). https://doi.org/10.3390/ijerph17155518

8.1.1. Artículo 1.. *Lack of Correlation between Accelerometers and Heart-Rate Monitorization during Exercise Session in Older Adults.*

ABSTRACT

Aging is increasing worldwide, and hence, aging-related health is also more relevant. Well-programmed physical exercise is now an indispensable tool to achieve active aging and preserve older people's health. Such "well-programmed" exercise requires efficient and useful tools to measure the activity. The objective of this study is to evaluate the effectiveness of accelerometers to estimate two different intensities of physical exercise in older people. Thirty-eight subjects (64.5 ± 5.3 years) were measured during two different sessions of physical exercise, one moderate in intensity, the other of low intensity. Heart rate and accelerometry were recorded and analyzed. The results show that the two variables in the physical exercise sessions are not highly correlated, and that accelerometry does not seem useful to assess low-intensity sessions not based on walking.

Keywords: heart rate, accelerometry, exercise session, intensity

INTRODUCTION

Evidence shows that the ratio of the aged population is growing worldwide due to declining birth rates and increased life expectancy(Fehlings et al., 2015). Biologically, aging is an inevitable process that occurs throughout the life of species, with different evolution(Jones, Scheuerlein, Salguero-Gomez, et al., 2014). In humans, this process implies a progressive deterioration of physiological systems in the last years of life(Park & Yeo, 2013). Aging is, therefore, a degenerative mechanism determined by genetic and environmental variables, in which lifestyle is strongly related to the development of the process(Park & Yeo, 2013). Therefore, certain daily habits such as physical exercise, physical activity, smoking, or stress can regulate this process positively or negatively.

As aging advances, the risk of fragility and disability increase(Fried et al., 2001). Although aging cannot be stopped, its effects can be countered by certain behaviors or lifestyles. Physical exercise and physical activity are undoubtedly health- and disease-related variables(de Souto Barreto, 2015). Physical inactivity accentuates risk factors related to mortality and disease, such as cardiovascular disease, diabetes mellitus, or some cancers(de Souto Barreto, 2015; Hollmann et al., 2007).

It is important to differentiate between physical activity and physical exercise, both of which are related to life-long health. On the one hand, physical activity refers to any movement produced by the muscle system that involves an increase in energy consumption; activities such as shopping, gardening, house-cleaning, etc... increase people's physical activity. On the other hand, physical exercise is a planned, structured, and repetitive physical activity aimed at improving one or more components of one's physical condition(Chodzko-Zajko et al., 2009). Due to the risk of inactivity and the benefits of physical activity, the general physical activity recommendations of the American College of Sports Medicine (ACSM) are to increase physical activity through the habitual practice of well-scheduled physical exercise(Chodzko-Zajko et al., 2009).

There are currently many physical exercise recommendations for the health of adults (American College of Sports, 2009; Garber, Blissmer, Deschenes, Franklin, Lamonte, Lee, Nieman, Swain, et al., 2011; O'Donovan et al., 2010) and older people in particular(Chodzko-Zajko et al., 2009). Following the ACSM recommendations, older people should perform aerobic, strength, and flexibility exercise and, if required, balance/neuromotor exercise(Chodzko-Zajko et al., 2009). These different exercise modalities involve different activities during physical exercise sessions.

In sports, the importance of quantifying physical exercise is well known. The training load is measured to improve exercise prescription and to be more efficient in the training process, achieving better fitness goals(Borresen & Lambert, 2009). In prescribed health-related physical exercise, individualized and tailored programs are currently being proposed to improve the impact of physical exercise on health(Buford et al., 2013). This implies that physical exercise must be quantified by valid and reliable tools. Not only is accurate and objective information necessary, but such information must be accessible, and if possible, inexpensive, to extend its use to the entire population.

Questionnaires and diaries have commonly been used to measure physical activity or physical exercise but they present certain problems of subjectivity and bias(Borresen & Lambert, 2009; Gorman et al., 2014). The Borg scale, used to measure the subjective perception of effort, is also commonly used to assess the intensity of exercise, but it does not always have a high relationship with the physiological changes produced during physical exercise(Chen et al., 2002). Heart-rate (HR) monitoring is a useful tool for measuring the intensity of aerobic physical exercise(Borresen & Lambert, 2009), as HR and work intensity have a linear relationship when below the maximum oxygen consumption.

Accelerometers have been used in recent years to measure people's overall physical activity over long periods of time (days, weeks), showing their usefulness in adolescents(Beltran-Carrillo et al., 2017), adults(Evenson et al., 2016), and older people(Corcoran et al., 2016). Accelerometry provides greater accuracy and precision than self-report measures or pedometers(Bailey et al., 2012).

Accelerometers allow interpreting the time, intensity, and frequency of physical activity (e.g., sedentary, light, moderate, or vigorous activity) or its combined subcomponents (e.g., moderate to vigorous physical activity, usually expressed as MVPA) during specific periods of time. Accelerometers are easy to transport and use and can analyze a large amount of data(Calahorro Canada et al., 2014).

Although accelerometry is considered a gold-standard measure to quantify people's daily physical activity levels, this method has some limitations. This instrument cannot quantify the activity of upper body movements, aquatic activity, cycling... so certain activities are underestimated(Fairclough et al., 2012). Moreover, accelerometers do not provide information about physical activity behavior(Fairclough et al., 2012). Finally, the great varieties of monitors, epoch lengths, and cut-off points selected are several factors that hinder comparisons between studies(Laguna et al., 2013).

Accelerometers are useful to quantify overall physical activity. However, as general physical activity recommendations promote physical exercise to increase daily physical activity and health(Chodzko-Zajko et al., 2009), it is necessary to ensure that the use of accelerometers will correctly quantify these scheduled and organized activities recommended for the general population.

The objective of this study is to evaluate the effectiveness of accelerometry to estimate two sessions of different physical exercise intensities in older people. For this purpose, heart-rate monitoring was used as a standard to correlate with accelerometer results.

MATERIAL AND METHODS

Sample

Thirty-eight subjects (13 males and 25 females; 64.5 ± 5.3 years old) participating in a physical exercise program twice a week were asked to take part in the experiment. Two sessions of this program, which were divided into two different intensities, were used for this purpose. The measurement was performed in the same place as their usual practice place, to maintain an ecological setting during measurement. The study was approved by the University ethical committee and was implemented following the Declaration of Helsinki. Written informed consent was obtained from the participants before any testing procedures.

Procedure

As participants had no previous experience in the use of these technologies (accelerometers and heart-rate monitors), they received a brief explanation of where to place the accelerometer and heart-rate monitor, how to adjust the elastic bands, and their use during physical activity practice. A monitor helped them place the devices. The accelerometers were placed on the right hip, the pulsometer monitor band was placed on the chest, three centimeters below the nipples, centered around the sternum. This was done just before the session began, and it took approximately 10 minutes each time to place all the devices and prepare them for measurement.

Two different physical exercise sessions were performed with two objectives: a moderate-intensity aerobic session and a low-intensity session focused on balance/neuromotor exercises. The two sessions consisted of 10 minutes of warm-up, three blocks of 10 minutes of exercise, interspersing a minute of rest between blocks to hydrate, and ten minutes of cool-down at the end. The moderate-intensity session consisted of walking for 6 minutes, and then walking for 4 minutes while bouncing a basketball. The low-intensity session consisted of walking slowly on lines drawn on the ground, and performing balance and coordination games in place, along with some core exercises on the ground. The warm-up and cool-down were the same in both sessions.

To ensure that the target intensity was maintained, the subjects' maximum heart rate (HRmax) was estimated using Tanaka's formula (208 - 0.7 x Age)(Tanaka et al., 2001a), and the subjects were monitored to maintain an HR between 65-75% of the HRmax during the moderate-intensity session, and below 65% of the HRmax during the low-intensity session. The different HRs of the sessions were recorded and compared with Student's *t*-test. The moderate-intensity session presented a mean HR of $M = 100.71 \pm 9.71$ beats per minute (bpm), and the low-intensity session presented a mean HR of 93.09 ± 10.72 bpm. The results showed a significant difference between the two sessions ($p = 0.002$).

Instruments

Heart-Rate Monitoring

HR was monitored with H10 pectoral bands using the Polar Team 2 instrument (Polar Team System, Polar Electro Oy, Kempele, Finland), which records the HR second-by-second directly from the chest. The second-by-second data was used to calculate the means of the minute-by-minute and the five-minute interval HR.

Accelerometers

ActiGraph GT3X monitor devices (ActiGraph, Pensacola, FL, USA) were used to obtain the accelerometry data. For the sake of precision and to obtain second-by-second information with the HR sensor, three-axis accelerometry (vector magnitude) was recorded, and a one-second epoch length was selected to record the data. (Santos-Lozano et al., 2013)cut-off points were selected to estimate energy expenditure because these authors used the same device and the same population for these cut points. We recorded for the analyses the second-by-second data, as well as the means of the minute-by-minute and 5-minute interval data.

Statistical Analysis

Pearson correlations between variables were calculated. Statistical significance was placed at $p = .05$. Pearson r-values were classified following Mukaka´s criteria: values between 0.9 and 1.0 were considered very highly correlated, between 0.7 and 0.9 highly correlated, between 0.5 and 0.7 moderately correlated, and values between 0.3 and 0.5 were considered low correlations(Mukaka, 2012). The minute-by-minute and five-minute interval accelerometry and heart-rate data were analyzed to calculate the linear regression between the two measurement tools. All statistical analyses were performed using the SigmaPlot 12.0 software.

Results

Heart Rate and Accelerometry correlations in different sessions

The average session results both of HR (beats per minute) and accelerometers (mean of the magnitude of the triaxial vector) of each of the subjects for the two sessions can be seen in Figure 1. Clear differences in accelerometry, as well as clear but lower differences in HR, can be observed.

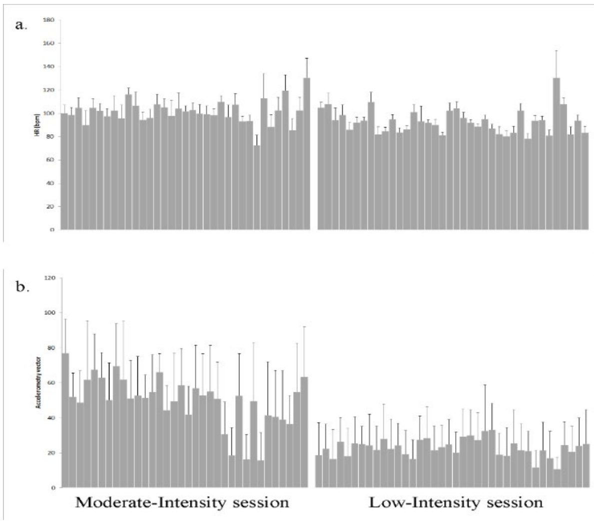


Figure 1: a. Mean and standard deviation of the heart rate at each session for each of the subjects participating in the sessions. b. Mean and standard deviation of the magnitude of the triaxial vector of the accelerometer of each session for each of the subjects participating in the sessions

Accelerometers show a subject's activity second-by-second. Changes in cardiac response (HR) to physical activity are delayed compared to changes in intensity during the efforts. The 5-minute intervals, where this delay is assimilated in the interval, were therefore expected to show higher correlations with the accelerometry results.

As can be seen in Table 1, the correlations were higher and more significant in the 5-minute intervals than in the minute-by-minute interval in the moderate-intensity session (Table 1). As expected, walking-based aerobic physical exercise showed significant correlations between HR and accelerometry, which were higher in the 5-minute interval (r = .519, p < .001) than in the minute-by-minute interval (r = .024, p = .297). Conversely, the low-intensity session, with slow movements and static exercises, did not correlate with any of the intervals.

Table 1.

Pearson Correlations between HR and Accelerometry data during different time intervals.

	Minute-by-minute		**5-minute intervals**	
	MOD	LOW	MOD	LOW
r	.407	.024	.519	.106
p	< .001	.297	< .001	.583
n	1789	1891	343	357

MOD = Moderate-intensity aerobic session. LOW = Low-intensity balance session

Linear regression analysis showed a positive and significant relationship between accelerometry (ACC) and HR during the moderate-intensity aerobic session (Figure 1), both for the minute-by-minute analysis (ACC = -38.393 + (0.861 · HR), Adjusted R^2 (Adj Rsqr) = 0.165; Figure 1a), and for the 5-minute intervals (ACC = -49.514 + (0.976 · HR), Adj Rsqr = 0.267; Figure 1b).

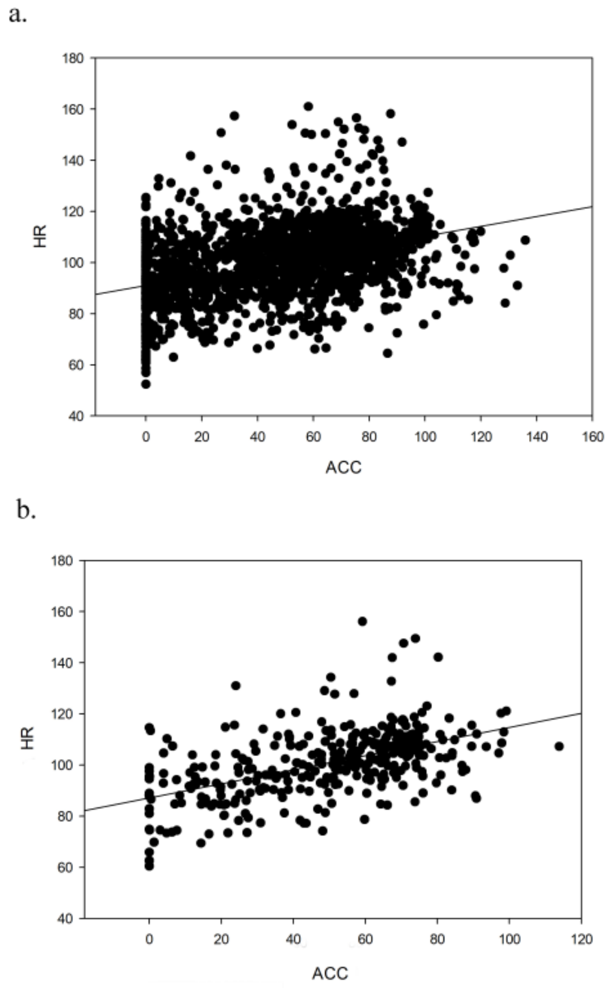
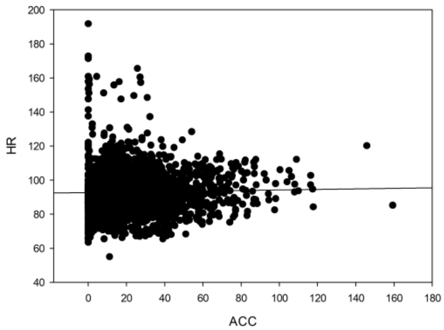


Figure 1. Linear regression of Heart Rate (beats per minute) and Accelerometry (one-minute mean for the vector magnitude of the three axes) in the moderate-intensity aerobic session. a. minute-by-minute. b. 5-minute intervals.

In the low-intensity session with balance exercises, the linear regression showed no significant adjustments for any of the intervals (Figure 2), either the minute-by-minute interval (ACC = 19.975 + (0.0376 · HR), Adj Rsqr = 0.000047; Figure 2a) or the 5-minute interval (ACC = 26.110 – (0.0348 · HR), Adj Rsqr = 0.000; Figure 2b).

a.



b.

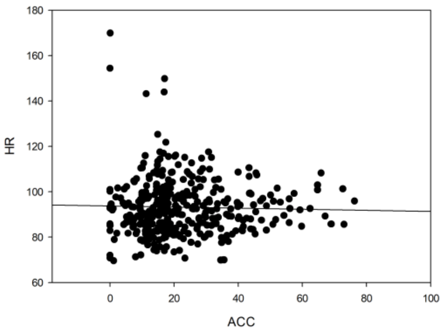


Figure 2. Linear regression of Heart Rate (beats per minute) and Accelerometry (one-minute mean for the vector magnitude of the three axes) in the low-intensity session. a. minute-by-minute. b. 5-minute intervals.

Heart Rate and Energy Expenditure Estimation.

Using Santos-Lozano's cut-off points(Santos-Lozano et al., 2013), the time spent in each session was calculated at different METs (Metabolic Equivalent Task defined as 3.5 ml O_2·kg−1·min−1) of intensity: time under 3 METs, time between 3 and 6 METs, and time over 6 METs.

When all the data obtained both from the moderate- and low-intensity sessions were conjointly analyzed, we observed a small negative correlation with the low-intensity modality (< 3 METs) (Table 2). This is consistent because the higher the subject's HR, the less time they spend consuming low energy (< 3 METs) because high HR requires high energy consumption.

Interestingly, when analyzing the sessions separately, this correlation did not appear in the moderate-intensity session (Table 3), and but it did emerge in the low-intensity session (Table 4). This is incongruous with the data shown in the linear regression, as the METs are calculated with the accelerometry data.

Table 2.

Pearson Correlations between HR and METs of both conditions.

HR	< 3 METs	3-6 METs	6+ METs
r	-.324	.167	.097
p	.006	.160	.416
n	72	72	72

METs (Metabolic Equivalent Task defined as 3.5 ml O_2·kg−1·min−1)

Table 3.

Pearson Correlations between HR and METs of moderate-intensity session.

HR	< 3 METs	3-6 METs	6+ METs
r	-.057	-.107	.029
p	.747	.549	.870
n	34	34	34

METs (Metabolic Equivalent Task defined as 3.5 ml O_2·kg−1·min−1)

Table 4.

Pearson Correlations between HR and METs of low-intensity session.

HR	< 3 METs	3-6 METs	6+ METs
r	-.497	-.089	.018
p	.002	.592	.911
n	38	38	38

METs (Metabolic Equivalent Task defined as 3.5 ml O_2·kg−1·min−1)

Discussion

The objective of this study was to evaluate the effectiveness of accelerometers in estimating physical activity during physical exercise sessions, as these sessions are generally recommended for increased activity and health (Chodzko-Zajko et al., 2009). This prescription of physical exercise includes sessions with different exercise modalities and different intensities (Chodzko-Zajko et al., 2009), which should be as personalized as possible(Buford et al., 2013), making the quantification of such exercise an important parameter in the management of training programs.

This study shows moderate correlations between HR and accelerometry in moderate-intensity aerobic sessions, but no correlation in low-intensity sessions based on balance.

There is also an almost non-existent correlation between HR in a physical exercise session and the energy expenditure calculated with accelerometers during the same session. The moderate correlation between HR and accelerometry during moderate-intensity aerobic sessions may allow the use of accelerometers to monitor these activities, at least for the five-minute intervals. However, with these correlation values, it should be kept in mind that, when using the accelerometer, considerable information is lost about the physical activity carried out during this type of session. Low-intensity exercises based on balance are completely underestimated with the use of accelerometers. Other physical exercise modalities that are recommended, such as resistance training sessions, are probably also underestimated by this device.

Accelerometers are often used to evaluate physical activity over extended periods of time, but not to quantify physical activity in particular physical exercise sessions(Gorman et al., 2014). However, to improve these levels of physical activity and health, it is recommended to perform physical exercise programs with different training-session modalities(Chodzko-Zajko et al., 2009), and it should be taken into account that these activities will surely be underestimated when using the accelerometer to calculate individuals' activity and energy expenditure.

In this study, two main limitations were found to consider accelerometers as useful for controlling exercise programs in older people. First, accelerometers do not present a high correlation with moderate aerobic sessions. Second, the accelerometer is completely inadequate to assess the intensity of low-intensity sessions based on balance and neuromotor exercises.

On another hand, as Schrack et al. indicated in their study, we must take into account that activities such as walking are more intense for less functional subjects, (Schrack et al., 2018)and this can hardly be taken into account by accelerometry. In fact, if less functionality involves more effort and more energy expenditure when walking or performing any other physical activity, we should have specific cut-off points for older people concerning their functionality, and not simply because of their age.

Different cut-off points have been proposed to accurately measure the physical activity of older people. The cut-off points that Sanchez-Lozano (Santos-Lozano et al., 2013) used in this article show a low deviation in low-intensity activities, such as those performed in this study, but higher deviations in other measures(Aguilar-Farias et al., 2019). To our knowledge, there are no cut-off points for older people according to their functionality, and this would probably be necessary to gather more accurate information about physical activity programs. Likewise, it would be necessary to have different cut-off points for different types of physical exercise to more accurately estimate the physical activity carried out by older people when participating in organized physical exercise programs to improve their health.

Conclusion

To conclude, we discourage the use of accelerometers to monitor physical exercise sessions in older people. Although its use seems appropriate to quantify daily physical (Gorman et al., 2014) activity, we consider that it would be interesting for such quantifications to take into account that the physical activity performed in organized physical exercise programs is probably being underestimated by accelerometry. Nevertheless, more research is needed to investigate the role of accelerometers for these purposes.

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Conflicts of Interest: The autors declare no conflicts of interest.

Appendix A

Figure A1. Actigraph gt3x position.

Figure A2. Polar Team 2 device

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8.1.2. Artículo 2.

Different Exercise Types Produce the Same Acute Inhibitory Control Improvements When the Subjective Intensity Is Equal

Nota. Este estudio se encuentra publicado.

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8.1.2. Artículo 2. *Different Exercise Types Produce the Same Acute Inhibitory Control Improvements When the Subjective Intensity Is Equal.*

Abstract

Twenty-eight active older people (67.19 ± 4.91 years) who engaged in physical exercise activity twice a week were recruited to participate in a counterbalanced experimental protocol. The participants performed three different exercise sessions on three different days, one based on aerobic activities, one based on strength exercises with elastic bands, and one based on stationary balance games. During all three sessions, they were encouraged to maintain a moderate subjective intensity (5–6 on the RPE10 scale), and their heart rate was recorded. In addition, all of the participants took a digital version of the Stroop test before and after each session. The study aimed to compare the acute cognitive impacts of different types of exercise sessions in older adults. The participants' heart rate differed between the exercise sessions, but they maintained the RPE intensity. There was a significant improvement in inhibitory control (Stroop test) after all sessions, with no differences between exercise sessions. Moreover, some participants agreed to be genotyped to record the single nucleotide polymorphism of BDNF rs6265. There were no differences between Val/Val and Met carriers at the beginning or end of the exercise sessions. The present study showed similar cognitive improvements with different exercise type sessions when the subjective intensity was maintained.

Keywords: aging; cognitive function; Stroop; physical exercise; exercise type

1. Introduction

Aging is a global process that implies the deterioration of different human systems over time [1]. The central nervous system is one of the most affected systems during the aging process [2]. The impact of aging on the brain produces cognitive function impairment [3]. However, the evidence promotes physical exercise to reduce cognitive impairment and even improve cognitive function during aging [4]. For years, scientific research has been studying the frequency, intensity, time, type (FITT) variables that modulate the impact of physical exercise on cognition [5].

Cognitive function is a concept that integrates a large number of cognitive domains. For example, regarding physical exercise, executive functions are a common domain studied in the literature and include variables such as work memory, attention, inhibition, and cognitive flexibility [6]. Moreover, these variables are particularly relevant during learning [7]. In addition, selective attention has been defined as the skill of focusing attention and avoiding distractions, and it has been widely studied due to its importance in the academic environment [8].

The benefits of physical exercise for cognitive function consist of both acute benefits after single sessions [9] and chronic improvements after prolonged exercise programs [5]. Different hypotheses explain acute and chronic cognitive improvement with physical exercise. The increase in brain blood flow, neurotrophic factors such as brain-derived neurotrophic factor (BDNF), the reduction in cortisol, or the control of chronic diseases such as hypertension or diabetes can explain the cognitive improvements [10]. In addition, different studies have investigated the effect of the intensity of exercise on the production of cognitive improvements [11–17]. Moreover, different studies have evaluated the different types of exercise. These studies have focused on aerobic exercise [18], resistance training [9,11], or different coordinative activities such as Tai Chi [19]. One of the most common forms of exercise training to improve health in older adults is multi-component programs, which include strength, aerobic, and balance exercises, and they have shown benefits even in hospitalized [20] and institutionalized [21] older adults. However, insufficient evidence exists about the impact of different exercise types on cognitive improvements. No comparative studies between different types of exercises have been published.

Moreover, BDNF seems to be a critical factor in cognitive function. In humans, BDNF secretion is regulated by the BDNF gene. During development, BDNF functions are concerned with neuronal growth and the survival and differentiation of neurons [22,23]. These characteristics, along with the well-established role of BDNF in synaptic plasticity, are translated into positive functional changes, making BDNF a key protein implicated in the formation and consolidation of memories [24]. This gene presents a single nucleotide polymorphism (SNP) named rs6262 SNP or BDNF Val66Met gene polymorphism. This SNP substitutes a valine (Val) for methionine (Met) in codon 66. The Met SNP has been found to reduce the BDNF secretion [25]. In addition, in hu-mans, Met carriers have shown reduced effects from exercise benefits on declarative memory [26]. The relevance of controlling the BDNF SNP when studying the impact of exercise on cognitive function seems clear.

Consequently, this study aims to compare the acute cognitive impacts of different types of exercise sessions in older adults. Moreover, the BDNF SNP will be controlled for the study.

2. Materials and Methods

2.1. Experimental Design

The participants attended the laboratory four times, once a week for four weeks. In their first session, they were informed about and signed the written consent for the research. In addition, they undertook the training protocol with the Stroop test software. Finally, they performed one of the three different exercise sessions in each of the other three sessions. The cognitive test preceded all of the exercise sessions, and the post-test was carried out 10 min after the end of the sessions.

The exercise sessions were performed at 9:30 in the morning on the same day of the week for all of the participants. In addition, all of the participants were aleatorily counterbalanced to control a possible learning bias.

The study was designed in compliance with the Declaration of Helsinki and ap-proved by the University's Project Evaluation Committee (evaluation code UMH.CID.DPC.02.17).

2.2. Participants

Twenty-eight participants (age 67.19 ± 4.91 years) were recruited for the study. All of them were physically independent, and all of them participated in organized physical exercise activities in their leisure time. Unfortunately, only 14 participants agreed to be genotyped to identify their Val66Met SNP.

2.3. Genetic Analysis

Saliva samples were collected with the Orange DNA Kit (OG-500 DNA Genotek Inc., Ontario, Canada). DNA was extracted following the manufacturer's protocols. In addition, a quantitative real-time StepOne PCR (Applied Biosystem, Massachusetts, USA)) was used to identify the SNP using a previously described protocol [27]. Participants were described if they carried (MET) or not (VAL) one or two methionine nucleotides. Eight participants were "VAL," and six were "MET" (five VAL/MET and one MET/MET).

2.4. Inhibitory Control Test

Computer software adaptation of the Stroop test was used to measure the inhibitory cognitive capacity [28]. The Stroop test is a standard tool to measure cognitive inhibition [29,30]. The tests were performed on 8-inch tablets (Lenovo TB3-850F, Lenovo Group Limited, Beijing, China).

The test has three different conditions to measure cognitive inhibition. The first condition is congruent, and words ("red, blue, yellow and green") are presented in black ink (Word Condition). The second condition is neutral, and "XXXX" is presented in different colored inks (Color Condition). The last condition is incongruent, and the words are written with non-coincident inks (Word + Color Condition).

In the three conditions, 50 words were presented to the participants. The failures, successes, and time to complete the 50 words were registered.

2.5. Exercise Sessions

Three different exercise sessions were used in the research. Each session was de-signed with different types of exercises (aerobic exercise, strength exercise with elastic bands, and balance exercises). All of the sessions started with the same 10-min warm-up and finished with the same 10-min cool-down. The central part of each exercise session lasted 30 min.

The warm-up and cool-down presented the same exercises but in reverse order. In the warm-up, the participants undertook 2 min of joint mobility (knees, hips, waist, shoulders, and elbows). Then, they walked for 4 min, increasing their speed every minute until they reached an RPE 5–6 (RPE10 scale). To finish, they conducted three aerobic exercises with a 40 s work and 20 s rest period (exercises can be seen here https://www.youtube.com/watch?v=iRwCUlPobmI&list=PLBUVHpzj7dwOAPml-ZZYXkSUyQeLcwPps).

In the cool-down, the same exercises were conducted in the reverse order, encouraging the participants to reduce RPE to 2–3 at the end of the 4 min walk.

The three sessions were developed on two basketball courts.

The balance session included 21 exercises that were increasingly difficult (exercises can be seen here https://www.youtube.com/watch?v=qBV67H-LJ_g&list=PLBUVHpzj7dwMrgUXWbdhzLQ3ktWRUA5_N). The session included three exercise blocks of 8–9 min of work (one minute each exercise with 40 s work and 20 s rest) with 1 or 2 min at the end to rest and rehydrate (10 min each block). The first block included nine walking exercises with a rope. The second and third block included six reach and pulls exercises with or without a pike, and they performed eight exercises (they repeated some exercises twice) with difficulty feeling secure. The participants did not need to perform all of the exercises, as they had to feel secure, so that they could decide not to increase the difficulty and repeat the previous exercise every moment. They were encouraged to maintain the 5–6 RPE.

The aerobic session included three exercise blocks of eight continuous minutes of work with two minutes of rest to rehydrate. The three blocks consisted of 4 min of walking with 5–6 RPE, and 4 min of walking bouncing a basketball ball; they were al-lowed to throw the ball to the basket only if they walked all of the basketball courts.

The strength session included three exercise blocks of 8 min of work with 2 min of rest to rehydrate. Eight exercises were used and each block was repeated (the exercises can be seen here https://www.youtube.com/watch?v=GJaMvoZBYh4&list=PLBUVHpzj7dwMrvvlDOSJOWx9OWgVQ6UAG). They worked for 40 s and rested for 20 s with each exercise, maintaining the 5–6 RPE.

In all of the sessions, the participants were encouraged to maintain a moderate in-tensity (5–6 RPE10 scale). They were continuously reminded of this intensity objective during the sessions. At the end of the sessions, all of the participants declared that they had maintained the objective intensity.

A Polar Team 2 Pro System (Polar Electro Oy, Kempele, Finland) was used to con-trol the physiological intensity of the participants during the sessions. Moreover, the participants' maximal heart rate (HRmax) was estimated with Tanaka's formula [31] to control the percentage of HRmax (%HRmax).

2.6. Statistical Analysis

A repeated-measure (RM) ANOVA 2 × 3 was used to evaluate the pre-post Stroop results of the three sessions and to analyze the effect of exercise (moment pre–post) vs. the type of exercise (aerobic, strength, and balance). The analysis was repeated for the three conditions of the Stroop test. In addition, the Bonferroni post hoc analysis was undertaken to compare the pairs.

To analyze the BDNF SNP, an RM ANOVA 2 × 3 × 2 was developed to include the two SNP genotypes. A bilateral signification of $p < 0.05$ was fixed. The Mauchly test was conducted to evaluate the sphericity of the data. The effect size was calculated with square partial eta ($\eta^2 p$), grouped into low (≤0.01), medium (≤0.06), and large (≤0.14) effects [32]. The data are presented as the media ± standard deviation. The analysis was performed with JASP 0.16 (Eric-Jan Wagenmakers, Department of the Psychological Methods University of Amsterdam, Nieuwe Achtergracht 129B, Amsterdam, Netherlands).

3. Results

3.1. Exercise Session Intensity

Despite the RPE encouragement and RPE10, the %HR differed significantly be-tween the different exercise sessions ($F(2, 53) = 5.21$, $p < 0.01$). That is a necessary consequence of the different exercise types. The aerobic session presented the highest heart rate intensity (67.69% ± 10.46% HRmax), followed by the strength session (62.4% ± 7.69% HRmax). Finally, the balance session presented the lowest heart rate values (57.8% ± 9.39% HRmax).

3.2. Stroop Test: Successes, Failures, and Time

The data showed small differences between the successes and failures in the pre–post analysis. There were no significant differences in a t-test. Only time indicated the pre–post differences in all of the conditions ($p < 0.001$). As a consequence, the RM ANOVA was performed with the time data.

3.3. Stroop Test: Word Condition

There were significant pre–post differences for the time in the Word Condition for all the sessions ($F(2, 58) = 10.25$, $p = 0.002$, $\eta^2 p = 0.150$), but there were no differences be-tween the types of exercise in the RM ANOVA 2

× 3 (F(2, 58) = 0.76, p = 0.472). The post hoc analysis did not find any significant data for the pre–post sessions (Figure 1).

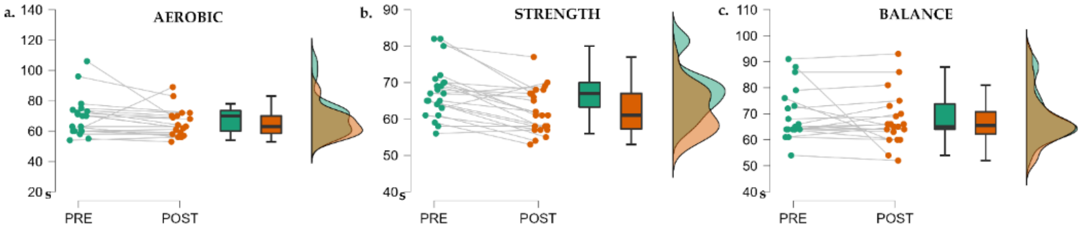

Figure 1. The raincloud plots for the different exercise sessions in the Word Condition. (a). Aerobic session. (b). Strength session. (c). Balance session. Time is measured in seconds (Y-axis).

3.4. Stroop Test: Color Condition

There were significant pre–post differences for the time in the Color Condition for all of the sessions ($F(2, 58) = 10.25$, $p < 0.001$, $\eta^2p = 0.326$), but there were no differences between the types of exercise in the RM ANOVA 2 × 3 ($F(2, 58) = 1.298$, $p = 0.281$). The post hoc analysis showed significant differences for the pre–post sessions only in the aerobic (PRE vs. POST: M = 4.57, SE = 1.45, $t(19) = 3.153$, $p = 0.038$) and strength session (PRE vs. POST: M = 5.73, SE = 1.35, $t(22) = 4.244$, $p = 0.001$) (Figure 2).

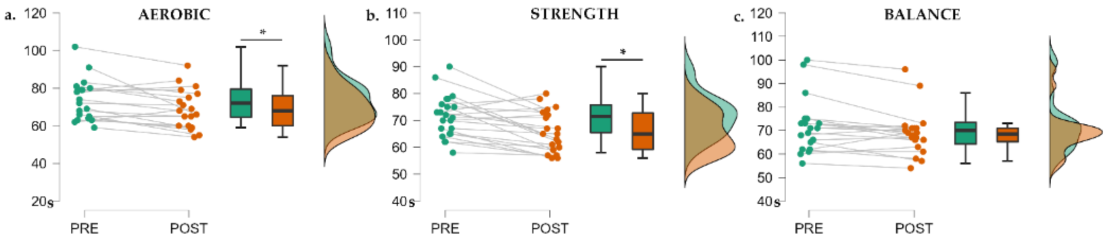

Figure 2. The raincloud plots for the different exercise sessions in the Color Condition. (a) Aerobic session. (b) Strength session. (c) Balance session. Time is measured in seconds (Y-axis). * <0.05 in the post hoc analysis.

3.5. Stroop Test: Word + Color Condition

There were significant pre–post differences for the time in the Word Condition for all of the sessions ($F(2, 58) = 17.48$, $p < 0.001$, $\eta^2p = 0.232$), but there were no differences between the types of exercise in the RM ANOVA 2 × 3 ($F(2, 58) = 0.17$, $p = 0.847$). The post hoc analysis did not find any significant data for the pre–post sessions (Figure 3).

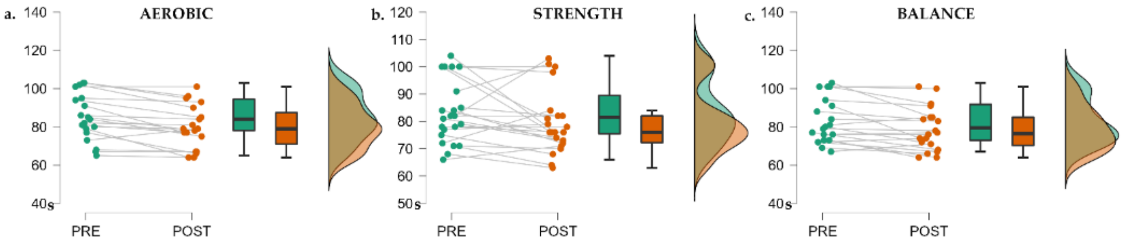

Figure 3. The raincloud plots for the different exercise sessions in the Word Condition. (a) Aerobic session. (b) Strength session. (c). Balance session. Time is measured in seconds (Y-axis).

3.6. BDNF SNP Influence

The RM ANOVA 2 × 3 × 2 was carried out to analyze the influence of the BDNF SNP in the different pre–post Stroop conditions. Unfortunately, no significant results were obtained for any of the Stroop conditions when we took care of the SNP.

4. Discussion

Many articles have been published regarding aerobic exercise and cognitive function [33]. However, there has been an increase in evidence related to other exercise types to improve cognition in the past years such as resistance training and balance/coordinative exercise (e.g., Tai Chi) [34–36].

In our study, all of the exercise types produced the same significant cognitive improvements, with no differences between the exercise types. Only in the Color Condition did there seem to be some differences in the post hoc analysis, but the RM ANOVA results did not support these differences.

These results can be determined by exercise intensity. In our study, the HR response differed between the different exercise types, and it was a foreseeable consequence of the exercise types. According to the American College of Sports Medicine (ACSM) guidelines [37], our strength and balance sessions were light (50–63% HRmax) and the aerobic session was of moderate intensity (64–76% HRmax). Previous studies have found greater acute improvements with higher intensity in aerobic [38] and strength training [11].

However, %HRmax is not a good tool for evaluating the intensity in the strength and balance exercises because the HR response is not related to fatigue in these activities. The intermittent nature of strength training, with short efforts interspersed with recovery periods, means that the heart rate response throughout the exercise sessions does not reflect what occurs at the physiological level [39,40]. While the release of hormonal factors and increased neural drive during efforts leads to an almost immediate increase in heart rate, it takes longer for the cardiovascular system to respond [41]. In our study, to maintain a constant intensity independent of the exercise type, we used the subjective perception with RPE10. As a result, all of the participants maintained a moderate intensity (5–6 RPE10) in all of the exercise sessions independently of the exercise type. The subjective intensity integrates the physiological and psychological signals related to the intensity [42] and may be better related to the cognitive response to acute exercise [33]. Therefore, the subjective intensity maintained could be the reason for the study not finding differences between the three exercise types in our research.

Few articles have analyzed different exercise types. However, in a recent meta-analysis, Gallardo-Gómez et al. [43] analyzed different exercise types concerning cognitive improvement with chronic exercise. In their results, resistance training seemed to be better able to improve cognitive function in older people. Our results cannot be compared with this interesting meta-analysis because we analyzed the acute effect of exercise. Our research did not seem to show differences between the exercise types when the subjective intensity was maintained.

Finally, we failed to corroborate the research hypothesis related to the BDNF SNP. In our hypothesis, the BDNF SNP should modulate the cognitive response after an acute exercise session. However, in agreement with other studies [44], in our research, the BDNF SNP did not modify the cognitive improvements after any different exercise session.

Several mechanisms have been proposed to explain the benefits of physical exercise for cognitive function [45]. One of the plausible underpinnings is enhanced hippo-campus neurogenesis [46], which, in turn, could be directly linked to BDNF [45]. As above-mentioned, the homonymous gene regulates BDNF secretion, but the levels re-leased could be downregulated in the presence of the Val66Met polymorphism. How-ever, our study has not found any influence of the said polymorphism on the cognitive response following exercise. For acute exercise, some distinct markers have been explored in their relationship to cognitive response such as catecholamines [47] and lactate [48]. Moreover aside from genetic factors and biological markers, which were investigated for their role in the exercise cognition relationship, other theories have attempted to explore the latter relationship through the psychological lens. Along this line of thought, exercise induced arousal could explain an improvement in the processing speed, assessed through the reaction time tasks. However, it is worth noting that the impact of arousal on the central domains of such tasks remains limited [11]. On the other hand, psycho-logical well-being, which is positively affected by physical exercise [49], has been established as a modulator of the learning process and has even been proposed as a determinant of academic achievement in young students [50,51].

5. Conclusions

This article shows a cognitive improvement after exercise but no differences be-tween different exercise types. It seems that aerobic, strength, and balance exercises can produce the same improvements if they are performed with the same subjective intensity, independently of the heart rate response. Moreover, BDNF SNP Val66Met does not appear to modulate this response, and all the participants obtained the same benefits regardless of their genetic background.

6. Limitations of the Study

This article presents some limitations that must be improved in future research. First, the number of participants was low, particularly for the BDNF SNP analysis, and the data could be non-significant due to the small amount of data. Moreover, some variables that can modulate the cognitive responses in acute exercises such as mood affects [52] were not measured.

Finally, this study was designed to analyze the differences between three different exercise types, and there was no control group to ensure that the cognitive differences in the pre–post analysis were due to exercise. However, in agreement with the literature and the presence of improvements in the three sessions, a stable response was shown that was probably due to the exercise session.

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Institutional Review Board Statement: The study was conducted in accordance with the Decla-ration of Helsinki and approved by the Institutional Review Board of Miguel Hernández Univer-sity (UMH.CID.DPC.02.17).

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8.1.3. Artículo 3.

Physical Exercise and Cognitive Function.

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8.1.3. Artículo 3. *Physical Exercise and Cognitive Function.*

Abstract

Cognitive function is a relevant skill along with the lifespan. Supporting cognitive function during the aging process and improving it in all the different stages of life should be of major interest. Nowadays, there is a clear relationship between physical exercise and cognitive function. However, we still need more research to understand this relationship's moderators and improve the efficiency of possible exercise programs to improve cognitive function. Behavioral and socioeco-nomic moderators present a lack of research in this field. Moreover, we need to gain a better understanding of the impact of FITT (frequency, intensity, time, and type) variables in cognitive re-sponse. Moreover, if we are looking to individualize the exercise program to increase its efficiency, it is important to take care of the individual characteristics of the participants. Consequently, we need to consider sex and age and study the exercise-cognition relationship in both sexes and at all ages. Only if we increase our understanding of all of these moderators will we have all the necessary clues to design efficient exercise programs to improve cognition.
Keywords: cognitive function; physical exercise; aging; BDNF

1. Livelong cognitive function

Cognitive skills are relevant predictors of academic achievement, employability, socioeconomic success, health, and longevity [1]. It has been shown that cognitive skills are consolidated during adolescence and achieve maximum efficiency during the youth [2]. However, during the aging process, there is a decrease in cognitive function with the years [3]. The cognitive function decline can be explained by the deterioration of the central nervous system during aging. Moreover, brain volume is reduced in regions including the frontal, parietal and temporal lobes and is possibly linked to the observed reductions in brain blood flow [4]. In addition, the decline in the hippocampus volume has been related to cognitive decline during aging [5]. Hippocampus is a cerebral structure that plays a central role in processes associated with declarative and visuospatial memory [6].

Moreover, some molecular changes can accelerate cognitive decline. These alter-nations include decreased levels of neurotrophic factors, such as BDNF (Brain-derived Neurotrophic Factor) and IGF-1 (Insulin-like Growth Factor-1), both leading to im-paired neuronal survival and synaptic decline [7]. In addition, at a vascular level, re-duced production of VEGF (Vascular Endothelial Growth Factor), a potent angiogenic factor, disrupts the creation of new blood vessels [8].

Cognitive decline affects activities of daily living in older people. However, it is essential to know that the decline rate is different between individuals and is influ-enced by many factors [1]. Consequently, it is crucial to identify the factors that can explain the slower rate of cognitive decline. For example, both physical activity and exercise were shown to attenuate it [9]. Therefore, understanding the mechanisms responsible for this cognitive protection with physical exercise is essential.

2. Physical inactivity, physical activity, and physical exercise relationship with cognitive function.

The study of physical inactivity's effects on cognitive decline is an exciting way to understand the relevance of physical activity. Furthermore, physical inactivity has been considered the most significant health problem in the XXI century [10]. Physical inactivity leads to a range of of adverse health consequences, including cognitive de-cline [11] and an increased risk of neurodegenerative diseases in older adults [12].

Physical activity and physical exercise are erroneously equated in some texts. It is important to differentiate both terms to understand the mechanisms regarding cognitive function [13]. Physical activity is any muscle movement that increases energy expenditure above the resting metabolic rate [14]. In contrast, physical exercise is a sub-set of physical activity that is planned, structured,repetitive and performed to improve or maintain one or more dimensions of fitness [14].

The "physical exercise" term is more common in the literature, as experimental research uses planned, structured and repetitive activities to study the relationship between physical exercise and cognition. A large body of research demonstrates the benefits of both acute [13,15-19] and chronic physical exercise [13,17-21] in improving cognitive function.

However, there are still many questions about the optimal type or dose of physical exercise to improve cognition efficiently. Moreover, we still do not know the influence of major moderators in this relationship. In the next section, we will discuss the role of some of the common moderators and highlight important questions that the research must still resolve to understand the relationship between physical exercise and cogni-tive function.

3. Physical exercise and cognitive function. An actual point of view of its relation-ship.

Many factors can moderate the physical exercise and cognitive response relation-ship [18,19]. Stillman, Cohen, Lehman and Erickson [18] classified the mechanisms moderating the exercise cognition relationship in three levels. Thus, their classification explains cognitive improvements through (a) molecular and cellular modifications (level 1), (b) changes in brain structure and functional changes (level 2), and (c) behavioral and socioemotional changes (level 3). However, recent research has focused on the analysis of the first two levels of the exercise cognition relationship; meanwhile, the behavioral influences remain unexplored [18]. As such, level one changes are most evident from the animal models, where observed benefits of physical exercise on the hippocampus imply enhanced spatial learning, memory, and exploration, all of which could be moderated by increased neurogenesis. [22]. In turn, the structural changes of level two have been reported in older adults, where physical exercise programs pro-moted increased hippocampal volume [23].

However, other moderators like sleep, mood, or psychological wellbeing have been studied less extensively, despite some promising research [18]. For example, exercise was shown to improve psychological wellbeing [24] and modulate learning and academic achievement in young students [25,26]. Consequently, more research on level three should be interesting to improve our understanding of the exercise cognition relationship.

Beyond these three levels, other moderators must be considered to increase the efficiency of the exercise cognition relationship. We commonly use the acronym FITT to speak about distinct variables of the physical exercise prescription: Frequency, Intensity, Time, and Type. There is much research on exercise intensity, which can significantly moderate the cognitive response after an acute exercise [27], with the most improvements attributable to high-intensity exercise. In terms of the time variable, there are some indications that low-volume sessions are conducive to the most benefits [27].

Regarding exercise type, most research articles analyze the effects of aerobic exercise on cognition. However, there is a growing research interest in the impact of resistance training on cognitive response, with some evidence that suggests positive improve-ments after both acute and chronic resistance exercise [17,20,28]. On the other hand, there is still a high heterogeneity in both the effects of resistance training and design protocols [20], and further research is needed on the doce response effects for cognitive enhancement [17]. Moreover, we have an absolute lack of knowledge about frequency.

Individualized protocols should be considered to improve the efficiency of the exercise prescription for cognitive benefits. However, we still lack knowledge about spe-cific populations. For example, most research has focused on older people and children [19], but adolescents and young people have been studied less [19]. Moreover, we al-ready know that sex can be a powerful moderator in the exercise-cognition relation-ship [21,29], but there are questions remaining about the influence of sex. For example, some studies have observed higher

levels of BDNF in men than in women, both after acute and chronic physical exercise [30]. In contrast, other studies have found better cognitive response after aerobic exercise in women rather than in men [29].
In conclusion, future research should aim at resolving these questions to promote evidence-based exercise prescription to improve cognitive function.

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8.2. Artículos no indexados en JCR.

8.2.1. Artículo 1.

Two months of combined physical exercise and cognitive training, over cognitive function in older adults: the results of the memtrain project pilot program

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8.2.1. Artículo *1. Two months of combined physical exercise and cognitive training, over cognitive function in older adults: the results of the memtrain project pilot program.*

Abstract:

Introduction: The MEMTRAIN project is a European Erasmus plus KA2 project were 5 sports associations from 5 different European countries and the Miguel Hernández University of Elche collaborate to create an exercise and cognitive training manual for older people. During the project, manual activities were tested in a pilot study.

Methods: Fifty-four subjects from five different countries participated in the project, the treated group did a two-month exercise and cognitive pilot program developed in accord with manual instructions (n = 44). At the same time, a group which only did cognitive training tasks were used as a control group (n = 10). This study was developed in an ecological environment with real participants of the different sports associations.

Results: After the pilot program, the participants in the pilot program improved their Inhibitory cognitive function measured with Stroop test and their Interference Index from the Stroop test. Moreover, there was an intragroup improvement in aerobic fitness, measured with six minutes walk test. No changes were observed in the word learning memory task, neither in agility Up & Go test.

Discussion: Results showed that physical exercise program with cognitive training tasks as is proposed in MEMTRAIN manual maybe could improve the executive function of older adults opposite with only cognitive training tasks.

Keywords: Exercise, Older People, Cognitive Function, Fitness

INTRODUCTION

The time is unstoppable, and is one direction process for human life, in the end, becomes death. Human has fear of the end, and the process which leads us to this end is called aging. Aging is the inevitable effect of time which implies physiological changes during lifespan(Park & Yeo, 2013). Aging is common to all living organisms, and not necessary implies always a deleterious process(da Costa et al., 2016). "Senescence" is the specific word to define those changes of aging leading to disease, disability, and death(da Costa et al., 2016). Anyway, as "aging" is commonly used in literature to speak about the decline of physical function during lifespan as a consequence of time, we will use the aging term.

Different theories are nowadays used to explain aging, theories related with human genetics, with external or internal damage, or combinations of them(da Costa et al., 2016). The consequence of this not clearly understood process is the decline of physiological function, leading to a reduction in adaptability, an increase in disease, and finally to death(Park & Yeo, 2013).

As a consequence of aging, all systems are modified, with individual and social health consequences. For example, cardiovascular diseases like the coronary artery, hypertension or heart failure are dangerously increased in older adults(Lakatta, 2002). At the same time, there is a gradual decline in muscle function, with a muscle wasting process leading to muscle atrophy and sarcopenia in older adults(Miljkovic et al., 2015; Ryall et al., 2008).

As the cardiovascular and muscle systems, the nervous system experiment an aging decline leading a loss of cognitive and brain function(Bherer et al., 2013). This cognitive decline can lead to cognitive dysfunctions like dementia, Alzheimer or Parkinson disease(Lautenschlager et al., 2012). Aging process will affect neurotrophic factors(Bherer et al., 2013), brain structures (Fletcher et al., 2016) and brain plasticity (Erickson et al., 2013) leading to a loss of function.

All these changes are the result of the interaction between environment, lifestyle, and genotype for all subjects(da Costa et al., 2016). That means, lifestyle and environment are in our hand to reduce functional and physiological aging decline, and one of our possibilities to improve the aging process is physical exercise(WHO, 2016). Physical exercise is defined as physical activity program planned and oriented to improve any dimension of fitness or physical performance.

Physical exercise has an impact in all physiological systems, for example, aerobic training is an essential component in cardiac rehabilitation programs, and is well related with cardiac performance in old people(Vigorito & Giallauria, 2014). Well, programmed exercise can reduce arterial pressure, increasing peak VO_2, reducing submaximal exercise heart rate…(Vigorito & Giallauria, 2014). In addition, well-oriented resistance training can improve muscular function during elderly, with high increased in strength (Peterson et al., 2010) and gains in muscle mass with and specific increase in satellite cells(Verdijk et al., 2009).

Moreover, physical fitness is related with cognitive function(Colcombe & Kramer, 2003a), fitness reduces the brain mass loss with aging(Fletcher et al., 2016), and physical exercise can increase gray matter volume(Erickson et al., 2014). This improvement will also improve motor performance of older people(Levin et al., 2017), reducing the risk of falls and improving balance(Lelard & Ahmaidi, 2015).

Furthermore, cognitive training also has positive effects over different cognitive domains(Fabre, Chamari, Mucci, Masse-Biron, et al., 2002). The combination of physical exercise and cognitive training programs seems to be also beneficial to improve cognitive function(Lauenroth et al., 2016). In fact, when physical exercise is combined with cognitive therapies, seems to be a complimentary enhanced in cognitive function(Gheysen et al., 2018).

With the challenge of an aging population, European Union (EU) started time ago, different plans and responses(European Commission, 2018), guiding principles for active aging, elaborating an Active Ageing Index, and other initiatives to improve health lifespan and aging. In the last two years, Erasmus+ KA2 projects from EU has funded the MEMTRAIN project(Práve ted´! o.p.s., 2018). MEMTRAIN project has been a collaborative project from six different European partners to build a manual of physical exercise and cognitive therapy for older people. Five of these European partners proposed different physical exercise and cognitive activities, and every one of these five partners elaborated a pilot program with some subjects from their countries.

In this ecological environment, the MEMTRAIN project decided to analyze some variables of physical performance (Up & Go test to measure agility and 6 minutes walk test to measure endurance) and cognitive responses (Stroop test with time-response register and Rey Auditory Verbal Learning Test). This kind of studies about exercise programs and cognitive function usually are developed in a laboratory environment, easier to measure the variables, but far from a real application of exercise programs. In this study, the subjects participated in MEMTRAIN pilot program, in different countries, with different technicians, with different activities. All the activities had the same objectives, structure and training orientation, but were developed in completely different ecological environments. All the instructors were professional technicians, non-researchers, and all the test were evaluated in the ecological training place by the usual instructor.

The objective of the study was to know the impact in physical and cognitive function of two months of MEMTRAIN pilot study once the project finished, compared with a control group that trained only cognitive tasks in also an ecological environment.

METHODS

PARTICIPANTS

This study involved 61 subjects (55 women and 6 men), but only 54 finished the study (48 women and 6 men). They were from Irish, Italian, Polish, Slovene and Czech nationality. The age range was between 58 and 84 years of age (67.28 ± 5.51). Subjects were included in a pilot program of physical exercise and cognitive training that is part of the European project Erasmus plus: Memtrain (n = 44, the Treated Group). Every national partner used their own participant in their ecological facilities. The Czech partner was selected to also create a control group (n = 10, Control Group). That means the participants were not randomized, and the two groups (Control Group and Treatment Group) were not homogeneous. This not controllable ecological limitation was keeping in mind for the statistical analysis. We can see in Table 1 the participant distribution in countries and its age.

Table 1: Age participant distribution by countries.

	Age	SD	n
Slovenia	64.6	3.5	11
Poland	64.8	1.2	6
Italy	70.5	6.6	13
Ireland	68.6	5.9	14
All Treated Group	67.6	5.6	44
Czech Republic (Control Group)	66.2	5.4	10

The study was designed in accord with Helsinki Declaration, and approved by the Ethics Committee of the university. Before initiating the research, participants received information about the program and its risks and signed an informed consent approved by the university's ethics committee.

INTERVENTION PROGRAM

The intervention pilot program was carried out in different countries 2 days a week for two months. Subjects from the treated group (n = 44) performed a 60-minute session where the activity consisted of performing aerobic exercise for 40 minutes and, finally, practiced cognitive games for 20 minutes. The control group (n = 10) was established in the Czech center, which only performed the 20 minutes of cognitive games activity. The type of activities carried out can be observed in the Erasmus + Meimtrain manual (https://memtrain.eu/wp-content/uploads/2018/09/Training-manual_final.pdf). There are consisted of dance, Nordic walking, seniors athletics or functional exercises. The cognitive training consisted of coordinative tasks with bilateral movements at different rhythms, and memory and mathematical games with words and images. All the information is explained in the manual.

The different groups did different physical activities. The Poland group did dance, the Irish group did athletics, the Italian participants trained functional exercises, and the Slovenian group did nordic walking. All the activities were managed by a local instructor, who was ordered to reach intensity enough to improve aerobic fitness. There was no control of intensity far away from the prescription.

One week at the beginning of the program, and one week in the end, local instructors evaluated all the variables to the subjects. First, the RAVL-Test was evaluated, and the Stroop test was measured in the middle of RAVL-Test, so it also was used as interference. After the cognitive tasks, the Up & Go test was measured, and the 6 minutes walk was the last test.

MEASUREMENT VARIABLES

The variables measured in this study were agility and dynamic balance, aerobic fitness, executive function, and short and long term word learning memory.

- Up & Go Test: To measure agility and dynamic equilibrium, the "8 foot and go test" was used. With a chair and a cone separated perpendicularly at a distance of 8 feet (2.44 meters). The subject, at the signal of "already", walked as fast as possible until reaching the cone to surround it and return as quickly as possible to the chair. The time it took to make the gesture was timed. Subjects repeated the test three times, taking time from the best trial.
- 6 Minutes Walk Test: To measure aerobic fitness, the test "6 Minutes Walk Test" was used, where 10 cones were placed at a distance of 5 yards (4.57 meters) between them, so cones traced a rectangular area of 50 yards (47.7 meters). At the "already" signal, the participants

walked around the area as fast as they could (without running) for 6 minutes. The total distance they were able to cover during those 6 minutes of walking were counted. Both the agility test and the aerobic fitness test are two tests belonging to a battery Senior Fitness Test(Roberta E Rikli & C Jessie Jones, 2013).

- Stroop Test: To measure the executive function, a digital application of the Test Stroop was used(Martín et al., 2012), created for the Erasmus + Memtrain project, which allowed us to record the response times of each response. The test consists of 3 phases of words and graphics of colored words that are combined in different ways. The first phase, called Congruent phase (Con.), is formed by the words blue, green, red and yellow written in black ink on a white background. In the second phase, Neutral phase (Neu.), groups of 4 x "XXXX" appear, colored in blue, red, green and yellow. The objective of this phase is to choose the color in which the X's are colored, and this is how the subjects are informed. The last phase was Incongruent phase (Inc.), is formed by the names of the colors (blue, green, red and yellow), but colored with "non-congruent" colors, that mean, for example, word Green with blue ink. The subject must respond to the color they see, and not the word they read. All phases have unlimited words and the duration of each one is 45 seconds, with breaks of 25 seconds, counting the number of successful responses and the response time. Subjects practice twice the first time they did it before they were measured. Every subject used always the same device to make tests. The three phases were done in the same order (Con.-Neu.-Inc.) at the pre and post-test, and also in the two training trials. The Interference index was calculated with the successful responses of the three phases: Interference Index = Inc. – [(Con. x Neu.) / (Con. + Neu.)]. This index represents the relation between the real performance of the incongruent phase respect the expected performance of the neutral and congruent phases, with higher values explaining a better inhibitory control function(Martin et al., 2012).

- Rey Auditory Verbal Learning Test: To evaluate short- and long-term memory, Ray's AVLP was used(Savage & Gouvier, 1992). It consists of administering a list of 15 words during 5 learning trials (trials 1 to 5), a distraction list, a reminder of learning (trial 6), a 20-25 minute phase where another interference task is performed (we used the Stroop test) and a final reminder of learning (trial 7). The subjects were informed about the test before to start. Two different lists previously described (Geffen et al., 1994) were used for pre and post-tests. Each country used a different order.

STATISTIC ANALYSES

As groups were ecological non-randomized groups, and Control Group (CG) was smaller than Treatment Group (TG), to compare groups and control the initial differences, and ANCOVA was performed for each test, the variables included in the ANCOVA fulfilled the assumptions of linearity and homogeneity of regression slopes. Two coverable were used in ANCOVA, the initial values of tests, and the age of subjects, because the cognitive response can be modulated by age. The effect size in the ANCOVA analysis is expressed as partial eta-squared (η_p^2), Eta-squared effect sizes are grouped as small ($\leq$ .01), medium ($\leq$ .06) and large ($\leq$ .14) as Cohen described(Cohen, 1988). In addition, a paired T-test was used for related samples to analyze the intragroup differences. The Cohen effect size for T-Test was analyzed with d of Cohen(Cohen, 1988, 1992), and the magnitudes of standardized effects sizes were considered as small (< 0.2), moderate (< 0.6), large (< 1.2) very large (< 2.0) and extremely large (> 2.0). The level of significance was established at $p < 0.05$. Not all subjects did all test. Analysis has been done with the data available.

RESULTS

All the data of the study are presented in table 2.

Table 2. Pre and post values for all variables.

TESTS DATA	TREATED GROUP				CONTROL GROUP			
	PRE		POST		PRE		POST	
	X	SD	X	SD	X	SD	X	SD
Con. Successes	28.63	8.13	29.97	8.94	29.71	11.41	34.20	40.80
Neu. Succeses	30.49	7.02	32.00	6.37	28.00	13.35	34.20	4.32
Inc. Succeses	17.67	8.06	19.95	7.73	12.00	8.50	9.90	8.17
Con. Time	1475.76	388.69	1408.56	379.10	1295.67	180.12	1258.33	158.93
Neu. Time	1386.25	304.58	1339.80	249.11	1135.06	143.85	1267.11	167.69
Inc. Time	2139.17	736.77	1950.67	602.42	2215.36	1059.30	2167.51	951.33
Interference Index	3.15	7.06	4.75	6.31	-0.47	13.70	-7.17	7.33
RAVLT 5 Trial	11.25	2.37	11.74	2.80	12.80	1.93	12.00	1.94
RAVLT 6 Trial	9.76	2.82	10.21	2.82	11.30	2.83	10.80	1.99
RAVLT 7 Trial	10.64	3.34	40.74	2.84	9.60	2.80	10.50	2.64
Up&Go	6.31	1.56	6.19	1.52	6.23	1.61	5.94	1.76
6 Min. Walk	645.63	86.77	657.63	79.40	542.90	125.79	545.30	132.65

After the pilot programs, and controlling the previous differences between different European groups in previous performance, number of subjects and age, with the ANCOVA analysis, there were differences between groups in the Interference Index and the Incongruent phases successes (Table 3).

Table 3. ANCOVA positive results

Incongruent Successes	Mean	SD	F	Sig.	η_p^2
Treated Group	19.95	7.73	10.64	p = 0.002	0.188
Control Group	7.67	6.65			
Interference Index	**Mean**	**SD**	**F**	**Sig.**	η_p^2
Treated Group	4.75	6.31	24.62	p < 0.001	0.344
Control Group	-8.64	5.58			

The other measurements did not present significant results in the ANCOVA analysis: Congruent successes p = 0.17; Neutral successes p = 0.24; Congruent time p = 0.43; Neutral time p = 0.56; Incongruent time p = 0.64; RAVLT trial 5, p = 0.22; RAVLT trial 6, p = 0.75; RAVLT trial 7, p = 52; Up & Go test p = 0.29; 6 minutes walk test, p = 0.18.

When we analyzed particularly each group with paired T-Test, we observed significant differences in Stroop test for the training group, in the most complex phase (Incongruent), for the successes (Table 4), and also in the time response (Table 5), despite this difference is not present in the ANCOVA, and we can not claim that this difference is produced by the program. However, it seems that, after the pilot exercise program, the participants were faster and responded more correct answers.

Table 4. Success in Incongruent condition

Training Group	n	Mean	SD	Sig.	Effect Size
PRE	44	17.67	8.06	p = 0.027	2.03
POST	44	19.96	7.73		
Control Group	**n**	**Mean**	**SD**	**Sig.**	**Effect Size**
PRE	7	12.00	8.51	p = 0.499	-0.72
POST	7	9.90	8.17		

Table 5. Response Time during Stroop test for Incongruent condition

Training Group	n	Mean	SD	Sig.	Effect Size
PRE	44	2139.17	736.77	p = 0.002	-1.97
POST	44	1950.67	602.42		
Control Group	**n**	**Mean**	**SD**	**Sig.**	**Effect Size**
PRE	7	2215.36	1059.29	p = 0.748	-0.16
POST	7	2167.51	951.33		

In addition, the Interference Index presents a tendency (p = 0.088) to improve, that is not observed in the control group (Table 6). But analyzing with care the data, the positive ANCOVA result maybe is related to the decline in control performance, more than an improvement in the training group.

Table 6. Paired T-Test for Interference Index

Training Group	n	Mean	SD	Sig.	Effect Size
PRE	44	3.15	7.06	p = 0.088	0.24
POST	44	4.75	6.31		
Control Group	**n**	**Mean**	**SD**	**Sig.**	**Effect Size**
PRE	7	-0.47	13.70	p = 0.236	-0.61
POST	7	-7.17	7.29		

Related with fitness, analyzing the paired T-Test, the participants in the Memtrain exercise pilot program improved their aerobic fitness measured by the Six Minute Walk Test (Table 7). The better previous performance of the Training group can be the reason to do not find significant results in ANCOVA and is coherent with older adults participants in exercise programs, that usually are people with better fitness than the non-participants(A. M. A. Picorelli et al., 2014).

In contrast, there were not significant differences for Up & Go test in Training group (p = 0.402), neither in control group (p = 0.348).

Table 7. Paired T-Test for Six minutes walk test results

Training Group	n	Mean	SD	Sig.	Effect Size
PRE	42	617.21	16.64	p = 0.024	1.09
POST	42	634.83	15.71		
Control Group					
PRE	10	542.90	39.78	p = 0.217	0.06
POST	10	545.30	41.95		

Verbal memory test seems to be not influenced with the training pilot program, as it did not change in the ANCOVA, neither in Paired T-Test.

DISCUSSION

Is well documented the improvement in physical performance with physical exercise in older adults, in the different dimension of fitness, like endurance(Vigorito & Giallauria, 2014), strength with resistance training (Peterson et al., 2010) or balance and postural control(Lelard & Ahmaidi, 2015). Moreover, is also well known the effect of physical exercise and fitness in the nervous system and cognitive function(Bherer et al., 2013; Colcombe & Kramer, 2003a), especially in executive functions(Boucard et al., 2012). And those improvements are usually related with physiological changes like, for example, increased neurogenesis(Curlik & Shors, 2013; Yau et al., 2014), an increase in neurotrophic factors(Phillips et al., 2014b), an improve in cerebral blood flow (Nishijima et al., 2016) or simply an increase in grey matter and white matter volume during aging(Erickson et al., 2014; Fletcher et al., 2016; Hayes et al., 2015).

In our study, MEMTRAIN pilot program increased the number of successful responses when we take into account the initial values and age, in the more complex tasks of the Stroop Test, that is, the Incongruent phase.

Moreover, maybe the reaction time during incongruent phase was also improved, but initial differences do not less us to be sure about this change, and ANCOVA did not report significant results. The Stroop Test evaluates the inhibitory control cognitive function and, with the MEMTRAIN app, we also evaluate the response time of the subjects. Moreover, the Interference Index, as a measure of global inhibitory control of the Stroop test(Martin et al., 2012), also improved in the training group..

Recently it has been published a correlation between aerobic fitness and Stroop test(Hyodo et al., 2016), that's interesting because our training group seems to improved their aerobic fitness in the intragroup analysis, and presented better results in inhibitory control test. Two months of MEMTRAIN program seems to be enough to improve 6 minutes walk test, at least when we analyze intragroup changes. This test correlates with aerobic fitness(Burr et al., 2011; Ross et al., 2010; Zhang et al., 2017). Interestingly, improvements in cognitive function have been usually related with improvements in aerobic consumptions and endurance(Baker et al., 2010; Colcombe & Kramer, 2003a; Erickson & Kramer, 2009; Griffin et al., 2011; Hayes et al., 2015). However this correlation is not always present in literature, and researchers sometimes fail to find a relation between the improvement in aerobic fitness and cognitive response(Young et al., 2015). Moreover, we can not claim that this improvement is really related to our program because ANCOVA did not show these results, and groups were previously highly different. Maybe the improvements in treatment group are mediated by previous fitness differences.

Or maybe the improvements were produced by the combination of physical and cognitive training, at has been seen in other studies(Fabre, Chamari, Mucci, Masse-Biron, et al., 2002; Lauenroth et al., 2016; Oswald et al., 2006). But we can not conclude any possibility as we have only a control group with cognitive training. Moreover, the control group did not improve in any variable. Some studies have observed cognitive improvements after cognitive training(Kelly et al., 2014; Kim et al., 2017). Maybe our cognitive techniques were not adequate, maybe 20 minutes two days a week is not enough to produce adaptations and improvements in cognitive tasks.

Finally, the Rey Auditory Verbal Learning test did not improve, this quality is considered declarative memory(Squire, 1992a), and it is related with the hippocampus function in the brain(Squire, 1992b). The hippocampus seems to be enhanced with exercise training and cognitive tasks(Curlik & Shors, 2013), it seems to increase its volume with aerobic exercise, at least in women(ten Brinke et al., 2015). Probably our pilot study was too short, or our aerobic fitness improves in a lesser degree that is necessary to improve the hippocampal structure and declarative memory. Or maybe declarative memory is not easy to improve with physical exercise. Indeed, maybe there is no relation between the aerobic fitness and memory(Young et al., 2015).

By the other hand, the two month pilot program neither was enough to improve Up&Go test, this test correlates with balance and gait tests(Herman et al., 2011), and even with some executive functions(Herman et al., 2011), but the MEMTRAIN program seems to be not enough to improve this variable in two months. Maybe it was too short time period.

CONCLUSIONS

It seems that two months of physical and cognitive training using the MEMTRAIN manual can improve inhibitory control in older people compared with only cognitive training. These results must be corroborated with more studies, and more different cognitive protocols must be used to analyze the possible combinatory benefits of physical exercise and cognitive training.

LIMITATIONS

This study has been developed in an ecological environment. The subjects were participants in physical programs from Poland, Slovenia, Ireland, Italy, and the Czech Republic. In all these countries, the physical instructors were responsible to measure the tests, that mean the researcher group has low control over the protocols, and the evaluator was not always the same person, and that can imply some bias. Furthermore, the control group was only formed in Czech Republic, and they were old people who participate in cognitive training programs, as they were from only one country and not absolutely sedentary, maybe that implies another bias.

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8.2.2. Artículo 2.

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8.2.2. Artículo 2. *Effect of six months ex ercise training in older adults. The results of the erasmus plus pace project.*

Abstract

The PACE (Physical Activity Enhancement) Project is a European Erasmus + KA2 project, funding by European Commission, who keeps in contact five organizations from five different European countries to create a manual about physical exercise programs for older adults. 132 adults from four different countries participate in a six-month pilot program, with different activities in the four different countries. Participants were divided into two groups, one of younger elders, from 50 to 65 years, and another of old elders, 65-75 years old. All the activities were designed to include aerobic and strength exercises. Physical fitness and well-being vitality were measured before and after six months of practice, all aggregated or divided in two blocks of three months separated by 3 months holiday period. Both groups improve leg strength and vitality well-being, and the older elders also improve aerobic resistance and arm strength. There were no differences between countries in the improvements, neither were differences between the six months continuum training or divided into two blocks of three months. All the activities described in de PACE document seems to have the same efficiency to improve physical fitness in older adults and offers different ways to achieve it.
Keywords: Exercise, Aging, Fitness, Well-being, Vitality

Introduction

Aging is a natural process in life, a consequence of time in systems designing for a limited life span. In humans, aging is a process with a loss of function, loss of adaptability, and finally death. During life span are inevitable some physiological changes in human body(Park & Yeo, 2013). A great increase in the human life span has been achieved in the last century, as a consequence of some behavioral and environmental changes(Jones, Scheuerlein, Salguero-Gomez, et al., 2014). As a consequence, there is a great increase in physiological changes produced by aging in our actual societies.

The most evident changes with aging are physical changes. During aging, there are a great number of physiological changes that will lead our bodies to a loss of physical performance and fitness(Park & Yeo, 2013). This impairment on physical fitness leads to common mobility limitations in elderly, and frequent dependent states(Miljkovic et al., 2015). We can group the different changes in three great areas: the loss of strength, the loss of endurance, and the loss of mobility.

Regarding strength, there are many physiological processes that underlies this loose, the most evident is sarcopenia that means, the loose of muscle mass. The European consensus on definition and diagnosis of sarcopenia include three criteria to identify sarcopenia: low muscle strength, low muscle quantity or quality, and low physical performance(Cruz-Jentoft, Bahat, Bauer, Boirie, Bruyere, et al., 2019). Some physiological processes are the cause for these loose quantity and quality in muscle mass.

With aging, there is a fast-to-slow fiber type shift associated with changes in motor neurons(Miljkovic et al., 2015). In muscle fiber, there is a reduction in excitation-contraction coupling, reducing the calcium flow, and affecting the muscle quality(Miljkovic et al., 2015). The reduction in mitochondrial content of muscle fiber with aging is another cause for a lesser functionality in muscle, impairing the muscle energy intake(Miljkovic et al., 2015). Looking at the whole muscle, there is an increase in intermuscular adipose tissue-related to a reduction in strength and functionality in older people(Addison et al., 2014).

Many molecular changes explain the reduction on muscle quality and quantity, as aging has an impact in fundamental molecules related to muscle health. The reduction in testosterone and growth hormone reduces the possibility of hypertrophy and muscular regeneration(Ryall et al., 2008). In addition, there is also a reduction in insulin-like growth factors related to proliferation, differentiation, and fusion of muscle satellite cells, the stem cells precursors of muscle mass(Ryall et al., 2008). Moreover, myogenic regulatory factors (MRF), involved in the growth and development of muscle cells, do not respond to exercise in older people as they do in young people(Ryall et al., 2008).

All this tissue and molecular changes in muscle go with a group of neural changes also related to muscle functionality(Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010). For example, there is a reduction in axon diameter of motor neurons with age. That implies a reduction in firing speed and a reduction in excitability of muscle fibers(Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010). This axonal reduction is accompanied by a significant reduction in motor neurons, and its consequent reduction of motor units, producing the atrophy of muscle denervated fibers(Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010).

Related to endurance lose with aging, it is evident the reduction in oxygen uptake with aging(Edvardsen et al., 2013). There are a number of physiological causes for this reduction in performance, like the reduction of maximal heart rate with aging(Tanaka et al., 2001b), changes in right ventricular diastolic function during exercise(M. Celik et al., 2015), lesser number of capillaries perfusing the lungs(Mendonca et al., 2017). The increased stiffness of the vascular system increase systolic and diastolic pressure during exercise, increasing heart afterload and, reducing volume stroke during exercise(Mendonca et al., 2017). The already mentioned reduction in mitochondria with aging implies the reduction in muscle fibers to use oxygen to produce ATP(Peterson et al., 2012), with the consequent reduction in arteriovenous difference O_2, and the reduction in oxygen consumption.

Finally, aging has an impact on neuromotor response, with coordination difficult, increased variability of movements respect young, slow movements, and problems with balance and gait(Seidler et al., 2010). As a consequence, older people present a high number of falls than young people(Seidler et al., 2010).

To compensate for this entire decline, physical exercise has proven to be the most efficient treatment(Chodzko-Zajko et al., 2009). Many studies have shown that resistance training can reduce strength decline, with improvements in muscle mass(Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Muller, et al., 2011; Peterson et al., 2010), and also improvements in motor unit recruitment, and motor unit firing rates(Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Muller, et al., 2011). These improvements are related to intensity, with grater improvements with higher intensities(Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Muller, et al., 2011), and with contraction velocity, where power exercise shows great improvements in strength and health-related conditions(Fragala et al., 2019). Strength training has also a positive impact on functionality and other health variables(Chodzko-Zajko et al., 2009).

Besides, aerobic exercise training, based on cycling, walking, or similar repetitive endurance activities improves oxidative capacity and redox status(Valenzuela, Castillo-Garcia, et al., 2019), improving heart conditions(Vigorito & Giallauria, 2014), reducing metabolic syndrome, and high arterial pressure(Chodzko-Zajko et al., 2009). Moreover, exercise can reduce the risk of falls, reducing disability risk, improving gait and walking speed, and functionality(Chodzko-Zajko et al., 2009).

Also, exercise shows the potential to improve psychological variables like quality of life, cognitive function and well-being(Chodzko-Zajko et al., 2009; D.K. Ehlers et al., 2018). Self-efficacy and self-esteem also are affected by exercise training(McAuley et al., 2005). It seems that aerobic training and moderate intensity is the most beneficial combination to improve well-being(Netz et al., 2005).

The PACE project pilot intervention aimed was to prove the different exercise programs proposed by the different European groups. As an efficiency measure, some physical and well-being variables were measured during the pilot study. This article presents the results of the program respect the improvements in physical and well-being measures.

Material and Methods.

Participants:

Participants were distributed in two groups in each country, one younger group selected by the rank age 50-65 years (YG; n = 79, 30 males and 49 females; Age = 58.39 ± 5.89 years), and the older group, selected by the rank age 65-75 years (OG; n = 53, 24 males and 29 females; Age = 69.34 ± 3.44). All participants were selected in each country. There were participants from four countries for the YG, and participants from three countries for the OG. The participants signed informed consent to participate in the project. They were selected with two criteria, aged more than 50 years old, and do not present a medical inconvenient to do physical exercise. The experiment was approved by the Ethics Committee of the authors' university.

Exercise programs:

All the participants, in each country, complete a six months program based on two days of physical exercise. Three of the four different countries distribute these six months in two periods of three months of training, with a period of two months of holidays in the middle of the program. One country organizes the six months program as a continuous program. These differences have been taken into account in the statistical analysis.

All the programs have the objective to improve the endurance of participants, and also their strength. All the information about the programs is in the PACE Project Memory. As a synopsis, younger participants (50-65 years) complete endurance activities, like running, Nordic walking or Zumba. The older group, complete activities of less intensity, like adapted gymnastics, fitness exercises, and stretching and walking activities.

Fitness and Well-being measurements

Different fitness measurements were used to measure physical fitness in both groups (YG and OG). Both groups used a Strength Grip test for arm strength, and one stand up test to measure leg strength. To measure endurance, the YG group used the Rockport walking test, a mile walking test to estimate oxygen consumption. Old group use the Six minutes' walk test, more adapted for their capacities. Finally, the OG also did Time Up and Go test, as a measure of agility and gait. Weight was also registered, and participants complete one Vitality test to measure well-being.

All evaluators of each country were trained together in one of the project meetings. And all the evaluators had videos and documentations about the protocols.

1. *Strength Grip Test*

Each country used its own strength grip dynamometer for the test. Subjects were placed stand, with 90 degrees of elbow flexion, and with the strength grip dynamometer adapted to their hand. They did their maximum strength during 3 seconds with right and left hand, and repeat three times with each hand alternatively. The medium of all six tests was used as a result.

2. *Stand Up Test*

The participant was placed in a chair without arms. Both hands crossed over their shoulders. They were asked to stand up and sit down in the chair as many times as they could in 30 seconds. The evaluator counts how many repetitions they did. This test was presented exactly equal to in Senior Fitness Test(R. E. Rikli & C. J. Jones, 2013).

3. *Rockport Walking Test*

Rockport Walking Test is a demonstrated indirect test to measure oxygen consumption. Subjects must walk one mile in a constant speed, and must register their heart rate and time spent to complete the distance. With this information, the age, sex, and weight of the participant, we can estimate the VO_2(Kline et al., 1987). Oxygen consumption is presented related to body weight, in ml/kg·min.

4. *Six minutes' walk test.*

In the Six minutes' walk test, participants must walk for six minutes, as fast as they can, and they can stop to rest during the test. The test is developed around a rectangular field of 50 yards. The total distance done in the six minutes is registered. The test was done with the exact specifications of the Senior Fitness Test(R. E. Rikli & C. J. Jones, 2013).

5. *Timed Up and Go test*

The participants are seated in a chair. In front of them, separated eight feet distance, there is a mark. When the evaluator speaks the start signal, the participant must stand up, walk around the mark, and come back to sit down again in the chair. The time placed to complete the test is registered. The test is done twice, and the best time is used as a result. The test has been done following the instructions of the Senior Fitness Test(R. E. Rikli & C. J. Jones, 2013).

6. *Subjective Vitality*

To measure well-being, it was used the Subjective Vitality Questionnaire(Ryan & Frederick, 1997). The questionnaire has 7 items about personal feelings related to vitality. Is rated on a Likert-type scale (1 to 7).

7. *Weight*

All participants were weighed at the beginning and at the end of the program. In each country was used a different weight, but each participant was weighted in the same instrument both times.

Statistical Analysis.

All data are presented as median and standard deviation. Paired T-Test was used for each test to analyze the impact of the exercise program on the different dimensions of fitness and well-being. Statistical significance was marked as $p < 0.05$. The effect size of the treatment was calculated by d of Cohen(Cohen, 1988, 1992). 95% Confidence Interval of the Difference (CI) is presented Effect sizes are reported as small (≤ 0.20), medium (≤ 0.50), or large (≤ 0.80)(Cohen, 1992).

To analyze the possible interaction in results of different country groups, or analyze possible differences between six months of continuous training against two blocks of three months training with a middle rest. Two 2x2 ANOVA was done, first of them, with the variables MOMENT (Pre vs Post) and Program (Continuous vs. Blocks). The other compared MOMENT and. Country (4 different countries)

Results

In the YG, we can observe a significative improvement in leg strength (Stand Up Test), Well-being (Subjective Vitality), and a small but significant loose of weight (Table 1). No changes were observed in arm strength, neither in oxygen consumption (Table 1).

Table 1: Results for Young Group

	PRE	POST	Sig.	n	d	CI
Weight	71.79 ± 15.19	71.57 ± 14.97	0.004	56	0.01	0.07 – 0.36
Stand Up Test	17.66 ± 5.62	18.48 ± 5.59	0.005	79	0.15	-1.38 - -0.26
Strength Grip	27.33 ± 8.71	27.36 ± 8.28	0.872	79		-0.54 – 0.46
VO_2 (ml/Kg·min)	34.21 ± 15.89	34.34 ± 15.72	0.793	56		-01.14 – 0.87
Subjective Vitality	4.93 ± 1.53	5.99 ± 0.65	< 0.001	79	0.90	-1.39 – -0.75

There were no interactions between these changes and the Program or the Country, as we can see in the results of the 2x2 ANOVA (Tables 2 and 3)

Table 2: Interactions between MOMENT x Program for the Young Group

	Sig.	F	ηp^2
Weight	.777	.080	.001
Stand Up Test	.648	.210	.002
Strength Grip	.848	.037	.000
VO_2 (ml/Kg·min)	.863	.030	.000
Subjective Vitality	.090	2.922	.022

Table 3: Interactions between MOMENT x Country for the Young Group

	Sig.	F	ηp²
Weight	.995	.005	.000
Stand Up Test	.844	.170	.003
Strength Grip	.994	.006	.000
VO_2 (ml/Kg·min)	.986	.014	.000
Subjective Vitality	.417	.880	.014

For the Old Group, there were improvements in Strength (arms and legs, measured as Strength Grip and Stand Up Test respectively), agility and gait (measured as Up and Go test), endurance (using Six Minutes' Walk Test) and well-being (measured as Subjective Vitality). In contrast, there were no changes in weight (Table 4).

Table 4: Results for Old Group

	PRE	POST	Sig.	n	d	CI
Weight	72.79 ± 13.1	72.73 ± 12.9	.261	53		-0.04 – 0.16
Stand Up Test	14.83 ± 4.16	15.81 ± 4.25	.000	52	0.23	-1.48 – -0.47
Strength Grip	24.98 ± 7.37	25.15 ± 7.39	.000	53	0.02	-0.27 – -0.08
Up and Go Test	5.48 ± 1.43	5.26 ± 1.32	.000	53	0.16	0.11 – 0.33
6 minutes´ walk	508.58± 114.09	512.25 ± 114.99	.031	53	0.03	-6.98 – -0.34
Subjective Vitality	4.68 ± 1.77	5.24 ± 0.99	.000	53	0.39	-0.80 – -0.33

Again, there are no interactions depending on Program (Table 5)

Table 5: Interactions between MOMENT x Program for the Old Group

	Sig.	F	ηp^2
Weight	.986	.000	.000
Stand Up Test	.708	.141	.001
Strength Grip	.977	.001	.000
Up and Go Test	.701	.149	.001
6 minutes´ walk	.841	.041	.000
Subjective Vitality	.757	.096	.001

In contrast, in the analysis for MOMENT x Countries, there were differences in Subjective Vitality (Table 6). And as we can see, these differences are explained because, in one of the countries, the starting values of Vitality were so high, that it was impossible to improve (Table 7). So, the participants of this country did not improve their Subjective Vitality.

Table 6: Interactions between MOMENT x Country for the Old Group

	Sig.	F	ηp^2
Weight	.999	.001	.000
Stand Up Test	.743	.298	.006
Strength Grip	.999	.001	.000
Up and Go Test	.840	.174	.004
6 minutes walk test	.910	.095	.002
VItality	.000	19.658	.284

Table 7: Results Pre and Post from each country.

	PRE	**POST**	**n**
Country 1	2.12 ± 0.35	3.97 ± 0.36	12
Country 2	4.71 ± 0.96	5.16 ± 0.73	20
Country 3	6.30 ± 0.59	6.15 ± 0.34	20

Discussion

This study shows a positive impact of the different programs used in old people, with an interesting difference that must be discussed. First of all, it can be seen that exercise programs proposed produce better improvements in the older group. The older group, aged 69.34 ± 3.44 years old, presents significant improvements in all the fitness and well-being variables. There is only a lack of improvement in weight, but weight is dependent on more variables than only physical exercise, for example, caloric consumption.

However, the amount of improvement in the physical variables of the older group is not too big. The effect sizes of the change show small changes for all the variables, excepting vitality, which presents a medium effect size. That means the programs produced an improvement in fitness, but a small improvement. The small changes in strength are probably due to the small amount of resistance training and small intensity because resistance training usually has bigger improvements in strength in old people(Peterson et al., 2010). And as we know, the intensity is relevant variable respects the strength improvements(Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Muller, et al., 2011).

Regarding endurance, other studies have shown important improvements in oxygen consumption for 6 months and one-year exercise training(Fujimoto et al., 2010; Okazaki et al., 2005). We used an adapted endurance test (six minute walk test) to measure this fitness dimension in the older group, to be sure they could do it despite their functional limitations, this test correlates with oxygen consumption(Zhang et al., 2017). Anyway, the improvements are small and maybe are related with a small intensity of exercise program.

However, despite the small improvements in fitness, subjective vitality, as a measure of well-being, increased to a moderate degree. We are already knew that well-being is improved with physical exercise(Cervelló et al., 2014; Pastor et al., 2019), and is not only related to fitness, but also with a social activity, self-esteem…

Respect the younger group, aged 58.39 ± 5.89 years, this group is larger, and more heterogeneous, as we can see in the larger standard deviations for the strength grip and stand up tests. In this younger group, the exercise program shows lesser improvements in physical fitness, with only changes in leg strength and with a small effect size. The strength improvements are clearly lower than usual improvements with recommended resistance training(Fragala et al., 2019; Mayer, Scharhag-Rosenberger, Carlsohn, Cassel, Muller, et al., 2011; Peterson et al., 2010). Moreover, oxygen consumption neither improves as usual it can change with aerobic training(Fujimoto et al., 2010; Okazaki et al., 2005). It is clear that exercise programs were designed with a lack of intensity and/or volume for the younger and more fitness participants.

At least, subjective vitality of this group increases with large effect size, probably not as a response of fitness changes, and maybe more related to social and personal aspects of well-being, related to the social activity and self-esteem.

Conclusión

In conclusion, the PACE program seems to present different alternatives to do exercise with older people, which can show the professionals new practice possibilities, in a safe manner. These programs seem enough to produce some improvements in the fitness of the older elders, and probably need more individualized intensities and volumes for the younger elders. In both cases, these programs present the capacity to improve well-being in older adults, and this is really good because all the starting programs have the most important aim to increase adherence and prevalence to practice and adherence is strongly related to well-being.

Future Projects will need to study how to increase volume and intensity, and how to individualize the training stimulus, to obtain the greatest improvements in fitness.

Limitations of the study

The principal limitation of the study is its multi-centric, multi-country design. Because different evaluators have done the tests, and despite the training, that can produce some bias which reduces the validity of the study. Another limitation is the lack of control group, as this study was designed to measure the implementation of the programs, and the project has not scientific objectives, not founds for control groups were solicited, and not control groups were measured.

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8.3. Documentos de transferencia. *Memtrain Manual y Pace Manual*

MEMTRAIN MANUAL

Nota. Manual de práctica del proyecto Erasmus Plus KA2 MEMTRAIN

PACE MANUAL

Nota. Manual de práctica del proyecto Erasmus Plus KA2 PACE

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