UNIVERSITAT DE BARCELONA

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Memoria presentada por

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Para optar al grado de: Doctor por la Universitat de Barcelona

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Agradecimientos:

Yo podría escribir un libro sobre los desafíos que he pasado para terminar esta tesis. Este proyecto empezó con la llegada de una brasileña que buscaba encontrar nuevas experiencias y nuevos desafíos en España, intentando superar el gran trauma que había sido la muerte de su papá. He tardado mucho tiempo en encontrarme, hasta que un día entré dentro de un laboratorio de Fisiología y encontré el gran protagonista de todo este proyecto. Manu tú sabes porque eres el primero de mi lista de agradecimientos, no tengo palabras para agradecer tu amistad, tu ilusión, tu capacidad de "sacar agua de las piedras", tu compromiso y profesionalidad. Tu no has sido solo mi tutor, has sido un amigo y muchas veces terapeuta. Gracias por motivarme en los momentos más difíciles, tu paciencia ha sido infinita.

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Resiliencia

“Cuidemos a las personas mayores, ellos nos enseñan mucho más de lo que nosotros podemos enseñarles”.

Resumen

Introducción: La danza aeróbica (AD) es una modalidad de ejercicio de las más practicadas en el mundo que ha demostrado múltiples beneficios en la salud de aquellas personas que la practican, especialmente en la mejora del fitness cardiorrespiratorio y muscular. La AD ha evolucionado a diversas modalidades de ejercicio utilizando múltiples superficies y materiales. Una de estas modalidades de AD es realizada sobre una plataforma de disipación de aire (ADP). Esta tesis doctoral examinó las respuestas agudas y crónicas, cardiorrespiratorias, metabólicas, mecánicas, musculares y el estrés oxidativo realizando una AD sobre una ADP ya que, hasta la fecha, este conocimiento era inexistente. Para ello, se establecieron 3 objetivos principales de acuerdo con los tres estudios planteados:

1º Comparar las respuestas agudas cardiorrespiratorias y metabólicas, la fatiga muscular y la percepción subjetiva del esfuerzo (RPE) entre una ADP y una superficie dura durante una sesión de AD grabada en video **(primer estudio)**

2º Comparar el componente lento del consumo de oxígeno ($\dot{V}O_2$, $\dot{V}O_{2sc}$), la eficiencia ventilatoria, el lactato sanguíneo y la RPE entre una sesión de AD en una ADP y una prueba de tapiz rodante a una intensidad de primer umbral ventilatorio (VT1) **(segundo estudio).**

3º Valorar los efectos de un programa de entrenamiento supervisado de 12 semanas de AD sobre una ADP en la composición corporal, el fitness cardiorrespiratorio y muscular y el estrés oxidativo en personas mayores obesas y con sobrepeso **(tercer estudio).**

Metodología: La presente tesis doctoral constó de 3 estudios experimentales. En el estudio 1 (primer objetivo), 25 mujeres adultas sanas (edad 23,3 ± 2,5 años) fueron reclutadas y realizaron aleatoriamente dos sesiones idénticas de AD: ADP vs. superficie rígida. Las variables ventilatorias, la frecuencia cardíaca, las concentraciones de lactato en sangre (fatiga metabólica), la altura de vuelo y la potencia en el salto con contramovimiento (fatiga muscular) fueron comparadas entre ambas sesiones de AD sobre distintas superficies. En el estudio 2 (segundo objetivo), 17 mujeres adultas (edad 23,5 ± 2,2 años) fueron seleccionadas y

efectuaron 3 sesiones de evaluación. En la primera sesión, se completó una prueba incremental hasta el agotamiento en tapiz rodante para determinar las respuestas cardiorrespiratorias pico y a VT1. En la segunda sesión, que tuvo lugar una semana después, las participantes fueron asignadas aleatoriamente a la prueba de AD en un ADP o al test en tapiz rodante a una velocidad a carga constante correspondiente a la intensidad de VT1. En la sesión 3, realizada una semana después, las participantes realizaron el protocolo pendiente que no se realizó en la sesión 2, en las mismas condiciones. El $\dot{V}O_{2sc}$, la eficiencia ventilatoria (pendiente de la $VE \cdot VCO_2^{-1}$), las concentraciones de lactato en sangre y la RPE fueron comparadas entre ambas sesiones.

En el tercer estudio, 32 personas mayores (67,1 ± 3,6 años) fueron asignadas a 3 grupos en función de su índice de masa corporal (IMC): Grupos de normopeso, sobrepeso y obesidad. Se comparó los efectos de un programa de entrenamiento de 12 semanas de AD sobre una ADP entre los tres grupos experimentales. Las variables principales comparadas en este estudio fueron el peso, la grasa corporal (%), la masa libre de grasa, la masa magra, el $\dot{V}O_2$ pico (fitness cardiorrespiratorio), la peroxidación lipídica (estrés oxidativo), la altura de vuelo y la potencia de las extremidades inferiores en un salto con contramovimiento, la fuerza muscular de los brazos, la agilidad y el equilibrio (fitness muscular).

Resultados: **En el primer estudio,** se observó un incremento significativo de la frecuencia cardíaca *(p < 0,05) y en los niveles de lactato ($p < 0,01$) en la ADP en comparación con la superficie rígida. Sin embargo, la fatiga muscular y la RPE fueron similares entre ambas superficies *(p < 0,05). **En el segundo estudio**, no se encontraron diferencias significativas en el $\dot{V}O_{2sc,}$ la eficiencia ventilatoria y la RPE ($p > 0,05$) entre la prueba de tapiz rodante y la sesión de AD en una ADP. Sin embargo, se detectaron concentraciones más altas de lactato en sangre en la sesión de AD en una ADP a los 10 min ($p = 0,003$) y 20 min ($p < 0,001$) en comparación con la prueba en tapiz rodante. **En el tercer estudio**, se observó una reducción del peso en las personas mayores con sobrepeso ($p = 0,016$) y obesas ($p < 0,001$); también se redujeron las concentraciones de malondialdehído en plasma en todos los grupos experimentales ($p < 0,05$). Los grupos experimentales con sobrepeso y obesidad mejoraron significativamente su VO_2 pico ($p < 0,01$). El grupo normopeso y el de obesidad mejoraron la producción de potencia de las extremidades inferiores ($p < 0,05$).

Conclusión: En el **primer estudio,** una sesión de AD sobre un ADP indujo una mayor frecuencia cardiaca (FC), ventilación pulmonar (VE), tasa de intercambio respiratorio (RER), equivalente respiratorio de oxígeno ($VE \cdot VO_2^{-1}$), equivalente de dióxido de carbono ($VE \cdot VCO_2^{-1}$) y concentraciones de lactato en sangre, produciendo una mayor respuesta cardiorrespiratoria y metabólica en comparación con una superficie más dura, sin inducir mayor fatiga muscular y RPE. En el **segundo estudio,** la sesión de AD en una ADP produjo valores similares de $\dot{V}O_{2sc}$, pendiente de la $VE \cdot VO_2^{-1}$ y de RPE en comparación con la prueba en tapiz rodante a una intensidad a carga constante de VT1 en mujeres adultas jóvenes sanas, a pesar de que la sesión de AD en una ADP indujo mayores concentraciones de lactato en sangre que la prueba en tapiz rodante. En el **tercer estudio**, un programa de entrenamiento de 12 semanas de AD en una ADP puede ser una estrategia efectiva para regular adaptaciones cardiorrespiratorias y musculares y mejorar los efectos del estrés oxidativo en personas mayores obesas y con sobrepeso.

Índice

Abreviaturas

AD: danza aeróbica

ADP: plataforma de disipación de aire

AF: actividad física

ATP: adenosintrifosfato

CAT: la catalasa

CMJ: salto con contramovimiento

CO_2: dióxido de Carbono

CRF: fitness cardiorrespiratório

GC: gasto cardíaco

FC: frecuencia cardiaca

FC_{max}: frecuencia cardiaca máxima

GPx: glutatión peroxidasa

H^+: iones de hidrógeno

H_2O_2: peróxido hidrógeno

HG: grupo experimental com normopeso

IMC: índice de masa corporal

LDL: lipoproteína de baja densidad

LPO: peroxidación lipídica

MET: equivalente metabólico de tarea

MDA: malondialdehído

$NO^{\bullet -}$: óxido nítrico reactivo

O_2: oxígeno

$O_2^{\bullet -}$: radical superóxido

• OH: radical hidroxilo

OG: grupo experimental con obesidad

$ONOO^{\bullet -}$: peroxinitrito

OMS: organización mundial de la salud

OWG: grupo experimental con sobrepeso

$P_{ET}CO_2$: presión parcial del dióxido de carbono en la espiración

$P_{ET}O_2$: presión parcial del oxígeno en la espiración

pH: logaritmo negativo de base 10 de la concentración de iones de hidrógeno

RER: tasa de intercambio respiratorio

RS: especies reactivas de nitrógeno

RONS: especies reactivas de oxígeno y nitrógeno

ROS: especies reactivas de oxígeno

RS: especies reactivas

RPE: percepción subjetiva del esfuerzo

SOD: superóxido dismutasa

TBARS: sustancias reactivas al ácido tiobarbitúrico

VCO_2: volumen de dióxido de carbono

VE: ventilación pulmonar

$VE \cdot VCO_2^{-1}$: equivalente ventilatorio para el dióxido de carbono

$VE \cdot VO_2^{-1}$: equivalente ventilatorio del oxígeno

$\dot{V}O_2$: consumo de oxígeno

$\dot{V}O_{2máx:}$ consumo máximo de oxígeno

$\dot{V}O_2$ pico: consumo pico de oxígeno

$\dot{V}O_{2sc}$: componente lento del consumo de oxígeno

VT: umbral ventilatorio

VT1: primer umbral ventilatorio

VT2: segundo umbral ventilatorio

1. INTRODUCCIÓN

1.1. Contextualización

Es innegable que el mundo desarrollado nos ha traído múltiples beneficios, desde el punto de vista tecnológico y científico. El entorno físico, económico y social en los que hoy en día vive la humanidad ha cambiado rápidamente, en particular desde el siglo pasado y es cuestionable lo que ha repercutido desde el punto de vista de la salud. Los notables avances médicos y tecnológicos en el último siglo han conseguido reducir la mortalidad, modificar los hábitos nutricionales y los estilos de vida, mejorar las condiciones de vida y la educación, así como el acceso de la población a los servicios sanitarios.[1] La tecnología es la gran responsable de los avances de la medicina y de la cura de muchas enfermedades, proporcionándonos una mayor esperanza de vida, resultado del avance de la ciencia en relación con la creación de nuevos medicamentos y vacunas, en el tratamiento de enfermedades, en el acceso al saneamiento y en las mejoras de la higiene.[2]

Desafortunadamente, el desarrollo tecnológico también ha contribuido a una reducción significativa de la actividad física, debido a modos más inactivos de tránsito, los cambios de los medios de transporte, los medios de comunicación, y, especialmente, las nuevas tecnologías de entretenimiento y ocio, lo que ha favorecido el aumento del comportamiento sedentario y, consecuentemente, de la obesidad.[3–5] Según datos de la Organización Mundial de la Salud (OMS), las personas con un nivel insuficiente de actividad física tienen un riesgo de muerte entre un 20% y un 30% mayor en comparación con las personas que alcanzan un nivel suficiente de actividad física; cada año podrían evitarse a nivel mundial entre cuatro y cinco millones de muertes si todas las personas se mantuvieran más activas físicamente.[6]

Las personas mayores son vistas como el principal grupo de edad con el nivel más alto de inactividad, ocupando el 65-80% de su tiempo en actividades sedentarias.[7] En las personas mayores, el aumento del comportamiento sedentario está identificado como un potencial factor de riesgo para la salud, estando relacionado a enfermedades cardiorrespiratorias, la pérdida de masa muscular y de la fuerza, y el aumento de la obesidad.[7–9] Tanto el sedentarismo como la obesidad son considerados como factores comportamentales, así como el tabaquismo y el consumo de alcohol,[10] estrechamente relacionados con la aparición de otras patologías, como el síndrome metabólico (resistencia a la insulina, dislipidemia, la diabetes mellitus tipo 2 y trastornos cardiovasculares), la apnea al dormir, la artritis, algunos tipos de cáncer y el aumento del estrés oxidativo; todos ellos factores contribuyentes a la disminución de la esperanza de vida. [10–13]

La importancia de la actividad física (AF) como estrategia para la reducción del comportamiento sedentario, la mejora de la salud, la prevención de enfermedades crónicas, el aumento de la esperanza y de la calidad de vida es más que evidente.[6,14,15] La AF atenúa los efectos causados por el envejecimiento cómo el deterioro fisiológico, la pérdida de la función física, de la capacidad cardiorrespiratoria, funcional, la pérdida de masa muscular y la disminución del estrés oxidativo,[11,16,17] previniendo el aparecimiento de enfermedades causadas por factores comportamentales y mejorando la calidad de vida principalmente de las personas mayores.

La tecnología también ha contribuido al desarrollo de dispositivos y metodologías de entrenamiento, que han sido implementadas en los gimnasios y centros deportivos ofertando una variedad de actividades con el objetivo de conseguir una mejor forma física, el bienestar físico y mental, y provocar cambios en el estilo de vida y en la imagen corporal.

Una de las actividades más demandadas y practicadas en los centros deportivos es la "danza aeróbica" (AD). La AD ha sido desarrollada principalmente para mejorar el fitness cardiorrespiratorio (CRF). Parámetros como la frecuencia cardíaca (FC), los niveles de lactato en sangre y el consumo de oxígeno ($\dot{V}O_2$) se han utilizado para evaluar la intensidad del ejercicio en las clases de AD. [18] Para que la AD sea efectiva, se ha sugerido que alrededor de 150 $min.semana^{-1}$ de actividad física de intensidad moderada (gasto de energía de 1000 kcal. $semana^{-1}$), con suficiente intensidad (≥60% del $\dot{V}O_{2máx}$), frecuencia (≥3 $d \cdot semana^{-1}$) y duración (≥16 semanas) pueden aumentar significativamente el $\dot{V}O_{2máx}$, además de provocar cambios en la composición corporal como pérdida de la grasa corporal en personas adultas sanas de mediana edad y mayores.[19] Las demandas fisiológicas de las clases de AD podrían depender, al menos en parte, de la intensidad del ejercicio (es decir, porcentaje de frecuencia cardíaca máxima, porcentaje de $\dot{V}O_{2máx.}$, gasto energético, concentración del lactato sanguíneo, etc.) y del tipo de superficie en el que se ejecuta.

1.2. Envejecimiento

Datos demográficos recientes evidencian el crecimiento de la población anciana en el mundo y su fracción de mayor longevidad. Según datos de la OMS, en 2019 el número de ancianos a nivel mundial era de 1 billón; pero las proyecciones realizadas apuntan a que, en 2030 este valor puede llegar a 1,4 billones y en 2050 a 2,1 billones.[20] En España, la población de personas mayores de 64 años ascendía a 9,28 millones de personas en el año 2020; entre 2002 y 2020 la población en este rango de edad aumentó en más de 2 millones de habitantes.[21] Según esta proyección, la esperanza de vida alcanzaría los 83,2 años en los hombres y los 87,7 años en las mujeres en el año 2035, lo que supone un incremento respecto a los valores actuales de 3,2 y de 2,3 años, respectivamente. Estos valores serían de 85,8 años para los hombres y de 90 años para las mujeres en el año 2066 (figura 1).[1]

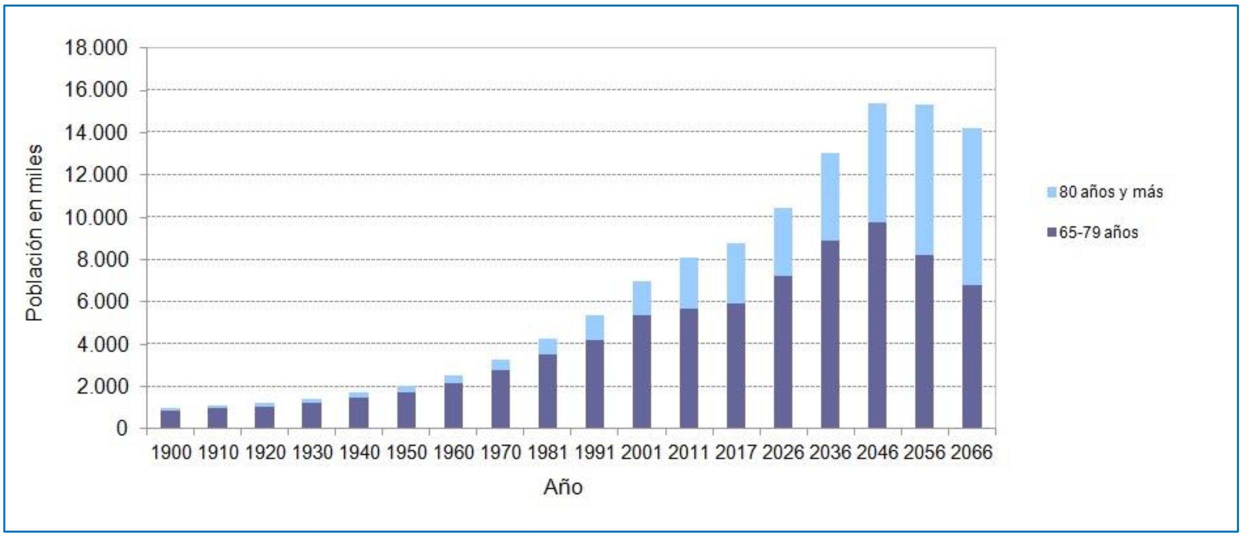


Figura 1. Evolución de la población mayor en España, 1900-2066 (fuente INE, 2017)

El envejecimiento humano es un proceso fisiológico y dinámico, complejo e individualizado, que comienza en la cuarta década de la vida y nos conduce finalmente a la muerte.[22] Es un proceso natural, multifactorial e irreversible, que puede cursar un envejecimiento exitoso, típico o patológico que se inicia en base a factores genéticos y ambientales. El envejecimiento biológico se caracteriza por cambios progresivos en el metabolismo y en las propiedades fisicoquímicas de las células, que conducen a alteraciones de la autorregulación, la regeneración, cambios estructurales en los tejidos y órganos funcionales, afectando a la esfera cognitiva, física, intelectual y psicológica, así como a la dependencia y la actividad social. [22] En definitiva, se asocia a una acumulación de procesos degenerativos que a su vez se sustentan en múltiples alteraciones y daños en las vías moleculares, comprometiendo finalmente las funciones celulares y tisulares.[23]

El envejecimiento induce fenómenos fisiológicos como la reducción del recuento celular, el deterioro de las proteínas tisulares, la atrofia tisular, la disminución de la tasa metabólica, la reducción de los fluidos corporales y la alteración del metabolismo del calcio, con progresión final hacia el envejecimiento patológico.[24] Además, el envejecimiento induce el acortamiento de los telómeros, reducción en la síntesis de adenosín trifosfato (ATP), alteraciones en la morfología y disfunción mitocondrial, deterioro de la defensa antioxidantes y alteraciones funcionales, el aumento las concentraciones de especies reactivas de oxígeno (ROS) y / o especies reactivas de nitrógeno (RNS), con una reducción de los antioxidantes endógenos provocando el aumento del estrés oxidativo. [24–27]

1.2.1. *El estrés oxidativo*

Los mecanismos oxidativos tienen un rol clave en la patogénesis de prácticamente todas las enfermedades, y también en el fenómeno del envejecimiento; paralelamente, el rol de los sistemas oxidantes es muy relevante en todos estos procesos. Está bien descrito en la literatura que el proceso de envejecimiento está asociado con el aumento de las concentraciones ROS y / o RNS, de la mano de una reducción de los sistemas antioxidantes endógenos.[25–27] El desequilibrio entre la defensa antioxidante y el aumento de la producción de radicales libres conduce al daño oxidativo, denominado estrés oxidativo.[28]

El estrés oxidativo es un factor crítico en el proceso de envejecimiento, directamente relacionado con una desregulación del sistema inmunológico y un estado redox alterado; ambos procesos contribuyen a un aumento de un estado inflamatorio sistémico debido a la activación de una variedad de mediadores inflamatorios a través del desequilibrio redox inducido por el estrés oxidativo. [29]

El desequilibrio redox relacionado con la edad, probablemente sea causado por el efecto neto de los sistemas de defensa antioxidantes debilitados y por el aumento incesante de ROS, como superóxido ($O_2^{\bullet -}$), radical hidroxilo ($^{\bullet}OH$), óxido nítrico reactivo ($NO^{\bullet}$), peroxinitrito ($ONOO^{-}$) y aldehídos lipídicos reactivos.[30] La defensa oxidativa es proporcionada por un número de moléculas, enzimas y vitaminas, incluyendo destacadamente la vitamina E, la vitamina C y el glutatión.[31,32] Cuando se produce un incremento de radicales libres, los sistemas de defensa antioxidantes pueden ser insuficientes. La eliminación incompleta de radicales reactivos conduce a la oxidación de lípidos, proteínas, ácidos nucleicos y glicoconjugados celulares con un nocivo impacto en la función de estas biomoléculas.[27,33–36]

Los altos niveles de ROS pueden causar daño directo a macromoléculas como lípidos, ácidos nucleicos y proteínas, además de ser un factor importante en la activación del sistema inmunológico durante el envejecimiento. [37,38] En última instancia, esto puede conducir a la muerte celular con consecuencias patológicas generalizadas,[34] además de aumentar el riesgo de enfermedades cardiovasculares, neurodegenerativas, diabetes mellitus tipo II y cáncer.[27,33–36]

Las especies reactivas de oxígeno y nitrógeno (RONS) son producidas en las células durante el metabolismo aeróbico, las mitocondrias son las fuentes primarias de ROS intracelulares (del 1–5% aproximadamente), debido a la fuga de electrones que resulta principalmente de la cadena de transporte de electrones.[39] El envejecimiento de las células musculares esqueléticas humanas está marcado por una disminución funcional progresiva de las mitocondrias, lo que resulta en la acumulación de ROS.[39,40] La disminución de la capacidad oxidativa mitocondrial con el envejecimiento está relacionado con una elevada producción de RONS y la activación de vías apoptóticas, induciendo la muerte celular programada, que se cree contribuye a la pérdida de masa muscular (sarcopenia),[41,42] principalmente en las fibras musculares del tipo II (glucolíticas) que presentan un contenido mitocondrial más bajo y son más susceptibles a la atrofia que las fibras de tipo (oxidativas).[43] La masa muscular disminuye aproximadamente un 6% por década después de la media edad; esta disminución gradual de la masa muscular se acompaña de una reducción simultánea de la fuerza,[44,45] del rendimiento muscular,[46] de una disminución de la tasa metabólica en reposo y de la adaptación metabólica,[47,48] de modo que el peso corporal se gana principalmente en forma de grasa (tejido adiposo) en lugar de masa magra, lo que perpetúa el desarrollo de la obesidad (figura 2). [47,49]

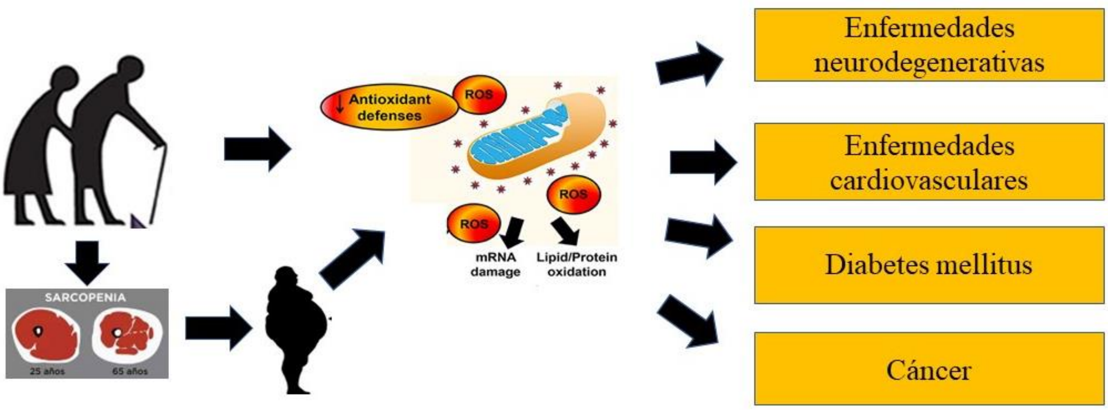


Figura 2. Aumento del estrés oxidativo en el envejecimiento, la sarcopenia y la obesidad relacionado con el riesgo de padecer enfermedades.

1.2.2. La obesidad

A nivel mundial, la prevalencia de la obesidad aumentó del 6,4% al 14,9% en mujeres adultas y del 3,2% al 10,8% en hombres adultos entre 1975 y 2014.[3] El sobrepeso y la obesidad son un problema creciente de salud pública mundial que afecta críticamente a las personas mayores de 65 años; empieza a aumentar después de la 3ª década de la vida, alcanzando el pico entre los 50 y los 80 años [50–52] . En España, la prevalencia de sobrepeso y obesidad es del 84% en la población anciana (figura 3).[53]

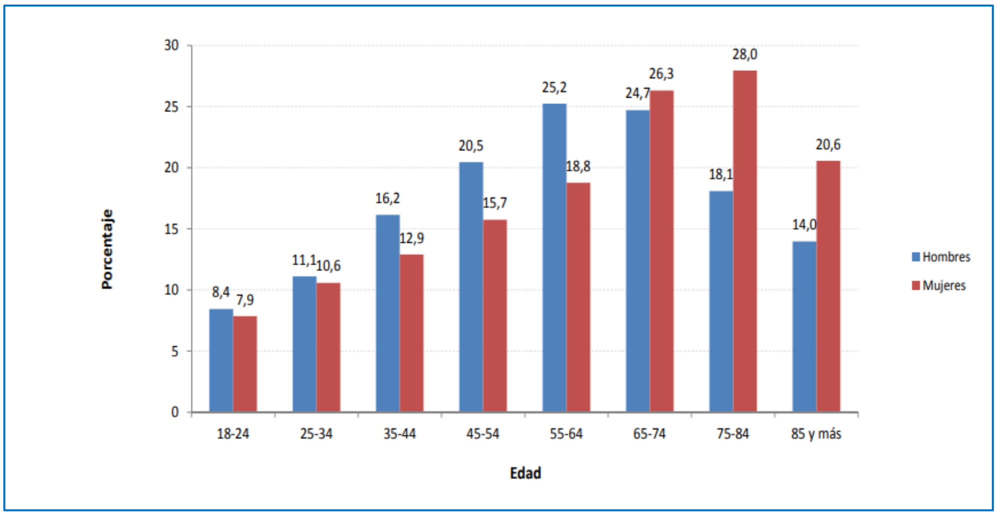


Figura 3. Porcentaje de adultos con obesidad (% IMC>30 kg/m^2) por sexo y grupo de edad en España (Fuente INE,2017)

La obesidad suele acelerarse por la inactividad crónica y es causada, principalmente, por una disminución progresiva en el gasto energético total (que puede darse por una, disminución de la actividad física y/o reducción de la tasa metabólica basal) en presencia de una ingesta calórica excesiva;[49] es una enfermedad crónica de origen multifactorial que se desarrolla a partir de la interacción de factores sociales, conductuales, psicológicos, metabólicos, celulares y moleculares.[54]

La OMS determina un estado de sobrepeso y obesidad cuando las personas presentan un índice de masa corporal (IMC) ≥ 25 kg/m^2 e IMC > 30 kg/m^2, respectivamente (figura 4).[52] El IMC se correlaciona con medidas más directas de la grasa corporal y está asociado a su vez con enfermedades metabólicas. Los estudios poblacionales han demostrado la relación existente entre tener un IMC ≥ 25 kg/m ^{2} y un IMC ≥ 30 kg/m^2 con un mayor deterioro funcional, cognitivo y el riesgo de mortalidad.[47,55,56] El IMC es una medida útil de la adiposidad general, ya que cada aumento de 5 kg/m^2 en el IMC se asocia con un incremento de la mortalidad del 30%, 40% más elevada por muerte cardiovascular y de un 60% a un 120% por muertes debido a la diabetes y a la mortalidad asociada a patologías hepáticas.[23,57]

IMC	DIAGNÓSTICO
BAJO PESO	<18.5
PESO NORMAL	18.5-24.9
SOBREPESO	25-29.9
OBESIDAD TIPO 1	30-34.9
OBESIDAD TIPO 2	35-39.9
OBESIDAD TIPO 3	≥40

Figura 4. Índice de masa corporal (IMC)

Tanto la obesidad como el IMC están directamente relacionados con el estrés oxidativo. [54] El aumento de tejido adiposo se caracteriza por un aumento en la producción y un almacenamiento de lípidos en el músculo esquelético. Estos lípidos intramusculares y sus derivados inducen una disfunción mitocondrial caracterizada por alteraciones de la capacidad de β- oxidación, aumentando la producción excesiva de RONS, y deteriorando la función metabólica que en última instancia es capaz de producir disfunción metabólica. [11]

El tejido adiposo, además de ser un órgano de almacenamiento de triglicéridos, es un tejido blando que produce ciertas sustancias bioactivas llamadas adipocinas; entre las adipocinas encontramos algunas con funciones inflamatorias, como la interleucina-6 (IL-6), Interleucina-1 (IL-1) y TNF-α. Estas citoquinas provocan un estado inflamatorio crónico por parte de los macrófagos y monocitos que inducen la producción de ROS, generando estrés oxidativo que se asocia con la producción irregular de adipocinas, contribuyendo al desarrollo del síndrome metabólico. Un ejemplo bien descrito en la literatura es el TNF-α que inhibe la actividad de la proteína C-reactiva, aumentando la interacción de los electrones con el oxígeno (O_2) para generar el anión superóxido. La sensibilidad de la proteína C-reactiva y de otros biomarcadores de daño oxidativo es mayor en individuos con obesidad y se correlacionan con el IMC, el porcentaje de grasa corporal, oxidación de la lipoproteína de baja densidad (LDL) y altos niveles de triglicéridos.[54] El tejido adiposo también tiene capacidad secretora de angiotensina II, que estimula localmente la actividad de NADPH-oxidasa contribuyendo a la ruta principal para la producción de ROS en los adipocitos.[54,58]

Existen varios mecanismos por lo cual la obesidad genera estrés oxidativo, como el peroxisomal de los ácidos grasos, que pueden producir RONS en reacciones de oxidación y $\dot{V}O_2$ que genera radicales libres en la cadena respiratoria mitocondrial que se encuentran acoplados a la fosforilación oxidativa en las mitocondrias.[59] El individuo obeso aumenta la carga mecánica y el metabolismo del miocardio, por lo tanto, aumenta el $\dot{V}O_2$ y, consecuentemente, aumenta la producción de ROS cómo el O_2^{-}, H_2O_2 y OH• derivado del aumento de la respiración mitocondrial y de la pérdida de electrones producidos en la cadena de transporte de electrones, lo que resulta en la formación del radical superóxido.[54,58]

Cuando la obesidad persiste durante mucho tiempo, las fuentes de antioxidantes se ven muy mermadas, disminuyendo la actividad de enzimas como el superóxido dismutasa (SOD) y la Catalasa (CAT). La actividad de la SOD y de la glutatión peroxidasa (GPx) en individuos con obesidad es significativamente menor en comparación con la de personas sanas, lo que refleja implicaciones para la salud relacionados directamente con la obesidad.[54,60] Además, los marcadores de defensa antioxidantes son menores según la grasa corporal y la obesidad central, ya que la acumulación de grasa puede causar daño celular que conduce a una alta producción de citoquinas como la TNF-α que, a su vez generan RONS en los tejidos, aumentando así la tasa de peroxidación lipídica. [54]

1.2.2.1. La peroxidación lipídica

La peroxidación lipídica (LPO) se produce en los ácidos grasos poliinsaturados de membranas biológicas. El proceso es iniciado por el radical OH•, cuando se captura un átomo de hidrógeno del carbono de metileno del ácido graso. El ácido graso, en condiciones aeróbicas, puede sufrir un reordenamiento molecular con el O_2, generando el OH•. Este producto es altamente reactivo y puede combinarse con otros radicales peroxilo no sólo de otras moléculas de lípidos, sino también pueden alterar la estructura de las proteínas de membrana.[61] El proceso de LPO consta de tres pasos: iniciación, propagación y terminación. En el paso de iniciación de la peroxidación lipídica, los prooxidantes como el OH• extraen el hidrógeno alílico formando el radical lipídico ($L^{\bullet}$) centrado en el carbono. En la fase de propagación, el $L^{\bullet}$ reacciona rápidamente con el O_2 para formar un radical peróxido lipídico ($LOO^{\bullet}$) que, a su vez extrae un hidrógeno de otra molécula lipídica generando una nueva $L^{\bullet}$ (que continúa la reacción en cadena) e hidroperóxido lipídico (LOOH). En la reacción de terminación, los antioxidantes como la vitamina E donan un átomo de hidrógeno al $LOO^{\bullet}$ y forman el radical de vitamina E correspondiente que es un producto no reactivo (figura 5).[62]

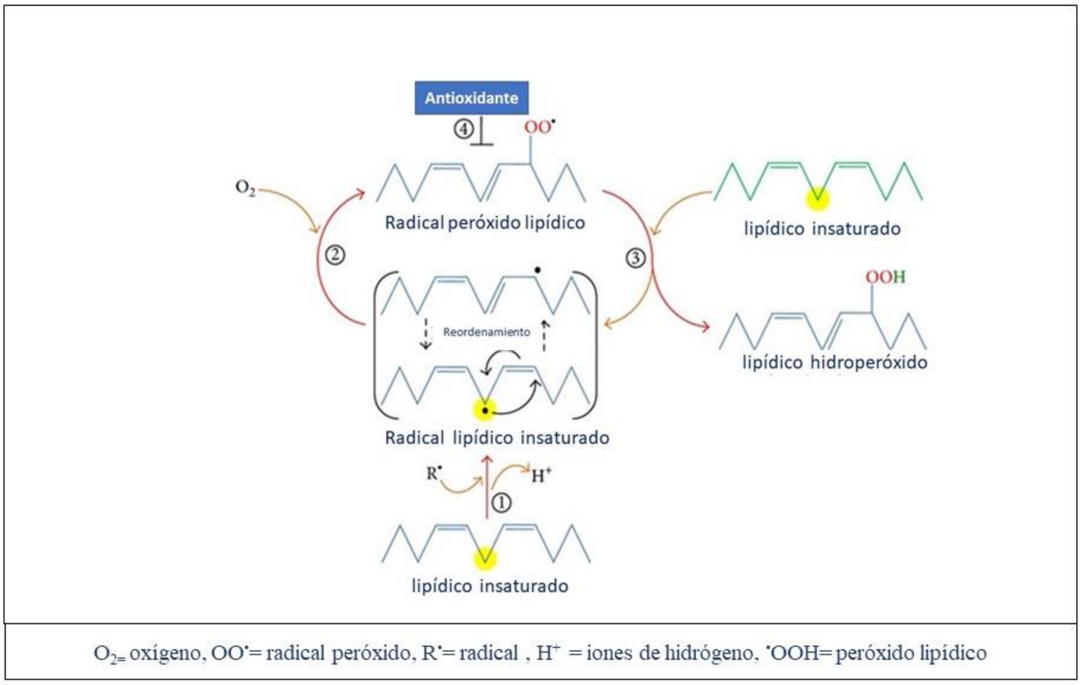


Figura 5. Proceso de peroxidación lipídica adaptado de Ayala et al. [62]

Una vez que este proceso ha comenzado, la LPO se propaga como una reacción en cadena inducida por ROS hasta que los niveles de peroxidación son lo suficientemente altos como para dar como resultado la producción de una molécula no radical.[61] La LPO puede provocar daño a la membrana celular debido a la alta concentración de lípidos presentes. Además, los productos finales de la LPO pueden ser tanto mutagénicos como cancerígenos, y desempeñan un papel clave en el envejecimiento y la progresión de la enfermedad.[63]

La concentración de la LDL circulante es la principal portadora de colesterol a los tejidos corporales; la oxidación de estas moléculas, tras el ataque de las RONS, está relacionada con la iniciación y progresión de la aterosclerosis y, finalmente, con la patogénesis de la enfermedad cardiovascular.[36] La oxidación de LDL es un proceso complejo en el que tanto la proteína como los lípidos sufren cambios oxidativos que pueden provocar la acumulación patológica de colesterol.[38] Los ácidos grasos polinsaturados son otras dianas importantes de la LPO, mediada por los OH•. La LPO produce varios aldehídos reactivos diferentes como trans -4-hidroxi-2-nonenal (4-HNE), malondialdehído (MDA) e isoprostanos (F_2 -IsoPs).[38] El aumento de la LPO estimula la proliferación de sustancias citotóxicas como H_2O_2 y MDA, que aumentan la probabilidad de padecer procesos ateroscleróticos que involucran lipoproteínas circulantes.[64] Cuanto mayor es la generación de ROS, mayor es la concentración de proteínas oxidadas (carboniladas) y productos de la LPO, incrementando los isoprostanos y el MDA en plasma.[64,65]

La LPO es mayor en la masa del músculo esquelético en adultos con obesidad[66] y diversos estudios han demostrado asociaciones entre la obesidad, un alto IMC y un aumento de las concentraciones de MDA en plasma.[67–69] Además, la sarcopenia está frecuentemente relacionada con la obesidad en personas mayores incrementando los niveles circulantes de productos de LPO como el MDA y consecuentemente, incrementando el riesgo de padecer enfermedades cardiovasculares.[70,71]

1.2.3. El ejercicio físico

La AF se refiere al movimiento corporal producido por la contracción de los músculos esqueléticos, que aumenta el gasto de energía. El ejercicio físico implica el movimiento planificado, estructurado y repetitivo para mejorar o mantener uno o más componentes de la condición física, es decir, la capacidad aeróbica, la potencia, la resistencia, la fuerza muscular, el equilibrio, la coordinación y la flexibilidad.[72–74] Aunque no se han establecido pautas sobre la cantidad de ejercicio físico necesaria para favorecer el proceso de envejecimiento, las directrices actuales determinan que todos los adultos deben evitar la inactividad (figura 6). Por supuesto, algo de AF es mejor que nada. El sedentarismo debería ser evitado al menos realizando AF diaria como caminar, bailar, actividades domésticas y actividades de bajo impacto articular.[19] Las recomendaciones de la OMS establecen que los adultos mayores de 65 años deben realizar de 150 minutos a 300 minutos de ejercicio aeróbico de intensidad moderada o de 75 a 150 minutos de ejercicio aeróbico de intensidad vigorosa; o una combinación equivalente de actividades moderadas e intensas a lo largo de la semana, y dos o más días de ejercicio de fortalecimiento muscular.[14] Desafortunadamente, sólo un tercio de las personas mayores cumplen con las recomendaciones y una gran mayoría de ellos que practican AF no alcanza las pautas en relación con el tiempo y la intensidad recomendada. Existe dos fenotipos en el envejecimiento en relación con la presencia o ausencia de AF y ejercicio, como se describe en la figura 6.[73,75]

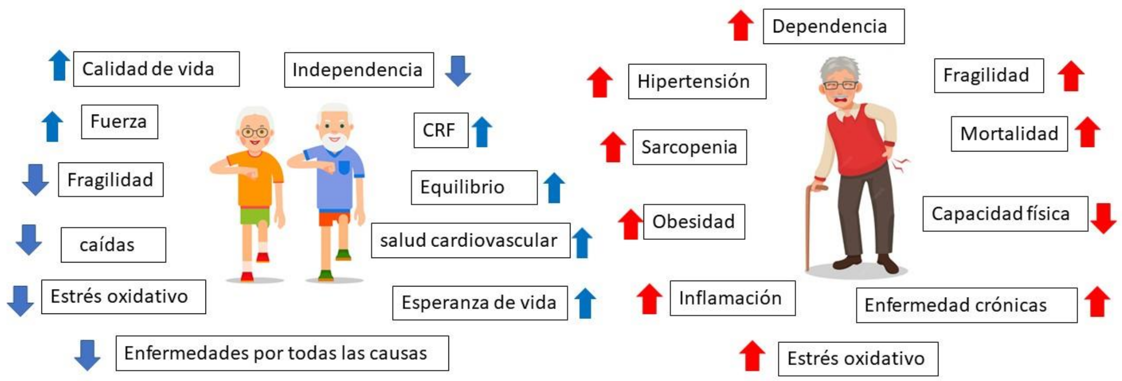


Figura 6. Esquema comparativo de los parámetros beneficiosos del envejecimiento activo (en azul) en comparación con los parámetros perjudiciales del envejecimiento sedentario (en rojo).

Un envejecimiento sedentario se asocia con una disminución de la capacidad física, lo que resulta en una mayor dependencia y en un deterioro al realizar actividades de la vida diaria, lo que conlleva un incremento de los factores de riesgo como la mortalidad, la obesidad, la sarcopenia, la fragilidad y la hipertensión en las enfermedades crónicas asociadas al envejecimiento.[75] En contrapartida el ejercicio practicado de por vida puede retrasar la aparición de, al menos, 40 enfermedades crónicas.[76] La práctica del ejercicio regular y estructurado puede minimizar los efectos de un estilo de vida sedentario, proporcionar beneficios sustanciales a la salud, la independencia, la fragilidad y el bienestar psicológico,[75,77–79] evitando el desarrollo de enfermedades crónicas como la obesidad, la sarcopenia, la hipertensión, la diabetes, la incapacidad física, mejorando la salud cognitiva y mental y, por ende, mejorando la calidad y la esperanza de vida,[75,77–79] El ejercicio físico proporciona beneficios en el CRF, en la composición corporal, [80,81] en la fuerza y la resistencia muscular,[82–84] en el equilibrio, en la capacidad funcional, en las actividades de la vida diaria y en la reducción de la incidencia de caídas en las personas mayores.[85–87] Además, puede favorecer acciones antioxidantes y antiinflamatorias adicionales y minimizar los efectos nocivos del envejecimiento asociados a la disfunción mitocondrial y la inflamación como los principales desencadenantes del estrés oxidativo.[79,88–90]

1.2.4. Relación entre el estrés oxidativo, la obesidad y el ejercicio físico

Es bien sabido que el ejercicio físico regular se ha convertido en uno de los recursos más beneficiosos para retrasar el deterioro fisiológico inducido por el envejecimiento y la obesidad; es un factor determinante para mantener un buen estado de salud y prevenir enfermedades. En particular la relación entre el estrés oxidativo y el ejercicio físico es compleja. Parece que los programas de ejercicio físico podrían reducir el estrés oxidativo en personas mayores y obesas, según el tipo, la intensidad y la duración de los estímulos.[91–93] Estudios previos encontraron diferentes niveles de peroxidación lipídica y sustancias reactivas al TBARS en individuos obesos en varios tipos de ejercicio a diferentes intensidades.[94–96]

Como respuesta aguda, el ejercicio físico aumenta la producción de RONS.[97,98] Una gran parte del O_2 que es utilizado para la producción de ATP produce RONS, principalmente durante el ejercicio; a medida que la demanda de O_2 es mayor, aumenta la liberación de RONS siendo proporcional a la intensidad del ejercicio. Esa producción de RONS puede ser dañina causando lesiones en la estructura celular, además de inducir procesos de destrucción celular como la autofagia y la apoptosis, y el reclutamiento de las células del sistema inmune e inflamatorias.[99] Durante el ejercicio físico, el complejo de la cadena de transporte de electrones mitocondrial, el fenómeno de la lesión isquemia-reperfusión y la inflamación se han identificado como fuentes principales de radicales libres, provocando un aumento de la actividad de la fosfolipasa, la NADPH oxidasa y la xantina oxidasa, incrementando el estrés oxidativo. [97,98] La liberación del RONS durante el ejercicio puede provocar efectos negativos en el tejido muscular, provocando una disminución de la fuerza e incrementando la fatiga; estos efectos son causados principalmente en personas desentrenadas, atletas con cargas excesivas de entrenamiento, personas obesas, personas con déficit nutricional y personas mayores.[92,100]

Los individuos obesos al realizar ejercicio pueden aumentar el trabajo muscular por tener un peso excesivo, y esto puede incrementar posteriormente la producción de radicales a través de una mayor fosforilación oxidativa y de la fuga de electrones en la cadena de transporte de electrones.[101,102] Diferentes estudios encontraron un aumento del estrés oxidativo, como el aumento de la LPO, en respuesta al ejercicio físico agudo principalmente en personas mayores y obesas.[92,94,100,103] El nivel de LPO aumenta significativamente inmediatamente y hasta las 48 h después del ejercicio, aunque esta respuesta también induce un aumento de las respuestas antioxidantes.[28,104] Aunque es evidente que la respuesta aguda al ejercicio físico aumenta el estrés oxidativo, este mismo estímulo parece ser necesario para permitir una regulación positiva en las defensas antioxidantes endógenas (hormesis)[102] y del sistema de defensa, promoviendo adaptaciones importantes en la función celular y una respuesta inmune más eficaz, mejorando así la protección frente a los efectos causados por el estrés oxidativo mediante mecanismos fisiológicos antioxidantes.[100]

Estas respuestas agudas al ejercicio físico inducen cambios crónicos o adaptaciones fisiológicas positivas, siempre y cuando el ejercicio físico pautado sea saludablemente adecuado. Diferentes estudios verificaron la disminución en la producción de radicales libres y un aumento de las defensas oxidantes en participantes que realizaban ejercicio aeróbico de moderada intensidad.[28,104,105] Yu et al. mostraron que el ejercicio aeróbico como correr, andar en bicicleta y bailar indujo niveles más bajos de MDA , además, tiene efectos protectores contra el daño por estrés oxidativo en personas mayores.[106] Hallazgos similares se encontraron en mujeres mayores obesas después de realizar un programa de ejercicio aeróbico durante 12 meses a una intensidad del 60-75% de la $FC_{máx}$.[107] Los autores concluyeron que el ejercicio aeróbico disminuye el estrés oxidativo cuando se acompaña de mejoras en la aptitud cardiorrespiratoria ($\dot{V}O_{2máx}$).[107]

Desde una perspectiva fisiológica, la disminución del estrés oxidativo puede estar relacionada con el $\dot{V}O_{2máx}$ y la mejora en la función mitocondrial que es una de las características del proceso de envejecimiento que conlleva una emisión elevada de ROS y de la activación de vías apoptóticas.[41] Las personas mayores que realizan ejercicio físico a largo plazo poseen valores de $\dot{V}O_{2máx}$ más altos[81,82,108,109], una mejor función mitocondrial[41,79,110–112] y, consecuentemente, una mayor resistencia al estrés oxidativo [79,111,113–117]. Además, la AF realizada regularmente contrarresta los efectos deletéreos del envejecimiento y de los desencadenantes del estrés oxidativo como la obesidad, disminuyendo la acumulación de lípidos intermusculares,[79,111] previniendo la pérdida de masa muscular (sarcopenia) y de la fuerza muscular[43,109,112,118,119], además de favorecer los mecanismos antioxidantes y antiinflamatorios adicionales (figura 7).[79,88–90]

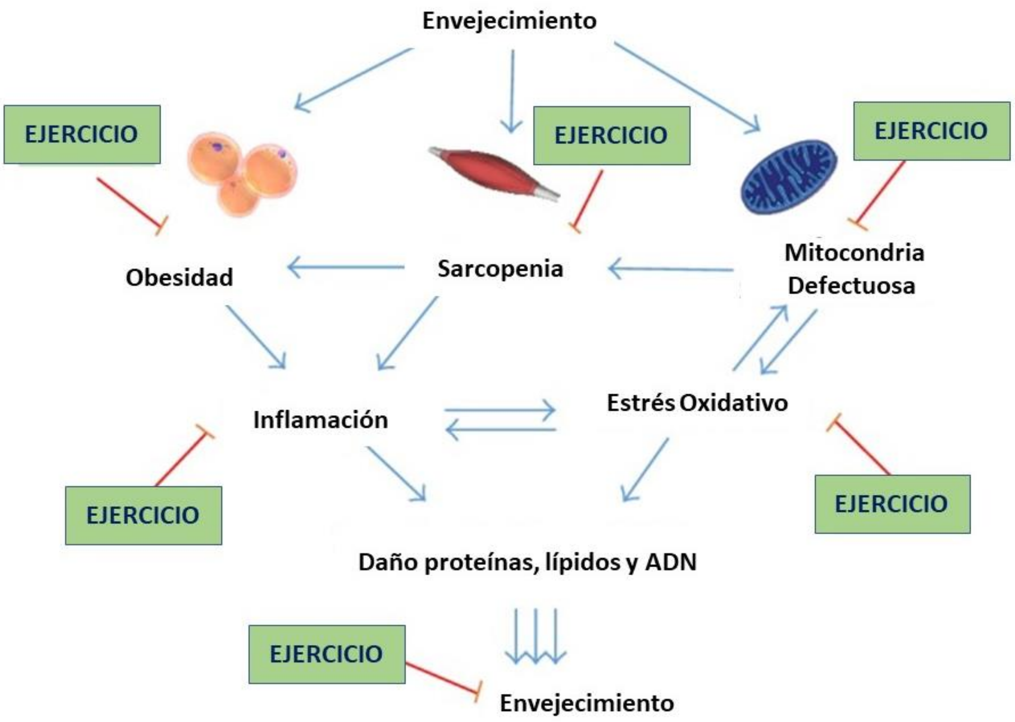


Figura 7. Relación entre el ejercicio físico, la actividad física regular, la sarcopenia, la obesidad y la disfunción mitocondrial como los principales desencadenantes del estrés oxidativo, la inflamación y del daño de proteínas, lípidos y ADN en el envejecimiento[79] Las flechas azules indican relación directa y las líneas rojas indican inhibición.

De acuerdo con la literatura, el ejercicio aeróbico cuando es realizado dos o tres veces por semana a una intensidad entre el 50 y el 80% del $\dot{V}O_{2máx}$., tiene un efecto positivo en el equilibrio oxidativo/antioxidante.[120]

2. EL EJERCICIO FÍSICO

2.1. *El ejercicio cardiorrespiratorio*

El ejercicio cardiorrespiratorio también denominado de resistencia y/o aeróbico consiste en estímulos que implican grandes grupos musculares en los que el individuo mantiene una carga de trabajo durante un período de tiempo prolongado. Cooper definió como aeróbico los ejercicios de baja/moderada intensidad, que podrían ser realizados por un período prolongado, gracias al equilibrio existente (steady state) entre el consumo y el débito de O_2 que el organismo necesita para la producción de energía. Clasificó como aeróbicos cinco modalidades de ejercicio: esquí de fondo, ciclismo, natación, correr/trotar y caminar.[121]

Entre los parámetros de la carga en el ejercicio de resistencia o aeróbico, la intensidad es una variable determinante para las adaptaciones cardiorrespiratorias y metabólicas del entrenamiento cardiorrespiratorio exitoso (tabla 1). Existe una respuesta positiva a una determinada intensidad del ejercicio, de tal manera que intensidades de ejercicio por debajo del umbral de estimulación adecuada, resultan insuficientes para inducir beneficios tales como cambios en la composición corporal y el aumento del $\dot{V}O_{2máx}$.[122] Según las recomendaciones de la American College of Sports Medicine (ACSM), los adultos deberían realizar actividades aeróbicas de intensidad moderada durante al menos 150 a 300 minutos a la semana o 75 a 150 minutos de actividades aeróbicas de intensidad moderada a vigorosa.[74]

Tabla 1. Clasificación relativa de la intensidad del ejercicio físico según el ACSM. [74]

Intensidad	%$VO_{2máx}$	% $FC_{máx}$	MET	RPE
Muy ligero	>37%	>57%	2,4	<10
Ligero	37%–45%	57%–63%	2.4–4.7	10-11
Moderada	46 %–63 %	64 %–76 %	4,7–7,1	12-13
Vigoroso	64 %–90 %	77 %–95 %	7,1–10,1	14-16
Casi máximo a máximo	≥90 %	≥96 %	≥ 10,2	17-19

% $VO_{2máx}$= porcentaje de consumo máximo de oxígeno, %$FC_{máx.}$= porcentaje de frecuencia cardiaca máxima, MET= equivalente metabólico de tarea, RPE= percepción subjetiva del esfuerzo

2.1.1. Respuestas agudas cardiorrespiratorias

Durante el ejercicio cardiorrespiratorio, ocurren algunos ajustes fisiológicos en función del aumento de la intensidad y/o volumen del ejercicio; el sistema cardiovascular y respiratorio necesita atender las demandas metabólicas y celulares del suministro de O_2 y de la eliminación de CO_2. Las adaptaciones conseguidas son de extrema importancia para la producción de energía mediante el metabolismo aeróbico, por ello, el sistema cardiovascular aumenta la tasa de funcionamiento aumentando la absorción y el transporte de O_2. En reposo respiras lentamente y este ritmo es suficiente para incorporar a los pulmones un flujo suficiente de O_2 y para eliminar el CO_2 resultante del metabolismo energético. Las moléculas de O_2 entran en el torrente sanguíneo, se unen a las moléculas de hemoglobina de los glóbulos rojos y son transportadas a través de las arterias, arteriolas y capilares para llevarlo hasta cada célula. Una vez en su interior, las moléculas de O_2 entran en las mitocondrias, donde van a utilizarse en la cadena transportadora de electrones para la producción continuada de ATP. Durante el ejercicio todos estos hechos se aceleran, especialmente, ante intensidades de ejercicio crecientes.[61]

Varios son los factores limitantes y determinantes en el funcionamiento del sistema cardiovascular y respiratorio durante el ejercicio cardiorrespiratorio, existiendo una interrelación entre ambos sistemas, sobre todo en la absorción y el transporte de O_2. Parte de la relación entre el sistema cardiovascular y respiratorio está asociada con la capacidad funcional por el gasto cardiaco (GC) que es la cantidad de sangre bombeada por minuto por el corazón (GC=VS x FC).[61] La FC es responsable en gran medida del aumento del GC principalmente por el aumento de la intensidad del ejercicio. Existe una relación lineal entre la FC y la intensidad del ejercicio, de tal manera que a medida que la intensidad del ejercicio aumenta, incrementa la FC hasta llegar a su máxima intensidad (Figura 8).[123]

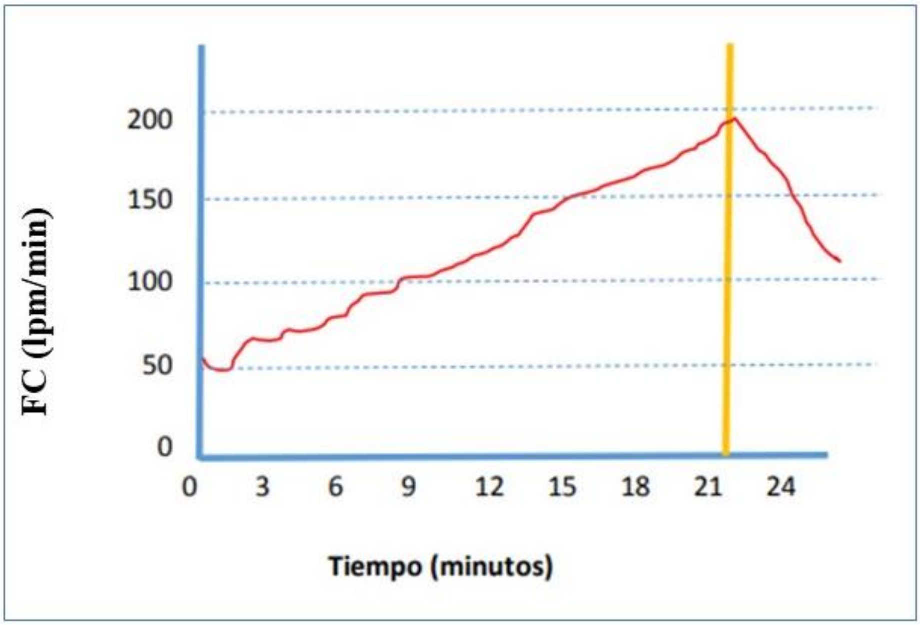


Figura 8. Respuesta aguda de la frecuencia cardiaca (FC) durante el ejercicio de carga incremental

El $\dot{V}O_2$ indica la cantidad de O_2 consumido por unidad de tiempo por el organismo, y es el resultado del cociente del GC y la diferencia arteriovenosa de la concentración O_2. El $\dot{V}O_2$ aumenta de forma progresiva en relación directa a la carga de trabajo hasta llegar a un máximo ($\dot{V}O_{2máx}$). El ritmo de movimientos respiratorios y su profundidad incrementan la respuesta cardiaca; el ventrículo izquierdo se llena de más cantidad de sangre, aumenta el GC, las arteriolas se dilatan y un número mayor de capilares se llenan de sangre.[61] Dado que el $\dot{V}O_{2máx}$ está determinado por el GC y por la capacidad muscular de captar oxígeno de la sangre, el entrenamiento aeróbico adecuado provoca un incremento del $\dot{V}O_{2máx}$.[123] Así como la FC, el $\dot{V}O_2$ también responde proporcionalmente a la intensidad del ejercicio. Como respuesta aguda al ejercicio, se produce un aumento lineal y progresivo del $\dot{V}O_2$ a medida que se incrementa la intensidad de ejercicio, aunque está linealidad se mantiene en cargas de trabajo submáximas y se pierde cuando el individuo llega a su $\dot{V}O_{2máx}$ produciéndose una teórica meseta (Figura 9). El $\dot{V}O_2$ se ajusta a intensidades de ejercicio a carga constante tras un periodo de adaptación que es más o menos rápida en función de la intensidad de trabajo requerida y la cinética del $\dot{V}O_2$ de cada sujeto [123]

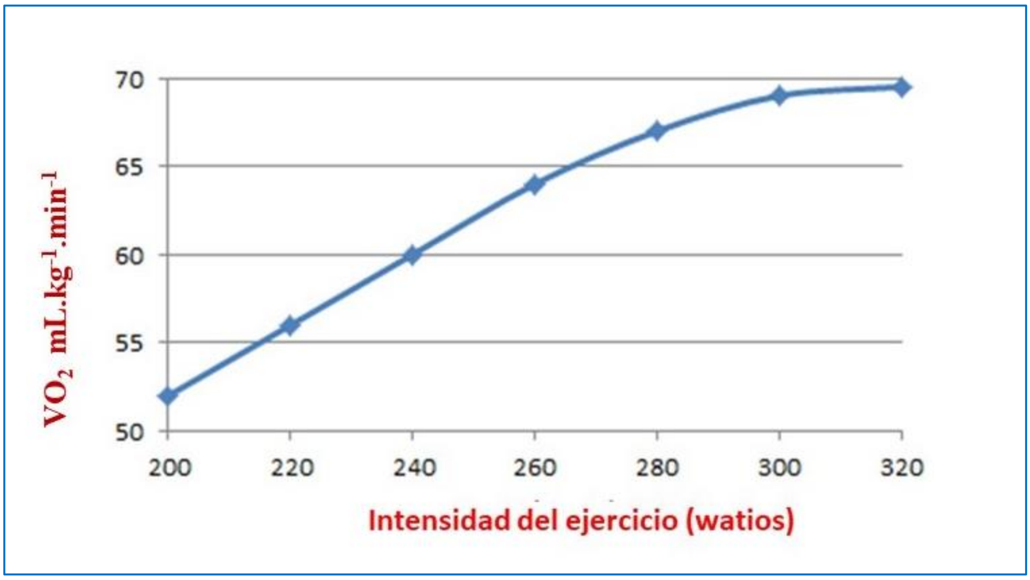


Figura 9. Respuesta aguda del consumo de oxígeno ($\dot{V}O_2$) durante el ejercicio incremental.

El patrón respiratorio durante el ejercicio incremental se caracteriza por un aumento de la ventilación pulmonar (VE). El aumento de la intensidad del ejercicio provoca incrementos en los intercambios gaseosos de O_2 y CO_2, en respuesta a este estímulo; los sistemas de transporte aumentan su funcionamiento, procurando establecer el intercambio adecuado de O_2 y CO_2 entre la respiración celular y VE. La VE se altera al inicio del ejercicio y se eleva gradualmente hasta que se estabiliza para atender las demandas metabólicas. Cuando la intensidad del ejercicio se encuentra entre el 50-80% del $\dot{V}O_{2máx}$ se alcanza el umbral ventilatorio (VT) que corresponde a un punto de incremento del aire ventilado por encima del aire consumido. Las necesidades de O_2 son bajas y el aporte ventilatorio es suficiente, pero si incrementamos la intensidad del ejercicio, hay un aumento paralelo del consumo de O_2 y de la producción de CO_2 que a su vez estimula los receptores del centro respiratorio con el consiguiente aumento de la VE.[61]

La regulación de la VE se mantiene por estímulos centrales y químicos como la temperatura corporal, el CO_2 y los iones de hidrógeno [H^+]. Cuando la intensidad del ejercicio aumenta, en situaciones de máximo esfuerzo, es común observar un patrón disneico por exceso de acumulación de iones [H^+] y de CO_2 en sangre arterial, forzando al sistema pulmonar a expulsar más CO_2 mediante el aumento del llenado pulmonar y, principalmente de la frecuencia respiratoria.[123]

En los alvéolos pulmonares tiene lugar el intercambio de O_2 y de CO_2 entre la atmósfera y la sangre, y por ello, gracias a la VE, la presión parcial alveolar de O_2 ($P_{ET}O_2$) en los alvéolos es mayor que la existente en los tejidos metabólicamente activos o en la sangre venosa procedente de los mismos. Así, la ventilación permite que la $P_{ET}O_2$ se mantenga constante (alrededor de 105 mmHg), y que el O_2 se mueva, siguiendo su gradiente de difusión desde los alvéolos a la sangre, para ser distribuido a los diferentes tejidos. A su vez, gracias a la VE, la presión parcial alveolar de CO_2 (P_{ET} CO_2) se mantiene bastante baja en los alvéolos pulmonares (en torno a 40 mmHg), creando un gradiente de presiones negativo para que el CO_2 procedente del metabolismo celular se difunda desde los tejidos, a través de la sangre capilar, hacia los alvéolos y, por tanto, hacia el exterior. Por todo ello, tanto la frecuencia de la respiración como la profundidad de la misma influyen sobre la cantidad de O_2 y de CO_2 que se intercambian entre el organismo y la atmósfera, y esto tiene especial importancia cuando realizamos ejercicio físico.[123]

La relación entre el volumen de aire espirado o ventilado y la cantidad de O_2 consumido por los tejidos se denomina equivalente ventilatorio de oxígeno ($VE \cdot VO_2^{-1}$). En ejercicio realizado a intensidad por encima del 55% del $\dot{V}O_{2máx}$, el $VE \cdot VO_2^{-1}$ alcanza valores de 25 litros de aire ventilado por litro de oxígeno; a medida que la intensidad aumenta el $VE \cdot VO_2^{-1}$ puede superar los 30 litros de aire ventilado por litro de oxígeno. En ese punto ocurre una hiperventilación por el incremento de aire expirado por encima del O_2 consumido. El $VE \cdot VO_2^{-1}$ es indicativo de las modificaciones en el equilibrio metabólico del organismo y también de la eficiencia respiratoria.[61]

La cantidad de O_2 consumido dependerá del "combustible" que se oxida utilizando una cantidad de grasa o de hidratos de carbono necesarios para producir ATP y satisfacer las necesidades energéticas del organismo; la tasa de intercambio respiratorio (RER) cuantifica la relación entre la cantidad del consumo de O_2 y la producción de CO_2 por minuto, y nos permite cuantificar el metabolismo energético y el tipo de sustrato oxidado (carbohidratos, ácidos grasos, aminoácidos). En reposo las necesidades de O_2 son bajas y es la grasa la que está siendo oxidada primordialmente para producir ATP. En este caso, el valor de RER es bajo, produciéndose una oxidación teórica del 100% de las grasas cuando el valor es de 0,70. Durante el ejercicio intenso, para producir ATP se oxidan principalmente los carbohidratos. Al respecto, el RER es elevado y suele aumentar por encima de 1,00, que a su vez es considerado como el valor teórico de referencia de oxidación al 100% de los hidratos de carbono.[61]

La respuesta aguda cardiorrespiratoria puede depender de la modalidad del ejercicio cardiorrespiratorio, de la masa muscular involucrada, de la intensidad, de la duración y también de la capacidad cardiorrespiratoria del individuo.[81,124–127]

2.1.1.1. *Los umbrales ventilatorios*

El VT es un importante marcador respiratorio del CRF; es utilizado para evaluar la aptitud aeróbica, determinar la intensidad óptima de entrenamiento principalmente en el ejercicio aeróbico y en modalidades deportivas de resistencia como carreras de atletismo, ciclismo, natación.[128-130]

Los primeros estudios definían el VT como la transición aeróbica-anaeróbica que acontece en un ejercicio incremental, debido a un aporte inadecuado de oxígeno a los músculos y al aumento de las concentraciones de lactato.[131–135]

Durante una prueba de ejercicio cardiorrespiratorio, a medida que la intensidad del ejercicio aumenta, la demanda de energía del músculo en ejercicio supera la capacidad de suministro de O_2. El aporte energético del metabolismo aeróbico ocurre desde el inicio del ejercicio; a medida que la intensidad del ejercicio aumenta y alcanza aproximadamente el 60% del $\dot{V}O_2$, el metabolismo anaeróbico está cada vez más presente. Si la intensidad de ejercicio sigue incrementando, el metabolismo anaeróbico se hace cada vez más partícipe, se comienzan a reclutar las fibras musculares tipo II (más glucolíticas), produciendo un aumento de las concentraciones de lactato que corresponden aproximadamente al doble del valor de reposo.[123] El aumento de las concentraciones de lactato aumentará la VE para eliminar el exceso de CO_2 derivado de la amortiguación del bicarbonato de la acidosis metabólica, manteniendo la homeostasis de la $P_{ET}CO_2$. Desde un punto de vista teórico, este momento metabólico que da lugar a un cambio en el patrón ventilatorio es definido como el primer umbral ventilatorio (VT1). Una mayor tasa de trabajo por encima del VT1, provocará un aumento desproporcionado de la VE en relación con la VCO_2, que se asocia al aumento de la $VE \cdot VCO_2^{-1}$ y a un descenso de la $P_{ET}CO_2$. Este momento metabólico dará lugar a un cambio en el patrón ventilatorio conocido como el punto de compensación respiratoria y/o segundo umbral ventilatorio (VT2) (tabla 2). [61]

Tabla 2. Alteraciones de los parámetros fisiológicos en los umbrales ventilatorios (VT1/VT2)

	VT1	VT2
VE	↑	↑
$VE \cdot VO_2^{-1}$	↑	↑
$VE \cdot VCO_2^{-1}$	↑	↑
$P_{ET}O_2$	↑	↑
$P_{ET}CO_2$	↔	↓

VT1= primer umbral ventilatorio, VT2= segundo umbral ventilatorio, VE= ventilación pulmonar, $VE \cdot VO_2^{-1}$= equivalente ventilatorio del oxígeno, $VE \cdot VCO_2^{-1}$= equivalente ventilatorio para el dióxido de carbono, $P_{ET}O_2$= Presión parcial del oxígeno en la espiración, $P_{ET}CO_2$= Presión parcial del dióxido de carbono en la espiración

↑: aumento con quiebra da linealidad; ↔: permanece constante; ↓: disminución con quiebra da linealidad.

El **VT1** se determina por el aumento del $VE \cdot VO_2^{-1}$ y del $VE \cdot VCO_2^{-1}$; indica que el organismo está elevando la tasa ventilatoria inducida por la progresión de la intensidad del ejercicio. **El VT2 indica** la intensidad de ejercicio en el que el punto de compensación respiratoria es progresivo. Puede ser observado por el segundo aumento no-lineal de la VE, o la quiebra de la linealidad del $VE \cdot VO_2^{-1}$ y del $VE \cdot VCO_2^{-1}$.[136]

Para determinar los VT, se han utilizado diferentes métodos como el porcentaje del $\dot{V}O_2$, FC, RPE y lactato sanguíneo.[137–140] Desde una perspectiva metabólica, el VT1 se asemeja al "umbral aeróbico" y la intensidad del ejercicio se considera suave entre el 40-60% del $\dot{V}O_{2max}$. El VT2 se asemeja a un momento metabólico similar al del "umbral anaeróbico". La intensidad del ejercicio es considerada entre moderada a intensa y se corresponde entre el 60-90% del $\dot{V}O_{2máx}$.[137] En los años 80, Skinner y McLellan definieron un modelo trifásico que establece las tres fases metabólicas según la intensidad del ejercicio (figura 10):[140]

Fase I- Amortiguación del lactato, con aumento en la producción de CO_2 (VCO_2), en relación con el $\dot{V}O_2$. La intensidad del ejercicio es considerada suave entre el 45-55% del $\dot{V}O_{2máx}$, 60-70% de la $FC_{máx.}$, lactato < 2 mmol·L $^{-1}$ y RPE 10-12.

Fase II- Incremento de la VE proporcional al VCO_2, sin aumento en la $P_{ET}CO_2$. La intensidad del ejercicio es moderada entre el 55-80% del $\dot{V}O_{2máx}$, 70-90% $FC_{máx}$, RPE 13-14 y lactato entre 2-4 mmol·L $^{-1}$.

Fase III- Compensación respiratoria debido a la acidosis metabólica, con descenso de la PCO_2. La intensidad del ejercicio es vigorosa, >80% $\dot{V}O_{2máx}$. y >90% $FC_{máx}$, RPE > 14, lactato >4 mmol·L $^{-1}$.[140]

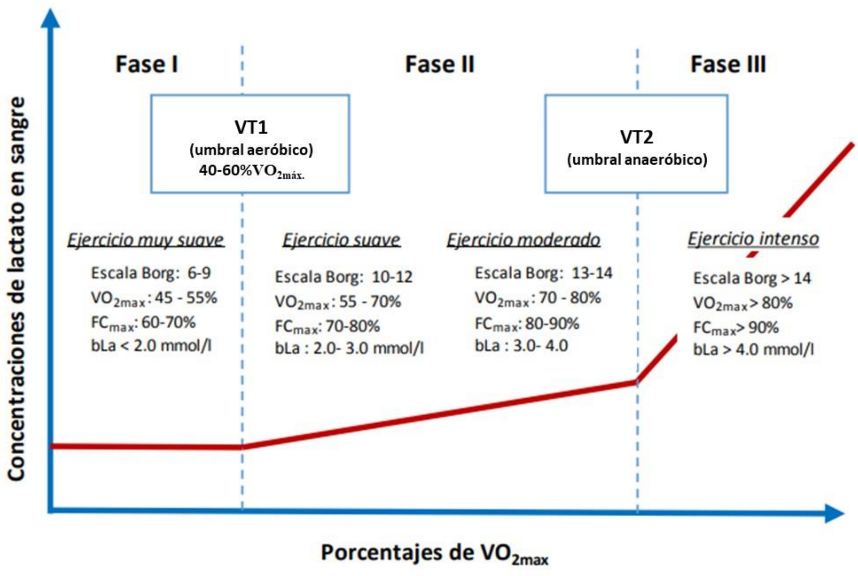


Figura 10. El modelo trifásico de Skinner et al. correspondiente a la relación entre el lactato en sangre (bla) y la intensidad de ejercicio, primer umbral ventilatorio (VT1), segundo umbral ventilatorio (VT2), frecuencia cardiaca máxima ($FC_{máx.}$), consumo máximo de oxígeno $\dot{V}O_{2máx}$ y escala de Borg.[140]

2.1.1.2. El componente lento del consumo de oxígeno

La evaluación de la cinética del $\dot{V}O_2$ se considera una práctica fundamental para analizar el efecto de la intensidad del ejercicio sobre los denominados ejercicios de resistencia [141] y ejercicios de fuerza[142] en varias poblaciones.[143–146] Específicamente, el $\dot{V}O_2$ pulmonar tiende a aumentar lentamente para la producción de potencia más allá de los 3 min durante una prueba de ejercicio de resistencia a una intensidad de carga constante prolongada, produciendo acidosis láctica sostenida y por encima del componente primario iniciado al comienzo del ejercicio. Este fenómeno ventilatorio producido en la cinética del $\dot{V}O_2$ es conocido como el componente lento del $\dot{V}O_2$ ($\dot{V}O_2sc$),[147] representa una pérdida de la eficiencia contráctil del músculo esquelético y se asocia, por lo tanto, a los procesos de fatiga.

La función cardiorrespiratoria puede verse afectada por diversos parámetros que condicionan una respuesta aguda, como la intensidad de carga, el $\dot{V}O_2$, el umbral de lactato (LT) y el VT, alterando la eficiencia mecánica y ventilatoria y, por ende, condicionando el desempeño cardiorrespiratorio.[142,148] A intensidades de ejercicio por debajo del LT y VT, se ha observado un estado estable de $\dot{V}O_2$ sin aumentar el $\dot{V}O_2sc$ y las concentraciones de lactato. A intensidades de ejercicio superiores al LT o VT, se ha verificado un aumento del $\dot{V}O_{2sc}$ en función del aumento de la intensidad del ejercicio y de las concentraciones de lactato sanguíneo. A una intensidad de carga del LT o del VT1, se ha observado un estado estacionario tanto del $\dot{V}O_2$ como de las concentraciones de lactato en sangre, así como un aumento leve-moderado del $\dot{V}O_2sc$, tanto en ejercicios de fuerza, como de resistencia.[130,142,149]

2.1.1.3. La eficiencia respiratoria

La eficiencia respiratoria es utilizada para evaluar el CRF y se ha convertido en una de las herramientas fisiológicas claves para comprender la relación entre la VE y la perfusión (flujo sanguíneo pulmonar) en los pulmones en diferentes tipos de ejercicio.[142,150–152] Es utilizado tanto en atletas, en personas sanas y con enfermedades cardíacas y/o ventilatorias[142,150–155] estableciendo la pendiente de la relación lineal entre la VE y el VCO_2 (pendiente de la $VE \cdot VCO_2^{-1}$) en pruebas incrementales hasta el VT1 y/o punto de compensación respiratoria (VT2), tanto en el ejercicio aeróbico como el de fuerza. [142,150,152,154–156]

Durante el ejercicio la VE aumenta en proporción a la demanda metabólica. El aumento de la intensidad del ejercicio induce aumentos en el contenido de CO_2, en las concentraciones de H^+ y del lactato sanguíneo. El aumento de la producción del CO_2 y el aumento de la VE, con el fin de mantener el equilibrio ácido-base (homeostasis del pH), provoca un desajuste en la ventilación-perfusión lo que afecta a la eficiencia ventilatoria.[157] El ejercicio de alta intensidad reduce la eficiencia durante el intercambio de gases, resultando en un desajuste de la VE/perfusión, lo que afecta en la perfusión muscular, reduciendo la tolerancia al ejercicio.[151,158,159] El desajuste de la perfusión y de la VE disminuye la eficiencia del intercambio de gases pulmonares, aumentando la VE a fin de eliminar más CO_2 y de disminuir PCO_2 arterial. Este desajuste afecta el rendimiento ventilatorio produciendo hiperpnea y disnea.[157]

La pendiente de la $VE \cdot VCO_2^{-1}$ se ha convertido en una herramienta para valorar la eficiencia ventilatoria.[142,152,154,155] Sin embargo, la pendiente de la $VE \cdot VCO_2^{-1}$ ha generado controversia debido a la carencia de estudios. Algunos estudios mostraron que la pendiente de la $VE \cdot VCO_2^{-1}$ es dependiente del tipo de ejercicio,[142,152,154,155,160] de la intensidad del ejercicio,[152,161] del sexo y de la condición física del individuo.[160]

2.1.2. Respuestas agudas metabólicas

La capacidad para realizar un trabajo físico requiere energía y, por ello, el cuerpo humano necesita de la conversión de energía química en energía mecánica. El organismo puede utilizar la vía aeróbica y anaeróbica para producir energía, pero la necesidad de una vía u otra cambia en función de la intensidad del ejercicio. El ejercicio aeróbico está directamente relacionado con respuestas que implican un metabolismo prioritariamente aeróbico, aunque dependiendo de la intensidad, también puede demandar la energía del sistema anaeróbico. El sistema oxidativo es la fuente primaria de ATP en reposo y durante el ejercicio aeróbico y se utilizan sobre todo hidratos de carbono y grasas como substratos energéticos.[123] En reposo, aproximadamente el 70% del ATP es producido por grasas y el 30% es producido por los hidratos de carbono.[61]

La molécula de ATP es necesaria para la contracción muscular y el ATP puede sintetizarse a partir del metabolismo anaeróbico mediante la formación de lactato, resultado de la glucólisis en condiciones en el que el sistema aeróbico supera la capacidad de suministro de O_2 al músculo durante el ejercicio. A medida que la intensidad y la duración del ejercicio aumenta, el metabolismo anaeróbico es cada vez más utilizado. Las reservas de glucógeno y fosfocreatina disminuyen, la glucosa sanguínea es transportada por la vía glucolítica formando ATP y piruvato.[61] La contribución del metabolismo anaeróbico ocurre desde el inicio del ejercicio, pero pasa a ser más significativo cuando la intensidad del esfuerzo sobrepasa el VT1, produciendo un estado metabólico de lactacidemia y un incremento de la relación lactato-piruvato en el músculo.[162]

El punto en el cual las concentraciones de lactato sanguíneo comienzan a aumentar por encima de los valores de reposo se denomina “Umbral Anaeróbico”, y se puede definir como la intensidad de ejercicio que se puede mantener por un tiempo prolongado (> 25 min) sin un incremento continuado del lactato (< 1 $mmol \cdot L^{-1}$).[133] Los primeros estudios correlacionaban el primer aumento en el lactato aproximadamente a 2 $mmol \cdot L^{-1}$.[131,163]

Cuando el ejercicio cardiorrespiratorio es realizado a una carga constante el comportamiento del lactato es estable.[142,149,164] Durante esta fase metabólica, tal intensidad de ejercicio puede mantenerse durante un largo período de tiempo sin que se produzcan cambios sustanciales en las concentraciones de lactato en sangre. El mantenimiento de concentraciones bajas y estables de lactato en sangre es un rasgo característico del metabolismo aeróbico en el ejercicio realizado a intensidades bajas o moderadas cercanas al umbral anaeróbico. Esto ocurre porque se alcanza un equilibrio entre los procesos de producción de lactato y los de depuración de lactato.[149]

Cuando la intensidad del ejercicio es intensa, el lactato en la sangre empieza a acumularse, lo que indica que las células musculares activas están apoyándose cada vez más en la glucolisis (metabolismo anaeróbico) para producir ATP. Si no se reduce la intensidad, se va haciendo cada vez más difícil incrementar o mantener la carga de trabajo y en poco tiempo la fatiga aparecerá provocando que el ejercicio cese o que la carga de trabajo tenga que ser disminuida.[61] Un trabajo con concentraciones altas de lactato requiere una alta eficiencia muscular[18,165] y produce una importante fatiga muscular.[166]

Kinderman et al. definieron la intensidad de carga óptima para el entrenamiento de resistencia como aquella carga de trabajo que se puede mantener durante un periodo prolongado de tiempo, y que debería estar en el rango del "umbral aeróbico-anaeróbico" de 4 $mmol \cdot L^{-1}$ de lactato.[167,168]

2.2. La fatiga mecánica

La fatiga muscular se ha definido como la reducción aguda y eventual en la capacidad de generar fuerza en el desempeño de una tarea. Se observa en diferentes tipos de ejercicios, [152,169,170] especialmente durante ejercicios de esfuerzos intensos por la incapacidad del sistema neuromuscular para producir energía, y se caracteriza principalmente por un cansancio generalizado.[61] Existen varios mecanismos que pueden estar relacionados con la fatiga, sumando factores neurales, metabólicos y periféricos, dando como resultado la fatiga neuromuscular.[61] La fatiga puede ocurrir como resultado de factores periféricos que limitan la capacidad de la célula muscular para producir energía (ATP) al ritmo requerido para mantener la intensidad del ejercicio. La fatiga muscular varía según el tipo de ejercicio, la intensidad y la duración.[149,152] Entre los parámetros metabólicos asociados a la fatiga neuromuscular encontramos la acumulación de metabolitos por el aumento de la acidosis (acúmulo de iones H^+, ADP, Pi y descenso del pH), inhibición de los iones de calcio en el filamento de troponina, reducción del flujo de calcio intramuscular en los túbulos transversos, hipoxia tisular, fallo bioenergético (disminución de fosfocreatina y reservas de glucógeno muscular), reducción de la liberación de acetilcolina y la inhibición de los procesos de excitación-contracción.[171] La fatiga muscular reflejada por variables mecánicas (fuerza, velocidad y producción de potencia), es el resultado del deterioro de las propiedades contráctiles del músculo o de su control neuromuscular.[172] Tradicionalmente, la fatiga neuromuscular ha sido estudiada utilizando formas aisladas de movimientos isométricos, concéntricos y excéntricos.[170]

Diversos estudios han utilizado el test de salto con contra-movimiento (CMJ) para medir la fatiga muscular.[149,152,169,170,172] El CMJ conlleva el ciclo de estiramiento-acortamiento que se realiza con un movimiento rápido de alargamiento del músculo seguido de una contracción rápida con el objetivo de promover un movimiento de gran potencia muscular; la influencia del componente elástico sobre la fuerza vertical es clave para incrementar el rendimiento durante el salto vertical. La disminución de la capacidad de rendimiento neuromuscular, como por ejemplo en un salto vertical, está asociada con la fatiga muscular.[149,152,169]

2.3. La percepción del esfuerzo

La RPE o escala de Borg es un método no invasivo para determinar la intensidad del ejercicio mediante la percepción subjetiva del esfuerzo. La RPE es una valoración subjetiva que indica la opinión del sujeto, detectando las sensaciones del esfuerzo durante el ejercicio mediante un sistema de delimitación que tiene en cuenta las respuestas fisiológicas y psicológicas durante el ejercicio.[173,174]

La RPE ha sido utilizada durante años como una alternativa de control del esfuerzo, para realizar ajustes necesarios y precisos en la intensidad, el volumen y el tipo de ejercicio. La versión original creada por Gunnar Borg en los años 60 consistía en una tabla de valoración numérica del 6 al 20 en el que a cada número se le asigna un valor cualitativo. Posteriormente, en la década de los 80 fue modificada en una escala de 0 a 10 (tabla 3).[173,174]

Tabla 3. Escala Original y modificada de Borg

Escala de Borg Original	
1	
6	
7	Muy, muy suave
8	
9	Muy suave
10	
11	Bastante Suave
12	
13	Algo Duro
14	
15	Duro
16	
17	Muy Duro
18	
19	Muy, muy duro
20	

Escala de Borg Modificada	
0	Muy, muy suave
1	Muy suave
2	Muy Suave
3	Suave
4	Moderado
5	Algo Duro
6	Duro
7	
8	Muy Duro
9	
10	Muy, Muy Duro

La RPE es asociada a evaluaciones de parámetros objetivos como la FC, el lactato, el $\dot{V}O_{2máx}$, etc. Diversos estudios han observado una relación entre la RPE, la FC y el $\dot{V}O_{2máx}$.[175–179] Además, existe una correlación entre la RPE y el VT.[180,181] El VT se asemejó a un valor de 11 en la RPE, mientras que una RPE de 14 correspondió con concentraciones de lactato de 2 mmol·L^{-1} y una RPE de aproximadamente 16,5 se asoció con concentraciones de lactato de 4 mmol·L^{-1}. Otro estudio asoció un valor de 11-13 a la intensidad de VT1.[182]

Las directrices generales para la prescripción de ejercicios aeróbicos respaldadas por el ACSM recomiendan hacer ejercicio a una intensidad correspondiente a una RPE de 11-14.[74]

2.4. *Respuestas crónicas al ejercicio cardiorrespiratorio*

Cada vez más investigaciones demuestran que hacer ejercicio cardiorrespiratorio produce numerosos beneficios para la salud a largo plazo. Una de las principales características del ejercicio cardiorrespiratorio está relacionado con adaptaciones centrales y periféricas que mejoran el $\dot{V}O_{2máx}$ y la capacidad del músculo para generar energía a través del sistema oxidativo.[123] Las personas que realizan este tipo de actividades poseen valores de $\dot{V}O_{2máx}$ más altos[81,82,108,109], una mejor función mitocondrial [41,79,110–112] y una menor acumulación de lípidos intermusculares que los sujetos sedentarios.[79,111] Estos factores están relacionados con una mejor función física y una prevención de la pérdida de masa y fuerza muscular,[43,109,112,118,119] así como con una disminución de las enfermedades cardiovasculares y baja mortalidad temprana,[183,184] además de una mayor resistencia al estrés oxidativo.[79,111,113–117]

Diversos estudios investigan el impacto de las adaptaciones de la biogénesis mitocondrial inducidas por el ejercicio desde la perspectiva del incremento del contenido y de la mejora en la función mitocondrial con diferentes paradigmas de intensidad del ejercicio.[41,79,110–112] El ejercicio cardiorrespiratorio mantenido de por vida es una de las intervenciones más sugeridas para prevenir la disminución de la disfunción mitocondrial, preservar la masa muscular y la funcionalidad (figura 11).[75,112,185]

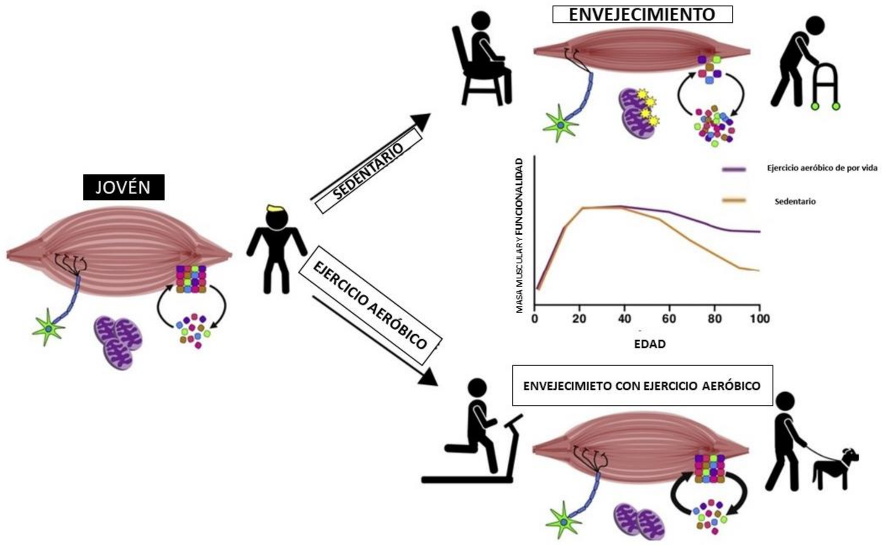


Figura 11. Esquema representativo de los beneficios del ejercicio aeróbico de por vida en relación a preservar la masa muscular, las unidades motoras, la función mitocondrial y la funcionalidad en el envejecimiento [112]

Los estudios demuestran que el ejercicio aeróbico realizado a largo plazo también debe ser considerado una estrategia viable para regular positivamente las adaptaciones mitocondriales, como la función mitocondrial y la proteostasis, principalmente, en personas mayores.[112,186–188] Distefano et al. demostraron que los sujetos mayores que eran físicamente activos tenían una función mitocondrial similar a la de los individuos jóvenes físicamente activos.[41] La disfunción mitocondrial es una de las características del proceso de envejecimiento que induce una producción elevada de ROS y la activación de vías apoptóticas.[41] Los programas de ejercicio cardiorrespiratorio podrían reducir el estrés oxidativo en las personas mayores y obesas, dependiendo del tipo de ejercicio y de la intensidad establecida.[91,92] Además, el ejercicio aeróbico regular puede reducir los niveles de prooxidantes y de MDA.[85,106,107] Se ha verificado que un programa de ejercicio cardiorrespiratorio mejoró el $\dot{V}O_{2máx}$, promoviendo una disminución los niveles de MDA y mejorando la capacidad antioxidante.[85] Yu et al. demostraron que el ejercicio aeróbico como correr, andar en bicicleta y bailar indujeron niveles más bajos de MDA y efectos protectores contra el daño por estrés oxidativo en personas mayores.[106] Se encontraron hallazgos similares en mujeres mayores obesas después de realizar un programa de ejercicio aeróbico durante 12 meses a una intensidad del 60-75% de la $FC_{máx}$.[107]

El mayor contenido mitocondrial, también está relacionado con una mejor función física y protección contra la pérdida de masa muscular relacionada con la edad.[75] La salud mitocondrial es crucial para mantener la función esquelética y preservar la unión neuromuscular, la unidad motora y la fuerza que esta es capaz de generar.[112,189]Algunos estudios cuestionan si el ejercicio cardiorrespiratorio es capaz de mantener la masa muscular.[75,190–192] Parece ser que ejercicio aeróbico en comparación con otros tipos de ejercicio tiene menos efecto sobre la masa magra.[193,194] Un estudio comparó personas mayores que nadaban y corrían con personas sedentarias y encontró medidas similares tanto en el tamaño muscular como en la de fuerza.[190] Por el contrario, otros estudios sí que revelaron cambios morfológicos[195] como pérdida de la masa grasa y aumento de la masa muscular.[80,81]

Otro estudio realizó un programa de ejercicio cardiorrespiratorio con mujeres que incluía caminar en cinta rodante a una intensidad superior al 70% del $\dot{V}O_{2máx}$ durante 30 minutos, seguido de 10 minutos de ejercicio de AD. El programa se llevó a cabo tres veces por semana durante 24 semanas. Los resultados mostraron que la fuerza del cuádriceps, la resistencia muscular y el $\dot{V}O_{2máx}$ mejoraba significativamente en el grupo que realizó el programa de ejercicio.[196] Al respecto, varios estudios han propuesto que el ejercicio cardiorrespiratorio mejora la fuerza muscular, la agilidad corporal, la flexibilidad,[83,197] la función corporal inferior,[198] la locomoción / agilidad y el equilibrio, atenuando así los riesgos de caídas en adultos mayores.[199] Aparte, se ha demostrado que los programas de ejercicio cardiorrespiratorio reducen el peso corporal, la masa grasa y el riesgo a padecer enfermedades cardiovasculares en mujeres con sobrepeso y obesas.[80]

Sin embargo, existen controversias con relación la reducción de peso, ya que otros estudios que utilizaron ejercicios cardiorrespiratorios como bailar, caminar, subir escaleras y bicicleta estática observaron una reducción poco significativa en el peso corporal.[200–202] Otro estudio similar verificó una reducción de peso aproximadamente del 1% (∼1 kg) por año durante un período de intervención que consistía en inducir un gasto energético de 1500 a 2000 kcal por semana de ejercicio aeróbico.[201]

2.4.1. El fitness Cardiorrespiratorio

El CRF es un importante indicador fisiológico del estado de salud y bien estar, se refiere a la capacidad de sistema cardiorrespiratorio para suministrar O_2 a los músculos y tejidos principalmente durante el ejercicio sostenido. Está relacionado con la capacidad del organismo para adaptarse a las demandas fisiológicas al realizar actividades de la vida diaria, implicando una relación tarea-demanda y la capacidad del individuo para realizarla.[203,204]

El CRF depende de la interacción de múltiples órganos y de un funcionamiento multisistémico relacionado principalmente con la VE, la difusión y la función vascular pulmonar, la función del ventrículo derecho e izquierdo (tanto la sístole como la diástole), el acoplamiento ventricular-arterial, la capacidad vascular para acomodar y transportar de manera eficiente la sangre desde el corazón dependiendo de las demandas de O_2, la capacidad de las células musculares para recibir y utilizar el oxígeno, los nutrientes suministrados por la sangre, así como la comunicación de estas demandas metabólicas con el centro de control cardiovascular.[205,206]

También denominado capacidad cardiorrespiratoria o aeróbica, el CRF determina la aptitud física y está relacionado con la función del cuerpo humano en condiciones de estrés fisiológico. En otras palabras, cuantifica la capacidad funcional del individuo relacionando los sistemas respiratorio y cardiovascular mediante el suministro de O_2 al sistema músculo/esquelético que requiere la producción de energía mediante la resíntesis de ATP, principalmente procedente del metabolismo aeróbico o de procesos oxidativos, convirtiéndose en un factor determinante durante el ejercicio físico de larga duración. [206,207]

El $\dot{V}O_{2máx}$ o pico ($\dot{V}O_{2pico}$) es la variable más objetiva y fiable para medir el CRF. El $\dot{V}O_{2máx}$, al menos en parte, parece depender de factores como el sexo, la genética, como por ejemplo el tamaño cardiaco y pulmonar, el tipo de fibras musculares, la FC y principalmente la edad.[123]

Existe una creciente evidencia de que el $\dot{V}O_{2máx}$ cambia con el paso de los años.[208–212] Esto se debe a diversos factores como la pérdida de masa muscular y a los cambios en el sistema cardiorrespiratorio; las arterias y las paredes arteriales se vuelven gruesas y duras debido a cambios anatómicos, el corazón muestra una disminución de la distensibilidad diastólica, disminución del volumen sistólico máximo, del volumen sanguíneo y de la FC. [24,123] Los tejidos pulmonares se vuelven menos elásticos y expansibles, la cantidad de fibras elásticas en la pared alveolar disminuye, se produce un incremento del espacio muerto anatómico-fisiológico, una disminución del volumen, de la frecuencia respiratoria y se incrementa la disfunción de los mecanismos de defensa.[24,123] Además, se caracteriza por un déficit de la función respiratoria y cardiovascular, así como de la insuficiencia en uno o más sistemas involucrados en la entrega de O_2 atmosférico a las mitocondrias de los tejidos y/o la eliminación de subproductos metabólicos del cuerpo. Estos factores multisistémicos implicados reducen el $\dot{V}O_{2\text{máx}}$ y, consecuentemente, el CRF (tabla 4).[94,95,97–99]

Tabla 4. Valores de $\dot{V}O_{2\text{máx}}$ en hombres y mujeres en función de la edad

Tabla de Valores MUJERES

Edad	Pobre	Muy pobre	Normal	Bueno	Muy bueno	Excelente
13 a 19	<25,0	25,1 a 30,9	31,0 a 34,9	35,0 a 38,9	39,0 a 41,9	>41,9
20 a 29	<23,6	23,7 a 28,9	29,0 a 32,9	33,0 a 36,9	37,0 a 41,0	>41,0
30 a 39	<22,8	22,9 a 26,9	27,0 a 31,4	31,5 a 35,6	35,7 a 40,0	>40,0
40 a 49	<21,0	21,1 a 24,4	25,5 a 28,9	29,0 a 32,8	32,9 a 36,9	>36,9
50 a 59	<20,2	20,3 a 22,7	22,8 a 26,9	27,0 a 31,4	31,5 a 35,7	>35,7
60	<17,5	17,6 a 20,1	20,2 a 24,4	24,5 a 30,2	30,3 a 31,4	>31,4

Tabla de Valores HOMBRES

Edad	Pobre	Muy pobre	Normal	Bueno	Muy bueno	Excelente
13 a 19	<35	35,0 a 38,3	38,4 a 45,1	45,2 a 50,9	51,0 a 55,9	>55,9
20 a 29	<33,0	33,0 a 36,4	36,5 a 42,4	42,5 a 46,4	46,5 a 52,4	>52,4
30 a 39	<31,5	31,5 a 35,4	35,5 a 40,9	41,0 a 44,9	45,0 a 49,4	>49,4
40 a 49	<30,2	30,2 a 33,5	33,6 a 38,9	39,0 a 43,7	43,8 a 48,0	>48,0
50 a 59	<26,1	26,1 a 30,9	31,0 a 35,7	35,8 a 40,9	41,0 a 45,3	>45,3
60	<20,5	20,5 a 26,0	26,1 a 32,2	32,3 a 36,4	36,5 a 44,2	>44,2

Un estudio observó una disminución longitudinal en el $\dot{V}O_{2\text{máx}}$ en cada una de las primeras 6 décadas en personas sanas en ambos sexos, sin embargo, la tasa de disminución se aceleró del 3% al 6% a partir de los 20 y 30 años, llegando al 20% a partir de los 70 años.[213] En otro estudio realizado con individuos entre 20 y

90 años (n=4631), se encontró que el $\dot{V}O_{2máx}$ disminuía por debajo de la media específica determinado por la edad y el sexo (mujeres <35,1 mL·kg^{-1}·min^{-1}; hombres <44,2 mL·kg^{-1}·min^{-1}); la disminución de 5mL·kg^{-1}·min^{-1} del $\dot{V}O_{2pico}$ se asoció a un 56% más de probabilidades de padecer factores de riesgo cardiovascular en ambos sexos.[214]

Valores bajos del $\dot{V}O_{2máx}$ están relacionados con un menor gasto energético, un mayor índice de masa corporal, una mayor circunferencia de cintura y cadera, sobrepeso y obesidad, el síndrome metabólico [215] y, sistémicamente, relacionado con un mayor riesgo de muerte prematura,[205,206,216–221] enfermedades cardiacas, diabetes, hipertensión, hipercolesterolemia y cáncer.[207–209,212,222] En contrapartida, el aumento del $\dot{V}O_{2máx}$ está asociado con beneficios cardiovasculares que incluyen un menor riesgo de padecer enfermedades coronarias, hipertensión,[223] y de prevenir enfermedades como la diabetes y el cáncer.[26,208,216,224] Además, el índice de mortalidad por todas las causas comentadas previamente es menor en personas con un adecuado CRF.[207-208, 218, 220, 225-227]

Tradicionalmente, la mejora del CRF se alcanza mediante el ejercicio cardiorrespiratorio caracterizado por diversas adaptaciones fisiológicas, entre ellas el $\dot{V}O_{2máx}$.[61]

3. LA DANZA AERÓBICA

3. La Danza Aeróbica (Antecedentes)

A finales de la década de los años 60, empezaron a surgir diferentes modalidades de ejercicio sistematizados basados en las evidencias de Cooper, entre ellos el "Isotonic". Creado por Jackie Sorensen en la década de los años 70, el Isotonic se basaba en un programa de ejercicios coreografiados al ritmo de la música, con una adaptación de distintas disciplinas como el *jogging*, diferentes tipos de bailes (jazz, ballet…) que se dieron a conocer mundialmente como la "danza aeróbica" (AD).[228] En los años 80, la AD era mundialmente popular por sus coreografías que incluían ejercicios denominados de impacto y movimientos balísticos, con ambos pies fuera del suelo, combinados con movimientos de ejercicios como correr, patear, saltar con ambos pies, elevaciones de rodilla, saltos de tijera, *jumping jacks*, etc.; también eran incorporados ejercicios que combinaban diferentes habilidades de estabilización, locomoción y equilibrio, todos al ritmo de la música (figura 12).[229]

Figura 12. Danza aeróbica años 80

Con el tiempo la AD fue evolucionando y, actualmente, existe una enorme oferta de diferentes tipos de AD para todos los públicos. Desde la década de los años 80, la AD ha crecido hasta convertirse en una de las actividades aeróbicas más practicadas en todo el mundo, principalmente, por las mujeres y muy demandada en los centros de mayores.[230] Mantiene las mismas características de su origen (movimientos coreografiados al ritmo de la música) y algunos estilos han introducido diferentes aparatos y superficies con el fin de aumentar la intensidad del ejercicio, reducir el impacto y disminuir la posibilidad de padecer lesiones.

La AD se caracteriza por una secuencia de ejercicios que incluyen movimientos del tronco, piernas, brazos, coregrafiados con diferentes pasos procedentes de dististas diciplinas como la gimnasia, el baile e incluso la danza, que son coordinados al ritmo de la música como ingrediente fundamental para determinar la velocidad y la ejecución de la sesión de AD. Los ejercicios realizados en la AD requieren que los participantes mantengan un pie en el suelo, lo que resulta en movimientos de saltos y rebotes con fuerzas de reacción como pueden ser los movimientos de las tijeras, los jumping-jacks; las acciones motoras que se efectúan pueden ser de bajo o alto impacto, diferentes estilos y utilizando diversos aparatos y superficies (figura 13).

Figura 13. Ejemplo de diferentes tipos de danza aeróbica (AD) con y sin aparatos

En resumen, es una modalidad de ejercicio físico que dependiendo del tipo, el estilo, la complejidad, la sobrecarga, la duración e intesidad, requiere diferentes demandas cardiorrespiratorias y metabólicas.[18,231,232] Se considera un modo de ejercicio excepcional debido a su beneficio en la aptitud cardiorrespiratoria,[124,233,234] además, de promover beneficios emocionales como sentimientos de felicidad, diversión, disfrute e integración social entre sus practicantes.[235] En particular, la AD es una forma atractiva de ejercicio cardiorrespiratorio para las personas mayores, ya que es una actividad que puede adaptarse a la edad y a las limitaciones físicas provocadas por el envejecimiento.[83,191] Es una de las actividades recomendada en el reciente Plan de Acción Mundial sobre Actividad Física 2018-2030 promovido por la OMS.[236]

3.1. Respuestas agudas en la danza aeróbica

3.1.1. Repuestas Cardiorrespiratorias

Podemos decir que la AD es un modo viable de entrenamiento cardiorrespiratorio, por promover una respuesta aguda rápida de elevación de la FC y del incremento del $\dot{V}O_2$.[18,231,232] Una sesión de AD alcanza normalmente intensidades superiores al 55% de la $FC_{máx}$.[237] Sin embargo, existe una amplia variación en la respuesta de FC, en la que muchos participantes no llegan a alcanzar la FC recomendada[238,239] y otros la exceden sobre los límites máximos recomendados.[240] Varios estudios encontraron durante una sesión de AD intensidades entre el 60 % y el 90 % de la $FC_{máx}$, correspondiente a un promedio del 77% del $\dot{V}O_{2máx}$.[231,232,241,245]

A diferencia de otros modos de ejercicio aeróbico como correr, nadar, andar en bicicleta, etc., donde la intensidad de ejercicio puede controlarse ajustando la velocidad y la sobrecarga, la AD es una actividad de movimiento libre donde la intensidad puede oscilar durante la sesión dependendo del estilo de AD.[127,242] La mayoría de los participantes no tienen conocimiento de cómo controlar la intensidad, por tanto, el principal problema se basa en el control de la intensidad. Esto es debido a que la ejecución de los movimientos puede variar mucho dependiendo de diversos factores como el alto y bajo impacto, si se realizan ejercicios con o sin implicación del movimiento de los brazos y de si se utilizan o no otro tipo de utensilios o aparatos que incrementen la intensidad del ejercicio.[237] Bell y Bassey compararon dos estilos de AD de bajo impacto y de alto impacto incluyendo el trabajo de los brazos. La AD de bajo impacto alcanzó una FC de 135 lpm/min y la de alto impacto con movimientos de brazos provocó un aumento hasta los 174 lpm/min.[237] Los autores concluyeron que el uso extensivo de los brazos por encima de la cabeza durante la AD resulta en un aumento del flujo sanguíneo y de la respuesta aguda del sistema nervioso simpático, lo que aumenta desproporcionadamente la FC.[243]

Existe una variedad de estudios comparando la AD con otros estilos y con otros modos de ejercicio cardiorrespiratorio como por ejemplo correr y pasear en bicicleta. Un estudio comparó una sesión de AD grabada con una prueba de correr en tapiz rodante, donde ambos ejercicios eran realizados a una intensidad progresiva hasta alcanzar intensidades máximas. Los autores concluyeron que la AD no producía la misma respuesta aguda en el $\dot{V}O_{2máx}$ y en la FC, siendo menor en comparación con la carrera máxima progresiva en tapiz rodante en la que si se alcanzaron valores máximos en el $\dot{V}O_{2máx}$ y la FC.[244] Sin embargo, Berry et al. no encontraron diferencias significativas en el $\dot{V}O_{2máx}$ y en la FC cuando compararon la carrera en cinta rodante con una sesión de AD con movimientos de brazos arriba y abajo. [243]

Por otro lado, Parker indicó que una sesión de AD inducía una menor intensidad relativa de FC en comparación con el ejercicio de correr.[246] En contrapartida, Oliveira et al. compararon las respuestas fisiológicas de una coreografía de claqué con una prueba máxima de correr (prueba de incremental) en bailarines. La coreografía de claqué provocó respuestas fisiológicas similares a la prueba de esfuerzo máximo corriendo; los sujetos alcanzaron un promedio de 83,8 ± 6,2% de la $FC_{máx}$ y 68,9 ± 11,3% del $\dot{V}O_{2máx}$.[247] Otro estudio demostró una intensidad relativa mayor en la AD (67% $\dot{V}O_{2máx}$) que caminando en relación al $\dot{V}O_{2max}$ (52% $\dot{V}O_{2máx}$).[229] Por su parte, Rixon et al. compararon diferentes tipos de AD (body pump y body combat) con una sesión de spinning (biclicleta) y encontraron diferentes respuestas en la FC (body pump 60,2%, body combat 73,2%, spinning 74,3% de $FC_{máx}$, respectivamente). [127]

Parece ser que la respuesta cardiorrespiratoria de una sesión de AD depende de la modalidad, sin embargo, la misma modalidad de AD puede demandar respuestas agudas diferentes de la FC y el $\dot{V}O_2$.[248–250] Rodrigues et al. verificaron diferentes zonas de intensidad en dos sesiones similares de AD, alcanzando un promedio del 38.8% del $\dot{V}O_{2máx}$ (14,5 ± 2,1 $mL \cdot kg^{-1} \cdot min^{-1}$) y del 51,9 % del $\dot{V}O_{2máx}$ (19,1 ± 1,7 $mL \cdot kg^{-1} \cdot min^{-1}$) en una sesión, y del 74 % de la $FC_{máx}$. (145 ± 17,9 lpm/min) y del 89% de la $FC_{máx}$. (174 ± 13,8 lpm/min) en otra sesión muy similar. Domene et al. realizaron estudios con la misma modalidad de AD y hallaron diferentes intensidades en la respuesta de la FC y del $\dot{V}O_2$. En uno de los estudios, la sesión de AD alcanzó una intensidad de 79% de la $FC_{máx}$ y del 66% del $\dot{V}O_{2máx}$.[249] En otro estudio, la FC no superó el 57% de la $FC_{máx}$. (139 ± 18 lpm/min).[248] Ambos estudios utilizaron el mismo modelo de AD (Zumba).[248,249]

3.1.2. Respuestas metabólicas

Desde una perspectiva metabólica, el AD es un ejercicio cardiorrespiratorio con predominio del sistema aeróbico con una implicación del metabolismo anaeróbico según avanza la sesión en intensidad y complejidad.[251–253] La clase de AD es un ejercicio a una intensidad más o menos a carga constante, sin embargo, como comentamos anteriormente no existe una intensidad fija y un control de la carga de trabajo como acontece en los, ejercicios cíclicos como correr y andar en bicicleta.

La carga de trabajo durante la AD depende principalmente de la capacidad física, de la motivación y de la capacidad de continuar a pesar del agotamiento, en contraste con la carrera en cinta rodante, en la que los participantes se ven obligados a continuar corriendo a una determinada velocidad y la carga de total de trabajo se regula y controla más fácilmente. Oliveira et al. utilizaron el umbral de lactato en una prueba incremental en cinta rodante para categorizar la intensidad del ejercicio durante una coreografía de claqué; las concentraciones de lactato fueron muy bajas (1,7 $mmol \cdot L^{-1}$) y la intensidad del ejercicio de claqué fue aproximadamente un 10% menor que la pautada en la cinta de correr a la intensidad del umbral de lactato.[247] En contrapartida, De Angelis et al. demostraron que la AD aumentó las concentraciones de lactato en sangre en mayor medida de lo esperado, mostrando una alta intensidad de ejercicio, una demanda metabólica y un estado no estacionario (lactato promedio 4,8 $mmol \cdot L^{-1}$, variación de entre 2,9 $mmol \cdot L^{-1}$ a 6,1 $mmol \cdot L^{-1}$).[18] Según De Angelis et al. la AD no es una diciplina puramente aeróbica, también implica la contribución del metabolismo anaeróbico; las altas concentraciones de lactato en sangre pueden ser debidas a los saltos realizados en las sesiones de AD.[18] Cuando el ejercicio es realizado de una forma global, hay una mayor exigencia, lo que puede conllevar una menor oxigenación a altas intensidades de ejercicio, provocando una mayor producción de lactato.[244,254] En el estudio de Edvardsen et al. los particpantes alcanzaron concentraciones de lactato de 6,4 $mmol \cdot L^{-1}$ (4,86-8,03), y 3 sujetos lograron una concentración de lactato en sangre >8 $mmol \cdot L^{-1}$.[255] Es evidente que el estilo y la variación de ejercicio de AD pueden demandar diferentes respuestas fisiológicas y metabólicas.[18,147,244,247,256]

Un ejercicio físico con concentraciones altas de lactato requiere una alta eficiencia muscular[18,165] y produce una importante fatiga muscular.[166] Wyon y Koutedakis informaron que las causas metabólicas de la fatiga en la AD están asociadas con la capacidad de mantener el suministro de energía durante el ejercicio, los posteriores períodos de recuperación inapropiados después del ejercicio prolongado de alta intensidad, la tasa de utilización de glucógeno que influye en las señales neuromusculares (reducidas por la disminución de los niveles de glucógeno) y, finalmente, la fatiga muscular percibida.[166]

3.1.3. Respuestas musculares

Fitness muscular es un término global que está asociado a la fuerza muscular, la resistencia y la potencia. La AD se considera una modalidad de ejercicio predominantemente aeróbico en el que, a diferencia de otros tipos de ejercicio aeróbico, se caracteriza por el uso de grandes grupos musculares de forma global. Por lo tanto, se supone que la cantidad de masa muscular involucrada es mayor en comparación con otras modalidades como correr, caminar o andar de bicicleta; esto sugiere la posibilidad de un mayor trabajo general de fuerza y una mejora de la fuerza en las extremidades superiores e inferiores ante estímulos de carga adecuados.[255] Las investigaciones sobre el efecto muscular agudo en la AD son escasas. Dependiendo de la modalidad de la AD, los movimientos realizados requieren una postura erguida y apoyos unilaterales con transferencia de la fuerza de la gravedad a través del centro de masas del cuerpo, implicando fuerzas de reacción en el suelo y torques articulares. [257]

La intensidad del ejercicio puede influir en la activación de las unidades motoras; cuando la intensidad del ejercicio es menor del 40% del $\dot{V}O_{2máx}$, existe una mayor activación de las fibras de contracción lenta (tipo I). Cuando la intensidad del ejercicio es progresiva existe una activación de fibras de contracción rápida (Tipo II), y a intensidades superiores al 80% del $\dot{V}O_{2máx}$, es característico el reclutamiento de las fibras de contracción rápida (tipo II B). Las fibras tipo II B se hipertrofian de forma selectiva y predominante en comparación con las fibras tipo I.[258] Bailar consiste predominantemente en ejercitar los grandes grupos musculares del tren inferior durante un tiempo determinado. La secuencia de movimientos coreografiados requiere que los participantes mantengan un pie en el suelo, y los saltos y rebotes en los que van implícitas fuerzas de reacción como las tijeras, los jumping-jacks, etc. provocan una mayor activación muscular de los glúteos, cuádriceps y gastrocnemios.[259] La potencia muscular también puede ser incrementada por el ciclo de estiramiento-acortamiento presente en muchos movimientos como los saltos de bajo y alto impacto, que implican fuerzas de reacción en el suelo y torques articulares elevados principalmente del tren inferior.[257,260]

3.2. Las respuestas crónicas en la danza aeróbica

3.2.1. Respuestas cardiorrespiratorias

La AD ha sido desarrollada principalmente para mejorar el CRF.[17,85,195,233,262] Se considera un modo de ejercicio excepcional debido a su beneficio en la salud cardiovascular.[191,233,234] El entrenamiento regular de programas de AD produce mejoras en el CRF, al menos, similares a las producidas por otros modos de ejercicio.[233,255]

Además, la AD puede ser una modalidad de ejercicio eficaz para personas sedentarias que tiene dificultades en alcanzar la intensidad de ejercicio recomendada para mejorar el CRF.[85,249] Un programa de AD de 12 sesiones en 8 semanas mostró un incremento del $\dot{V}O_2$ más elevado en personas con bajo CRF comparado con personas que tenían un CRF alto.[249] Leelarungrayub et. al evaluaron los efectos de un programa de AD de 6 semanas con sesiones de 50 minutos a una intensidad moderada (65-85% $FC_{máx}$), en un grupo de mujeres sedentarias. Los autores encontraron un aumento significativo en el $\dot{V}O_{2máx.}$ (29,1 a 36,9 $mL \cdot kg^{-1} \cdot min^{-1}$). [85]

Sin embargo, existen controversias sobre la eficacia de algunos estilos de AD; parece que algunas modalidades de AD no mejoran el CRF en personas obesas.[238,239,263] Domene et. al realizaron un programa de AD de 8 semanas en mujeres obesas y no encontraron mejoras del $\dot{V}O_{2máx}$.[263] En otro programa de AD de 12 semanas con mujeres obesas no se encontraron cambios aparentes en el $\dot{V}O_{2pico}$. En este estudio la intensidad de las sesiones variaba entre el 50% y el 72% de la $FC_{máx}$. [238]

En relación a las personas mayores, diversos estudios han verificado los beneficios cardiorrespiratorios que la AD produce independientemente de la modalidad de AD. [83,191,195,197,264] Diversas modalidades de AD han mostrado mejorar el CRF en las personas mayores.[191] Hopkins et al. encontraron mejoras del CRF después de una intervención de 12 semanas de AD de bajo impacto en mujeres mayores .[197] A su vez, programas de AD de mayor duración (8 meses) a una intensidad de 13-14 de la RPE, son una alternativa excelente para mejorar el CRF en pacientes mayores con insuficiencia cardiaca, especialmente al incrementar considerablemente el $\dot{V}O_{2máx}$ en valores próximos al 34%.[265] También se han descrito mejoras en el $\dot{V}O_{2máx}$ en personas mayores que realizaron 60 minutos de AD de bajo impacto (50-70% $FC_{máx}$), durante 10 semanas, 3 días a la semana.[264] Por su parte, Hui et al. realizaron 23 sesiones de baile durante 12 semanas y observaron cambios significativos en la FC reposo en personas mayores.[195]

3.2.2. Respuestas en la composición corporal

Los programas de AD pueden producir cambios importantes en la composición corporal como pérdida de peso, cambios en el IMC, la masa grasa,[80,191,192,195] pudiendo ser tan efectivo como otros tipos de ejercicio.[266,267] Un programa de ejercicio de tres meses de AD de bajo impacto puede ser tan efectivo como otras modalidades de ejercicio como el running y el ciclismo en mujeres obesas para disminuir significativamente el peso corporal (-3,1 y -3,3, kg respectivamente) y el porcentaje de grasa (-6,1 y -5,3 %, respectivamente). Del mismo modo, un programa de AD realizado por mujeres obesas produjo cambios importantes en la composición corporal en tan solo 8 semanas.[268]

En contrapartida, también existe una controversia en la literatura científica con relación a la modalidad, la intensidad y la duración de la AD y los cambios metabólicos que se puedan producir.[191,197,249,264] Un estudio cuestionó la efectividad de la AD con relación a los cambios en la composición corporal, como el IMC y la pérdida de masa grasa. [249] Otros estudios que investigaron los cambios en la composición corporal en personas mayores después de un programa de ejercicio de AD, no hallaron cambios significativos en la adiposidad.[197,264] Parece ser que algunas modalidades de AD no alcanzan el gasto energético recomendado, siendo este gasto variable y dependiente de la modalidad de AD.[248,249] Para que la AD sea efectiva para promover la pérdida de peso, es recomendable que las personas gasten 300 Kcal/entrenamiento [74] Domene et al compararon dos modalidades similares de AD (zumba) y encontró diferencias en el gasto energético total (411 ± 66 *vs.* 210 ± 46 kcal); ambas modalidades de AD eran realizadas a intensidad moderada a vigorosa. [248]

En otro estudio, se asoció un IMC alto a una menor intensidad de esfuerzo y a un menor gasto energético.[269] Sin embargo, la AD cuando es realizada con suficiente intensidad (≥60% del $\dot{V}O_{2máx.}$) y frecuencia (≥3 d · semana^{-1}) [19] puede provocar cambios en la composición corporal como pérdida de la grasa corporal en personas jóvenes sanas, mayores y adultos de mediana edad con obesidad.[234,266] En mujeres jóvenes, programas de AD de 12 semanas, realizando 3 sesiones semanales de 50 minutos a una intensidad entre el 70% y el 85 % de la $FC_{máx}$, también produce una disminución del porcentaje de grasa corporal.[234]

En mujeres de 33 a 66 años con obesidad, la AD de alta intensidad (70% al 85%, $\dot{V}O_{2máx}$) a una RPE de 13-17 mostró su efectividad al reducir el IMC, la grasa, la circunferencia de la cintura y el peso corporal. [266] Además, las personas mayores que practican AD tienen un menor IMC y una menor prevalencia de padecer enfermedades metabólicas. [270]

3.2.3. Respuestas musculares

Aunque exista una gran evidencia sobre los beneficios de la AD, se vislumbra una notable contradicción en la literatura. Diversos estudios cuestionan los efectos de los programas de AD sobre la fuerza muscular, la potencia y la resistencia muscular.[80,83,191,195,197]

Un estudio que comparó el caminar a una intensidad de 9-11 de la RPE y la AD a una intensidad de 13-17 sobre la RPE, encontró que la fuerza de extensión de las piernas fue significativamente mayor en el grupo de AD en comparación con el grupo que caminó.[266] A su vez, un programa de AD de bajo impacto con sesiones de 60 minutos (50-70% de $FC_{máx.}$), 3 d · semana^{-1} durante 10 semanas, encontró mejoras significativas en la fuerza muscular de las extremidades inferiores en personas mayores.[264] En contrapartida, una intervención de 12 semanas de AD no produjo mejoras de la fuerza de las extremidades inferiores.[195]

En otros estudios donde también se efectuaron intervenciones de AD, los participantes aumentaron la fuerza de las extremidades inferiores, sin hallar resultados significativos en la fuerza de las extremidades superiores.[196,271] Los resultados contradictorios sobre el efecto de la AD en la fuerza muscular del tren superior se puede relacionar con la falta de especificidad de estímulos relacionados con el entrenamiento de las extremidades superiores. Sin embargo, parece ser que la práctica de la AD a largo plazo se asocia con un mejor equilibrio corporal y una mayor fuerza y potencia muscular.[272]

En relación al efecto que podría tener en las personas mayores que practicaban diversas modalidades de AD, los mejores niveles de fuerza muscular, resistencia muscular, potencia muscular, equilibrio y velocidad de marcha se mejoran significativamente en aquellos que son activos con respecto a las personas mayores inactivas.[83] Las personas mayores practicantes de AD pueden mejorar significativamente la resistencia muscular del tren inferior, la fuerza, el equilibrio, la agilidad y la marcha a través de la AD, reduciendo la prevalencia de caídas.[83,191,195,197,264]

3.3. Las superficies inestables

La popularidad de las superficies inestables empezó en los años 80 cuando los entrenadores realizaban ejercicios de rebote con atletas y astronautas (figura 14). Una de las características de este tipo de dispositivo es la inestabilidad y la amortiguación que se produce durante el ejercicio.[273] Varios estudios han propuesto que una superficie elástica flexible reduce el trabajo mecánico y el coste energético al generar fuerza muscular en comparación con realizar saltos en una superficie dura.[274,275] Además, se ha demostrado que el tipo de superficie afecta a la fatiga muscular,[276] el trabajo mecánico[274] y el gasto energético.[275]

Durante los saltos sobre una superficie elástica flexible, parte del trabajo mecánico lo proporciona el sistema musculoesquelético. Otra parte importante la proporciona el almacenamiento y la recuperación de la energía elástica debido al tipo de superficie. Al saltar, las piernas presentan una rigidez por parte de la mecánica de interacción musculoesquelético y el entorno externo de la fase de locomoción de contacto del suelo.

Al saltar sobre una superficie dura se reduce el trabajo mecánico realizado por las piernas y el gasto energético al generar fuerza muscular. Por el contrario, el aumento de la rigidez de las piernas sobre una superficie elástica flexible aumenta el trabajo mecánico realizado por la superficie.[275] En las acciones motoras humanas, el costo energético está determinado por la energía requerida para generar fuerza muscular y la energía requerida para realizar trabajo mecánico.[277,278]

Figura 14. Ejemplo de superficie inestables (Mini-trampolin)

Al analizar diferentes superficies inestables, se ha observado como el mini-trampolín promueve los mismos beneficios en la fuerza y equilibrio que otros tipos de ejercicio como el aguagym y entrenamiento resistido.[279,280] Alguno de los efectos mecánicos detectados es que la presión a la que se somete a los pies al realizar AD en una superficie inestables como el mini-trampolín, es menor comparado con la misma sesión de AD realizada en una superficie dura.[126] Un estudio comparó un programa de ejercicios en el mini-trampolín con un programa de fuerza tradicional y encontró ganancias similares en la fuerza.[279]

El mini-trampolín reduce la pérdida de energía elástica y facilita la velocidad de movimiento resultando en un incremento de la máxima potencia y un mayor reclutamiento de unidades motoras durante la acción del salto, principalmente en las extremidades inferiores.[281] Otra de las propiedades atribuibles a este tipo de superficies es que disminuye el impacto y la fatiga neuromuscular [282] [283284]

El ejercicio en las superficies elásticas (más blandas) está especialmente indicado en las personas mayores obesas y con sobrepeso que presentan un CRF bajo y problemas articulares, principalmente en las extremidades inferiores, ya que puede reducir el riesgo de padecer lesiones articulares al mejorar el equilibrio y la fuerza.[285,286] Al respecto, este tipo de superficies son idóneas para prevenir lesiones en este tipo de poblaciones, en comparación con superficies más rígidas donde las acciones motrices de alto impacto articular como correr, trotar y saltar pueden derivar en una mayor prevalencia a padecer lesiones articulares.[287]

3.3.1. Respuestas agudas en las superficies inestables

Actualmente, las superficies inestables son uno de los dispositivos más utilizados en las clases de AD. Este tipo de dispositivo ayudan a que los programas de ejercicios tengan un efecto rebote promoviendo un ejercicio divertido, intenso y con baja percepción del esfuerzo.[288] Las clases de AD realizadas sobre una superficie inestable se han convertido en un excelente ejercicio aeróbico de bajo impacto para mejorar el $\dot{V}O_2$ y el CRF.[289–295] Hardin et al. concluyeron que una superficie blanda promueve un aumento mayor del $\dot{V}O_2$ en comparación con una superficie más dura.[296] Otros estudios han demostrado que el ejercicio realizado sobre superficies inestables puede ser más intenso comparado con el ejercicio en el suelo.[273,297] Rodríguez et al. demostraron que el mini-trampolín aumentaba las respuestas cardiovasculares en comparación con una superficie de madera dura durante una carrera estacionaria, clasificando el ejercicio sobre el mini-trampolín como de intensidad moderada a vigorosa (76,5 ± 15,5 % $FC_{máx.}$).[273] Van Schoor et al. asumieron que las demandas fisiológicas más altas inducidas por el mini trampolín podrían deberse al rebote constante y a la inestabilidad producida por una superficie elástica.[298] Esta mayor demanda fisiológica implicaría un mayor esfuerzo para realizar el ejercicio y mantener el equilibrio en las superficies inestables. El aumento de la intensidad puede ser debido al aumento de la carga de trabajo producido por un incremento de la cantidad de saltos.[282,283,299] Beerse y Wu realizaron un estudio comparando la intensidad de trabajo entre una superficie inestable y otra rígida. Los participantes eran capaces de saltar 3 veces más en la superficie inestable que, en la superficie rígida, disminuyendo la fatiga neuromuscular.[282]

En cuanto a los requerimientos cardiorrespiratorios y metabólicos, el trabajo en bipedestación regular está condicionado por las propiedades mecánicas de la superficie. [296,300] Una sesión de 50 minutos de mini-trampolín realizada por mujeres jóvenes alcanzó una intensidad relativa del 75% del $\dot{V}O_{2pico}$ y 160,3 lpm/min (FC).[294] El incremento de las respuestas cardiorrespiratorias puede ser debido a la necesidad de estabilizar el cuerpo, solicitando capacidades motoras como el equilibro, la fuerza y la coordinación motora, y, por ende, demandando un mayor esfuerzo para realizar el ejercicio.[84,281,291,301–303]

Realizar ejercicio sobre una plataforma inestable puede ser una buena alternativa para personas sedentarias y obesas que tienen dificultad en alcanzar las intensidades de ejercicio recomendadas. Como es de esperar la condición física influye en la intensidad relativa que conlleva realizar este tipo de ejercicio físico en las superficies inestables.

Un estudio encontró una mayor intensidad de trabajo en personas sedentarias con sobrepeso y obesas (48% al 71% del $\dot{V}O_{2pico}$ y 67% al 86% de la $FC_{máx}$) que en atletas (35% al 69% del $\dot{V}O_{2pico}$ y 59 al 83% de la $FC_{máx.}$).[304] Cugusi et al. hallaron una intensidad del 72,2 ± 3,3% de la $FC_{máx}$ (132,3 ± 7,7 lpm/min) y un gasto energético de 317,3 ± 45,7 kcal en una sesión de mini-trampolín en mujeres con sobrepeso (36,7±10,6 años, IMC: 26,8±1,6 kg/m^2).[124]

3.3.2. *Respuestas crónicas en las superficies inestables*

Realizar programas de AD sobre las plataformas inestables induce mejoras sustanciales adaptativas de las respuestas cardiorrespiratorias en comparación con los programas de AD realizados en una superficie rígida.[126] Sukkeaw et al. compararon un programa 40 minutos de AD en un mini-trampolín y en una superficie rígida, 3 veces por semana a una intensidad del 60-80% de la $FC_{máx}$ en mujeres de 35-45 años. Ambos ejercicios aumentaron el $\dot{V}O_{2pico}$, pero la respuesta en el mini-trampolín fue mayor (24,31 ± 4,67 $mL·kg^{-1}·min^{-1}$/ 36,19± 4.67 $mL·kg^{-1}·min^{-1}$) comparado con la superficie rígida (22,61 ± 2,59 $mL·kg^{-1}·min^{-1}$/ 34,14± 2,5 $mL·kg^{-1}·min^{-1}$).[126]

Las personas mayores, sedentarias y obesas también adquieren interesantes adaptaciones cardiorrespiratorias cuando realizan ejercicio en superficies inestables, incrementando la intensidad de ejercicio y, consecuentemente, mejorando el CRF.[81,291,305] Un grupo de personas mayores (73±1 años) se ejercitaron 4 $d·sem^{-1}$ en sesiones de 60 minutos en el mini-trampolín a una intensidad relativa entre el 55 y el 65 % de la $FC_{máx}$ durante 1 mes y luego al 75 % durante 3 meses. Se observaron incrementos del 16 % en el $\dot{V}O_{2pico}$.[305] Otro estudio encontró un aumento de 4,4% del $\dot{V}O_{2máx}$ en mujeres sedentarias que realizaron un programa de ejercicio sobre el mini-trampolín a una intensidad entre el 70 y el 85% de la $FC_{máx.}$, durante 11 semanas (5 d·sem^{-1}).[291] Cugusi et al. realizaron un de programa AD en el mini-trampolín de 3 sesiones semanales de 60 minutos a una intensidad progresiva del 40-90 % de la FC de reserva y a una RPE de 15 durante 12 semanas. El ejercicio sobre el mini-trampolín mejoró significativamente el $\dot{V}O_{2máx.}$ (15,4 a 16,9 mL·kg^{-1}·min^{-1}) y la capacidad de trabajo (104 a 123 vatios) en mujeres con sobrepeso. [81]

En general, los estudios que utilizaron plataformas inestables están enfocados a la mejora de la fuerza, el rendimiento en el salto, el equilibrio postural,[126,279,281,290,301,306,307] promoviendo una mayor respuesta coordinativa muscular y articular, integración espacial, [281] mayores amplitudes de movimiento articular, [290,301] mejora del equilibrio y de la estabilidad corporal,[81,126] además de aumentar la altura del salto de longitud y vertical, la velocidad de carrera y la potencia anaeróbica en atletas.[306]

En las personas mayores, estudios realizados demostraron que el ejercicio realizado en superficies inestables induce mejoras en el equilibrio y la fuerza.[279,280] Oliveira et al. compararon 2 programas de ejercicio de bajo impacto (aguagym y el mini-trampolín) con un programa realizado en el suelo. El programa de ejercicio realizados sobre el mini-trampolín produjo resultados similares a otros modos de ejercicio en el equilibrio de las personas mayores.[280] Otro estudio realizó un programa de ejercicio utilizando el mini-trampolín verificando ganancias similares en la fuerza en comparación con un programa de fuerza tradicional.[279] La movilidad funcional y la velocidad de marcha también se ve favorecida en las personas mayores con este tipo de superficies inestables.[81,279,281,308]

Existe poca evidencia con relación a los cambios producidos por los programas de ejercicio utilizando las plataformas inestables en la composición corporal. Los pocos estudios que existen encontraron una notable reducción de la grasa corporal y una disminución poco apreciable en el IMC.[84,126,288,292,309] Otros no hallaron cambios en el peso, en el porcentaje de grasa corporal y en la grasa abdominal.[291,305] Parece ser que la duración y la intensidad de las sesiones no han sido suficientes para promover cambios significativos en la composición corporal. Cugusi et al. evaluaron los efectos de un programa de 12 semanas de AD en un mini-trampolín (55-60 min), a una intensidad de 15 en la RPE, al 40-90% FC reserva, en 18 mujeres (edad 38,05±10,5 años, IMC: 27,6±2,1 kg/m^2) 3 d·sem^{-1}. Las participantes presentaron una disminución significativa de la grasa (26,6±5.0 a 23,6 ± 5,1 kg) [81] Nuhu et al. encontraron cambios significativos en la circunferencia de cintura y cadera en 60 pacientes con diabetes mellitus tipo II (edad 39 años y IMC de 25,2 kg/m^2) en un programa de 8 semanas de AD sobre un mini-trampolín, 3 d·sem^{-1} . Las sesiones duraban entre 20 y 30 min a una intensidad del 40 al 60% de la $FC_{máx.}$[84] Otro estudio realizó un programa en un mini-trampolín de 20-30 minutos (40-60% $FC_{máx.}$), 3 d·sem^{-1}, durante 9 semanas en diabéticos tipo II (39,44 ± 8,61 años). Se detectaron mejoras significativas en el IMC (26,1 a 25,6 kg/m^2).[295] Pietro et al realizaron una intervención de 60 min de ejercicio sobre el mini-trampolín a una intensidad relativa entre el 55 y el 65% de la $FC_{máx}$, en personas mayores. Las sesiones eran realizadas 4 d·sem^{-1} durante 4 meses; a pesar de la disminución del 24 % en concentraciones de ácidos grasos libres, no hubo cambios en la grasa abdominal.[305]

3.3.3. La plataforma de disipación de aire

Recientemente, se han utilizado la ADP en las clases de AD. Dicha plataforma se compone de un área de un metro de diámetro y 20 cm de altura que descansa sobre un elastómero que contiene aire a una determinada presión atmosférica. A través de orificios permite la entrada de aire minimizando el impacto y evitando la sobrecarga de las articulaciones y del aparato muscular (figura 15)

Figura 15. La plataforma de disipación de aire (ADP)

La metodología de sesión la ADP es similar a la AD; consiste en una combinación de ejercicios de diferentes modalidades como la gimnasia, el running, el boxeo y la danza, incluyendo movimientos de tronco, brazos y principalmente de las piernas.

Una de las características de la ADP es la variedad de ejercicios como saltos, rebotes y la pliometría, además de la utilización de diversos materiales como gomas, bastones, mancuernas, maracas, etc. Además, la ADP no tiene coreografía, el monitor cambia de ejercicio cada 16 segundos y los movimientos son realizados al ritmo de la música, lo que permite que el participante dosifique la intensidad del ejercicio y disfrute de la sesión (figura 15).

La duración es de aproximadamente 45 minutos y se divide en 3 partes:

1- Calentamiento (5 a 10 minutos)
2- Parte principal (30 minutos, con 4 bloques de aproximadamente 7 minutos)
3- Vuelta a la calma (5 minutos)

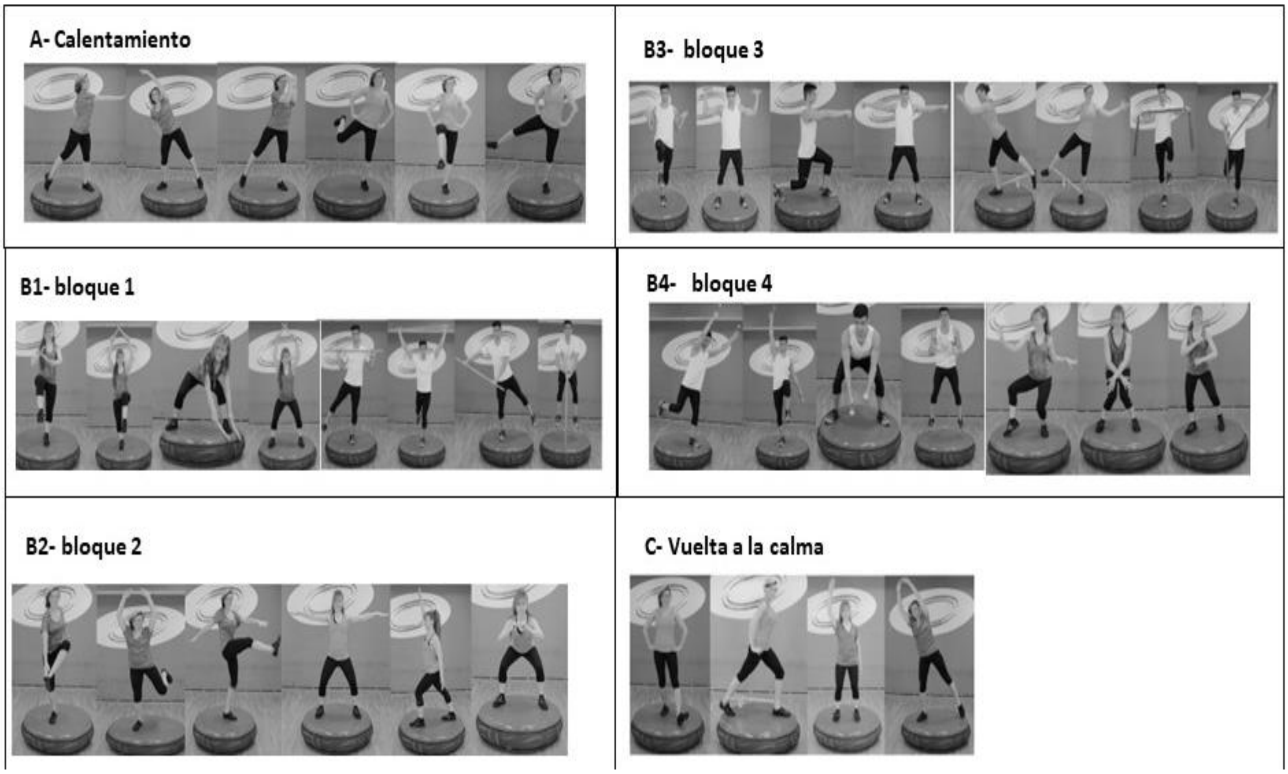


Figura 16. Ejemplo de una sesión de ADP

4. PROBLEMÁTICA Y JUSTIFICACIÓN

4. Problemática y justificación

Existe poca información actualizada y pocas evidencias sobre las respuestas agudas y crónicas de la AD principalmente cuando este ejercicio es realizado en superficies inestables. Hasta donde sabemos no existe evidencia sobre la ADP.

Una de las principales características de una sesión de AD en una superficie inestable es que se produce una mayor respuesta cardiorrespiratoria en comparación con el ejercicio en una superficie rígida.[296, 273,297] Sin embargo, los estudios se centraron en valorar la respuesta de la FC y del $\dot{V}O_2$,[273,294] y no hemos encontrado estudios que evaluaran la intensidad del ejercicio mediante los umbrales ventilatorios (VT1 y VT2), el lactato en la sangre, la cinética del $\dot{V}O_2$ ($\dot{V}O_{2sc}$) y la eficiencia respiratoria en la AD realizada en superficies inestables.

Además, los estudios que evaluaron el $\dot{V}O_{2sc}$ y la eficiencia ventilatoria eran realizados con otras modalidades de ejercicio cardiorrespiratorio como correr y ciclismo donde la intensidad puede ser pautada por la velocidad y la carga de trabajo.[130,142,149] Es importante encontrar la intensidad de ejercicio adecuada, una vez que la intensidad del ejercicio puede afectar a la eficiencia del intercambio de gases, aumentar la fatiga y reducir la tolerancia el ejercicio.[151,158,159]

Existe una importante controversia en la literatura científica sobre los efectos crónicos de la AD realizada en suelo en el CRF,[237–239,249,269] en la fuerza muscular[80,195] y en la composición corporal.[80,195] En contrapartida realizar la AD en superficies inestables parece promover mayores respuestas en el CRF[126 305 291 81] y el fitness muscular (fuerza, potencia y equilibrio)[126,279,281,290,301,306,307] cuando son comparadas con la AD en el suelo. Podrían ser una alternativa para las personas mayores, sedentarias, con sobrepeso u obesidad que poseen un bajo CRF y que presentan problemas articulares principalmente en las extremidades inferiores, lo que limita la posibilidad de realizar ejercicio de alto impacto articular como correr, trotar y saltar en superficies duras.[287] Realizar AD sobre plataformas inestables disminuye el impacto, la fatiga neuromuscular y parecen estar asociada a una mayor tolerancia al ejercicio, un menor índice de fatiga y a una disminución de los episodios por trauma debido a sobrecargas excesivas por esfuerzos repetitivos provocado por continuos impactos en superficies rígidas.[282–284]

La literatura científica advierte sobre las posibles lesiones asociadas con el impacto en determinados tipos de AD en superficies rigída.[310,311] La presión en los pies al realizar AD en una superficie inestable es menor comparando con la AD realizada en una superficie dura, lo que permite que el participante realice una mayor carga de trabajo y sea mantenida durante más tiempo. Esto puede ayudar a determinadas personas que tienen dificultades en adquirir una intensidad de ejercicio recomendada, especialmente las personas mayores que presentan una capacidad limitada de adaptación a los programas de ejercicio debido a los efectos biológicos del envejecimiento, como la reducción del lecho capilar, la densidad mitocondrial, un mayor déficit y débito de O_2 y consecuentemente, una cinética del $\dot{V}O_2$ más lenta.[312] Esta problemática puede ser agravada en personas obesas y con sobrepeso que no alcanzan una intensidad de ejercicio suficiente en las sesiones de AD.[313]

A pesar de que algunos estudios demuestran una alta intensidad y bajo impacto articular al realizar AD en superficies inestables, es necesario mayor conocimiento y dosificar de forma adecuada la intensidad de ejercicio, ya que el ejercicio muy extenuante puede aumentar el estrés oxidativo.[88,97] Además, las personas mayores presentan una mayor percepción de esfuerzo asociado al trabajo submáximo, debido a los cambios en la capacidad fisiológica, lo que provoca desafortunadamente un efecto secundario negativo de evitar actividad física estresante, es decir, los mayores tienen miedo de realizar ejercicio de alta intensidad.[75,26975]

Curiosamente, las intervenciones de AD va un paso más allá al mejorar la motivación intrínseca y la asistencia de los pacientes; la tasa de abandono es más baja en comparación con otros programas de ejercicios como correr, spinning y entrenamiento resistido.[265] Sin embargo, se ha observado que la duración de las intervenciones de la AD en las superficies inestables varía tanto en tiempo de la sesión como en la cantidad de sesiones, lo que no permite extraer conclusiones sobre cuál sería la dosis correcta para obtener resultados, una vez que los estudios han producido cambios poco significativos en el IMC y en la composición corporal,[84,126,288,292,309] y gran parte de las intervenciones realizadas con personas mayores son enfocadas a la evaluación del equilibrio y de la fuerza. [126,279,281,290,301,306,307] De los expuesto arriba se extrae que faltan evidencias y estudios en diferentes modalidades de AD en superficies inestables sobre el estrés oxidativo y CRF principalmente con personas mayores, obesas y con sobrepeso.

Por las propiedades de una ADP y las características de la sesión de AD sobre la ADP, especulamos con la posibilidad de que realizar ejercicio sobre estas plataformas podría ser una buena solución para las personas mayores y sedentarias con obesidad y/o patologías asociadas al aparato locomotor y cardiorrespiratorio, disminuyendo el impacto sobre la superficie de contacto al realizar la AD, evitando sobrecargas musculoesqueléticas y lesiones prematuras y, por ende, mejorando el fitness cardiorrespiratorio y muscular. Sin embargo, no existen estudios científicos que aborden las respuestas cardiorrespiratorias, metabólicas, mecánicas y de estrés oxidativo agudas y crónicas en el ejercicio realizado sobre la ADP.

Por lo tanto, este proyecto pretende investigar los efectos agudos y crónicos cardiorrespiratorios, metabólicos, mecánicos y de estrés oxidativo de las sesiones (respuestas agudas) y de un programa de ejercicio (respuestas crónicas) realizado sobre una ADP en diferentes poblaciones.

5.OBJETIVOS E HIPÓTESIS

5. Objetivos e hipótesis

El principal objetivo de esta tesis es estudiar las respuestas cardiorrespiratorias, metabólicas, mecánicas y de estrés oxidativo agudas y crónicas producidas por la AD realizada en una ADP en personas adultas jóvenes y mayores.

Los objetivos específicos (OE) que nos hemos marcado para el presente proyecto de tesis doctoral son:

OE1. *Evaluar las respuestas cardiorrespiratorias, metabólicas, y la fatiga muscular, así como la RPE comparando la misma sesión de AD entre una ADP y una superficie dura en adultas jóvenes sanas.*

(artículo I)

a. Definir los umbrales ventilatorios (VT1 y VT2) y las variables cardiorrespiratorias mediante la prueba incremental en cinta rodante.

b. Evaluar la intensidad de una sesión de AD en una ADP mediante las respuestas metabólicas (lactato en sangre), cardiorrespiratorias ($\dot{V}O_2$, FC, VE, RER, $VE \cdot VO_2^{-1}$ y $VE \cdot VCO_2^{-1}$), la fatiga muscular mediante la prueba de salto y la percepción de esfuerzo (RPE).

c. Evaluar la intensidad de una sesión de AD en superficie rígida mediante las respuestas metabólicas (lactato en sangre), cardiorrespiratorias (FC, VE, RER, $VE \cdot VO_2^{-1}$ y $VE \cdot VCO_2^{-1}$), la fatiga muscular mediante la prueba de salto y la percepción de esfuerzo (RPE).

d. Comparar las respuestas cardiorrespiratorias, metabólicas y la fatiga muscular entre ambas sesiones de AD en superficie rígida y en una ADP.

OE2. *Comparar el* $\dot{V}O_{2sc}$*, la eficiencia ventilatoria (pendiente de la* $VE \cdot VCO_2^{-1}$*) y las respuestas metabólicas (concentraciones de lactato en sangre) entre una sesión de AD en una ADP y una prueba en tapiz rodante a carga constante a la intensidad de VT1 en mujeres adultas jóvenes sanas.* ***(artículo II)***

a. Definir el VT1 y las respuestas cardiorrespiratorias pico mediante la prueba incremental hasta el agotamiento.
b. Evaluar el comportamiento del $\dot{V}O_{2sc}$, la eficiencia ventilatoria y las respuestas metabólicas en una sesión de AD en una ADP.
c. Evaluar el comportamiento del $\dot{V}O_{2sc}$, la eficiencia ventilatoria y las respuestas metabólicas en una prueba de tapiz rodante a carga constante a la intensidad de VT1.
d. Comparar comportamiento del $\dot{V}O_{2sc}$, la eficiencia ventilatoria y las respuestas metabólicas entre ambas sesiones AD en una ADP y prueba constante a intensidad de VT1.

OE3. *Determinar los efectos de un programa de ejercicio de AD de 12 semanas realizado sobre una ADP en el CRF, el fitness muscular, la composición corporal y su impacto sobre el estrés oxidativo en personas mayores.* ***(artículo III)***

a. Estudiar los efectos del programa de AD en el IMC y la composición corporal (peso, porcentaje de grasa, masa libre de grasa y masa magra) medida por bioimpedancia en personas mayores.

b. Evaluar el estrés oxidativo mediante la peroxidación lipídica (MDA) en plasma después de un programa de 12 semanas de entrenamiento de AD en una ADP en personas mayores.

c. Evaluar el CRF ($\dot{V}O_2$pico) mediante el test de step de 3 minutos después de un programa de 12 semanas de entrenamiento de AD en una ADP en personas mayores.

d. Evaluar en fitness muscular después de un programa de 12 semanas de entrenamiento de AD en una ADP en personas mayores:

    i. Valorar la agilidad y equilibrio mediante el 8 foot UP&GO test.

ii. Evaluar la fuerza del tren superior mediante el test de flexión y extensión de codo con mancuernas de 2kg para mujeres y de 4kg para hombres.

iii. Evaluar la fuerza explosiva de las extremidades inferiores mediante un test para determinar la potencia y la altura de vuelo.

6. METODOLOGÍA

6. Metodología

Previamente, se realizó una búsqueda de la literatura científica sobre los efectos de la AD realizadas en el suelo y los efectos del ejercicio realizado sobre superficies inestables en diferentes poblaciones. Una vez finalizada la revisión, se realizaron 3 estudios:

- En el primer estudio un grupo de jóvenes mujeres sanas realizaron una misma sesión de ejercicio comparando dos condiciones diferentes. En un estudio experimental aleatorizado, las participantes realizaron la misma coreografía sobre una ADP o sobre el suelo. Se evaluaron en ambas sesiones las respuestas cardiorrespiratorias, metabólicas y la fatiga, con el objetivo de determinar qué tipo de superficie induce mayores beneficios. **(artículo I)**

- En el segundo estudio, un grupo de mujeres sanas fueron asignadas aleatoriamente a una sesión de AD en una ADP y a una prueba en tapiz rodante a una intensidad de carga constante correspondiente a VT1. El objetivo era descubrir como ambos ejercicios influyen en el componente lento del consumo de oxígeno ($\dot{V}O_{2sc}$), la eficiencia ventilatoria ($VE \cdot VCO_2^{-1}$ pendiente) y las concentraciones de lactato en sangre. **(artículo II)**

- Una vez determinada las diferencias entre ambas superficies y ambas modalidades de ejercicio, se evaluaron los efectos de un programa de 12 semanas de AD realizada sobre una ADP en el fitness cardiorrespiratorio, muscular y en el estrés oxidativo en personas mayores con normopeso (HG), sobrepeso (OWG) y obesas (OG)**. (artículo III)**

7.INFORME DE LOS DIRECTORES

UNIVERSITAT DE BARCELONA

El Dr Manuel V. Garnacho Castaño i la Dra Norma Alva B. com a directors d'aquesta tesi doctoral, fem constar que:

La memòria presentada per la Sra. Alessanda Moreira Reis i titulada: "Respuestas cardiorrespiratorias, metabólicas, mecánicas y de estrés oxidativo, agudas y crónicas, en la danza aeróbica realizada sobre una plataforma de disipación de aire en personas jóvenes y mayores" és una tesi doctoral elaborada en format d'articles. Recull els resultats originals obtinguts per la doctoranda. Els seus resultats han estat publicats o preparats per a ser sotmesos per a la seva publicació a revistes internacionals amb revisió per parells.

La Sra. Alessandra Moreira Reis ha participat activament en l'elaboració dels articles presentats en aquesta tesi, ha dut a terme el disseny dels experiments i el treball experimental i ha contribuït a l'anàlisi crítica de les dades i resultats. A més, també ha participat en la redacció dels articles.

Els articles presents a la tesi són:

1. **Article original:**

Cardiorespiratory, Metabolic and Muscular Responses during a Video-Recorded Aerobic Dance Session on an Air Dissipation Platform. **Moreira-Reis A**, Maté-Muñoz JL, Hernández-Lougedo J, García-Fernández P, Pleguezuelos-Cobo E, Carbonell T, & Garnacho-Castaño MV. *International Journal of Environmental Research and Public Health*. 2020; 17(24): 9511.
Cuartil: Q1. Factor de impacto: 3.390. Rank: 42/176. CATEGORY: PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH (Index JCR)
DOI: https://doi.org/10.3390/ijerph17249511
Nº cites: 2 (WOS).
La doctoranda ha col·laborat en la conceptualització, ha dut a terme la posta a punt metodològica, la realització dels experiments, l'anàlisi formal i la redacció de l'esborrany inicial.

2. **Article original:**

Similar Slow Component of Oxygen Uptake and Ventilatory Efficiency Between an Aerobic Dance Session on an Air Dissipation Platform and a Constant-load Treadmill Test in Heathy Women. **Moreira-Reis A**, Maté-Muñoz JL, Hernández-Lougedo J, García-Fernández P, Heredia-Elvar JR, Pleguezuelos E, Carbonell T, Bocanegra NA, Garnacho-Castaño MV. *Biology (Basel). 2022;11(11):1646*.
Cuartil: Q1. Factor de impacto: 5,168. Rank: 21/94. CATEGORY: Biology (Index JCR).
DOI: https://doi.org/10.3390/biology11111646
Nº cites: 0 (WOS).

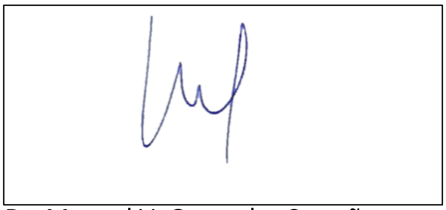
La doctoranda va realitzat el treball experimental, la recol·lecció de mostres, i anàlisi de dades.

3. **Article original:**

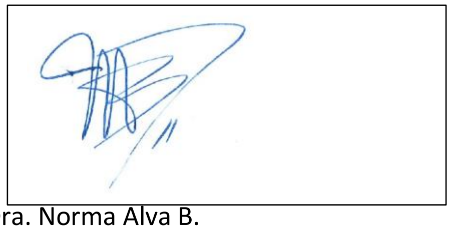
Aerobic Dance on an Air Dissipation Platform Improves Cardiorespiratory, Muscular and Cellular Fitness in the Overweight and Obese Elderly. **Moreira-Reis A,** Maté-Muñoz JL, Hernández-Lougedo J, Vilches-Sáez S, Benet M, García-Fernández P, Pleguezuelos E, Carbonell T, Alva N, Garnacho-Castaño MV. *Biology (Basel). 2022; 11(4):579.*
Cuartil: Q1. Factor de impacto: 5,168. Rank: 21/94. CATEGORY: Biology (Index JCR).
DOI: https://doi.org/10.3390%2Fbiology11040579
Nº cites: 1 (WOS).

La doctoranda va realitzat el treball experimental, la recol·lecció de mostres, anàlisi de dades i la redacció del manuscrit.

Barcelona, 26 de juny 2023



Dr. Manuel V. Garnacho Castaño



Dra. Norma Alva B.

8. ARTÍCULOS PUBLICADOS

Artículo I

Cardiorespiratory, Metabolic and Muscular Responses during a Video-Recorded Aerobic Dance Session on an Air Dissipation Platform

Alessandra Moreira-Reis [1], José Luis Maté-Muñoz [2], Juan Hernández-Lougedo [2], Pablo García-Fernández [3], Eulogio Pleguezuelos-Cobo [4], Teresa Carbonell [1], Norma Alva [1] and Manuel Vicente Garnacho-Castaño [5]

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Abstract

Background: Aerobic dance (AD) is an appropriate physical activity for improving cardiorespiratory fitness. This study aimed to compare cardiorespiratory and metabolic responses, and muscle fatigue between an air dissipation platform (ADP) and a hard surface during a video-recorded AD session. Methods: 25 healthy young women (23.3 ± 2.5 years) completed three sessions. In session 1, participants performed an incremental test to exhaustion on a treadmill. One week after session 1, participants were randomly assigned in a crossover design to perform video-recorded AD sessions on an ADP and on a hard surface (sessions 2 and 3). Cardiorespiratory and metabolic responses were assessed during AD sessions. Muscular fatigue was measured before and after AD sessions by a countermovement jump test. Results: Significantly higher heart rate, respiratory exchange ratio, pulmonary ventilation, ventilatory oxygen equivalent, and ventilatory carbon dioxide equivalent were observed on an ADP than on a hard surface ($p < 0.05$). Despite a significant increase in lactate levels on an ADP ($p \leq 0.01$), muscular fatigue and perceived exertion rating were similar on both surfaces ($p > 0.05$). Conclusions: Video-recorded AD on an ADP increased the cardioventilatory and metabolic responses compared to a hard surface, preventing further muscle fatigue.

Keywords: ventilatory threshold, cardiopulmonary exercise test, fitness class, blood lactate, fatigue

1. Introduction

Group classes in fitness centers are a very popular physical activity among women and, particularly, aerobic dance (AD) is one of the most practiced worldwide. In this period of pandemic due to severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2), thousands of practitioners who performed AD classes in fitness centers have stopped training due to conditions of confinement. EHealth and exercise videos, television and mobiles are technologies that could be used to maintain physical function and mental health [1] during periods of confinement. AD led by fitness instructors through a video-recorded session could be a very interesting alternative to maintain or improve cardiorespiratory and metabolic fitness during periods of confinement.

Heart rate (HR), blood lactate levels and oxygen uptake (VO_2) have been used as measurement parameters to assess the exercise intensity in AD classes [2]. De Angelis et al. proved that AD increased HR, VO_2 and blood lactate concentrations to a greater extent than expected, showing a high exercise intensity, metabolic demand and a non-steady state [2]. The cardiorespiratory and metabolic requirements for regular bipedal work are conditioned by the mechanical properties of the surface [3,4]. Hardin et al. [3] concluded that a harder surface decreased VO_2 compared to a softer surface. Rodrigues et al. demonstrated that an elastic surface (i.e., mini-trampoline) increased cardiovascular responses compared to a hardwood surface during a stationary running [5]. The authors assumed that the higher physiological demands induced by the mini-trampoline could be due to constant rebounds and instability produced by an elastic surface. This increased physiological demand would involve greater effort to carry out the exercise and maintain balance on the mini-trampoline. Moreover, soft surfaces may reduce the risk of joint injuries from high impact [6]. The physiological demands of AD classes could depend, at least in part, on the exercise intensity (i.e., percentage of maximal heart rate, percentage of maximal VO_2, energy expenditure, blood lactate, etc.) and the type of surface.

The type of surface has been demonstrated to affect muscle fatigue [7], mechanical work [8] and energy cost [9]. Several studies have proposed that a compliant elastic surface reduces mechanical work and energy cost of generating muscle force compared with hopping or running on a hard surface [8,9]. In human motor actions, the energy cost is determined by the energy required to generate muscle force and the energy required to perform mechanical work [10,11]. During human hopping on a compliant elastic surface, part of the mechanical work is supplied by the musculoskeletal system. Another important part is provided by storage and recovery of elastic energy in the surface. As a consequence of increasing leg stiffness on a compliant elastic surface, the mechanical work done by the surface is increased. In contrast, the mechanical work done by the legs is reduced. Consequently, the energy cost is reduced by generating muscle force [9]. It is tempting to speculate that the different mechanical work and energy costs induced by different surfaces on the musculoskeletal system could lead to variations in muscular fatigue. Several studies have used vertical jump height (i.e., counter movement jump) before and after exercise to assess the extent of muscular fatigue [12,13]. However, muscular fatigue assessed by a countermovement jump test before and after an AD session has not been explored by comparing an ADP and a hard surface.

Recently, an air dissipation platform (ADP) has been incorporated by our research group into AD classes. The ADP consists of an area that rests on an elastomer that contains air and that allows air to enter and exit through holes. One of the main characteristics of this device is instability and rebound damping produced during exercise, just as it occurs on a mini-trampoline [5]. In theory, cardiorespiratory and metabolic responses on an ADP should be increased compared to a hard surface; however, this statement has not yet been scientifically confirmed. This knowledge would be a key factor in determining whether the exercise intensity during a video-recorded AD class on an ADP is enough to produce improvements in cardiorespiratory fitness.

This study aimed to assess the acute cardiorespiratory and metabolic responses induced by an ADP and a hard surface (marble floor) during a video-recorded AD session. The secondary aim was to determine the muscular fatigue induced by an ADP and a hard surface as well as the rate of perceived exertion (RPE). We hypothesized that a video-recorded AD session on an ADP produces higher acute cardiorespiratory and metabolic responses (blood lactate) compared to AD on a harder surface. In addition, a video-recorded AD session on an ADP is probably an ideal alternative to increase exercise intensity, maintaining similar RPE and muscular fatigue.

2. Materials and Methods

2.1. Experimental Approach to the Problem

Participants completed three test sessions at the Exercise Physiology laboratory. Sessions were conducted under the same environmental conditions (temperature 20–22.5 °C, atmospheric pressure: 715–730 mm Hg, and relative humidity 40–50%) and in the same time frame (+1 h). Participants refrained from any high-intensity physical effort for 48 h and abstained from any type of physical exercise for 24 h before starting the first session.

In session 1, an incremental test until exhaustion was completed on a treadmill to determine cardiorespiratory responses and ventilatory thresholds (VTs). One week after session 1, participants were randomly assigned in a crossover design to carry out AD sessions on an ADP and on a hard surface (session 2 and 3). The AD class was video recorded by a certified fitness instructor a week before. This video session was projected on a giant screen individually to each participant during the AD classes on an ADP or a marble floor (hard surface). Sessions 2 and 3 were rigorously identical and cardiorespiratory and metabolic responses, muscular fatigue and RPE were evaluated one week apart.

2.2. Participants

The participants recruited were 25 healthy young women (age, 23.3 ± 2.5 years; weight, 58.4 ± 6.8 kg; height, 162.6 ± 5.5 cm; and body mass index, 22.1 ± 2.4 kg/m^2). All of them performed light or moderate physical activity a maximum of 2–3 times per week. Exclusion criteria were (a) the use of any medication or performance-enhancing drugs, (b) smoking or alcohol intake, (c) the intake of any nutritional supplement that could alter cardiorespiratory performance, (d) any cardio-vascular, metabolic, neurological, pulmonary, or orthopedic disorders that could limit exercise performance, (e) being an elite athlete. Participants were informed of all experimental tests and signed an informed consent form. The study protocol received approval from the Ethics Committee of the University (13/2018) and adhered to the tenets of the Declaration of Helsinki.

2.3. Incremental Treadmill Test

The incremental cardiopulmonary exercise test (CPET) until exhaustion included a 5-min warm-up on a motorized treadmill (TechnoGym, Runrace 1400HC, Forlí, Italy) at a self-selected light intensity (~5–6 $km \cdot h^{-1}$), followed by 5-min of dynamic joint mobility drills and stretching exercises. After 3-min rest time, the CPET on a treadmill commenced at an initial load of 5 $km \cdot h^{-1}$ (1% slope) which was increased in steps of 0.5 $km \cdot h^{-1}$ every 30 s.

Respiratory exchange data were recorded during the CPET using a breath-by-breath open-circuit gas analyzer (Vmax spectra 29, Sensormedics Corp., Yorba Linda, CA, USA). VO_2max, minute ventilation (VE), carbon dioxide production (VCO_2), ventilatory equivalent for oxygen ($VE \cdot VO_2^{-1}$), ventilatory equivalent for carbon dioxide ($VE \cdot VCO_2^{-1}$), respiratory exchange ratio (RER), oxygen partial pressure on expiration ($PetO_2$), partial pressure of carbon dioxide on expiration ($PetCO_2$) were monitored. HR was checked every 5 s by telemetry (RS-800CX, Polar Electro OY, Kempele, Finland).

In the CPET, maximum or peak cardiorespiratory indices and VTs (first ventilatory threshold: VT1 and second ventilatory threshold: VT2) were determined to identify the relative exercise intensity of AD classes. As in a previous study [14], two investigators separately identified VT1 and VT2. If there was lack of agreement, the opinion of a third observer was considered. VT1 was defined as the workload (velocity) at which both $VE \cdot VO_2^{-1}$ and $PetO_2$ increase, without a concomitant increase in $VE \cdot VCO_2^{-1}$. Similarly, VT2 was defined as the workload (velocity) at which $VE \cdot VO_2^{-1}$ and $VE \cdot VCO_2^{-1}$ increase, accompanied by a drop in $PetCO_2$ [15].

2.4. Aerobic Dance Sessions

AD sessions were conducted on an ADP and on a marble floor (hard surface) (sessions 2 and 3). The ADP consists of an area of one meter in diameter and 20 cm high that rests on an elastomer that contains air at atmospheric pressure and that allows air to enter and exit through holes. The same general warm-up was carried out as in the CPET. After a 3-min rest period, each subject performed a 40-min AD session of individual exercise on an ADP or a marble floor. The AD class consisted of three phases: a 5-min of specific warm-up, a 30-min aerobic or principal phase, and 5-min cool-down.

The aerobic phase of the AD session was structured by an experienced instructor to be of light intensity at most 75% HRmax (RPE ~11–12), moderate intensity at most 85% HRmax (RPE ~13–14), or heavy intensity at most 90% HRmax (RPE ~15–17) [16]. The AD sessions were based on global and multi-articular movements in which large muscle groups participated, including jumps, arm and leg movements, trunk flexions, etc. The exercise intensity of the AD classes was controlled by varying the muscle mass involved (deeper movements, increased bending, arm activity) as well as modifying the direction, the impact of the movements and the range.

To verify that both AD classes (ADP vs. hard surface) were rigorously the same, a video of an AD class was recorded a week before. Participants were instructed to imitate the motor tasks to be performed by an expert instructor to the rhythm of the music (Figure 1). Since all participants were familiarized with AD classes, the motor tasks were not difficult to replicate.

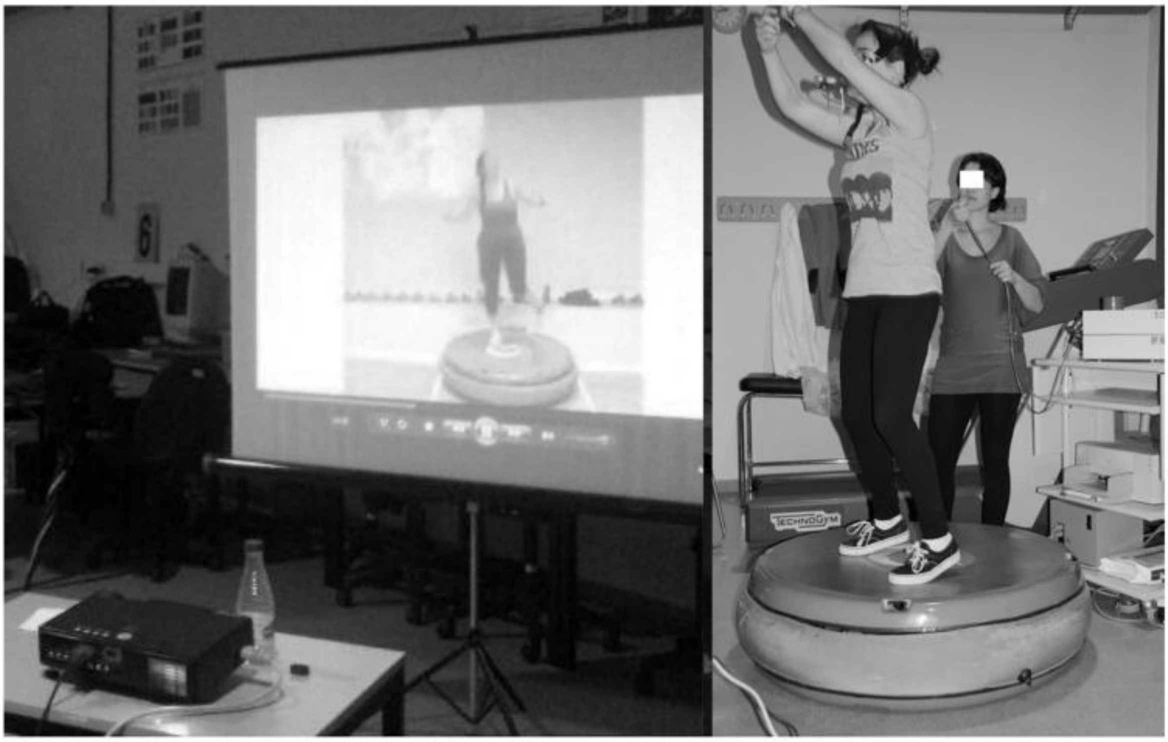

Figure 1. Aerobic dance session performed on an air dissipation platform. The video session was projected on a giant screen individually to each participant.

2.5. Cardiorespiratory, Metabolic and Muscular Assessment

Respiratory exchange data were recorded during AD classes using a breath-by-breath open-circuit gas analyzer, as previously in the CPET.

Blood lactate and RPE were measured at rest (before warm-up) and every 10 min during AD classes (10-min, 20-min, 30-min and 40-min). Blood lactate levels were determined from finger capillary blood using a portable lactate analyzer (Lactate Pro LT-1710, Arkray Factory Inc., KDK Corporation, Siga, Japan), while RPE was determined by using the Borg Scale [17].

Before and after AD classes, muscular fatigue of lower limbs was evaluated by the countermovement jump (CMJ) test using a force platform (Quattro Jump model 9290AD; Kistler Instruments, Winterthur, Switzerland), as in previous studies [13,18]. The CMJ was initiated while standing on the force platform with hands on hips and legs extended. Next, the knees were first flexed to 90° (eccentric action) and immediately explosively extended in a coordinated manner (concentric action) trying to reach maximum vertical height. During the flight stage, the knees were fully extended and contact with the ground was made with the toes first. The participants were instructed to keep their hands on the hips and avoid any sideways or backward/forward movements during the flight stage.

Participants carried out 3 CMJs separated by a rest time of 30 s, and the mean values of vertical flight height and mean power (3 CMJs) were used in the subsequent analyses. Loss of vertical jump height and power output have been used to assess muscle fatigue before and after an exercise session [13,18]. The force platform was connected to a computer and the software package of Kistler (Quattro Jump software, version 1.1.1.4, (Kistler Instruments, Winterthur, Switzerland) was used to quantify the kinetic and kinematic variables. The vertical ground reaction force (GRF) data were obtained during the jump (range 0–10 kN; sampling frequency 0.5 kHz). The vertical component of the center of mass (COM) velocity was estimated using the impulse method [19]. Net impulse was taken by integrating the GRF from 2 s before the first movement of the participant [20]. The vertical velocity of COM was calculated by dividing the net impulse by the participant's body mass [21]. Maximum velocity reached at the end of the concentric muscle action of the jump was considered as maximum take-off velocity (V_{max}). Flight height (cm) was calculated from V_{max} of the COM and the deceleration of gravity. Height = $((V_{max})^2/2 \times 9.81)$. Power was calculated from the unfiltered force–time history using the impulse momentum principle [22]. Mean relative power ($watts \cdot kg^{-1}$) was calculated as the product of mean velocity and vertical component of the vertical ground reaction force.

2.6. Statistical Analysis

The Shapiro–Wilk test was used to check the normal distribution of data, provided as means, standard deviation (SD), confidence intervals (95% CI) and percentages. A t-student for paired samples was applied to identify significant differences between an ADP and a hard surface in cardiorespiratory and metabolic responses. Cohen's d effect sizes ($d < 0.4$, small; ≥ 0.4, moderate; ≥ 0.8, large) were calculated to assess the magnitude of difference among experimental conditions [23].

A general linear model with a two-way analysis of variance (ANOVA) for repeated measures was performed to verify significant differences between an ADP and a marble hard surface in lactate levels and RPE. The two factors were exercise mode (ADP and marble floor) and time (corresponding to 4 checkpoints performed in both AD classes). When appropriate, a Bonferroni post hoc adjustment for multiple comparisons was implemented. An ANOVA for repeated measures was performed to determine muscular fatigue. The partial eta-squared (η_p^2) was computed to determine the magnitude of the response to both exercise modes. The statistical power (SP) was also calculated. All statistical methods were performed using the software package SPSS Statistics version 25.0 for Mackintosh (SPSS, Chicago, IL, USA). Significance was set at $p < 0.05$.

3. Results

Descriptive data related to the CPET in treadmill are presented in Table 1. The predicted maximum heart rate (197 beats·min^{-1}) of the experimental group was not reached (187.1 ± 8.1 beats·min^{-1}). The functional capacity of the healthy young women was good (VO_2: 42.4 ± 7.5).

Table 1. Cardiorespiratory results attained during incremental treadmill test

Variables	Mean	SD
Participants	N = 25	
Peak HR (beats.min^{-1})	187.1	8.1
Peak VO_2 (l.min^{-1})	2.4	0.5
Peak VO_2 (ml.kg^{-1}.min^{-1})	42.4	7.5
Peak VCO_2 (l.min^{-1})	2.9	0.5
Peak RER	1.2	0.1
Peak VE (l.min^{-1})	84.5	15.9
Peak VE/VO_2	35.6	4.9
Peak VE/VCO_2	31.7	2.3
METs	12.1	2.1
Peak Velocity (km.h^{-1})	12.0	1.6
HR at VT_1 (beats.min^{-1})	152.2	15.1
HR at VT_1 (%)	81.3	7.2
VO_2 at VT_1 (l.min^{-1})	1.5	0.5
VO_2 at VT_1 (ml.kg^{-1}.min^{-1})	26.0	7.3
VO_2 at VT_1 (%)	61.3	11.2
VCO_2 at VT_1 (l.min^{-1})	1.3	0.4
RER at VT_1	0.9	0.1
VE at VT_1(l.min^{-1})	37.4	10.4
$VE.VO_2^{-1}$ at VT_1	25.0	3.2
$VE.VCO_2^{-1}$ at VT_1	28.9	3.0
METs at VT1	7.4	2.1
Velocity at VT_1 (km.h^{-1})	7.1	1.1
HR at VT_2 (beats.min^{-1})	174.8	12.2
HR at VT_2 (%)	93.4	6.1
VO_2 at VT_2 (l.min^{-1})	2.2	0.5
VO_2 at VT_2 (ml.kg^{-1}.min^{-1})	36.9	7.0
VO_2 at VT_2 (%)	87.0	6.7
VCO_2 at VT_2 (l.min^{-1})	2.2	0.5
RER at VT_2	1.0	0.1
VE at VT_2 (l.min^{-1})	61.2	14.6
$VE.VO_2$ VT_2	28.6	3.5
$VE.VCO_2^{-1}$ at VT_2	27.6	2.4
METs at VT_2	10.5	2.0
Velocity at VT_2 (km.h^{-1})	9.8	1.4

Abbreviations used: HR = heart rate; MET = metabolic equivalent; RER = respiratory exchange ratio; SD = standard deviation; VCO_2 = carbon dioxide production; VE = minute ventilation; $VE{\cdot}VO_2^{-1}$ = ventilatory equivalent for oxygen; VO_2 = oxygen uptake; VT_1 = first ventilatory threshold; VT_2 = second ventilatory threshold.

The differences among the experimental conditions are shown in Table 2. Significant higher acute responses in HR (p = 0.002, t = 3.5, moderate effect d = 0.4), RER (p = 0.031, t = 2.3, moderate effect d = 0.4), VE (p = 0.026, t = 2.4, small effect d = 0.3), $VE \cdot VO_2^{-1}$ (p = 0.001, t = 3.7, moderate effect d = 0.5) and $VE \cdot VCO_2^{-1}$ (p = 0.039, t = 2.2, small effect d = 0.2) were found on an ADP compared with a hard surface (marble floor). No significant differences were detected in the rest of the acute cardiorespiratory responses among experimental conditions ($p > 0.05$).

Table 2. Acute cardiorespiratory responses during both experimental conditions

	ADP (SD)	% peak values$^{\lambda}$	MF (SD)	% peak values$^{\lambda}$
HR (beats.min^{-1})	171.7 (12.6)*	91.8	165.7 (14.6)	88.6
VO_2 (l.min^{-1})	1.8 (0.3)	72.0	1.7 (0.3)	71.6
VO_2 (ml.kg^{-1}.min^{-1})	30.0 (3.5)	70.9	29.8 (3.7)	70.4
VCO_2 (l.min^{-1})	1.7 (0.2)	59.0	1.6 (0.3)	57.4
RER	1.0 (0.1)$^{\delta}$	81.2	0.9 (0.1)	79.4
VE (l.min^{-1})	59.0 (9.6)$^{\delta}$	69.8	55.5 (11.6)	65.7
$VE.VO_2^{-1}$	34.1 (4.1)*	96.0	32.2 (3.7)	90.5
$VE.VCO_2^{-1}$	34.3 (3.2)$^{\delta}$	100	33.4 (3.4)	100
METs	8.6 (1.4)	70.9	8.5 (1.1)	70.3

Data are presented as mean and standard deviation (SD). Abbreviations used: ADP = Air dissipation platform; HR = heart rate; MET = metabolic equivalent; MF = marble floor; RER = respiratory exchange ratio; VCO_2 = carbon dioxide production; VE = minute ventilation; $VE \cdot VO_2^{-1}$ = ventilatory equivalent for oxygen; VO_2 = oxygen uptake. * Significantly different from MF, $p < 0.01$. $^{\delta}$ Significantly different from MF, $p < 0.05$. $^{\lambda}$ percentage considers peak values obtained in the incremental treadmill test.

In blood lactate concentrations, a significant exercise mode x time interaction effect was observed (p = 0.024, $F_{(4,88)} = 2.9$, $\eta_p^2 = 0.1$, SP = 0.8). A significant time effect was observed ($p < 0.001$, $F_{(4,88)} = 44.0$, $\eta_p^2 = 0.7$, SP = 1.0), and also a exercise mode effect (p = 0.002, $F_{(1,22)} = 12.5$, $\eta_p^2 = 0.4$, SP = 0.9). The Bonferroni test confirmed higher blood lactate levels when exercising on an ADP than a hard surface at 20-min, 30-min and 40-min ($p \leq 0.01$) (Figure 2A). RPE followed the same evolution in both exercise groups ($p > 0.05$) (Figure 2B).

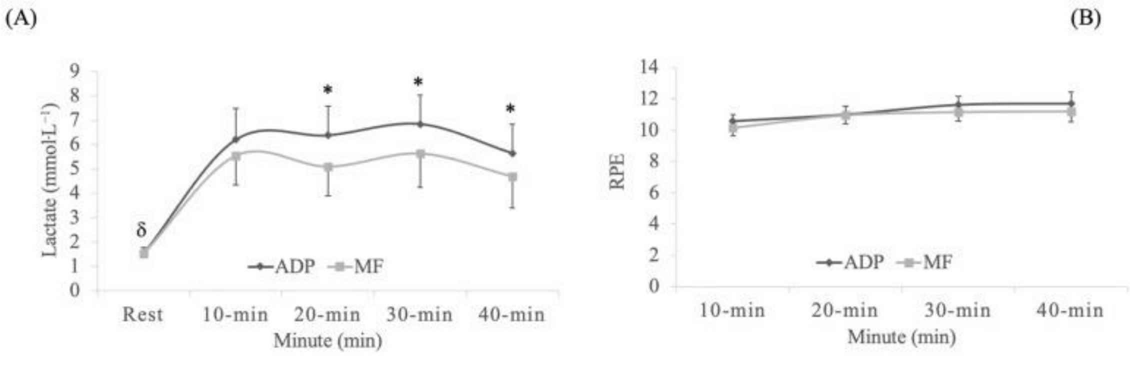

Figure 2. Blood lactate levels (**A**) and rating of perceived exertion (RPE) (**B**) during aerobic dance sessions. * Significantly different from marble floor at times 20-min, 30-min and 40-min, $p \leq 0.01$. Data are provided as mean and 95% confidence intervals (95% CI). $^{\delta}$ Significantly different from checkpoint at times10-min, 20-min, 30-min and 40-min in both experimental conditions, $p < 0.001$. Abbreviations used: ADP = air dissipation platform; MF = marble floor (hard surface).

In blood lactate concentrations, a significant exercise mode x time interaction effect was observed ($p = 0.024$, $F_{(4,88)} = 2.9$, $\eta_p^2 = 0.1$, SP = 0.8). A significant time effect was observed ($p < 0.001$, $F_{(4,88)} = 44.0$, $\eta_p^2 = 0.7$, SP = 1.0), and also a exercise mode effect ($p = 0.002$, $F_{(1,22)} = 12.5$, $\eta_p^2 = 0.4$, SP = 0.9). The Bonferroni test confirmed higher blood lactate levels when exercising on an ADP than a hard surface at 20-min, 30-min and 40-min ($p \leq 0.01$) (Figure 2A). RPE followed the same evolution in both exercise groups ($p > 0.05$) (Figure 2B).

In the CMJ test, no significant exercise mode × time interaction effect, time and exercise mode effects were observed ($p > 0.05$) (Figure 3).

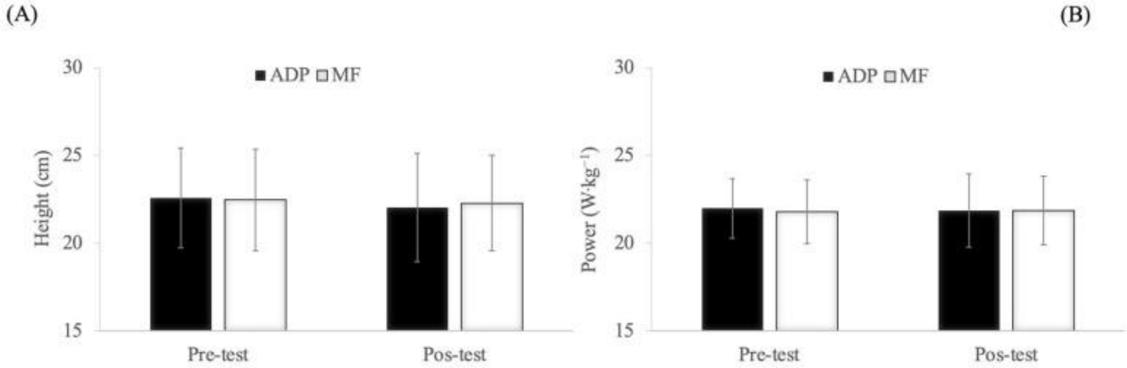

Figure 3. Muscular fatigue assessed by countermovement jump (CMJ) test before and after the aerobic dance classes. (**A**) Mean height (cm) in CMJ. (**B**) Mean power ($W \cdot kg^{-1}$) in CMJ. No significant differences were detected among experimental conditions. Abbreviations used: ADP = air dissipation platform; MF = marble floor (hard surface).

4. Discussion

The main finding of this study was that AD led by fitness instructors through a video-recorded session induced a higher HR, VE, RER, $VE \cdot VO_2^{-1}$, $VE \cdot VCO_2^{-1}$ and blood lactate concentrations on an ADP than on a hard surface. AD performed on both surfaces induced similar muscular fatigue in the lower extremities and feeling of physical exertion (RPE).

The HR was greater on an ADP (+3.8%) than on a hard surface. Recently, Rodrigues et al. [5] observed that elastic surfaces (mini-trampoline 76.5% of HRmax) increased the HR response compared to a hard surface (67.4% of HRmax) during a stationary running. It is possible that the higher HR observed on an ADP could be due to the rebounding and instability induced by the elastic surface, and consequently it would involve a greater effort to maintain balance during AD session [5]. AD in both surfaces indicated a percentage of peak HR similar to those reported in aerobic step dance performed with load (89.8%) [24]. However, the HR was higher on both surfaces than those observed in tap dance (83.8%) [25] and in an aerobic step dance performed without overload (84.5%) [24]. AD activities such as body pump, body combat and spinning have shown a low HR (60.2%, 73.2%, 74.3% of HRmax, respectively) [26]. Apart from the contact surface, the discrepancy in HR response could be attributed to the different dance modalities and class methodologies used for AD.

The observed HR in both surfaces demonstrated that a video-recorded AD session could be an adequate alternative for improving or maintaining cardiorespiratory fitness in healthy young women. The American College of Sports Medicine (ACSM) guidelines determines that vigorous intensity (≥~6 metabolic equivalents (METs), 77–95% of HRmax) of physical activity performed 3 $d \cdot wk^{-1}$ for a total of ~75 $min \cdot wk^{-1}$ or 20 $min \cdot d^{-1}$ improves or maintains cardiorespiratory fitness [27].

In this regard, both AD sessions may be considered as a vigorous exercise intensity (ADP: 8.6 MET/91.8% of HRmax vs. hard surface: 8.5 METs/88.6% of HRmax).

Blood lactate levels were increased to a greater extent on an ADP compared to a hard surface. Brito et al. [28] showed that unstable surfaces such as sand produced greater blood lactate levels in comparison to hard surfaces (4 $mmol \cdot L^{-1}$ and 2.8 $mmol \cdot L^{-1}$) during a soccer game. The authors concluded that playing on hard surfaces such as asphalt decreased the lactate anaerobic pathway more than playing on unstable surfaces. This appreciation suggests that differences in blood lactate levels between an ADP and a hard surface could be due to the fact that the impact forces induced by the damping are reduced on the platform. The instability and contact times on ADP would increase, causing increased muscle activation in the agonist and antagonist muscles as occurs on unstable surfaces [29]. This amplified muscle activation could accentuate the muscular work and, consequently, the lactate anaerobic metabolic pathway could be further activated. Future studies should be focused on comparing the activation of metabolic pathways between unstable and stable surfaces as long as the intensity of exercise proposed was the same.

In a similar study [25], lower blood lactate levels were found during a tap dance choreography compared to our study (1.7 $mmol \cdot L^{-1}$ vs. 6.3 $mmol \cdot L^{-1}$ and 5.2 $mmol \cdot L^{-1}$, respectively). We suggested that the differences observed between studies could be attributed to exercise intensity. The relative exercise intensity established in both AD activities was interpreted based on the ventilatory parameters obtained during an incremental treadmill test. To this end, VT1 and VT2 were determined by expert evaluators since it has been well established that performance in endurance exercise is linked to VTs [30,31]. To our knowledge, no studies have used VTs during an incremental treadmill test as a reference to identify the relative exercise intensity in an AD class performed on elastic and hard surfaces. Nevertheless, Oliveira et al. [25] used the lactate threshold in an incremental treadmill test to categorize the exercise intensity during a tap dance choreography. The lactate threshold and VT1 are certainly connected and occur at a comparable exercise intensity in several forms of exercise [32,33]. This disagreement among studies could be supported by the fact that tap dance exercise intensity was approximately 10% less than the lactate threshold. Our outcomes showed a relative exercise intensity above VT1 and next to VT2 in both surfaces. Accordingly, higher HR (ADP 8.7%, marble floor 5.4%), VO_2 (ADP 2.8%, marble floor 2.1%) and METs (ADP 5.8%, marble floor 4.7%) were observed in both AD sessions than in a tap dance choreography [25]. This augmented cardiorespiratory response justified, at least in part, a greater blood lactate levels observed in our study.

These differences in blood lactate concentrations among studies highlight the relevance of previously knowing exercise intensity (HR) through check points (ventilatory or lactate thresholds) that determine the metabolic changes in each participant. In this way, practitioners of activities such as fitness classes would know the workload or relative intensity (HR or VO_2) corresponding to the session. Additionally, researchers would be able to understand the underlying adaptive physiological mechanisms of the various AD modalities.

It is clear that knowledge of these VTs has been a key factor in discovering the cardiorespiratory exercise intensity and, consequently, understanding why there was a greater metabolic stress than in other studies. Ventilatory adaptation to CO_2 production threshold (VT1) is interpreted as the first non-linear increases in VCO_2 and ventilation due to the bicarbonate buffering of H^+ produced by a gradual increase in blood lactate levels above resting values [34]. VT2 is accepted as the second breakpoint in the ventilation response chiefly produced by a pH decrease as bicarbonate is saturated by the rising production of lactate (acidosis) [35]. Probably, the higher VE, RER, $VE \cdot VO_2^{-1}$, $VE \cdot VCO_2^{-1}$ detected on an ADP than on a marble floor could be due to this increase in acidosis and relative intensity very close to that observed during the incremental treadmill test in VT2.

In theory, this increased cardiac and metabolic stress would imply a higher VO_2 on an ADP than on a marble floor. However, VO_2 was similar among surfaces. VO_2 results differed from others that showed how elastic surfaces increased HR and VO_2 to a larger magnitude than hard surface [5]. Although we have not found studies evaluating several surfaces in AD modalities, a study on competitive tennis players revealed that the HR and blood lactate levels were higher on a softer surface, maintaining similar VO_2 [36]. Given these discrepancies, we did not find a rational physiological and biomechanical explanation. More studies are necessary to draw adequate conclusions.

VO_2 was similar in both surfaces (ADP: 70.9% vs. hard surface 70.4% of VO_2max). Analogous findings were found during stationary running on an elastic surface (68.9% of VO_2max) and aerobic step dance performed without overload (68.9% of VO_2max) confirming an adequate relative exercise intensity to provide cardiovascular improvements [25]. Nevertheless, VO_2 (78.3% of VO_2max) was increased in aerobic step dance carried out with overload [24]. External overload could be an added resource to increase the relative intensity (% of HRmax and VO_2max) produced by the rebound effect and the instabilities of the elastic surfaces.

Muscular fatigue has been assessed by CMJ test in several studies that analyzed cardiorespiratory and metabolic responses [12,13,18]. Despite finding a greater cardiometabolic and ventilatory stress on an ADP than on a hard surface, mechanical fatigue on an ADP was not augmented compared to a hard surface. We suspect that an ADP reduced the mechanical work done by the lower limbs by increasing leg stiffness on compliant elastic surface. Our arguments cannot be objectively corroborated since leg stiffness on an ADP was not measured, thus these interpretations remain purely speculative. However, it is assumed that the mechanical work is reduced by increasing leg stiffness on a compliant elastic surface [8,9]. Therefore, the joint strain and muscle fatigue could be minimized by using elastic surfaces. Soft surfaces may reduce the risk of joint injuries at high impact [6].

It would be logical to identify a greater perception of effort in response to a higher cardioventilatory and metabolic stress on an ADP; however, the RPE of the participants was the same throughout the session. The RPE is an excellent parameter to subjectively quantify the exercise intensity in fitness sessions [37]. It was the first time that participants used an ADP; therefore, the motivation to use a different apparatus could have been a differential factor for having a lesser sensation of physical effort. The greater feeling of pleasure on an ADP than on the marble floor was verified by the participants. More research would be necessary to determine the psychological and emotional benefits and adherence that this type of device could produce.

An AD session on an ADP could increase cardiorespiratory and metabolic demands by diminishing mechanical stress on the joints and muscle mass. Thus, this type of aerobic activity could be very suitable for elderly people (skeletal fragility) because they could achieve the same functional exercise intensity with less mechanical stress. Determining exercise intensity based on the type of surface in an AD class by using VTs would allow us to know whether acute cardioventilatory and metabolic responses are intense enough to promote long-term improvements (adaptations) in cardiorespiratory fitness.

Finally, the findings of this study are relevant because a video-recorded AD session on an ADP could be an excellent alternative to perform physical activity during forced periods of confinement due to pandemics (i.e., SARS-CoV-2). Long stays at home are likely to encourage sedentary behaviors such as spending more time sitting, lying down, playing video games, etc., leading to an increased risk and potential worsening of chronic health conditions. In this environment, the practice of physical activity at home is more than justified. Performing safe, simple and easy to implement exercises at home is very suitable to avoid airborne coronavirus and maintain fitness levels [38]. The ADP is a safe, simple and small device that can be used at home. The findings reported in this study demonstrated that a video-recorded AD session on an ADP induced a suitable exercise intensity. The supervision of fitness instructors would be recommended during AD sessions on an ADP to establish adequate guidelines for improving cardiorespiratory fitness in exercise home-programs. AD on an ADP performed 3 $d \cdot wk^{-1}$ for a total of ~75 $min \cdot wk^{-1}$ or 20 $min \cdot d^{-1}$ could be a very interesting alternative to maintain or improve cardiorespiratory and metabolic fitness according to the ACSM guidelines.

5. Conclusions

A video-recorded AD class on an ADP increases greater cardiorespiratory and metabolic responses than on a harder surface, without inducing greater muscular fatigue and feeling of physical exertion.

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Author Contributions

Conceived and designed the experiments: A.M.-R., J.L.M.-M. and M.V.G.-C.; performed the experiments: A.M.-R., J.L.M.-M., J.H.-L., P.G.-F., E.P.-C., T.C., N.A. and M.V.G.-C.; analyzed the data: A.M.-R., J.L.M.-M. and M.V.G.-C.; contributed reagents/materials/analysis tools: A.M.-R., J.L.M.-M., J.H.-L., P.G.-F., E.P.-C., T.C., N.A. and M.V.G.-C.; wrote the paper: A.M.-R., J.L.M.-M. and M.V.G.-C. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Artículo II

Similar Slow Component of Oxygen Uptake and Ventilatory Efficiency between an Aerobic Dance Session on an Air Dissipation Platform and a Constant-Load Treadmill Test in Healthy Women

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Abstract

Simple Summary

The evaluation of the kinetics of oxygen uptake is considered an essential practice to analyze the effect of exercise intensity, mainly in endurance exercise. This study aimed to compare the slow component of oxygen uptake, ventilatory efficiency, blood lactate concentration, and the rating of perceived exertion between an aerobic dance session on an air dissipation platform and a constant-load treadmill test. Seventeen young adult and healthy women (aged 23.5 ± 2.2 years) completed three evaluation sessions. In session 1, an incremental test to exhaustion was completed. In sessions 2 and 3, the participants were randomly assigned to the aerobic dance session on an air dissipation platform or to a treadmill test at a constant-load corresponding to the first ventilatory threshold. No significant differences were found between the constant-load treadmill test and aerobic dance session on an air dissipation platform regarding the slow component of oxygen uptake, ventilatory efficiency, and the rating of perceived exertion. Higher blood lactate concentrations were observed in the aerobic dance session on an air dissipation platform than in the constant-load treadmill test. In conclusion, two different exercise modalities elicited similar slow components of oxygen uptake, ventilatory efficiency, and ratings of perceived exertion, even though the blood lactate concentrations were different.

Abstract

There is a lack of evidence about the slow component of oxygen consumption ($\dot{V}O_2sc$), and ventilatory efficiency (slope $VE \cdot VCO_2^{-1}$) during an aerobic dance (AD) session on an air dissipation platform (ADP) despite the key role played in endurance exercises. This research was designed to assess $\dot{V}O_2sc$ ventilatory efficiency, and blood lactate concentration by comparing two exercise modes: AD session on an ADP versus treadmill test at a constant-load intensity of the first ventilatory threshold (VT1). In the first session, an incremental treadmill test was completed. In sessions 2 and 3, the participants were randomly assigned to the AD session on an ADP or to a treadmill constant-load test at VT1 intensity to determine their cardioventilatory responses. In addition, their blood lactate levels and ratings of perceived exertion (RPE, CR-10) were evaluated. No significant differences were found between the constant-load treadmill test and AD session on an ADP with respect to $\dot{V}O_2sc$, VE VCO_2^{-1} slope, and RPE ($p > 0.05$). Higher blood lactate concentrations were observed in an AD session on an ADP than in a constant-load treadmill test at 10 min ($p = 0.003$) and 20 min ($p < 0.001$). The two different exercise modalities showed similar $\dot{V}O_2sc$, and $VE \cdot VCO_2^{-1}$ slope, even though the blood lactate concentrations were different.

1. Introduction

The evaluation of the kinetics of oxygen uptake ($\dot{V}O_2$) is considered an essential practice to analyze the effect of exercise intensity on so-called endurance exercises [1] and resistance exercises [2] in several populations [3,4,5,6]. Specifically, the pulmonary $\dot{V}O_2$ has a tendency to raise beyond 3 min during any constant work rate exercise involving sustained lactic acidosis, and above that of the primary component initiated at exercise onset. This ventilatory response generated in the kinetics of $\dot{V}O_2$ is known as the slow component of $\dot{V}O_2$ ($\dot{V}O_2sc$) [7].

Cardioventilatory function could be altered by various parameters that condition the acute response of the $\dot{V}O_2sc$, such as the load intensity, the lactate threshold (LT), and the ventilatory threshold (VT) [2,8]. At exercise intensities below LT and VT, a steady state of $\dot{V}O_2$ has been observed without increasing the $\dot{V}O_2sc$ and blood lactate concentration. At exercise intensities above the LT or VT, an increase in the $\dot{V}O_2sc$ has been verified depending on the increase in the exercise intensity and the blood lactate concentration. At a load intensity of the LT or the first ventilatory threshold (VT1), a steady state of both the $\dot{V}O_2$ and the blood lactate concentration has been observed, as well as a slight-moderate increase in the $\dot{V}O_2sc$, both in endurance exercises and resistance exercises [2,9,10].

Cardiorespiratory performance is also frequently assessed by means of ventilatory efficiency. The relationship between ventilation (VE) and perfusion in the lungs is a key respiratory physiological mechanism to determine ventilatory efficiency in healthy people, athletes [11,12], and in those with respiratory diseases [13]. The VE/perfusion mismatch decreases the efficiency of pulmonary gas exchange, causing a state of hyperpnea and dyspnea that affects ventilatory performance [14]. The slope between the linear relationship of VE and carbon dioxide ($VE \cdot VCO_2^{-1}$ slope) has been frequently used as a prognostic marker of ventilatory efficiency during an incremental test up to the anaerobic or ventilatory threshold [15,16], the ventilatory compensation point [11], in constant-load endurance and resistance exercise tests, and in resistance exercises of moderate and very high intensities [17,18].

As with the $\dot{V}O_2sc$, exercise intensity also modulates the ventilatory efficiency response [18]. As exercise intensity increases, ventilation is increased to remove CO_2 and maintain homeostatic control of pH [12], arterial hypoxemia [19], and lactic acidosis [20], thereby conditioning ventilatory efficiency [18]. At a constant-load intensity of the LT, similar to VT1, it has been proposed that both endurance exercises and resistance exercises maintain an efficient $VE \cdot VCO_2^{-1}$ slope in a predominantly aerobic metabolism with a low blood lactate concentration (~2.7 $mmol \cdot L^{-1}$) [17]. It has been suggested that both the $\dot{V}O_2sc$ and ventilatory efficiency could be conditioned, at least in part, by the type of exercise [17,21]. The $\dot{V}O_2sc$ is higher in cycling compared to running exercises [21], and it even increases to a greater extent in the half-squat exercise compared to the cycle ergometer test at LT intensity [2]. However, the $VE \cdot VCO_2^{-1}$ slope has generated controversy due to the lack of further studies in this regard with which to draw more accurate conclusions. Some studies showed that the $VE \cdot VCO_2^{-1}$ slope is dependent on the mode of exercise [22], whereas others discard this hypothesis [11].

Aerobic dance (AD) classes are a very popular type of exercise worldwide, especially among women. AD is a choreographed activity of moderate to vigorous intensity accompanied by music and perceived as enjoyable [23,24]. Parameters such as $\dot{V}O_2$, heart rate (HR), and blood lactate concentration have been frequently used to determine the exercise intensity during a normal AD session [25]. Recent contributions from our research group have determined that the execution surface in AD activities can influence cardiorespiratory and metabolic responses. Unstable surfaces with a higher elastic component, such as an air dissipation platform (ADP), could increase the blood lactate concentration (~6 $mmol \cdot L^{-1}$) and cardioventilatory response during an AD session higher than on hard surfaces [26]. This increase in acute cardioventilatory and metabolic responses after the ADP session can be due to a decline in the damping-induced impact forces and an enhance in instability and contact times. From a physiological perspective, greater muscular tissue stimulation is expected in agonist and antagonist muscles [27]. This amplified activation can increase muscle work, causing a higher demand of the anaerobic metabolic pathway compared to a hard surface [28].

Other studies have shown that the type of AD conditions the exercise intensity to a greater degree compared to various intensities on a treadmill [29]. Therefore, it seems that the efficacy of AD exercises depends on the type of dance, the exercise intensity, and the surface of execution.

A steady state of $\dot{V}O_2$ and blood lactate concentration, as well as an adequate ventilatory efficiency with a low blood lactate concentration (~2.7 mmol·L^{-1}), has been observed at a load intensity of the LT or the VT1 in predominantly aerobic metabolism (2, 9, 10, and 17). However, higher cardioventilatory responses and blood lactate concentrations (~6 mmol·L^{-1}) have been verified in an AD session on an ADP compared to a hard surface [26]. Given the differences observed between several exercise modes, the treadmill, and various types of AD, it is plausible to propose that AD session on an ADP could condition the kinetics of $\dot{V}O_2$ by increasing the $\dot{V}O_2$sc and decreasing ventilatory efficiency to a greater extent than a treadmill test at an intensity of VT1 (~3 mmol·L^{-1}), in which aerobic metabolism predominates. However, to the best of our knowledge, the $\dot{V}O_2$sc and ventilatory efficiency during an AD session on an ADP have not been studied to date. This knowledge would allow us to investigate other variables to interpret how the intensity of exercise is modulated in an AD session on an ADP. The purpose of this study was to assess the $\dot{V}O_2$sc, the VE·VCO_2^{-1} slope, and blood lactate concentration by comparing a constant speed treadmill test at VT1 loading intensity with an AD test on an ADP in healthy young adult women. We hypothesize that an AD test on an ADP raises the $\dot{V}O_2$sc and the VE·VCO_2^{-1} slope to a greater degree than a treadmill trial at VT1 loading intensity.

2. Materials and Methods

2.1. Study Design

This is a cross sectional, comparative study. The participants completed three assessment sessions over 21 days in the exercise physiology laboratory. In the first test session, an incremental treadmill trial to exhaustion was completed to assess peak and VT1 cardiorespiratory responses. At the second testing session, which took place one week later, participants were randomly assigned to either the AD test on an ADP or a treadmill trial with a constant speed corresponding to the intensity of VT1. One week later, session 3 was held, in which the participants performed the pending protocol that was not conducted in session 2, and under the same conditions. The objective in sessions 2 and 3 was to determine the cardioventilatory responses for the subsequent analysis of the $\dot{V}O_2$sc and VE·VCO_2^{-1} slope. Blood lactate concentration and rating of perceived exertion (RPE, CR-10) produced in sessions 2 and 3 were evaluated. The participants refrained from any type of physical exertion 24 h before starting the evaluation sessions.

2.2. Participants

Seventeen healthy women (23.5 ± 2.2 years, 58.6 ± 6.8 kg, 162.6 ± 0.1 cm, and 22.4 ± 2.5 body mass index) who were lightly physically active or moderate a maximum of 2 to 3 times per week completed the three test session. Participants were familiarized with the experimental procedures (AD and treadmill protocols). The following exclusion criteria were established: (1) any cardiovascular, metabolic, neurological, pulmonary, or orthopedic disorders that could limit exercise performance; (2) being an elite athlete; (3) tobacco or alcohol intake; and (4) the use of any performance-enhancing medication, drug, or supplement. The participants were informed of all experimental tests and signed an informed consent form. The study protocol received the approval of the University Ethics Committee and was carried out in accordance with the principles of the Declaration of Helsinki.

2.3. Treadmill Test

Before the start of the evaluation sessions on a treadmill (TechnoGym, Runrace 1400HC, Forlí, Italy), a 5-min warm-up was carried out at a speed of 5–6 km h^{-1}, followed by 5 min of dynamic joint mobility exercises. Next, the incremental treadmill protocol was started at an initial speed of 5.5 km h^{-1} (1% slope), which was increased by 0.5 km h^{-1} every 30 s, until exhaustion. The constant speed test was performed at VT1 load intensity for 20 min.

2.4. Aerobic Dance

Each participant performed an AD session on an ADP. The ADP consists of a platform of one meter in diameter and 20 cm high, which rests on an elastomer that contains air at atmospheric pressure and allows for the entry and exit of air through holes. The air stored in the area produces a rebound effect, lessening the impact and rising instability during movements on the platform. First, a 5-min warm-up on the ADP was performed, followed by 5 minutes of dynamic joint mobility exercises. Subsequently, the main part of the AD test was carried out on an ADP, which lasted 20 min. The AD test was implemented by an experienced trainer to be executed at a constant light to moderate intensity as in a previous study [26].

2.5. Cardiorespiratory Record

In the two sessions on a treadmill and in the AD session on an ADP, respiratory exchange data were recorded using a breath-to-breath open-circuit gas analyzer (Vmax spectra 29, Sensormedics Corp., Yorba Linda, CA, USA), which had been previously calibrated. The following variables were recorded: $\dot{V}O_2$, VE, carbon dioxide production (VCO_2), ventilatory oxygen equivalent ($VE \cdot \dot{V}O_2^{-1}$), ventilatory equivalent of carbon dioxide ($VE \cdot VCO_2^{-1}$), respiratory exchange rate (RER), partial pressure of oxygen at expiration ($PetO_2$), and partial pressure of carbon dioxide at expiration ($PetCO_2$). HR was controlled every 5 sec by telemetry (RS-800CX, Polar Electro OY, Helsinki, Finland). VT1 was defined as the workload (speed) at which increases occurred in both $VE \cdot \dot{V}O_2^{-1}$ and $PetO_2$, with no concomitant increase in $VE \cdot VCO_2^{-1}$ [30].

During the constant-load test at an intensity of VT1 on a treadmill and the AD session on an ADP, the kinetics of pulmonary $\dot{V}O_2$ were evaluated. Pulmonary $\dot{V}O_2$ data were recorded during the 2 min prior to the start of the constant test (baseline state). Baseline $\dot{V}O_2$ ($\dot{V}O_{2B}$) was considered to mean the last 60 s before the start of the test. The fundamental kinetics (Phase II) of $\dot{V}O_2$ were determined using the criteria described above and were adjusted to a mono-exponential function, $\dot{V}O_2(t) = \dot{V}O_{2B} + \Delta\, \dot{V}O_{2FP} \bullet (1^{\,-\,e\,-\,(t-TR/\tau)})$ [31], where $\dot{V}O_2(t)$ is the value of pulmonary $\dot{V}O_2$ at any time *t* of the kinetics of $\dot{V}O_2$, $\dot{V}O_{2B}$ is the value of basal $\dot{V}O_2$, $\Delta\, \dot{V}O_{2FP}$ is the increase in $\dot{V}O_2$ above the reference values and determines the range of the fundamental phase, and τ is the time constant of the fundamental phase. TR is the delay time. The exponential region of each participant was adjusted individually [32]. To determine the $\dot{V}O_2sc$ (Phase III), the data of pulmonary $\dot{V}O_2$ were recorded. Finally, the $\dot{V}O_2sc$ was determined in each participant: $\Delta\, \dot{V}O_2sc = \dot{V}O_{2peak} - (\dot{V}O_{2B} + \Delta\, \dot{V}O_{2FP})$ [32].

2.6. Metabolic Fatigue and Rating of Perceived Exertion

Metabolic fatigue was assessed by means of a transportable lactate apparatus (Lactate Pro LT-1710, Arkray Factory Inc., KDK Corporation, Siga, Japan). For this purpose, blood lactate concentration was quantified in the capillary of the index finger at rest, at 10 min and at the end of the test. The RPE was controlled applying the Borg scale (CR-10) [33] and was assessed in accordance with blood lactate measurements.

2.7. Statistical Analysis

The Shapiro-Wilk test was applied for testing multivariate normality. To apply the statistical treatment, the data were presented as mean, percentages and confidence intervals (95% CI).

A Student's *t*-test for paired samples was utilized to verify statistically significant changes between both experimental sessions (ADP vs. treadmill test). A two-way analysis of variance (ANOVA) for repeated measures was completed to confirm significant differences between an AD session on an ADP and a constant-load treadmill test with respect to blood lactate concentration and RPE. When appropriate, a Bonferroni post hoc adjustment for multiple comparisons was implemented. The magnitude of the response was calculated using the partial eta-squared (ηp^2). Sample size was estimated with $\alpha = 0.05$ (5% probability of type I error) and $1 - \beta = 0.80$ (power 80%). The statistical power (SP) was also calculated using G*Power 3. The Pearson product–moment correlation coefficients were calculated to determine significant relationships between the VE and the VCO_2. SPSS Statistics software package version 25.0 for Mackintosh (SPSS, Chicago, IL, USA) was used for statistical procedures. Statistical significance was set at $p < 0.05$.

3. Results

The data related to the incremental treadmill test are indicated in Table 1.

Table 1. Cardioventilatory data achieved during the incremental treadmill test.

Variable	N	Minimum	Maximum	Mean	SD
HR (beats•min^{-1})	17	173.0	198.0	187.2	7.4
Absolute peak VO_2 (L•min^{-1})	17	1.7	3.6	2.4	0.5
Relative peak VO_2 (mL•kg^{-1}•min^{-1})	17	30.1	54.8	41.4	7.5
Peak VCO_2 (L•min^{-1})	17	2.0	3.9	2.9	0.5
Peak RER	17	1.1	1.4	1.2	0.1
Peak VE (L•min^{-1})	17	54.7	109.7	84.7	17.0
Peak VE•VO_2^{-1}	17	29.0	47.0	36,5	5.1
Peak VE•VCO_2^{-1}	17	28.0	36.0	32.5	2.2
Peak Speed (km•h^{-1})	17	9.5	15.0	12.2	1.7
HR at VT1 (beats•min^{-1})	17	127.0	174.0	150.1	13.1
Absolute VO_2 at VT1 (L•min^{-1})	17	0.6	2.5	1.5	0.5
Relative VO_2 at VT1 (mL•kg^{-1}•min^{-1})	17	11.1	37.1	25.4	7.2
VCO_2 at VT1 (L•min^{-1})	17	0.5	2.2	1.3	0.4
RER at VT1	17	0.7	1.0	0.9	0.1
VE at VT1 (L•min^{-1})	17	17.9	59.6	37.7	10.4
VE•VO_2^{-1} at VT1	16	21.0	34.0	25.4	3.6
VE•VCO_2^{-1} at VT1	16	24.0	34.0	28.8	3.2
Speed at VT1 (km•h^{-1})	17	5.0	9.0	7.1	1.2

Abbreviations used: HR = heart rate; RER = respiratory exchange rate; SD = standard deviation; VCO_2 = carbon dioxide production; VE = minute ventilation; VE·VCO_2^{-1} = ventilatory equivalent of carbon dioxide; VE·VO_2^{-1} = ventilatory oxygen equivalent; VO_2 = oxygen uptake; VT1 = first ventilatory threshold

No significant differences were found between the constant-load treadmill test at VT1 intensity and the AD session on an ADP with respect to the V.O2sc ($p = 0.642$; Figure 1) and the VE·VCO_2^{-1} slope ($p = 0.520$; Figure 2).

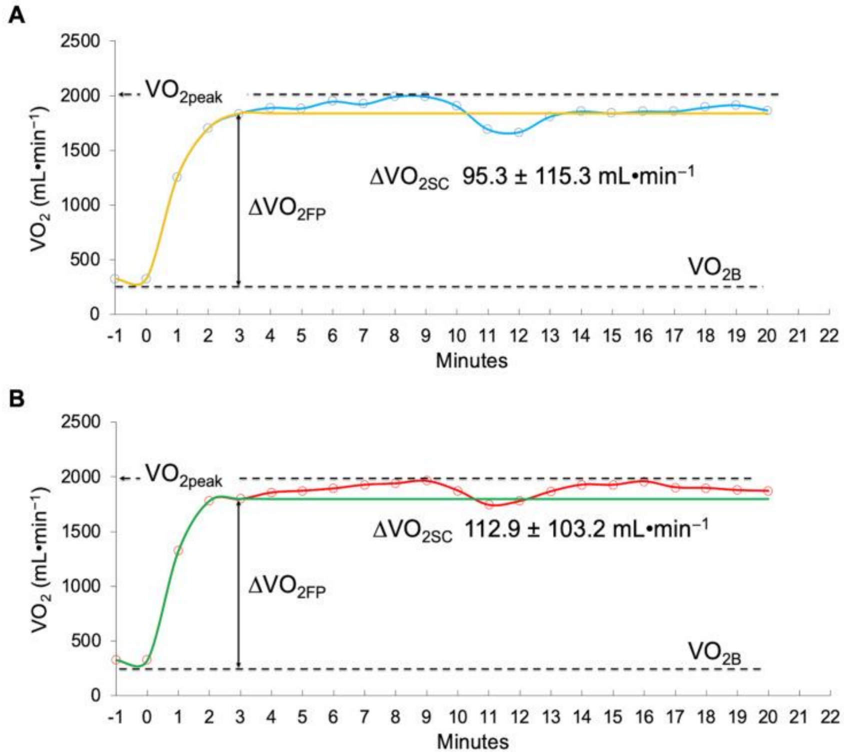

Figure 1. Slow component of oxygen uptake ($\dot{V}O_{2}sc$): (A) Aerobic dance on an air dissipation platform (blue line: $\dot{V}O_{2sc}$ of participants; yellow line: $\dot{V}O_{2sc}$ expected at VT_1) (B) Constant speed treadmill test at VT1 intensity (red line: $\dot{V}O_{2sc}$ of participants; green line: $\dot{V}O_{2sc}$ expected at VT_1). Abbreviations: ΔVO_{2FP} = increase in oxygen uptake in the fundamental phase; VO_{2B} = baseline oxygen consumption

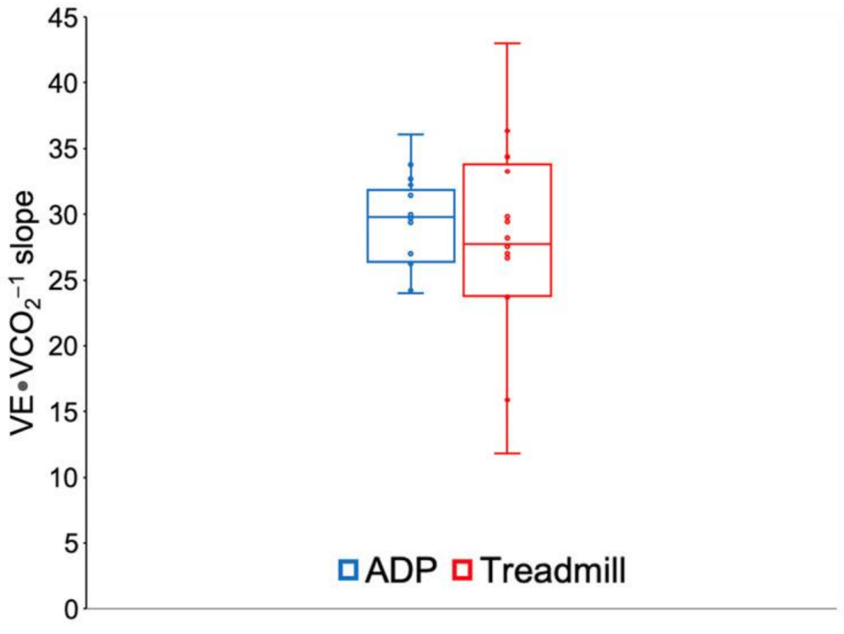

Figure 2. Ventilatory efficiency ($VE \bullet VCO_2^{-1}$ slope) during aerobic dance (AD) exercise on an air dissipation platform (ADP) and constant-load treadmill test at VT1 intensity.

Excellent correlations were verified between the VE and VCO_2 in the constant-load treadmill test (r = 0.93; $p < 0.001$) and in the AD session on an ADP (r = 0.83; $p < 0.001$).

The differences between the constant-load treadmill test at VT1 intensity and the AD session on an ADP concerning the blood lactate concentration and RPE are shown in Table 2.

Table 2. Differences in blood lactate concentrations and RPE between an AD session on an ADP and a constant-load treadmill test at VT1 intensity

	ADP (95% CI)			Treadmill (95% CI)			*P1*	*P2*	*P3*
	Rest	10 min	20 min	Rest	10 min	20 min	ES/SP	ES/SP	ES/SP
Lactate (mmol•L^{-1})	1.5*	5.9$^{\Psi}$	6.5$^{\#}$	1.5*	3.8$^{\delta}$	2.9	**< 0.001**	**< 0.001**	**< 0.001**
	(1.2-1.7)	(4.6-7.4)	(5.2-7.7)	(1.3-1.7)	(3.0-4.6)	(2.3-3.7)	(0.5-0.9)	(0.8-1.0)	(0.6-0.9)
RPE		10.3	10.7		10.8	11.6	0.300	**0.034**	0.318
		(9.8-10.8)	(10.0-11.4)		(9.6-12.0)	(9.9-13.3)	(0.1-0.2)	(0.3-0.6)	(0.1-0.2)

Abbreviations used: AD: aerobic dance; ADP: air dissipation platform; ES: effect size; RPE: ratio of perceived effort; SP: statistical power; VT1: first ventilatory threshold. P^1 Significant differences for exercise mode x time interaction effect. P^2 Significant differences for time effect. P^3 Significant differences for exercise mode effect. Data are provided as mean and 95% confidence intervals (95% CI). Bonferroni post hoc adjustment for multiple comparisons: $^{\Psi}$Significant differences compared to 10 min treadmill (p = 0.003). $^{\#}$Significant differences compared to 20 min treadmill (p < 0.001). *Significant differences compared to 10 min and 20 min (p < 0.001, AD on an ADP; p ≤ 0.002, treadmill). $^{\delta}$Significant differences compared to 20 min treadmill (p = 0.016)

Regarding the blood lactate concentration, a significant interaction effect (mode·time) was observed ($p = 0.001$, $\eta p^2 = 0.6$, SP = 0.9). Significant time and mode effects were detected ($p < 0.001$, $\eta p^2 = 0.9$, SP = 1.0; $p < 0.001$, $\eta p^2 = 0.6$, SP = 0.9, respectively). The Bonferroni post hoc adjustment determined significantly higher blood lactate concentrations in the AD session on an ADP than in the constant-load treadmill test at 10 min ($p = 0.003$) and 20 min ($p < 0.001$). Concerning the RPE, no significant interaction and mode effects were verified ($p > 0.05$). A significant time effect was found ($p = 0.034$, $\eta p^2 = 0.3$, SP = 0.6).

4. Discussion

Contrary to our study hypothesis, the main finding was that although the AD session on an ADP induced higher blood lactate concentrations than the constant-load treadmill test, both protocols (treadmill versus ADP) elicited similar responses in the $\dot{V}O_2$sc, ventilatory efficiency, and RPE in the healthy young adult women**.**

The results observed with respect to the $\dot{V}O_2$sc (absolute values: 95.3 mL in 20 min; relative values: 4.68 mL·min^{-1}) were slightly lower (not significant) than those verified in the treadmill test (absolute values: 113 mL in 20 min; relative values: 5.65 mL·min^{-1}). In previous studies with samples of similar characteristics, we found slightly higher values in African American women (absolute values: 120 mL in approximately 9 min; relative values: 13.33 mL·min^{-1}) and much higher values in Caucasian women (absolute values: 170 mL in ~8 min; relative values: 21.25 mL·min^{-1}) at an intensity of 25% above the gas exchange threshold in a cycle ergometer test [34]. It is likely that the differences observed can be attributed to the exercise intensity applied in each study and to the fact that the cycle ergometer tends to raise the $\dot{V}O_2$sc, to a greater extent than a treadmill at the same relative intensity [21].

Another study found increases in $\dot{V}O_2$ 599 mL·min^{-1} in women with lupus erythematosus and 540 mL·min^{-1} in healthy sedentary women during a 6-minute walk test on a treadmill at an intensity of 3 MET [35]. Despite being a lower intensity test compared to our study, the $\dot{V}O_2$ rose to a greater extent beyond the third minute to the sixth than during our twenty-minute test, indicating that cardiorespiratory fitness could also be another fundamental element that conditions the $\dot{V}O_2$sc [36]. We did not find a relationship between cardiorespiratory fitness and the $\dot{V}O_2$sc reported in other studies [37].

The physiological mechanisms that influence $\dot{V}O_2$sc are diverse as well as uncertain. The kinetics of $\dot{V}O_2$ showed a similar steady state from the third minute in the AD session and in the treadmill test, justifying the similarity of the exercise intensity in both tests, which were corroborated by a very similar $\dot{V}O_2$sc. In theory, the blood lactate concentration should not increase in response to a clearly aerobic metabolism in both experimental conditions. However, the blood lactate concentration increased significantly after the AD session on an ADP compared to the treadmill test, evidencing a transition to increased anaerobic metabolism [38]. In the AD session on an ADP, there was a paradoxical result, since the increase in the blood lactate concentration would indicate an exercise intensity above the LT or anaerobic threshold [39], which in theory should increase the $\dot{V}O_2$sc. The fact that the $\dot{V}O_2$sc did not increase could be due, at least in part, to the fact that there was a significant degree of energy contribution from anaerobic sources.

It is likely that the supply of O_2 to active skeletal muscle was deficient, since the intensity of muscle contraction was intense enough to cut off arterial and venous flow, causing other predominantly anaerobic metabolic sources to be activated [40]. In this regard, it is possible that an elastic surface such as an ADP contributed to the increased blood lactate levels. Previous research has shown that elastic or softer surfaces increase blood lactate concentration to a greater extent than hard surfaces, while maintaining a stationary and similar $\dot{V}O_2$ [26,41]. Instability and contact times increase during an AD session on an ADP. The impact forces induced by the damping are reduced, causing greater muscle activation in the agonist and antagonist muscles [27]. This amplified muscle activation could increase muscle work and potentiate a higher demand from the anaerobic sources compared to a hard surface [28]. In addition, a significant part of the energy from the anaerobic sources cannot be quantified by gas exchange [42], which explains, to a certain extent, why an increase in the $\dot{V}O_2$ and $\dot{V}O_2$sc amplitude was not observed. It is likely that the increased lactate production during an AD session would be beneficial to supplying the anaerobic source demands induced by an ADP. More studies will be needed to substantiate such claims.

The increased anaerobic environment produced by the increased blood lactate concentration in the AD session on an ADP would be expected to induce an increase in the VE·VCO$_2^{-1}$ slope [18]. The increase in exercise intensity induces an increase in the blood lactate levels, CO_2 levels, and the number of hydrogen ions [H^+]. The accumulation of lactate and [H^+] is mainly due to intracellular glycolysis [43,44], and they are both released into the extracellular fluid [45,46]. In theory, the ventilatory efficiency would decrease as a result of the increasing ventilation required to eliminate the CO_2 produced in order to maintain pH homeostasis, causing a mismatch in the ventilation–perfusion relationship. However, no changes were noted in terms of ventilatory efficiency between both exercise modalities; thus, this mismatch in the ventilation–perfusion relationship did not occur, which is typical as the exercise intensity increases [18]. This confirms that the exercise intensity in both modalities was not high enough to cause this mismatch in the ventilation–perfusion ratio.

Comparing them with other studies with healthy adult women, we found similar values (VE·VCO$_2^{-1}$ slope of 28.7) during an incremental protocol on a treadmill [47]. In another study, slightly lower VE·VCO$_2^{-1}$ values (24.1) were reported during a cycle ergometer test in healthy adult women [11]. In strenuous high-intensity exercise with blood lactate concentrations close to 18 mmol·L^{-1}, the VE·VCO_2^{-1} slope could exceed values of 40 [18].

From a mechanistic perspective, the VE·VCO_2^{-1} slope data (Figure 2) showed different variabilities between the treadmill test and the AD session on an ADP. The analysis of the differences between both modes of exercise accounted for the different variances between both groups. In this case, no homogeneity of variances was identified between both groups (homoscedasticity).

Few studies have compared the VE·VCO_2^{-1} slopes between different exercises modalities. Our findings showed that two different exercise modalities with similar responses in $\dot{V}O_2$ and the $\dot{V}O_2$sc and different metabolic responses had similar ventilatory efficiency values. Other studies found no difference between treadmill and cycle ergometer tests, although both exercise modalities showed a lower VE·VCO_2^{-1} slope compared to a robotics-assisted tilt table [48]. There appears to be a trend towards a similar VE·VCO_2^{-1} slope between different exercise modalities at the same relative intensity [12].

A similar RPE was observed in both exercise modalities, which indicates the enjoyment that the AD session can produce [24].

Several of this study's limitations should be considered. AD is a complex exercise modality for assessing the $\dot{V}O_2$sc, since maintaining constant $\dot{V}O_2$ kinetics, unlike the constant-load test (treadmill), depends on the intensity, which is always determined by the AD monitor. Although the kinetics of $\dot{V}O_2$ were similar between both exercise modes, the movements performed in the AD session on an ADP were different from those observed in the treadmill test. This different methodology could have influenced the final results.

5. Conclusions

Our findings indicated that the AD session on an ADP and the treadmill test at a constant-load intensity of VT1 elicited similar $\dot{V}O_2$sc, VE·VCO_2^{-1} slope, and RPE values in healthy young adult women, despite the fact that the AD session on an ADP induced higher blood lactate concentrations than the treadmill test.

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Author Contributions

Conceived and designed the experiments A.M.-R. and M.V.G.-C.; performed the experiments, A.M.-R., J.L.M.-M., J.H.-L., T.C., N.A., J.R.H.-E., P.G.-F. and M.V.G.-C.; analyzed the data, A.M.-R., J.R.H.-E. and M.V.G.-C.; contributed reagents/materials/analysis tools A.M.-R., E.P., J.L.M.-M., J.H.-L., T.C., N.A., J.R.H.-E. and M.V.G.-C.; wrote the paper. A.M.-R., N.A. and M.V.G.-C. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

The study protocol approval from the ethics committee of the university and adhered to the tenets of the Declaration of Helsinki.

Informed Consent Statement

Not applicable**.**

Conflicts of Interest

The authors declare no conflict of interest.

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Artículo III

Aerobic Dance on an Air Dissipation Platform Improves Cardiorespiratory, Muscular and Cellular Fitness in the Overweight and Obese Elderly

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Simple Summary: Aerobic dance is considered a viable strategy to prevent the effects of aging, mainly in obese and overweight elderly people. This study aimed to evaluate the effects of aerobic dance on an air dissipation platform (ADP) on body composition, oxidative stress and muscular and cardiorespiratory fitness in 32 elderly adults (67.1 ± 3.6) who were divided into 3 groups based on body mass index: healthy (HG), overweight (OWG) and obese (OG). Training program of aerobic dance on an ADP was carried out twice a week for 12 weeks at an intensity of 6–8 on the scale of subjective perception exertion (Borg Scale, CR-10). There was a significant decrease in malondialdehyde concentrations in all experimental groups. OWG and OG significantly improved their peak oxygen uptake. An interaction effect was observed in vertical flight height and power output, during the jump test. HG increased the vertical jump height, and HG and OG improved the power output of the lower extremities. In conclusion, aerobic dance on an ADP may be an effective alternative to lose weight, prevent oxidative stress and improve cardiorespiratory fitness in obese and overweight elderly people.

Abstract Background: Obesity is a global health problem associated with a high number of comorbidities that decrease functional capacity, especially in elderly people. Aerobic dance is considered a viable strategy to prevent the effects of aging, mainly in obese and overweight elderly people. This study aimed to evaluate the effects of aerobic dance on an air dissipation platform (ADP) on body composition, oxidative stress and muscular and cardiorespiratory fitness in elderly people. Methods: In total, 32 elderly adults (67.1 ± 3.6) were divided into 3 groups based on body mass index: healthy (HG), overweight (OWG) and obese (OG). Training program of aerobic dance on an ADP was carried out twice a week for 12 weeks. Results: OWG ($p = 0.016$) and OG decreased their weight ($p < 0.001$). There was a significant decrease in malondialdehyde concentrations in all experimental groups ($p < 0.05$). OWG and OG significantly improved their peak oxygen uptake ($p < 0.01$). HG increased the vertical jump height ($p < 0.05$), and HG and OG improved the power output of the lower extremities ($p < 0.05$). Conclusions: The aerobic dance on an ADP may be an effective alternative to lose weight, prevent oxidative stress and improve cardiorespiratory fitness in obese and overweight elderly people.

Keywords: obesity, body composition, elderly, oxidative stress, human performance, cardiorespiratory fitness, aerobic dance, health promotion

1. Introduction

Obesity is a global health problem associated with a high number of comorbidities that affect quality of life and decrease functional capacity, especially in elderly people. Globally, the prevalence of obesity in adults increased from 6.4% to 14.9% in women and from 3.2% to 10.8% in men between 1975 and 2014 [1]. Population studies have shown the relationship between a body mass index (BMI) higher than 25 kg/m^2 (especially a BMI ≥ 30 kg/m^2) and greater functional impairment [2,3]. In elderly people, BMI ≥ 25 kg/m^2 is related to chronic diseases, metabolic syndrome, diabetes [4], frailty [5] and increased mortality [5,6].

At the cellular level, increased concentrations of reactive oxygen and nitrogen species (RONS), combined with the reduction in endogenous antioxidants are common features for both, the aging process and obesity, increasing oxidative stress [7,8,9]. The imbalance between the antioxidant systems and free radical overproduction leads to cell oxidative damage affecting tissue components such as lipids, proteins or deoxyribonucleic acid (DNA) molecules [10].

Obesity leads to an increase in adipose tissue, triggering the release and storage of lipids in the skeletal muscle. These intramuscular lipids and their derivatives induce a mitochondrial dysfunction characterized by alterations in β-oxidation capacity, therefore, increasing oxidative stress (ROS) and impairing metabolic function [11]. The main products of lipid peroxidation are lipid hydroperoxides where malondialdehyde (MDA) is commonly formed as a secondary by product. It has been described that lipid peroxidation is greater in skeletal muscle mass in obese adults [12]. Several studies have shown that sarcopenia, high BMI and increased MDA concentrations are all parameters [13,14,15] related to an augmented risk of cardiovascular diseases [16,17] and incidence of atherosclerotic processes involving circulating lipoproteins [10].

Countless studies point to regular physical activity as one of the most beneficial resources for delaying the physiological deterioration induced by aging and obesity [18,19,20]. Specifically, aerobic dance (AD) is one of the most practiced aerobic activities in the world, mainly in senior centers [21]. AD is characterized by a sequence of impact movements choreographed to the rhythm of the music. Several studies have proposed that AD improves muscular strength, cardiorespiratory endurance, body agility, flexibility [22,23], lower body function [24] and locomotion/agility and balance, thus attenuating risks of falling in elderly adults [25]. AD exercise programs have been shown to reduce body weight, fat mass and cardiovascular disease risks in overweight and obese women [26], as well as improve maximal oxygen uptake (VO_2), decrease MDA levels and enhance antioxidant capacity [27]. From a psychological perspective, AD has been confirmed to have a positive effect on cognition in older people [28].

Exercise programs for the elderly that include unstable surfaces have been proposed to induce improvements in physical capabilities, such as muscle strength, power and balance [29,30], functional mobility, gait performance [19] and appear to be a good alternative to reduce the impact on joints [31]. Unstable surfaces have been shown to be a suitable alternative for improving cardiorespiratory fitness and producing positive changes in body composition in overweight women [32]. In addition, several studies have shown that exercise performed on unstable surfaces can be more intense compared to exercise on the ground [33,34,35].

Recently, our research group incorporated an air dissipation platform (ADP) in AD sessions. The ADP contains an area that rests on an elastomer with holes through which air flows. The amount of air that remains in the area produces rebound damping, reducing impacts during exercise and increasing instability. In a previous study, we demonstrated that an AD session on an ADP increased metabolic and cardiorespiratory responses compared to a hard surface, maintaining the perception of greater effort and muscle fatigue. [35]. We suggested that an AD exercise program on an ADP carried out 3 $d \cdot wk^{-1}$ for 75 $min \cdot wk^{-1}$ or 20 $min \cdot d^{-1}$ could maintain or improve metabolic and cardiorespiratory fitness, according to the American College of Sports Medicine (ACSM) guidelines [18].

To our knowledge, there are no studies assessing the effects of AD on an ADP on oxidative stress and cardiorespiratory and muscular function in obese or overweight older people. Therefore, this study aimed to investigate the chronic effects of an exercise program of AD performed in an ADP on cardiorespiratory and muscular fitness and oxidative stress in overweight and obese older people.

2. Materials and Methods

2.1. Subsection

The exercise program was explained in detail to the participants in the preliminary meeting. In the first session, all subjects were rigorously evaluated for comorbidities and diseases and their medical history was analyzed. In addition, their level of physical activity was checked up using an international physical activity questionnaire (IPAQ-E) for measurement of physical activity in people over 65 years of age [36].The AD program in an ADP lasted 12 weeks. Before (pre-test) and after (post-test) the AD program, the same tests were carried out by the same evaluators to determine the effects of the exercise program in an ADP on body composition, oxidative stress and cardiorespiratory and muscular fitness. Previously, a familiarization session was performed of the muscular and cardiorespiratory fitness tests. The participants did not perform any physical effort for 48 h before the tests. The tests and the order of the tests were defined as follows (Figure 1): 1st assessment of body composition, 2nd capillary blood collection, 3rd assessment of muscular fitness (lower extremity strength, upper extremity strength, jump test), 4th assessment of agility and dynamic balance (8 foot UP & Go test) and 5th assessment of cardiorespiratory fitness (YMCA test). A 5 min rest was established between each test.

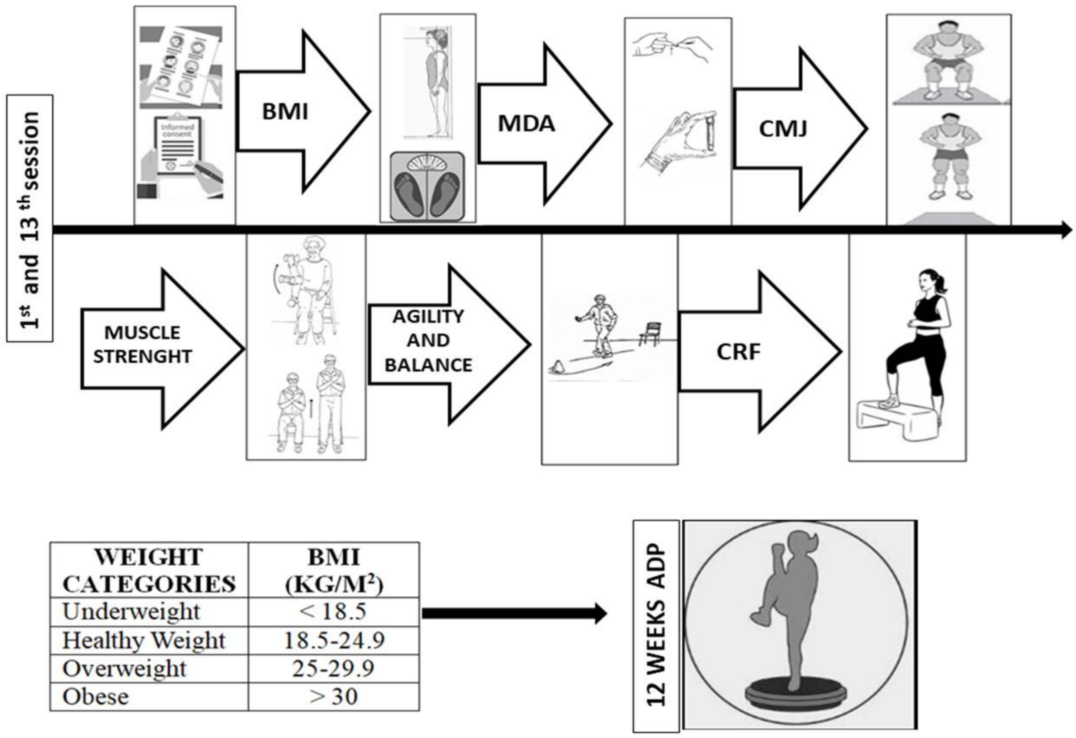

Figure 1: Protocol test. Abbreviations: BMI = body mass index, CMJ = counter movement jump, CRF = cardiorespiratory fitness and MDA = malondialdehyde.

2.2. Participants

Participants of this study were members of the centers for the elderly in the community of Madrid. In total, 58 healthy older adults between 60 and 78 years old were recruited. Finally, 32 participants (age = 67.1 ± 3.6 years; weight = 67.5 ± 16.6 kg; height = 155.4 ± 6.7 cm; BMI = 27.9 ± 6.2 $kg \cdot m^{2-1}$) were included in this study. In total, 28 women and 4 men were assigned to 3 groups based on BMI according to established guidelines by the World Health Organization [37]: eutrophic (18.5–24.9 $kg\ m^2$), overweight (25–29.9 kg/m^2) and obese (≥30 kg/m^2): healthy group (HG, n = 10; men, n = 1), overweight group (OWG, n = 10; men, n = 2) and obese group (OG, n = 12; men, n = 1).

Participants with orthopedic prostheses or implanted pacemaker, cardiovascular neurological, musculoskeletal, infectious and oncological diseases were excluded from the study. In addition, all participants who missed 10% of the exercise sessions in the ADP were excluded from the final data analysis. The participants were informed of all experimental procedures and each participant provided written informed consent to participate in the study. This investigation was approved by the Institutional Review Board (Identification number: 13/2018) according to the principles and policies of the Declaration of Helsinki.

2.3. Body Composition

Body composition was calculated by bioimpedance using the electric Bioimpedance model scale (InBody 3.0, Biospace, Seoul, Korea). The variables assessed were weight, body fat (BF), body fat percentage (% BF), fat-free mass (FFM) and lean mass (LM) [38]. Height was measured with a standard stadiometer, and BMI was calculated as weight (kg)/height (m^2).

2.4. Oxidative Stress

Blood samples for oxidative stress determination were collected by finger pricking. After puncture, blood was immediately collected in EDTA-K2 Microvette tubes (SAR-STEDT, Nümbrecht, Germany). The tubes were centrifuged at 600× *g* for 15 min (4 °C). To avoid peroxidation amplification, butylated hydroxytoluene (antioxidant) and the iron chelator EDTA were added to fresh plasma samples. Then, plasma was stored at −80 °C until assessment of MDA as determined by thiobarbituric acid-reactive substance concentrations (TBARS), a product of lipid peroxidation, following Yagi's technique with minor modification [39]. Results were expressed in uM compared to a standard curve prepared with MDA.

2.5. Muscular Fitness

After a 5 min general warm-up (movements, joint mobility, push-ups, jumps, etc.), the participants began the assessment of muscle fitness.

2.5.1. Countermovement Jump

The countermovement jump (CMJ) was used to measure the vertical flight height and the power output of the lower extremities on a contact platform (ChronoJump, Bosco System, Barcelona, Spain). Three CMJs were performed at the participant's maximum capacity with a 30 s rest between each jump. The mean values of height and mean power output of the three jumps were used in the subsequent analyses [40].

2.5.2. Arm Curl Test

Sitting, at the signal of the evaluator, the participant performed an elbow flexion–extension (bicep flexion) with both limbs throughout the range of motion as many times as possible for 30 s. The test started with the dominant arm and ended with the non-dominant. A single series was performed and 1 min rest was established between each attempt. A 2 kg dumbbell was used for women and 4 kg for men [41].

2.5.3. Agility and Dynamic Balance

Agility and dynamic balance were assessed using the 8 foot UP & Go test. At the investigator's signal, the participant should get up from the chair and walk 8 feet (2.44 m), turn around and sit back down. Two attempts were executed and the shortest time of the two attempts was recorded [42]. A 3 min rest was applied between attempts.

2.6. Cardiorespiratory Fitness

The cardiorespiratory fitness was assessed using the YMCA step test. At a 30 cm high stride, participants performed 24 steps per minute at a rate of 96 bits per minute for 3 min [43]. Heart rate values were recorded using a polar heart rate monitor (RS-800CX, Polar Electro OY; Kempele, Finland) during the exercise and 1 min after exercise (1 min HBC). Peak oxygen consumption was estimated according to the guidelines established in a previous study by Beutner et al., who established a linear regression model (YMCA model) taking into account age, sex and 1 min HBC. The regression coefficients for each of the variables were: −0.15 for 1 min HBC, −4.2 for the gender variable, −0.38 for the age variable and 78.2 as a constant [44].

2.7. Exercise Program

All sessions were led by the same instructor. Two AD classes on an ADP were conducted per week for 12 weeks (Appendix A, Figure A1). The duration of the classes was 45 min divided into 10 min of warm-up, 30 min of the main part and 5 min of cool down. The AD class consisted of global and combined lower and upper body exercises such as jumps with both feet, knee raises, flexion with elbow extension, kick with shoulder abduction, squats, leg flexion and extension, jumping jacks, scissors, calisthenics, plyometrics etc. The music that accompanied the exercises was selected to mark the right time of transition between the different types of exercise. The exercise changes were performed every 16 s and the intensity of the class was controlled by the Borg rating of perceived exertion (RPE, Borg Scale CR-10) [45] following the guidelines established in previous studies [46]. Upper body exercises consisted of performing elbow flexion–extensions, shoulder abductions–adductions and shoulder flexion–extension with dumbbells and elastic bands simultaneously while dancing to the rhythm of the music. The participants had to perform a high number of repetitions (≈15 repetitions) with light resistance. After 16 s, the muscle group was changed to another upper extremity exercise (Table 1).

Table 1: Summary of characteristic and expect RPE of dance session performed on air dissipation platform.

Variable/Weeks	1 - 3	4 - 8	9 - 12
Sessions for week	2	2	2
Exercise intensity	moderate	intensity	vigorous
Expected RPE (1-10)	5 - 6	6 - 7	7 - 8

In addition to performing all the exercises on the platform, materials such as dumbbells, rubber bands, maracas, sticks and pikes were also used (Appendix A, Figure A2).

2.8. Statistical Analysis

The Shapiro–Wilk test was used to check the normal distribution of the data, which are reported as means and standard deviation (SD), means and confidence intervals (95% CI). To identify significant differences between the HG, OWG and OG, a general linear model with a two-way analysis of variance (ANOVA) for repeated measures was applied (group × time). When appropriate, a post hoc Bonferroni adjustment was implemented for multiple comparisons. The partial eta-squared (η_p^2) was computed to determine the magnitude of the response to exercise program. The statistical power (SP) was also calculated. All statistical tests were performed using the software package SPSS version 23.0 for Apple Macintosh (SPSS Inc., Chicago, IL, USA). Significance was set at $p < 0.05$.

3. Results

3.1. Body Composition

The data related to body composition are shown in Table 2.

Table 2. Body composition variable

	Assessment	HG	OWG	OG	P[1]/ES/SP	P[2]/ES/SP	P[3]/ES/SP
Participants (n)		10	10	12			
Weight (kg)	Pre†	58.20 (4.21)	68.29 (5.70)	80.16 (9.94)	**0.028**	**0.001**	**< 0.001**
	Post‡	58.22 (3.57)	67.51 (5.61)*	78.98 (9.54)*	0.23/0.68	0.33/0.95	0.62/1.00
Body mass index (kg·m^{-2})	Pre	24.23 (1.24)	28.83 (1.13)	32.17 (1.93)	0.121	**0.002**	**< 0.001**
	Post	24.16 (0.99)	28.59 (0.87)	31.71 (1.95)	0.14/0.42	0.30/0.92	0.84/1.00
Fat Mass (kg)	Pre	22.02 (3.28)	26.22 (2.51)	31.65 (4.54)	0.732	0.078	**< 0.001**
	Post	21.72 (2.69)	25.46 (2.17)	31.30 (4.22)	0.02/0.09	0.11/0.42	0.61/1.00
Body Fat (%)	Pre	36.79 (4.29)	38.56 (3.43)	40.78 (6.32)	0.901	**0.038**	0.180
	Post	36.23 (3.78)	37.74 (3.56)	40.25 (5.98)	0.01/0.06	0.15/0.56	0.12/0.35
Fat-Free Mass (kg)	Pre	37.91 (3.91)	41.78 (5.09)	46.72 (9.99)	0.971	0.095	**0.030**
	Post	38.20 (3.83)	42.15 (5.31)	47.13 (9.76)	0.00/0.05	0.10/0.39	0.23/0.67
Lean Mass (kg)	Pre	20.91 (2.70)	22.92 (3.01)	25.81 (6.16)	0.401	0.960	**0.041**
	Post	20.57 (2.33)	23.02 (3.19)	26.02 (6.08)	0.07/0.20	0.00/0.05	0.21/0.62
Basal Metabolic Rate (kcal.day^{-1})	Pre	1182.11 (82.28)	1276.20 (108.51)	1383.64 (224.23)	0.775	0.155	**0.027**
	Post	1195.89 (82.62)	1281.20 (114.61)	1389.00 (211.44)	0.02/0.09	0.07/0.292	0.24/0.68

Data are provided as mean ± standard deviation (SD). Abbreviations: ES = effect size; HG = healthy group; OG = obesity group; OWG = overweight group; SP = statistical power. [1]Significant differences for group x time interaction effect. [2]Significant differences for time effect. [3]Significant differences for group effect. Bonferroni's multiple comparisons determined: *Significant differences compared to pretest (p <0.05). †Significant differences between experimental groups in pretest (p <0.05). ‡Significant differences between experimental groups in posttest (p <0.05)

3.2. Oxidative Stress

In MDA, an interaction effect (group × time) and a time effect ($p = 0.032$, ES = 0.25, SP = 0.66; $p < 0.001$, ES = 0.70, SP = 1.00, respectively) were verified; however, a group effect was not detected ($p > 0.05$). The Bonferroni post hoc determined a significant decrease in MDA concentrations in the three experimental groups after the training program ($p < 0.05$) (Figure 2).

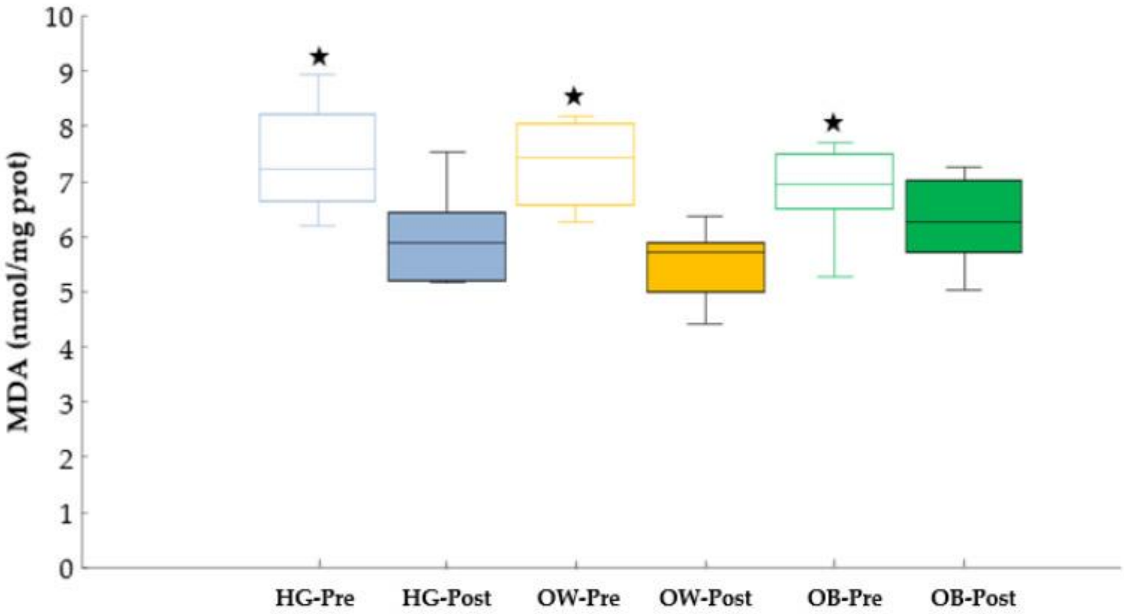

Figure 2. Lipid peroxidation, measured as TBARS concentrations. Abbreviations used: HG = healthy group; MDA = malondialdehyde; OG = obesity group; OWG = overweight group. ★ Significant differences compared to posttest ($p < 0.001$ in HG; $p < 0.001$ in OWG; $p = 0.024$ in OG).

3.3. Cardiorespiratory Fitness

The data related to cardiorespiratory and muscular fitness are shown in Table 3

Table 3. Cardiorespiratory and muscular fitness variables

	Assessment	HG	OWG	OG	*P1* for interaction/ES/SP	*P2* for time/ES/SP	*P3* for group/ES/SP
Participants (n)		10	10	12			
VO_2peak ($ml.kg^{-1}.min^{-1}$)	Pre	30.38 (3.62)	28.66 (2.41)	29.45 (2.89)	**0.008**	**0.005**	0.763
	Post	29.87 (2.39)	30.13 (3.09)*	30.93 (2.46)*	0.29/0.83	0.24/0.83	0.02/0.09
Strength DA (repetitions)	Pre	21.00 (2.21)	21.60 (3.17)	18.55 (2.54)	0.696	**0.003**	**0.031**
	Post	23.20 (2.04)	22.80 (3.91)	20.91 (2.77)	0.03/0.10	0.27/0.87	0.22/0.66
Strength NDA (repetitions)	Pre	21.20 (1.23)	21.80 (3.43)	18.09 (3.11)	0.754	**0.001**	**0.01**
	Post	23.00 (2.11)	23.40 (3.95)	20.64 (2.46)	0.02/0.09	0.32/0.94	0.28/0.81
8 foot UP & Go (seconds)	Pre	5.93 (0.49)	6.00 (0.59)	6.12 (0.94)	0.481	**0.008**	0.786
	Post	5.34 (0.31)	5.72 (0.62)	5.24 (1.77)	0.05/0.17	0.22/0.79	0.02/0.08
Jump height (cm)	Pre	9.21 (2.05)	9.84 (1.79)	11.05 (4.23)	**0.001**	**0.001**	0.226
	Post	10.66 (2.10)*	9.93 (2.10)	11.17 (4.53)	0.17/0.95	0.13/0.92	0.04/0.31
Power output (watts)	Pre†	390.64 (66.35)	466.28 (60.33)	554.76 (173.51)	**0.044**	**0.005**	< **0.001**
	Post	418.25 (65.31)*	462.99 (64.41)	577.03 (168.11)* ‡	0.08/0.60	0.09/0.82	0.29/0.99

Data are provided as mean ± standard deviation (SD). Abbreviations: DA = dominant arm; ES = effect size; HG = healthy group; NDA = no dominant arm; OG = obesity group; OWG = overweight group; SP = statistical power. [1]Significant differences for group x time interaction effect. [2]Significant differences for time effect. [3]Significant differences for group effect. Bonferroni's multiple comparisons determined: *Significant differences compared to pretest ($p < 0.05$). †Significant differences between experimental groups in pretest ($p < 0.05$). ‡Significant differences compared to HG ($p < 0.001$) and OWG ($p = 0.001$) in posttest

Regarding the estimated VO_{2peak}, an interaction effect (group × time) ($p = 0.008$) was observed. The Bonferroni test determined that the OWG and OG significantly improved their VO_{2peak} ($p = 0.005$ and $p = 0.002$, respectively). No interaction effect (group × time) was detected in the strength of the arms and in the 8 foot UP & Go test ($p > 0.05$). However, an interaction effect (group × time) was observed in vertical flight height ($p = 0.001$) and power output ($p = 0.044$) during the jump test. Bonferroni test determined that only HG increased the vertical jump height after training program ($p < 0.05$). Furthermore, the power output of lower limbs was improved in HG and OG after the training program ($p < 0.05$).

4. Discussion

The main finding of this study was that a 12-week AD exercise program on an ADP successfully reduced body weight, decreased lipid peroxidation (MDA) and increased VO_2peak in obese and overweight elderly. Moreover, the OG showed an improvement in balance and agility and also in the strength of both arms over time (pre vs. post). One of the main objectives of an exercise program in obese and overweight people is to lose weight and gain lean mass. Our results indicated that only OWG and OG decreased their weight after the intervention program while HG maintained weight and lean mass. It should be noted that weight loss in elderly may have an effect on reducing lean mass, which could increase the risk of sarcopenia [3,47]. However, no significant changes in lean mass in OWG and OG were detected after the AD program; although aerobic exercise compared to other types of exercise has less effect on lean mass [47,48]. It has been evidenced that weight loss and maintenance of lean mass decrease the risk of developing metabolic diseases, reducing skeletal muscle deterioration and disability, hospitalizations and early mortality [49]. An exercise program of two sessions per week of AD in an ADP for at least 12 weeks could be a sufficient stimulus to reduce weight and maintain lean mass, reducing the risk of metabolic diseases and the deterioration of muscle mass in obese and overweight older people. More studies are needed to corroborate such claims. The role of oxidative stress in the aging process appears mainly related to the decrease in antioxidant systems, and the loss of functionality of other detoxifying systems, causing the accumulation of oxidized lipids, proteins or DNA molecules, negatively impacts on the homeostatic cellular mechanisms [7,8,9].

The level of lipid peroxidation was similar in all the experimental groups before starting the exercise program. At the end of the AD program, the MDA levels were significantly attenuated. Although MDA levels have not been investigated after an exercise program on an ADP, the results were similar to several studies in which other exercise programs were applied [27,50]. Yu et al. showed that aerobic exercise such as running, cycling and dancing induced lower MDA levels and protective effects against oxidative stress damage in older people [50]. Similar findings were found in obese elderly women after performing an aerobic exercise program for 12 months at an intensity of 60–75% of maximum HR. The authors concluded that aerobic exercise decreases oxidative stress when accompanied by gains in cardiorespiratory fitness [51]. From a physiological perspective, the decrease in oxidative stress may be related to an improvement in mitochondrial function. Mitochondrial dysfunction is one of the characteristics of the aging process inducing an elevated emission of ROS and the activation of apoptotic pathways [52]. It seems that exercise programs could reduce oxidative stress in the elderly and obese people, depending on the type of exercise and the intensity established [53,54]. Previous studies found different levels of lipid peroxidation and TBARS in obese individuals at several types of exercise and intensities [55,56,57].

One of the purposes of this study was to be able to control exercise intensity on an ADP. Our previous findings demonstrated that exercise on an ADP stimulates a greater cardiorespiratory and metabolic response compared to exercise on a hard surface [35]. The exercise intensity of the sessions was controlled using the Borg scale of 0 to 10. The instructor regularly reported the ranges and intensity changes, following the aforementioned scale, which allowed the control of intensity levels within the ranges of moderate to vigorous intensity (RPE 5 to 8), ensuring that the subjects were not exposed to strenuous efforts [46]. Studies have shown to improve the cardiorespiratory fitness by controlling exercise intensity with RPE [46,58]. OWG and OG increased their VO_{2peak} at the prescribed intensities, demonstrating the efficacy of the exercise program on an ADP. In contrast, HG did not improve their VO_{2peak}, suggesting that the implemented exercise program (2 sessions per week) could be sufficient stimulus to improve VO_{2peak} in overweight and obese older people, but not for older people with a normal weight. Improvements in VO_{2peak} are of crucial relevance to the health of obese and overweight people. Several studies have shown that an increase of 1 MET (3.5 mL/kg/min O_2) in exercise capacity reduced the adjusted risk for mortality in 13% [59] and reduces the risk of mortality or suffering a cardiovascular event by 13–15% [60]. OWG and OG increased ~1.5 mL/kg/min O_2 similar to other AD studies using a mini trampoline [27,61]. Cugusi et al. found a significant increase in VO_{2max} (1.5 mL/kg/min, from 15.4 to 16.9 mL/kg/min,) in overweight women after a 12-week exercise program on a mini trampoline [32].

Van Schoor et al. assumed that the higher physiological demands induced by the mini trampoline could be due to the constant rebounding and instability produced by an elastic surface [61]. This higher physiological demand would imply a greater effort to perform the exercise and maintain balance on an ADP. In addition, soft surfaces can reduce the risk of high-impact joint injuries by improving balance and strength in older people [29,30], especially in obese and overweight people. This suggestion could account for, at least in part, the improvements in agility and balance observed in obese older people. However, the exercise program on an ADP was not adequate stimulus to significantly improve agility and balance in the OWG and HG. Nonetheless, the results of the 8 foot UP & Go test can be considered normal [62]. Contrary to what might be expected, the rebound effect produced by ADP did not improve jumping ability in overweight and obese people despite including plyometric in the AD program. However, HG improved vertical jump ability by demonstrating increased lower extremity strength, consistent with other studies where jump training appears to be more effective in non-obese older people [63].

A twice-weekly AD program on an ADP preserved explosive strength levels in the lower extremities in overweight and obese older people. Preventing loss of muscle strength, as well as cardiorespiratory fitness, is crucial for the elderly to maintain their functional ability to perform activities of daily living independently [59,64,65]. Muscle mass declines by roughly 3–8% per decade after the age of 30 and increases even more after the age of 60 [66,67]; this gradual decrease in muscle mass is accompanied by a simultaneous reduction in strength [68], in muscle performance and a decrease in cardiorespiratory fitness [59,64,69,70]. In addition, as a preventive measure, this type of training with instabilities could improve neuro-muscular and musculoskeletal functions and reduce the risk of falls, using exercises for strength, postural balance, muscle coordination, joint range of motion and spatial orientation with a multi-component approach [29,30].

This study presents some limitations. Some participants did not attend the posttest, which significantly reduced the sample size. The initial sample of 58 participants was reduced to 32 participants at the end of study. Data from participants who failed to complete more than two AD sessions were not considered for the final statistical analysis [46] but they continued to perform the exercise program.

4. Conclusions

In conclusion, a training program of aerobic exercise on an ADP should be considered a viable strategy to positively regulate cardiorespiratory and muscular adaptations and to ameliorate the effects of oxidative stress in obese and overweight older people.

Acknowledgments

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Appendix A

Figure 1

Session of ADP with the elderly.

Figure A2

The air dissipation platform (ADP), materials such as dumbbells, elastic bands, maracas, sticks and paddles used in the sessions.

Author Contributions

Conceived and designed the experiments A.M.-R. and M.V.G.-C.; performed the experiments, A.M.-R., J.L.M.-M., J.H.-L., T.C., N.A., M.B., S.V.-S., P.G.-F. and M.V.G.-C.; analyzed the data, A.M.-R., S.V.-S. and M.V.G.-C.; contributed reagents/materials/analysis tools A.M.-R., E.P., J.L.M.-M., J.H.-L., M.B., T.C., N.A., S.V.-S. and M.V.G.-C.; wrote the paper. A.M.-R., N.A. and M.V.G.-C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

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Footnotes

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9. RESULTADO

9. Resultados

Artículo I – Se ha observado una frecuencia cardiaca (FC) significativamente más alta *(p* $< 0,05$), un aumento significativo en los niveles de lactato (*p* $< 0,01$) en ADP comparando con la superficie rígida. A pesar de la ADP provocar un aumento de las respuestas cardiorrespiratorias y metabólicas, la fatiga muscular y el índice de esfuerzo percibido (RPE) fueron similares en ambas superficies *(p* $< 0,05$).

Artículo II- No se encontraron diferencias significativas entre la prueba de cinta rodante de carga constante comparando con la sesión de AD en un ADP con respecto al $\dot{V}O_{2sc}$, pendiente $VE \cdot VCO_2^{-1}$ y RPE (*p* > 0.05). Se observaron concentraciones más altas de lactato en sangre en una sesión de AD en un ADP que en una prueba de cinta ergométrica de carga constante a los 10 min (*p* $= 0,003$) y 20 min (*p* $< 0,001$).

Artículo III- Las personas mayores con OWG (*p* $= 0.016$) y OG disminuyeron su peso (*p* $< 0,001$). Hubo una disminución significativa del estrés oxidativo (concentraciones de malondialdehído) en todos los grupos experimentales (*p* $< 0,05$). OWG y OG mejoraron significativamente su consumo máximo de oxígeno (*p* $< 0,01$). HG aumentó la altura del salto vertical (*p* $< 0,05$), y HG y OG mejoraron la producción de potencia de las extremidades inferiores (*p* $< 0,05$).

10. DISCUSIÓN

10. Discusión

Esta tesis presenta tres estudios que profundizan principalmente en el conocimiento de las respuestas agudas y crónicas en la AD realizada sobre una ADP en personas jóvenes y mayores. Es por ello que se abordan los siguientes aspectos:

1- Las respuestas agudas cardiorrespiratorias, metabólicas y la fatiga en una sesión de AD sobre una ADP en comparación con la misma sesión de AD sobre una superficie rígida.
2- Las respuestas agudas del comportamiento del componente lento del consumo de oxígeno, de la eficiencia respiratoria y las concentraciones de lactato en la ADP y una prueba constante en la cinta a intensidades de VTI
3- Las repuestas crónicas en un programa de 12 semanas de ADP en el fitness cardiorrespiratorio, muscular y celular en personas mayores

1- Las respuestas agudas cardiorrespiratorias, metabólicas y la fatiga muscular

El principal hallazgo de este estudio fue que la AD dirigida por una instructora de fitness a través de una sesión grabada en video indujo una mayor FC, VE, RER, $VE{\cdot}VO_2^{-1}$, $VE{\cdot}VCO_2^{-1}$ y concentraciones de lactato en sangre en una ADP que en una superficie dura. La AD realizada en ambas superficies indujo similar fatiga muscular en las extremidades inferiores, así como una menor percepción de esfuerzo físico (RPE).

La FC fue mayor en la ADP (+3,8%) que en la superficie dura. Recientemente, Rodrigues et al. observaron que las superficies elásticas (mini-trampolín 76,5 % de la $FC_{máx}$) aumentaban la respuesta de la FC en comparación con una superficie dura (67,4 % de la $FC_{máx}$) durante una carrera estacionaria. Es posible que la mayor FC observada en una ADP se deba al efecto rebote y a la inestabilidad inducida por la superficie elástica, lo que conllevaría realizar un mayor esfuerzo para mantener el equilibrio durante la sesión de AD.[273] La AD en ambas superficies indicó un porcentaje de FC_{pico} similar al detectado en el baile aeróbico efectuado en el step con carga (89,8%).[314] Sin embargo, la FC fue mayor en ambas superficies que la observada en una coreografía de claqué (83,8%) [273] y en un baile aeróbico en el step realizado sin sobrecarga (84,5%).[314] Las actividades de AD como body pump, body combat y spinning han mostrado una FC baja (60,2%, 73,2%, 74,3% de la $FC_{máx}$, respectivamente).[127] Además de la superficie de contacto, la discrepancia en la respuesta de la FC podría atribuirse, al menos en parte, a las diferentes modalidades de baile y metodologías de clase utilizadas para cada sesión de AD.

La FC observada en ambas superficies demostró que una sesión de AD grabada en video podría ser una alternativa adecuada para mejorar o mantener la aptitud cardiorrespiratoria en mujeres jóvenes sanas. Las pautas del ACSM determinan que la intensidad vigorosa (≥~6 equivalentes metabólicos (MET), 77–95% de la $FC_{máx}$.) de actividad física realizada 3 $d·sem^{-1}$ para un total de ~75 $min·sem^{-1}$ o 20 $min·d^{-1}$ mejora o mantiene la aptitud cardiorrespiratoria.[222] En este sentido, ambas sesiones de AD pueden considerarse como una intensidad de ejercicio vigorosa (ADP: 8,6 MET/91,8% de la $FC_{máx}$ vs superficie dura: 8,5 METs/88,6% de $FC_{máx}$).

Los niveles de lactato en sangre aumentaron en mayor medida en una ADP en comparación con la misma sesión de AD realizada en superficie dura. Brito et al. mostraron que las superficies inestables como la arena producían mayores niveles de lactato en sangre en comparación con las superficies duras (4 $mmol·L^{-1}$ y 2,8 $mmol·L^{-1}$, respectivamente) durante un partido de fútbol. Los autores concluyeron que jugar en superficies duras como el asfalto disminuía la vía anaeróbica del lactato en mayor medida que las superficies inestables.[316] Esta apreciación sugiere que las diferencias en los niveles de lactato en sangre entre una ADP y una superficie dura podrían deberse al hecho de que las fuerzas de impacto inducidas por la amortiguación se reducen en la ADP. La inestabilidad y los tiempos de contacto en la ADP aumentarían, provocando una mayor activación muscular en los músculos agonistas y antagonistas, al igual que se ha verificado en las superficies inestables.[317] Esta activación muscular amplificada podría acentuar el trabajo muscular y, en consecuencia, incrementar las demandas energéticas de la vía metabólica anaeróbica del lactato. Los estudios futuros deberían centrarse en comparar la activación de las vías metabólicas entre superficies inestables y estables siempre que la intensidad del ejercicio propuesta fuera la misma.

En un estudio similar, se encontraron niveles más bajos de lactato en sangre durante una coreografía de claqué en comparación con nuestro estudio (1,7 $mmol·L^{-1}$ frente a 6,3 mmol·L^{-1} y 5,2 mmol·L^{-1}, respectivamente).[247] Sugerimos que las diferencias observadas entre los estudios podrían atribuirse a la intensidad del ejercicio. La intensidad relativa del ejercicio establecida en ambas actividades de AD se interpretó a partir de los parámetros ventilatorios obtenidos durante un test incremental en cinta ergométrica. Con este fin, evaluadores expertos determinaron VT1 y VT2, ya que se ha establecido que el rendimiento en el ejercicio de resistencia está relacionado con los VT.[129,318] Hasta donde sabemos, ningún estudio ha utilizado los VT durante una prueba incremental en cinta ergométrica como referencia para identificar la intensidad relativa del ejercicio en una clase de AD realizada en superficies elásticas y duras. Sin embargo, Oliveira et al. utilizó el umbral de lactato en una prueba incremental en cinta ergométrica para categorizar la intensidad del ejercicio durante una coreografía de claqué.[247] El umbral de lactato y VT1 ciertamente están relacionados y ocurren en un momento metabólico similar y a una intensidad de ejercicio comparable en varias formas de ejercicio.[128,164] Este desacuerdo entre los estudios podría estar respaldado por el hecho de que la intensidad del ejercicio de claqué fue aproximadamente un 10 % por debajo del umbral de lactato. Nuestros resultados mostraron una intensidad de ejercicio relativa por encima de VT1 y próxima a VT2 en ambas superficies. En consecuencia, se observó una mayor FC (ADP 8,7 %, suelo de mármol 5,4 %), $\dot{V}O_2$ (ADP 2,8 %, suelo de mármol 2,1 %) y MET (ADP 5,8 %, suelo de mármol 4,7 %) en ambas sesiones de AD que en la coreografía de claqué.[247] Esta respuesta cardiorrespiratoria aumentada justificó, al menos en parte, los mayores niveles de lactato en sangre observados en nuestro estudio.

Estas diferencias en las concentraciones de lactato en sangre entre estudios resaltan la relevancia de conocer previamente la intensidad del ejercicio (FC) a través de puntos de control (VT o de lactato) que determinan los cambios metabólicos en cada participante. De esta forma, los practicantes de actividades como las clases de fitness conocerían la carga de trabajo o la intensidad relativa (FC o $\dot{V}O_2$) correspondiente a la sesión. Además, los investigadores podrían comprender los mecanismos fisiológicos adaptativos subyacentes de las diversas modalidades de AD.

Está claro que el conocimiento de los VT ha sido un factor clave para conocer la intensidad del ejercicio cardiorrespiratorio y, en consecuencia, comprender por qué se produce un estrés metabólico mayor que en otros estudios. La adaptación ventilatoria al umbral de producción de CO_2 (VT1) se interpreta como los primeros aumentos no lineales en el VCO_2 y de la ventilación debido a la amortiguación del bicarbonato de los H^+ producida por un aumento gradual en los niveles de lactato en sangre por encima de los valores de reposo.[163] VT2 se acepta como el segundo punto de ruptura en la respuesta de la ventilación producido principalmente por una disminución del pH a medida que el bicarbonato se satura por el aumento de la producción de lactato (acidosis).[319] Probablemente, la VE, la RER, el $VE \cdot VO_2^{-1}$ y el $VE \cdot VCO_2^{-1}$ más alto detectado en una ADP comparando con el piso de mármol podría ser debido al aumento de la acidosis y a la intensidad relativa muy cercana a VT2 observada en prueba incremental en la cinta ergométrica.

En teoría, este mayor estrés cardíaco y metabólico implicaría un mayor $\dot{V}O_2$ en una ADP que en una superficie dura. Sin embargo, el $\dot{V}O_2$ fue similar entre ambas superficies. Los resultados observados en el $\dot{V}O_2$ difieren de otros estudios que mostraban cómo las superficies elásticas aumentaban la FC y el $\dot{V}O_2$ en mayor magnitud que las superficies duras.[273] Aunque no hemos encontrado estudios que evalúen la respuesta del $\dot{V}O_2$ en varias superficies en modalidades de AD, un estudio en tenistas competitivos reveló que la FC y los niveles de lactato en sangre eran más altos en una superficie más blanda, manteniendo un $\dot{V}O_2$ similar.[320] Son necesarios más estudios para sacar conclusiones adecuadas sobre el efecto de diferentes tipos de superficie en el $\dot{V}O_2$ en las modalidades de AD.

El $\dot{V}O_2$ fue similar en ambas superficies (ADP: 70,9% vs. superficie dura: 70,4% del $\dot{V}O_{2máx}$). Se encontraron hallazgos análogos durante la carrera estacionaria sobre una superficie elástica (68,9 % del $\dot{V}O_{2máx}$) y el baile aeróbico con step realizados sin sobrecarga (68,9 % del $\dot{V}O_{2máx}$), lo que confirma una intensidad de ejercicio relativa adecuada para proporcionar mejoras cardiovasculares.[247] Sin embargo, el $\dot{V}O_2$ (78,3% del $\dot{V}O_{2máx}$) se incrementó en el baile aeróbico con step realizado con sobrecarga.[314] La sobrecarga externa podría ser un recurso añadido para aumentar la intensidad relativa (% de $FC_{máx}$ y $\dot{V}O_{2máx}$) producida por el efecto rebote y las inestabilidades de las superficies elásticas durante las sesiones de AD.

La fatiga muscular ha sido evaluada mediante la prueba del CMJ en varios estudios que analizaron las respuestas metabólicas y cardiorrespiratorias. [142,149,169] A pesar de encontrar un mayor estrés cardiometabólico y ventilatorio en una ADP que en una superficie dura, la fatiga muscular en una ADP no aumentó en comparación con una superficie dura.

Nuestros resultados sugieren que la ADP redujo el trabajo mecánico realizado por las extremidades inferiores al aumentar la rigidez en las piernas sobre la superficie elástica. Nuestros argumentos no pueden corroborarse objetivamente ya que no se midió la rigidez de las piernas en una ADP, por lo que estas interpretaciones siguen siendo puramente especulativas. Sin embargo, suponemos que el trabajo mecánico se reduce al aumentar la rigidez de la pierna en una superficie elástica compatible.[274,275] Por lo tanto, la tensión articular y la fatiga muscular podrían minimizarse mediante el uso de superficies elásticas. Las superficies blandas pueden reducir el riesgo de lesiones articulares en caso de alto impacto.[298]

Sería lógico identificar una mayor percepción de esfuerzo en respuesta a un mayor estrés cardio ventilatorio y metabólico en una ADP; sin embargo, la RPE de los participantes fue la mismo durante toda la sesión. La RPE es un excelente parámetro para cuantificar subjetivamente la intensidad del ejercicio en sesiones de fitness.[177] Era la primera vez que los participantes usaban una ADP, por tanto, la motivación para utilizar un aparato novedoso podría haber sido un factor diferencial para tener una menor sensación de esfuerzo físico. La mayor sensación de placer sobre una ADP que sobre la superficie dura fue constatada por los participantes. Serían necesarias más investigaciones para determinar los beneficios psicológicos, emocionales y la adhesión que podría producir este tipo de dispositivos.

Una sesión de AD en una ADP podría aumentar las demandas cardiorrespiratorias y metabólicas al disminuir el estrés mecánico en las articulaciones y en la masa muscular. Así, este tipo de actividad aeróbica podría ser muy adecuada para personas mayores (fragilidad esquelética) porque podrían alcanzar la misma intensidad de ejercicio funcional con menos estrés mecánico. Determinar la intensidad del ejercicio en función del tipo de superficie en una clase de AD mediante el uso de VT nos permitiría saber si las respuestas metabólicas y cardio ventilatorias agudas son lo suficientemente intensas como para promover mejoras a largo plazo (adaptaciones) en la aptitud cardiorrespiratoria.

Finalmente, los hallazgos de este estudio son relevantes porque una sesión de AD grabada en video en una ADP podría ser una excelente alternativa para realizar actividad física, por ejemplo, durante períodos forzados de confinamiento por pandemias (es decir, SARS-CoV-2). Es probable que las estancias prolongadas en el hogar fomenten comportamientos sedentarios, como pasar más tiempo sentado, acostado, jugando a videojuegos, etc., lo que conlleve a un posible empeoramiento de la salud. En este entorno, la práctica de actividad física en casa está más que justificada. Realizar ejercicios seguros, sencillos y fáciles de implementar en casa podría ser muy adecuado para evitar contagios y mantener los niveles de forma física.[321] El ADP es un dispositivo seguro, sencillo y pequeño que se puede utilizar en casa. Los hallazgos que se reportan en este estudio demostraron que una sesión de AD grabada en video en una ADP indujo una intensidad adecuada de ejercicio. Se recomendaría la supervisión de instructores de acondicionamiento físico durante las sesiones de AD en una ADP para establecer pautas adecuadas para mejorar el acondicionamiento cardiorrespiratorio en los programas de ejercicios en el hogar. AD en una ADP realizado 3 $d \cdot sem^{-1}$ por un total de ~75 $min \cdot sem^{-1}$ o 20 $min \cdot d^{-1}$ podría ser una opción muy interesante para mantener o mejorar la aptitud cardiorrespiratoria y metabólica de acuerdo con las pautas del ACSM.

2- *La respuesta del comportamiento de $\dot{V}O_{2sc}$, la eficiencia respiratoria y las concentraciones de lactato*

Contrariamente a la hipótesis de nuestro estudio, el hallazgo principal fue que, aunque la sesión de AD en una ADP indujo concentraciones de lactato en sangre más altas que la prueba de cinta rodante a una intensidad de ejercicio a carga constante de VT1, ambos protocolos provocaron respuestas similares en el $\dot{V}O_{2sc}$, la eficiencia ventilatoria y la RPE en mujeres adultas jóvenes sanas.

Los resultados observados con respecto al $\dot{V}O_{2sc}$ (valores absolutos: 95,3 mL en 20 min; valores relativos: 4,68 $mL \cdot min^{-1}$) fueron ligeramente inferiores (no significativos) a los verificados en la prueba de cinta rodante (valores absolutos: 113 mL en 20 min; valores relativos: 5,65 $mL \cdot mín^{-1}$). En estudios previos con muestras de similares características, se encontraron valores ligeramente superiores en mujeres afroamericanas (valores absolutos: 120 mL en aproximadamente 9 min; valores relativos: 13,33 $mL \cdot min^{-1}$) y valores muy superiores en mujeres caucásicas (valores absolutos: 170 mL en ~8 min, valores relativos: 21,25 mL·min^{-1}) a una intensidad del 25% por encima del umbral de intercambio gaseoso en una prueba de cicloergómetro.[322] Es probable que las diferencias observadas puedan atribuirse a la intensidad del ejercicio aplicado en cada estudio y al hecho de que el cicloergómetro tiende a elevar el $\dot{V}O_{2sc}$ en mayor medida que una cinta rodante a la misma intensidad relativa.[161]

Otro estudio encontró aumentos en el $\dot{V}O_2$ de 599 mL·min^{-1} en mujeres con lupus eritematoso y de 540 mL·min^{-1} en mujeres sanas sedentarias durante una prueba de caminar de 6 minutos en una cinta rodante a una intensidad de 3 MET.[323] A pesar de ser una prueba de menor intensidad en comparación con nuestro estudio, el $\dot{V}O_2$ aumentó en mayor medida del tercer al sexto minuto que durante nuestra prueba de veinte minutos, lo que indica que la aptitud cardiorrespiratoria mediada por algún tipo de patología también podría ser otro elemento fundamental que condiciona el $\dot{V}O_{2sc}$.[324,325]

Los mecanismos fisiológicos que influyen en el $\dot{V}O_{2sc}$ son diversos a la vez que inciertos. La cinética del $\dot{V}O_2$ mostró un estado estacionario similar a partir del tercer minuto en la sesión de AD y en el test de cinta ergométrica, lo que justifica la similitud de la intensidad del ejercicio propuesta en ambos tests, corroborado por un $\dot{V}O_{2sc}$ muy similar en ambos modos de ejercicio.

En teoría, la concentración de lactato en sangre no debería aumentar en respuesta a un metabolismo claramente aeróbico en ambas condiciones experimentales. Sin embargo, la concentración de lactato en sangre aumentó significativamente después de la sesión de AD en una ADP en comparación con la prueba de cinta rodante, lo que evidencia una transición hacia un aumento del metabolismo anaeróbico.[326] En la sesión de AD en una ADP, hubo un resultado paradójico, ya que el aumento en la concentración de lactato en sangre indicaría una intensidad de ejercicio por encima del UL o umbral anaeróbico, [327] que en teoría debería aumentar el $\dot{V}O_{2sc}$. El hecho de que el $\dot{V}O_{2sc}$ no aumentara podría deberse, al menos en parte, al hecho de que hubo un grado significativo de aporte energético de fuentes anaeróbicas que no pueden ser cuantificadas mediante el intercambio de gases.

Es probable que el suministro de O_2 al músculo esquelético activo fuera deficiente, ya que la intensidad de la contracción muscular fue lo suficientemente intensa como para cortar el flujo arterial y venoso, provocando la activación de otras fuentes metabólicas predominantemente anaeróbicas.[328] En este sentido, es posible que una superficie elástica como la ADP contribuyera al aumento de los niveles de lactato en sangre. Investigaciones anteriores han demostrado que las superficies elásticas o más blandas aumentan la concentración de lactato en sangre en mayor medida que las superficies duras, al tiempo que mantienen un estado estacionario y similar del $\dot{V}O_2$.[261,320] Al respecto, la inestabilidad y los tiempos de contacto aumentan durante una sesión de AD en una ADP. Las fuerzas de impacto inducidas por la amortiguación se reducen, provocando una mayor activación muscular en los músculos agonistas y antagonistas.[317] Esta activación muscular amplificada podría aumentar el trabajo muscular y potenciar una mayor demanda de las fuentes anaeróbicas en comparación con una superficie dura.[316] Además, una parte importante de la energía procedente de las fuentes anaeróbicas no puede cuantificarse por intercambio gaseoso,[329] lo que explica, en cierta medida, por qué no se observó un aumento del $\dot{V}O_2$ y del $\dot{V}O_{2sc}$.

En teoría, el aumento del metabolismo anaeróbico producido por el aumento de la concentración de lactato en sangre en la sesión de AD en una ADP debería producir un aumento en la pendiente de la $VE \cdot VCO_2^{-1}$.[155] El incremento de la intensidad del ejercicio induce un aumento de los niveles de lactato en sangre, de los niveles de CO_2 y de $[H^+]$. La acumulación de lactato e $[H^+]$ se debe principalmente a la glucólisis intracelular,[330,331] y ambos se liberan al líquido extracelular.[332,333] En teoría, la eficiencia ventilatoria disminuiría como consecuencia del aumento de la ventilación necesaria para eliminar el CO_2 producido con el fin de mantener la homeostasis del pH, provocando un desajuste en la relación ventilación-perfusión. Sin embargo, no se observaron cambios en términos de eficiencia ventilatoria entre ambas modalidades de ejercicio; por lo tanto, este desajuste en la relación ventilación-perfusión no ocurrió, lo cual es típico a medida que aumenta la intensidad del ejercicio.[155] Esto confirma que la intensidad del ejercicio en ambas modalidades no fue lo suficientemente alta como para causar este desajuste en la relación ventilación-perfusión.

Comparándolos con otros estudios con mujeres adultas sanas, encontramos valores similares (pendiente de la $VE \cdot VCO_2^{-1}$ de 28,7) durante un protocolo incremental en una cinta rodante.[334] En otro estudio, se informaron valores ligeramente inferiores de la pendiente de la $VE \cdot VCO_2^{-1}$ (24,1) durante una prueba de cicloergómetro en mujeres adultas sanas.[150] En ejercicio extenuante de alta intensidad con concentraciones de lactato en sangre cercanas a 18 $mmol \cdot L^{-1}$, la pendiente de la $VE \cdot VCO_2^{-1}$ podría exceder un valor de 40.[155]

Pocos estudios han comparado las pendientes de la $VE \cdot VCO_2^{-1}$ entre diferentes modalidades de ejercicios. Nuestros hallazgos mostraron que dos modalidades diferentes de ejercicio con respuestas similares en el $\dot{V}O_2$ y el $\dot{V}O_{2sc}$, y diferentes respuestas metabólicas tuvieron valores de eficiencia ventilatoria similares. Otros estudios no encontraron diferencias entre las pruebas en cinta rodante y en cicloergómetro, aunque ambas modalidades de ejercicio mostraron una pendiente de la $VE \cdot VCO_2^{-1}$ más baja en comparación con una mesa basculante asistida por robot.[335] Parece haber una tendencia hacia una pendiente de la $VE \cdot VCO_2^{-1}$ similar entre diferentes modalidades de ejercicio que pautan la misma intensidad relativa.[151]

Se observó una RPE similar en ambas modalidades de ejercicio, lo que indica el disfrute que puede producir la sesión de AD. [336]

3- Las respuestas crónicas en el CRF, el fitness muscular y el estrés oxidativo en un programa de 12 semanas en personas mayores

El principal hallazgo de este estudio fue que un programa de ejercicio AD de 12 semanas en una ADP redujo con éxito el peso corporal, disminuyó la peroxidación lipídica (MDA) y aumentó el $\dot{V}O_2$ pico estimado en personas mayores obesas y con sobrepeso. Además, el OG mostró una mejora en el equilibrio y en la agilidad y también en la fuerza de ambos brazos (pre vs. post). Uno de los principales objetivos de un programa de ejercicio en personas obesas y con sobrepeso es perder peso y ganar masa magra. Nuestros resultados indicaron que solo OWG y OG redujeron su peso después del programa de intervención, mientras que el HG mantuvo el peso y la masa magra. La pérdida de peso en las personas mayores puede tener un efecto en la reducción de la masa magra, lo que podría aumentar el riesgo de sarcopenia.[47,193] Sin embargo, no se detectaron cambios significativos en la masa magra en el OWG y el OG después del programa de AD; aunque el ejercicio aeróbico en comparación con otros tipos de ejercicio podría tener menos efecto sobre la masa magra.[193,194] Se ha evidenciado que la pérdida de peso y el mantenimiento de la masa magra disminuyen el riesgo de desarrollar enfermedades metabólicas, reduciendo el deterioro del músculo esquelético y la discapacidad, las hospitalizaciones y la mortalidad temprana.[49] Un programa de ejercicio de 2 $d \cdot sem^{-1}$ de AD en una ADP durante al menos 12 semanas podría ser un estímulo suficiente para reducir el peso y mantener la masa magra, reduciendo el riesgo de enfermedades metabólicas y el deterioro de la masa muscular en personas mayores obesas y con sobrepeso. Se necesitan más estudios para corroborar tales afirmaciones.

El papel del estrés oxidativo en el proceso de envejecimiento parece estar relacionado principalmente con la disminución de los sistemas antioxidantes, lo que provoca que la acumulación de lípidos, proteínas o moléculas de ADN oxidadas impacte negativamente en los mecanismos celulares homeostáticos.[25–27] El nivel de peroxidación lipídica fue similar en todos los grupos experimentales antes de iniciar el programa de ejercicio. Al final del programa de AD, los niveles de MDA se atenuaron significativamente. Aunque los niveles de MDA no se han investigado después de un programa de ejercicio en una ADP, los resultados fueron similares a varios estudios en los que se aplicaron otros programas de ejercicio.[85,106] Yu et al. mostraron que el ejercicio aeróbico como correr, andar en bicicleta y bailar indujo niveles más bajos de MDA y efectos protectores contra el daño por estrés oxidativo en personas mayores.[106] Hallazgos similares se encontraron en mujeres mayores obesas después de realizar un programa de ejercicio aeróbico durante 12 meses a una intensidad del 60-75% de la $FC_{máx}$. Los autores concluyeron que el ejercicio aeróbico disminuía el estrés oxidativo cuando se acompañaba de mejoras en la aptitud cardiorrespiratoria.[107] Desde una perspectiva fisiológica, la disminución del estrés oxidativo puede estar relacionada con una mejora en la función mitocondrial. La disfunción mitocondrial es una de las características del proceso de envejecimiento que induce una emisión elevada de ROS y la activación de vías apoptóticas.[41] Estos estudios señalan que los programas de ejercicio podrían reducir el estrés oxidativo en personas mayores y obesas, según el tipo de ejercicio y la intensidad establecida.[91,92] Estudios previos encontraron diferentes niveles de peroxidación lipídica y TBARS en individuos obesos en varios tipos de ejercicio e intensidades.[94–96]

Uno de los propósitos de este estudio fue poder controlar la intensidad del ejercicio en una ADP. Nuestros hallazgos previos demostraron que el ejercicio en una ADP estimulaba una mayor respuesta metabólica y cardiorrespiratoria en comparación con el ejercicio en una superficie dura.[261] La intensidad del ejercicio de las sesiones se controló mediante la escala de Borg de 0 a 10. El instructor informaba periódicamente de los rangos y cambios de intensidad, siguiendo la escala antes mencionada, lo que permitía controlar los niveles de intensidad dentro de los rangos de intensidad moderada a vigorosa (RPE 5 a 8), asegurando que los sujetos no estuvieran expuestos a esfuerzos extenuantes.[177] Los estudios han demostrado mejorar la aptitud cardiorrespiratoria mediante el control de la intensidad del ejercicio con RPE.[177,239] OWG y OG aumentaron su $\dot{V}O_{2pico}$ estimado a las intensidades prescritas, lo que demuestra la eficacia del programa de ejercicios en una ADP. Por el contrario, HG no mejoró su $\dot{V}O_{2pico}$, lo que sugiere que el programa de ejercicio implementado (2 $d \cdot sem^{-1}$) podría ser un estímulo suficiente para mejorar el $\dot{V}O_{2pico}$ en personas mayores con sobrepeso y obesidad, pero no para personas mayores con peso normal. Las mejoras en el $\dot{V}O_{2pico}$ son de importancia crucial para la salud de las personas obesas y con sobrepeso. Varios estudios han demostrado que un aumento de 1 MET (3,5 $mL \cdot kg^{-1} \cdot min^{-1}$ O_2) en la capacidad de ejercicio reduce el riesgo de mortalidad o de sufrir un evento cardiovascular en un 13-15%.[337] OWG y OG aumentaron ~1,5 $mL \cdot kg^{-1} \cdot min^{-1}$ O_2 de manera similar a otros estudios de AD que utilizaron un mini trampolín.[81,298] Cugusi et al. encontraron un aumento significativo en el $\dot{V}O_{2máx}$ (1,5 $mL \cdot kg^{-1} \cdot min^{-1}$, de 15,4 a 16,9 $mL \cdot kg^{-1} \cdot min^{-1}$) en mujeres con sobrepeso después de un programa de ejercicio de 12 semanas en un mini trampolín.[81]

Van Schoor et al. asumieron que las demandas fisiológicas más altas inducidas por el mini trampolín podrían deberse al rebote constante y la inestabilidad producida por una superficie elástica.[298] Esta mayor demanda fisiológica implicaría un mayor esfuerzo para realizar el ejercicio y mantener el equilibrio en una ADP. Además, las superficies blandas pueden reducir el riesgo de lesiones articulares de alto impacto al mejorar el equilibrio y la fuerza en las personas mayores,[285,286] especialmente en personas obesas y con sobrepeso. Esta sugerencia podría explicar, al menos en parte, las mejoras en la agilidad y el equilibrio observados en las personas mayores obesas.

Sin embargo, el programa de ejercicios en una ADP no fue un estímulo adecuado para mejorar significativamente la agilidad y el equilibrio en OWG y HG. No obstante, los resultados de la prueba UP & Go de 8 pies pueden considerarse normales.[338] Contrariamente a lo que cabría esperar, el efecto rebote producido por ADP no mejoró la capacidad de salto en personas con sobrepeso y obesidad a pesar de incluir la pliometría en el programa de AD. Sin embargo, el HG mejoró la capacidad de salto vertical al demostrar una mayor fuerza en las extremidades inferiores, en consonancia con otros estudios en los que el entrenamiento con saltos parece ser más efectivo en personas mayores no obesas.[339]

Un programa de AD 2 $d \cdot sem^{-1}$ en una ADP preservó los niveles de fuerza explosiva en las extremidades inferiores en personas mayores con sobrepeso y obesas. La prevención de la pérdida de fuerza muscular, así como de la aptitud cardiorrespiratoria, es crucial para que las personas mayores mantengan su capacidad funcional para realizar las actividades de la vida diaria de forma independiente.[112,223,227]

La masa muscular disminuye aproximadamente entre un 3% y un 8% por década después de los 30 años y aumenta aún más después de los 60 años; [340,341] esta disminución gradual de la masa muscular se acompaña de una reducción simultánea de la fuerza,[45] del rendimiento muscular y de una disminución de la capacidad cardiorrespiratoria .[112,212,218,223] Además, como medida preventiva, este tipo de entrenamiento con inestabilidades podría mejorar las funciones neuromusculares y musculoesqueléticas y reducir el riesgo de caídas, utilizando ejercicios de fuerza, equilibrio postural, coordinación muscular, amplitud de movimiento articular y orientación espacial.[285,286]

11. CONCLUSIÓN

11. Conclusión

-Una sesión de AD sobre una ADP incrementó la FC, la VE, la RER, el $VE \cdot VO_2^{-1}$ y el $VE \cdot VCO_2^{-1}$ en mayor medida que la misma sesión de AD sobre una superficie dura en mujeres jóvenes adultas.

-Sin embargo, el $\dot{V}O_2$ observado fue similar en ambas superficies.

-Una sesión de AD sobre una ADP aumentó las concentraciones de lactato en sangre en mayor medida que la misma sesión de AD sobre una superficie dura en mujeres jóvenes adultas.

-A pesar de este incremento en la respuesta cardioventilatoria (FC, VE, RER, $VE \cdot VO_2^{-1}$, $VE \cdot VCO_2^{-1}$) y metabólica (lactato en sangre), la fatiga muscular evaluada mediante un CMJ, fue similar al realizar la misma sesión de AD sobre una ADP vs. superficie dura en mujeres jóvenes adultas.

-La mayor respuesta cardioventilatoria (FC, VE, RER, $VE \cdot VO_2^{-1}$, $VE \cdot VCO_2^{-1}$) y metabólica detectada en la sesión de AD sobre una ADP no produjo una mayor RPE que la misma sesión de AD sobre una superficie dura en mujeres jóvenes adultas

-Una sesión de AD sobre una ADP incrementó las concentraciones de lactato en sangre en mayor medida que una prueba en tapiz rodante a una intensidad a carga constante correspondiente a VT1 en mujeres jóvenes adultas.

-A pesar de este incremento en las concentraciones de lactato en sangre, el $\dot{V}O_{2sc}$ detectado en ambos modos de ejercicio (ADP vs tapiz rodante) fue similar en mujeres jóvenes adultas.

-Dado el mayor incremento observado en las concentraciones de lactato en sangre en la sesión de AD sobre una ADP en comparación con la prueba a carga constante en tapiz rodante a una intensidad de VT1, se esperaba un mayor incremento de la pendiente de la $VE \cdot VCO_2^{-1}$ en la ADP. Sin embargo, la eficiencia ventilatoria fue similar en ambas modalidades de ejercicio en mujeres jóvenes adultas.

-La RPE fue similar entre ambas modalidades de ejercicio (AD sobre una ADP vs tapiz rodante a una intensidad de VT1).

-Un programa de entrenamiento de AD en una ADP de 12 semanas redujo el peso corporal en personas mayores con obesidad y sobrepeso.

-Un programa de entrenamiento de AD en una ADP de 12 semanas disminuyó la peroxidación lipídica en personas mayores con obesidad y sobrepeso.

-Un programa de entrenamiento de AD en una ADP de 12 semanas incrementó el $\dot{V}O_2$ pico estimado en personas mayores con obesidad y sobrepeso.

-Las personas mayores con obesidad mejoraron el equilibrio y la agilidad después de un programa de entrenamiento de AD en una ADP de 12 semanas.

-Las personas mayores con obesidad mejoraron la fuerza de las extremidades superiores después de un programa de entrenamiento de AD en una ADP de 12 semanas

-Las personas mayores con obesidad y sobrepeso no mejoraron la capacidad de salto después de un programa de entrenamiento de AD en una ADP de 12 semanas, aunque las personas mayores obesas mejoraron la potencia de las extremidades inferiores.

-No se detectaron incrementos significativos de la masa muscular en personas mayores con obesidad y sobrepeso después de un programa de entrenamiento de AD en una ADP de 12 semanas.

12. LIMITACIONES Y FUTURAS LÍNEAS DE INVESTIGACIÓN

12. Limitaciones y futuras líneas de investigación

Diversas limitaciones deben ser consideradas:

- Una limitación de nuestros estudios fue el reducido tamaño de la muestra. La muestra puede ser que no represente la población diana, debido a que se trata de un estudio experimental, en que los participantes han accedido a participar de forma voluntaria.
- Algunos participantes de la muestra del estudio con personas mayores no asistieron a las evaluaciones efectuadas después del programa de ejercicio (postest), lo que redujo significativamente el tamaño de la muestra. La muestra inicial de 58 participantes se redujo a 32 participantes al final del estudio. Los datos de los participantes que no completaron más de dos sesiones de AD no se consideraron para el análisis estadístico final, pero continuaron realizando el programa de ejercicios. Debido a la pandemia, no ha sido posible incluir la muestra del grupo control.
- Las sesiones de los estudios que analizaban las respuestas agudas se realizaban con vídeo, y es posible que la motivación no sea la misma que realizando sesiones en directo con una monitora
- El ambiente del laboratorio donde se realizaban las pruebas no es el entorno habitual para realizar este tipo de sesión que habitualmente se realiza de forma colectiva y no individualizada

Como propuestas de futuras líneas de investigación consideramos que podría ser interesante:

- Investigar y medir la reducción del impacto en la plataforma, así como la activación electromiografía de la musculatura implicada al realizar la AD en la superficie rígida y en la ADP.
- Evaluar las respuestas agudas y crónicas controlando la intensidad de las sesiones con frecuencímetro.
- Determinar el efecto de un programa de ejercicio de AD sobre una ADP en otros biomarcadores del estrés oxidativo, de glucosa, del perfil lipídico (triglicéidos, colesterol, LDL, HDL, etc), del perfil hormonal (cortisol, testosterona, etc.)
- Sería interesante estudiar las respuestas agudas y crónicas de AD en la ADP en otros sectores de la población (niños, sedentarios, diferentes patologías relacionadas con el envejecimiento, osteoporosis, musculoesqueléticas, pacientes de cáncer, cardiópatas, etc.)
- Analizar la adherencia al ejercicio de los programas de ejercicio de AD sobre una ADP
- Estudios de investigación cualitativa detectando los beneficios psicológicos, emocionales, etc.

13. REFERENCIA

13.Referencia

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14. ANEXOS

Formulario de consentimiento informado

Proyecto

Respuestas cardiorrespiratorias, metabólicas, mecánicas y de estrés oxidativo, agudas y crónicas, en la danza aeróbica realizada sobre una plataforma de disipación de aire en personas adultas jóvenes y mayores

Fecha:

Nombre:

DNI:

Teléfono:

Por favor contesta a las siguientes preguntas:

1. ¿Has obtenido información precisa referida al proyecto? Si______No_____
2. ¿Has tenido oportunidad de plantear preguntas y discutir sobre el estudio con los investigadores? Si______No_____
3. ¿Has recibido contestaciones adecuadas a tus preguntas? Si______No_____
4. ¿Has recibido suficiente información acerca del estudio? Si______No_____
5. ¿Con qué investigador/es has hablado?

   ----

6. ¿Has entendido que eres libre de retirarte del estudio sin dar explicaciones? Si______No_____
7. ¿Estás de acuerdo en la publicación de los resultados del estudio en foros científicos y revistas especializadas? Si______No_____

Habiendo sido informado de las condiciones de participación, manifiesto que comprendo los procedimientos y sus posibles riesgos, que participo bajo mi propia responsabilidad y que consiento, libre y voluntariamente, participar en este estudio para analizar los efectos agudos cardiorrespiratorios y metabólicos sobre el ejercicio realizado en una plataforma de disipación de aire en personas de la tercera edad

El Investigador responsable del proyecto manifiesta que la persona participante tiene la posibilidad de abandonar su participación en el estudio, en cualquier momento y sin la obligación de dar explicaciones de su voluntad.

Firma:

INVESTIGADOR PRINCIPAL

Dr. Manuel Vicente Garnacho Castaño

DOCTORANDO

Srta. Alessandra Moreira Reis

Afiliaciones

Departamento de Fisiología e Inmunología. Facultad de Biología. Universidad de Barcelona.

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Congresos

29 NOVIEMBRE A 1 DE DICIEMBRE 2018

El Comité Organizador del

XVII CONGRESO INTERNACIONAL DE LA

SOCIEDAD ESPAÑOLA DE MEDICINA DEL DEPORTE

CERTIFICA QUE

la COMUNICACIÓN CIENTÍFICA de título

Efectos de un programa de ejercicios con inestabilidades en el fitness de las personas mayores

cuyos AUTORES son

Moreira A, Serra-Payá N, Palau G, Sánchez S, Suárez D, Ferrer M, Barba F, Estivill A, Vilches S, Garnacho-Castaño MV.

ha sido presentada en el XVII CONGRESO INTERNACIONAL DE LA SOCIEDAD ESPAÑOLA DE MEDICINA DEL DEPORTE, celebrado los días 29 y 30 de noviembre y 1 de diciembre de 2018, en el Hotel Beatriz Toledo Auditorium de Toledo.

El presidente del Comité Organizador

Dr. D. Pedro Manonelles

Effect of a training program with an *air dissipation platform* on oxidative profile and cardiovascular fitness in healthy elderly

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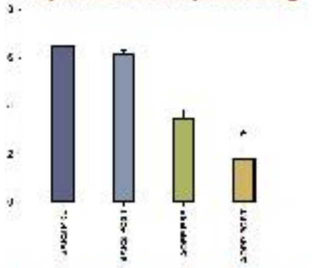
Introduction

Cellular homeostasis depends on cell's ability to handle oxidative stress, mainly produced by its own metabolism, and to maintain functionality regarding environmental changes. The increase in the life span correlates with the increase in age-related pathologies where oxidation of molecules and tissues exceeds clearing and repair mechanisms. Hence, boost in oxidative stress, mainly attributed to defective mitochondria[1] and oxidative damage of the mitochondrial membrane[2], is associated with the onset of cardiovascular diseases, showing a cumulative effect over time.

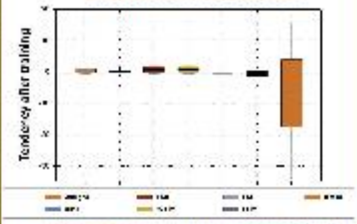
The positive effects of physical exercise on cardiovascular and cellular fitness in the elderly have been widely confirmed[1]. Aerobic choreographed activities on an *air-dissipation platform* allow shock absorption during exercise, being an exceptional alternative for seniors who initiate an exercise program, especially to avoid overloads and initial injuries, while improving cardiovascular fitness[1]. The objective of the study was to evaluate the effects of an exercise program on cardiovascular fitness and oxidative stress parameters

Figure 2:
Lipoperoxidation and Protein oxidation in plasma after and post training



Values are mean ± standard error. * $p<0.005$.
[TBARS in nmol/ml, AOPP: Advanced oxidative protein products in mol oxidized protein/ mg protein]

Figure 3:
Biometric evolution



Values are mean ± standard error of the individual differences between pre and post training measurements.
[BMI: Body mass index; FMI: fat mass index; %FM: percentage of fat mass; LM: lean mass; FFM: fat free mass; Basal: Basal Metabolism]

Material and methods

Ten healthy seniors (66 ± 1,2 years old) were recluted from the Seniors Center of Alcorcon (Madrid). The inclusion criteria were: (i) Have medical permission to exercise. (ii) Do not have any hip or knee prosthesis.
The volunteers performed a 12-week (12w) exercise program (2 sessions per week) on an air-dissipation platform (Figure 1). Electric bioimpedance (InBody 3.0, Biospace, Seoul, Korea) was measured Fat Free Mass (MLG). Body Fat (BF). Percentage of Body Fat (% GC). Lean mass (LM).
Blood samples were drawn using heparinized tubes at the beginning of training (Pre-test) and after finishing it (Post-test).
The lipid peroxidation was determined in the plasma using the thiobarbituric acid reactive substances (TBARS) procedure, with malondialdehyde (MDA) being quantified as the final reactive product. The protein oxidation was determined by measuring the advanced oxidation protein products (AOPP[2]).

Figure 1: Protocol of training

Table 1:
Body composition variables at the beginning and end of training

	Basal metab	Weigth (Kg)	BMI	% FM
Pre	1287 ± 39,1	69 ± 2,4	29 ± 0,9	39 ±1,7
Post	1293 ± 40,0	69 ± 2,5	29 ± 0,9	38 ± 1,8

Values are mean ± standard error.
BMI: Body mass index; %FM: Percentage of fat mass].

Results and discussion

The 12w exercise program had beneficial effects by inducing a significant reduction in post-training TBARS and AOPP levels ($p < 0.05$) in plasma. (Figure 2).
An increase in cardiovascular performance was also observed, by increasing VO_{2max} and reducing heart rate (data not shown). Training did not change body composition indicators (Table 1& Figure 3), suggesting that the level and duration of the training evaluated is minimal but efficient to induce redox modulation.

Conclusions

In conclusion, a 12w-exercise program on air-dissipation platform decreases plasma lipid and protein oxidation
In elderly people, this training program was effective improving cardiovascular fitness without significant differences in body composition.

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Cardiorespiratory, Metabolic and Muscular Responses during a Video-Recorded Aerobic Dance Session on an Air Dissipation Platform

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Abstract: Background: Aerobic dance (AD) is an appropriate physical activity for improving cardiorespiratory fitness. This study aimed to compare cardiorespiratory and metabolic responses, and muscle fatigue between an air dissipation platform (ADP) and a hard surface during a video-recorded AD session. Methods: 25 healthy young women (23.3 ± 2.5 years) completed three sessions. In session 1, participants performed an incremental test to exhaustion on a treadmill. One week after session 1, participants were randomly assigned in a crossover design to perform video-recorded AD sessions on an ADP and on a hard surface (sessions 2 and 3). Cardiorespiratory and metabolic responses were assessed during AD sessions. Muscular fatigue was measured before and after AD sessions by a countermovement jump test. Results: Significantly higher heart rate, respiratory exchange ratio, pulmonary ventilation, ventilatory oxygen equivalent, and ventilatory carbon dioxide equivalent were observed on an ADP than on a hard surface ($p < 0.05$). Despite a significant increase in lactate levels on an ADP ($p \leq 0.01$), muscular fatigue and perceived exertion rating were similar on both surfaces ($p > 0.05$). Conclusions: Video-recorded AD on an ADP increased the cardioventilatory and metabolic responses compared to a hard surface, preventing further muscle fatigue.

Keywords: ventilatory threshold; cardiopulmonary exercise test; fitness class; blood lactate; fatigue

1. Introduction

Group classes in fitness centers are a very popular physical activity among women and, particularly, aerobic dance (AD) is one of the most practiced worldwide. In this period of pandemic due to severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2), thousands of practitioners who performed AD classes in fitness centers have stopped training due to conditions of confinement. EHealth and exercise videos, television and mobiles are technologies that could be used to maintain physical function and mental health [1] during periods of confinement. AD led by fitness instructors through a video-recorded session could be a very interesting alternative to maintain or improve cardiorespiratory and metabolic fitness during periods of confinement.

Heart rate (HR), blood lactate levels and oxygen uptake (VO_2) have been used as measurement parameters to assess the exercise intensity in AD classes [2]. De Angelis et al. proved that AD increased HR, VO_2 and blood lactate concentrations to a greater extent than expected, showing a high exercise intensity, metabolic demand and a non-steady state [2]. The cardiorespiratory and metabolic requirements for regular bipedal work are conditioned by the mechanical properties of the surface [3,4]. Hardin et al. [3] concluded that a harder surface decreased VO_2 compared to a softer surface. Rodrigues et al. demonstrated that an elastic surface (i.e., mini-trampoline) increased cardiovascular responses compared to a hardwood surface during a stationary running [5]. The authors assumed that the higher physiological demands induced by the mini-trampoline could be due to constant rebounds and instability produced by an elastic surface. This increased physiological demand would involve greater effort to carry out the exercise and maintain balance on the mini-trampoline. Moreover, soft surfaces may reduce the risk of joint injuries from high impact [6]. The physiological demands of AD classes could depend, at least in part, on the exercise intensity (i.e., percentage of maximal heart rate, percentage of maximal VO_2, energy expenditure, blood lactate, etc.) and the type of surface.

The type of surface has been demonstrated to affect muscle fatigue [7], mechanical work [8] and energy cost [9]. Several studies have proposed that a compliant elastic surface reduces mechanical work and energy cost of generating muscle force compared with hopping or running on a hard surface [8,9]. In human motor actions, the energy cost is determined by the energy required to generate muscle force and the energy required to perform mechanical work [10,11]. During human hopping on a compliant elastic surface, part of the mechanical work is supplied by the musculoskeletal system. Another important part is provided by storage and recovery of elastic energy in the surface. As a consequence of increasing leg stiffness on a compliant elastic surface, the mechanical work done by the surface is increased. In contrast, the mechanical work done by the legs is reduced. Consequently, the energy cost is reduced by generating muscle force [9]. It is tempting to speculate that the different mechanical work and energy costs induced by different surfaces on the musculoskeletal system could lead to variations in muscular fatigue. Several studies have used vertical jump height (i.e., counter movement jump) before and after exercise to assess the extent of muscular fatigue [12,13]. However, muscular fatigue assessed by a countermovement jump test before and after an AD session has not been explored by comparing an ADP and a hard surface.

Recently, an air dissipation platform (ADP) has been incorporated by our research group into AD classes. The ADP consists of an area that rests on an elastomer that contains air and that allows air to enter and exit through holes. One of the main characteristics of this device is instability and rebound damping produced during exercise, just as it occurs on a mini-trampoline [5]. In theory, cardiorespiratory and metabolic responses on an ADP should be increased compared to a hard surface; however, this statement has not yet been scientifically confirmed. This knowledge would be a key factor in determining whether the exercise intensity during a video-recorded AD class on an ADP is enough to produce improvements in cardiorespiratory fitness.

This study aimed to assess the acute cardiorespiratory and metabolic responses induced by an ADP and a hard surface (marble floor) during a video-recorded AD session. The secondary aim was to determine the muscular fatigue induced by an ADP and a hard surface as well as the rate of perceived exertion (RPE). We hypothesized that a video-recorded AD session on an ADP produces higher acute cardiorespiratory and metabolic responses (blood lactate) compared to AD on a harder surface. In addition, a video-recorded AD session on an ADP is probably an ideal alternative to increase exercise intensity, maintaining similar RPE and muscular fatigue.

2. Materials and Methods

2.1. Experimental Approach to the Problem

Participants completed three test sessions at the Exercise Physiology laboratory. Sessions were conducted under the same environmental conditions (temperature 20–22.5 °C, atmospheric pressure: 715–730 mm Hg, and relative humidity 40–50%) and in the same time frame (+1 h). Participants refrained from any high-intensity physical effort for 48 h and abstained from any type of physical exercise for 24 h before starting the first session.

In session 1, an incremental test until exhaustion was completed on a treadmill to determine cardiorespiratory responses and ventilatory thresholds (VTs). One week after session 1, participants were randomly assigned in a crossover design to carry out AD sessions on an ADP and on a hard surface (session 2 and 3). The AD class was video recorded by a certified fitness instructor a week before. This video session was projected on a giant screen individually to each participant during the AD classes on an ADP or a marble floor (hard surface). Sessions 2 and 3 were rigorously identical and cardiorespiratory and metabolic responses, muscular fatigue and RPE were evaluated one week apart.

2.2. Participants

The participants recruited were 25 healthy young women (age, 23.3 ± 2.5 years; weight, 58.4 ± 6.8 kg; height, 162.6 ± 5.5 cm; and body mass index, 22.1 ± 2.4 kg/m^2). All of them performed light or moderate physical activity a maximum of 2–3 times per week. Exclusion criteria were (a) the use of any medication or performance-enhancing drugs, (b) smoking or alcohol intake, (c) the intake of any nutritional supplement that could alter cardiorespiratory performance, (d) any cardiovascular, metabolic, neurological, pulmonary, or orthopedic disorders that could limit exercise performance, (e) being an elite athlete. Participants were informed of all experimental tests and signed an informed consent form. The study protocol received approval from the Ethics Committee of the University (13/2018) and adhered to the tenets of the Declaration of Helsinki.

2.3. Incremental Treadmill Test

The incremental cardiopulmonary exercise test (CPET) until exhaustion included a 5-min warm-up on a motorized treadmill (TechnoGym, Runrace 1400HC, Forlí, Italy) at a self-selected light intensity (~5–6 km·h^{-1}), followed by 5-min of dynamic joint mobility drills and stretching exercises. After 3-min rest time, the CPET on a treadmill commenced at an initial load of 5 km·h^{-1} (1% slope) which was increased in steps of 0.5 km·h^{-1} every 30 s.

Respiratory exchange data were recorded during the CPET using a breath-by-breath open-circuit gas analyzer (Vmax spectra 29, Sensormedics Corp., Yorba Linda, CA, USA). VO_2max, minute ventilation (VE), carbon dioxide production (VCO_2), ventilatory equivalent for oxygen ($VE \cdot VO_2^{-1}$), ventilatory equivalent for carbon dioxide ($VE \cdot VCO_2^{-1}$), respiratory exchange ratio (RER), oxygen partial pressure on expiration ($PetO_2$), partial pressure of carbon dioxide on expiration ($PetCO_2$) were monitored. HR was checked every 5 s by telemetry (RS-800CX, Polar Electro OY, Kempele, Finland).

In the CPET, maximum or peak cardiorespiratory indices and VTs (first ventilatory threshold: VT1 and second ventilatory threshold: VT2) were determined to identify the relative exercise intensity of AD classes. As in a previous study [14], two investigators separately identified VT1 and VT2. If there was lack of agreement, the opinion of a third observer was considered. VT1 was defined as the workload (velocity) at which both $VE \cdot VO_2^{-1}$ and $PetO_2$ increase, without a concomitant increase in $VE \cdot VCO_2^{-1}$. Similarly, VT2 was defined as the workload (velocity) at which $VE \cdot VO_2^{-1}$ and $VE \cdot VCO_2^{-1}$ increase, accompanied by a drop in $PetCO_2$ [15].

2.4. Aerobic Dance Sessions

AD sessions were conducted on an ADP and on a marble floor (hard surface) (sessions 2 and 3). The ADP consists of an area of one meter in diameter and 20 cm high that rests on an elastomer that contains air at atmospheric pressure and that allows air to enter and exit through holes. The same general warm-up was carried out as in the CPET. After a 3-min rest period, each subject performed a 40-min AD session of individual exercise on an ADP or a marble floor. The AD class consisted of three phases: a 5-min of specific warm-up, a 30-min aerobic or principal phase, and 5-min cool-down.

The aerobic phase of the AD session was structured by an experienced instructor to be of light intensity at most 75% HRmax (RPE ~11–12), moderate intensity at most 85% HRmax (RPE ~13–14), or heavy intensity at most 90% HRmax (RPE ~15–17) [16]. The AD sessions were based on global and multi-articular movements in which large muscle groups participated, including jumps, arm and leg movements, trunk flexions, etc. The exercise intensity of the AD classes was controlled by varying the muscle mass involved (deeper movements, increased bending, arm activity) as well as modifying the direction, the impact of the movements and the range.

To verify that both AD classes (ADP vs. hard surface) were rigorously the same, a video of an AD class was recorded a week before. Participants were instructed to imitate the motor tasks to be performed by an expert instructor to the rhythm of the music (Figure 1). Since all participants were familiarized with AD classes, the motor tasks were not difficult to replicate.

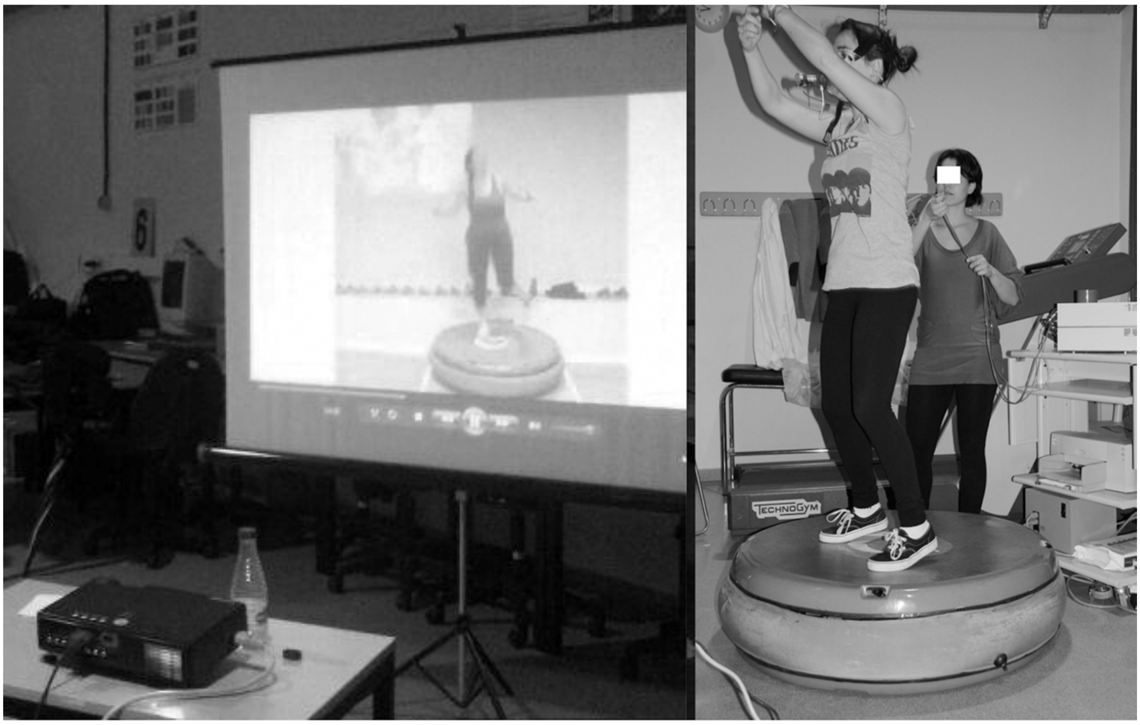

Figure 1. Aerobic dance session performed on an air dissipation platform. The video session was projected on a giant screen individually to each participant.

2.5. Cardiorespiratory, Metabolic and Muscular Assessment

Respiratory exchange data were recorded during AD classes using a breath-by-breath open-circuit gas analyzer, as previously in the CPET.

Blood lactate and RPE were measured at rest (before warm-up) and every 10 min during AD classes (10-min, 20-min, 30-min and 40-min). Blood lactate levels were determined from finger capillary blood using a portable lactate analyzer (Lactate Pro LT-1710, Arkray Factory Inc., KDK Corporation, Siga, Japan), while RPE was determined by using the Borg Scale [17].

Before and after AD classes, muscular fatigue of lower limbs was evaluated by the countermovement jump (CMJ) test using a force platform (Quattro Jump model 9290AD; Kistler Instruments, Winterthur, Switzerland), as in previous studies [13,18]. The CMJ was initiated while standing on the force platform with hands on hips and legs extended. Next, the knees were first flexed to 90° (eccentric action) and immediately explosively extended in a coordinated manner (concentric action) trying to reach maximum vertical height. During the flight stage, the knees were fully extended and contact with the ground was made with the toes first. The participants were instructed to keep their hands on the hips and avoid any sideways or backward/forward movements during the flight stage.

Participants carried out 3 CMJs separated by a rest time of 30 s, and the mean values of vertical flight height and mean power (3 CMJs) were used in the subsequent analyses. Loss of vertical jump height and power output have been used to assess muscle fatigue before and after an exercise session [13,18]. The force platform was connected to a computer and the software package of Kistler (Quattro Jump software, version 1.1.1.4, (Kistler Instruments, Winterthur, Switzerland) was used to quantify the kinetic and kinematic variables. The vertical ground reaction force (GRF) data were obtained during the jump (range 0–10 kN; sampling frequency 0.5 kHz). The vertical component of the center of mass (COM) velocity was estimated using the impulse method [19]. Net impulse was taken by integrating the GRF from 2 s before the first movement of the participant [20]. The vertical velocity of COM was calculated by dividing the net impulse by the participant's body mass [21]. Maximum velocity reached at the end of the concentric muscle action of the jump was considered as maximum take-off velocity (V_{max}). Flight height (cm) was calculated from V_{max} of the COM and the deceleration of gravity. Height = $((V_{max})^2/2 \times 9.81)$. Power was calculated from the unfiltered force–time history using the impulse momentum principle [22]. Mean relative power (watts·kg^{-1}) was calculated as the product of mean velocity and vertical component of the vertical ground reaction force.

2.6. Statistical Analysis

The Shapiro–Wilk test was used to check the normal distribution of data, provided as means, standard deviation (SD), confidence intervals (95% CI) and percentages. A t-student for paired samples was applied to identify significant differences between an ADP and a hard surface in cardiorespiratory and metabolic responses. Cohen's d effect sizes ($d < 0.4$, small; ≥ 0.4, moderate; ≥ 0.8, large) were calculated to assess the magnitude of difference among experimental conditions [23].

A general linear model with a two-way analysis of variance (ANOVA) for repeated measures was performed to verify significant differences between an ADP and a marble hard surface in lactate levels and RPE. The two factors were exercise mode (ADP and marble floor) and time (corresponding to 4 checkpoints performed in both AD classes). When appropriate, a Bonferroni post hoc adjustment for multiple comparisons was implemented. An ANOVA for repeated measures was performed to determine muscular fatigue. The partial eta-squared (η_p^2) was computed to determine the magnitude of the response to both exercise modes. The statistical power (SP) was also calculated. All statistical methods were performed using the software package SPSS Statistics version 25.0 for Mackintosh (SPSS, Chicago, IL, USA). Significance was set at $p < 0.05$.

3. Results

Descriptive data related to the CPET in treadmill are presented in Table 1. The predicted maximum heart rate (197 beats·min^{-1}) of the experimental group was not reached (187.1 ± 8.1 beats·min^{-1}). The functional capacity of the healthy young women was good (VO_2: 42.4 ± 7.5).

The differences among the experimental conditions are shown in Table 2. Significant higher acute responses in HR ($p = 0.002$, $t = 3.5$, moderate effect $d = 0.4$), RER ($p = 0.031$, $t = 2.3$, moderate effect $d = 0.4$), VE ($p = 0.026$, $t = 2.4$, small effect $d = 0.3$), $VE{\cdot}VO_2^{-1}$ ($p = 0.001$, $t = 3.7$, moderate effect $d = 0.5$) and $VE{\cdot}VCO_2^{-1}$ ($p = 0.039$, $t = 2.2$, small effect $d = 0.2$) were found on an ADP compared with a hard surface (marble floor). No significant differences were detected in the rest of the acute cardiorespiratory responses among experimental conditions ($p > 0.05$).

Table 1. Cardiorespiratory results attained during the incremental treadmill test.

Variables	Mean (SD)
Peak HR (beats·min^{-1})	187.1 (8.1)
Peak VO_2 (L·min^{-1})	2.4 (0.5)
Peak VO_2 (mL·kg^{-1}·min^{-1})	42.4 (7.5)
Peak VCO_2 (L·min^{-1})	2.9 (0.5)
Peak RER	1.2 (0.1)
Peak VE (L·min^{-1})	84.5 (15.9)
Peak Velocity (km·h^{-1})	12.0 (1.6)
HR at VT_1 (beats·min^{-1})	152.2 (15.1)
HR at VT_1 (%)	81.3 (7.2)
VO_2 at VT_1 (L·min^{-1})	1.5 (0.5)
VO_2 at VT_1 (mL·kg^{-1}·min^{-1})	26.0 (7.3)
VO_2 at VT_1 (%)	61.3 (11.2)
VCO_2 at VT_1 (L·min^{-1})	1.3 (0.4)
RER at VT_1	0.9 (0.1)
VE at VT_1(L·min^{-1})	37.4 (10.4)
Velocity at VT_1 (km·h^{-1})	7.1 (1.1)
HR at VT_2 (beats·min^{-1})	174.8 (12.2)
HR at VT_2 (%)	93.4 (6.1)
VO_2 at VT_2 (L·min^{-1})	2.2 (0.5)
VO_2 at VT_2 (mL·kg^{-1}·min^{-1})	36.9 (7.0)
VO_2 at VT_2 (%)	87.0 (6.7)
VCO_2 at VT_2 (L·min^{-1})	2.2 (0.5)
RER at VT_2	1.0 (0.1)
VE at VT_2 (L·min^{-1})	61.2 (14.6)
Velocity at VT_2 (km·h^{-1})	9.8 (1.4)

Abbreviations used: HR = heart rate; MET = metabolic equivalent; RER = respiratory exchange ratio; standard deviation = SD; VCO_2 = carbon dioxide production; VE = minute ventilation; VO_2 = oxygen uptake; VT_1 = first ventilatory threshold; VT_2 = second ventilatory threshold. (n = 25).

Table 2. Acute cardiorespiratory responses during both experimental conditions.

Variables	ADP	% Peak Values $^{\lambda}$	MF	% Peak Values $^{\lambda}$
HR (beats·min^{-1})	171.7 (12.6) *	91.8	165.7 (14.6)	88.6
VO_2 (L·min^{-1})	1.8 (0.3)	72.0	1.7 (0.3)	71.6
VO_2 (mL·kg^{-1}·min^{-1})	30.0 (3.5)	70.9	29.8 (3.7)	70.4
VCO_2 (L·min^{-1})	1.7 (0.2)	59.0	1.6 (0.3)	57.4
RER	1.0 (0.1) $^{\delta}$	81.2	0.9 (0.1)	79.4
VE (L·min^{-1})	59.0 (9.6) $^{\delta}$	69.8	55.5 (11.6)	65.7
VE·VO_2^{-1}	34.1 (4.1) *	96.0	32.2 (3.7)	90.5
VE·VCO_2^{-1}	34.3 (3.2) $^{\delta}$	100	33.4 (3.4)	100
METs	8.6 (1.4)	70.9	8.5 (1.1)	70.3

Data are presented as mean and standard deviation (SD). Abbreviations used: ADP = Air dissipation platform; HR = heart rate; MET = metabolic equivalent; MF = marble floor; RER = respiratory exchange ratio; VCO_2 = carbon dioxide production; VE = minute ventilation; VE·VO_2^{-1} = ventilatory equivalent for oxygen; VO_2 = oxygen uptake. * Significantly different from MF, $p < 0.01$. $^{\delta}$ Significantly different from MF, $p < 0.05$. $^{\lambda}$ percentage considers peak values obtained in the incremental treadmill test.

In blood lactate concentrations, a significant exercise mode x time interaction effect was observed ($p = 0.024$, $F_{(4,88)} = 2.9$, $\eta_p^2 = 0.1$, SP = 0.8). A significant time effect was observed ($p < 0.001$, $F_{(4,88)} = 44.0$, $\eta_p^2 = 0.7$, SP = 1.0), and also a exercise mode effect ($p = 0.002$, $F_{(1,22)} = 12.5$, $\eta_p^2 = 0.4$, SP = 0.9). The Bonferroni test confirmed higher blood lactate levels when exercising on an ADP than a hard surface at 20-min, 30-min and 40-min ($p \leq 0.01$) (Figure 2A). RPE followed the same evolution in both exercise groups ($p > 0.05$) (Figure 2B).

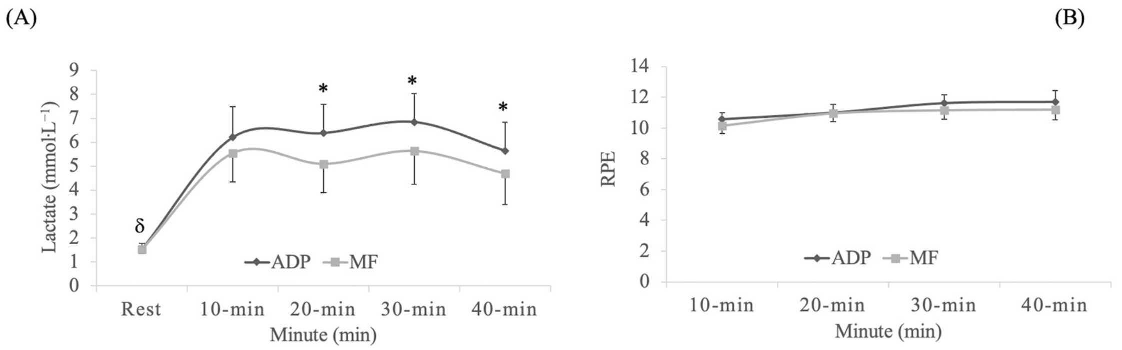

Figure 2. Blood lactate levels (**A**) and rating of perceived exertion (RPE) (**B**) during aerobic dance sessions. * Significantly different from marble floor at times 20-min, 30-min and 40-min, $p \leq 0.01$. Data are provided as mean and 95% confidence intervals (95% CI). $^{\delta}$ Significantly different from checkpoint at times10-min, 20-min, 30-min and 40-min in both experimental conditions, $p < 0.001$. Abbreviations used: ADP = air dissipation platform; MF = marble floor (hard surface).

In the CMJ test, no significant exercise mode × time interaction effect, time and exercise mode effects were observed ($p > 0.05$) (Figure 3).

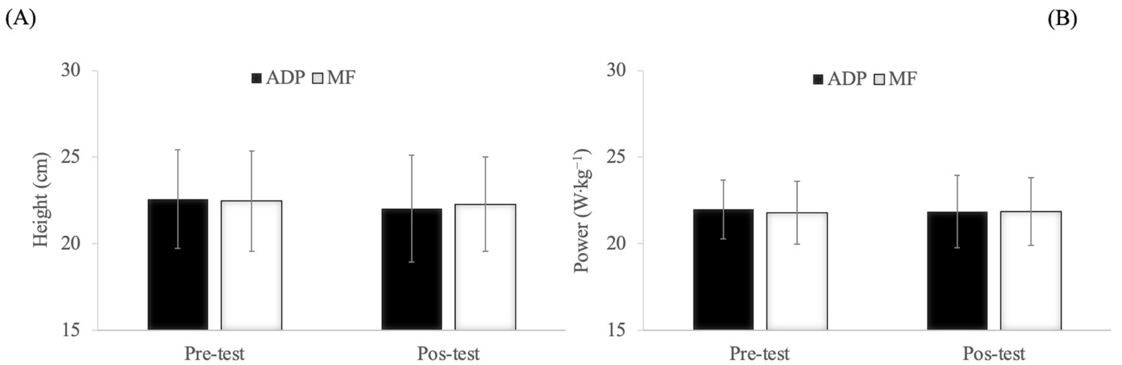

Figure 3. Muscular fatigue assessed by countermovement jump (CMJ) test before and after the aerobic dance classes. (**A**) Mean height (cm) in CMJ. (**B**) Mean power ($W \cdot kg^{-1}$) in CMJ. No significant differences were detected among experimental conditions. Abbreviations used: ADP = air dissipation platform; MF = marble floor (hard surface).

4. Discussion

The main finding of this study was that AD led by fitness instructors through a video-recorded session induced a higher HR, VE, RER, $VE \cdot VO_2^{-1}$, $VE \cdot VCO_2^{-1}$ and blood lactate concentrations on an ADP than on a hard surface. AD performed on both surfaces induced similar muscular fatigue in the lower extremities and feeling of physical exertion (RPE).

The HR was greater on an ADP (+3.8%) than on a hard surface. Recently, Rodrigues et al. [5] observed that elastic surfaces (mini-trampoline 76.5% of HRmax) increased the HR response compared to a hard surface (67.4% of HRmax) during a stationary running. It is possible that the higher HR observed on an ADP could be due to the rebounding and instability induced by the elastic surface, and consequently it would involve a greater effort to maintain balance during AD session [5]. AD in both surfaces indicated a percentage of peak HR similar to those reported in aerobic step dance performed with load (89.8%) [24]. However, the HR was higher on both surfaces than those observed in tap dance (83.8%) [25] and in an aerobic step dance performed without overload (84.5%) [24]. AD activities such as body pump, body combat and spinning have shown a low HR (60.2%, 73.2%, 74.3% of HRmax, respectively) [26]. Apart from the contact surface, the discrepancy in HR response could be attributed to the different dance modalities and class methodologies used for AD.

The observed HR in both surfaces demonstrated that a video-recorded AD session could be an adequate alternative for improving or maintaining cardiorespiratory fitness in healthy young women. The American College of Sports Medicine (ACSM) guidelines determines that vigorous intensity (≥~6 metabolic equivalents (METs), 77–95% of HRmax) of physical activity performed 3 d·wk^{-1} for a total of ~75 min·wk^{-1} or 20 min·d^{-1} improves or maintains cardiorespiratory fitness [27]. In this regard, both AD sessions may be considered as a vigorous exercise intensity (ADP: 8.6 MET/91.8% of HRmax vs. hard surface: 8.5 METs/88.6% of HRmax).

Blood lactate levels were increased to a greater extent on an ADP compared to a hard surface. Brito et al. [28] showed that unstable surfaces such as sand produced greater blood lactate levels in comparison to hard surfaces (4 mmol·L^{-1} and 2.8 mmol·L^{-1}) during a soccer game. The authors concluded that playing on hard surfaces such as asphalt decreased the lactate anaerobic pathway more than playing on unstable surfaces. This appreciation suggests that differences in blood lactate levels between an ADP and a hard surface could be due to the fact that the impact forces induced by the damping are reduced on the platform. The instability and contact times on ADP would increase, causing increased muscle activation in the agonist and antagonist muscles as occurs on unstable surfaces [29]. This amplified muscle activation could accentuate the muscular work and, consequently, the lactate anaerobic metabolic pathway could be further activated. Future studies should be focused on comparing the activation of metabolic pathways between unstable and stable surfaces as long as the intensity of exercise proposed was the same.

In a similar study [25], lower blood lactate levels were found during a tap dance choreography compared to our study (1.7 mmol·L^{-1} vs. 6.3 mmol·L^{-1} and 5.2 mmol·L^{-1}, respectively). We suggested that the differences observed between studies could be attributed to exercise intensity. The relative exercise intensity established in both AD activities was interpreted based on the ventilatory parameters obtained during an incremental treadmill test. To this end, VT1 and VT2 were determined by expert evaluators since it has been well established that performance in endurance exercise is linked to VTs [30,31]. To our knowledge, no studies have used VTs during an incremental treadmill test as a reference to identify the relative exercise intensity in an AD class performed on elastic and hard surfaces. Nevertheless, Oliveira et al. [25] used the lactate threshold in an incremental treadmill test to categorize the exercise intensity during a tap dance choreography. The lactate threshold and VT1 are certainly connected and occur at a comparable exercise intensity in several forms of exercise [32,33]. This disagreement among studies could be supported by the fact that tap dance exercise intensity was approximately 10% less than the lactate threshold. Our outcomes showed a relative exercise intensity above VT1 and next to VT2 in both surfaces. Accordingly, higher HR (ADP 8.7%, marble floor 5.4%), VO_2 (ADP 2.8%, marble floor 2.1%) and METs (ADP 5.8%, marble floor 4.7%) were observed in both AD sessions than in a tap dance choreography [25]. This augmented cardiorespiratory response justified, at least in part, a greater blood lactate levels observed in our study.

These differences in blood lactate concentrations among studies highlight the relevance of previously knowing exercise intensity (HR) through check points (ventilatory or lactate thresholds) that determine the metabolic changes in each participant. In this way, practitioners of activities such as fitness classes would know the workload or relative intensity (HR or VO_2) corresponding to the session. Additionally, researchers would be able to understand the underlying adaptive physiological mechanisms of the various AD modalities.

It is clear that knowledge of these VTs has been a key factor in discovering the cardiorespiratory exercise intensity and, consequently, understanding why there was a greater metabolic stress than in other studies. Ventilatory adaptation to CO_2 production threshold (VT1) is interpreted as the first non-linear increases in VCO_2 and ventilation due to the bicarbonate buffering of H^+ produced by a gradual increase in blood lactate levels above resting values [34]. VT2 is accepted as the second breakpoint in the ventilation response chiefly produced by a pH decrease as bicarbonate is saturated by the rising production of lactate (acidosis) [35]. Probably, the higher VE, RER, VE·VO_2^{-1}, VE·VCO_2^{-1}

detected on an ADP than on a marble floor could be due to this increase in acidosis and relative intensity very close to that observed during the incremental treadmill test in VT2.

In theory, this increased cardiac and metabolic stress would imply a higher VO_2 on an ADP than on a marble floor. However, VO_2 was similar among surfaces. VO_2 results differed from others that showed how elastic surfaces increased HR and VO_2 to a larger magnitude than hard surface [5]. Although we have not found studies evaluating several surfaces in AD modalities, a study on competitive tennis players revealed that the HR and blood lactate levels were higher on a softer surface, maintaining similar VO_2 [36]. Given these discrepancies, we did not find a rational physiological and biomechanical explanation. More studies are necessary to draw adequate conclusions.

VO_2 was similar in both surfaces (ADP: 70.9% vs. hard surface 70.4% of VO_2max). Analogous findings were found during stationary running on an elastic surface (68.9% of VO_2max) and aerobic step dance performed without overload (68.9% of VO_2max) confirming an adequate relative exercise intensity to provide cardiovascular improvements [25]. Nevertheless, VO_2 (78.3% of VO_2max) was increased in aerobic step dance carried out with overload [24]. External overload could be an added resource to increase the relative intensity (% of HRmax and VO_2max) produced by the rebound effect and the instabilities of the elastic surfaces.

Muscular fatigue has been assessed by CMJ test in several studies that analyzed cardiorespiratory and metabolic responses [12,13,18]. Despite finding a greater cardiometabolic and ventilatory stress on an ADP than on a hard surface, mechanical fatigue on an ADP was not augmented compared to a hard surface. We suspect that an ADP reduced the mechanical work done by the lower limbs by increasing leg stiffness on compliant elastic surface. Our arguments cannot be objectively corroborated since leg stiffness on an ADP was not measured, thus these interpretations remain purely speculative. However, it is assumed that the mechanical work is reduced by increasing leg stiffness on a compliant elastic surface [8,9]. Therefore, the joint strain and muscle fatigue could be minimized by using elastic surfaces. Soft surfaces may reduce the risk of joint injuries at high impact [6].

It would be logical to identify a greater perception of effort in response to a higher cardioventilatory and metabolic stress on an ADP; however, the RPE of the participants was the same throughout the session. The RPE is an excellent parameter to subjectively quantify the exercise intensity in fitness sessions [37]. It was the first time that participants used an ADP; therefore, the motivation to use a different apparatus could have been a differential factor for having a lesser sensation of physical effort. The greater feeling of pleasure on an ADP than on the marble floor was verified by the participants. More research would be necessary to determine the psychological and emotional benefits and adherence that this type of device could produce.

An AD session on an ADP could increase cardiorespiratory and metabolic demands by diminishing mechanical stress on the joints and muscle mass. Thus, this type of aerobic activity could be very suitable for elderly people (skeletal fragility) because they could achieve the same functional exercise intensity with less mechanical stress. Determining exercise intensity based on the type of surface in an AD class by using VTs would allow us to know whether acute cardioventilatory and metabolic responses are intense enough to promote long-term improvements (adaptations) in cardiorespiratory fitness.

Finally, the findings of this study are relevant because a video-recorded AD session on an ADP could be an excellent alternative to perform physical activity during forced periods of confinement due to pandemics (i.e., SARS-CoV-2). Long stays at home are likely to encourage sedentary behaviors such as spending more time sitting, lying down, playing video games, etc., leading to an increased risk and potential worsening of chronic health conditions. In this environment, the practice of physical activity at home is more than justified. Performing safe, simple and easy to implement exercises at home is very suitable to avoid airborne coronavirus and maintain fitness levels [38]. The ADP is a safe, simple and small device that can be used at home. The findings reported in this study demonstrated that a video-recorded AD session on an ADP induced a suitable exercise intensity. The supervision of fitness instructors would be recommended during AD sessions on an ADP to establish adequate guidelines for improving cardiorespiratory fitness in exercise home-programs. AD on an ADP performed 3 $d \cdot wk^{-1}$

for a total of ~75 min·wk^{-1} or 20 min·d^{-1} could be a very interesting alternative to maintain or improve cardiorespiratory and metabolic fitness according to the ACSM guidelines.

5. Conclusions

A video-recorded AD class on an ADP increases greater cardiorespiratory and metabolic responses than on a harder surface, without inducing greater muscular fatigue and feeling of physical exertion.

Author Contributions: Conceived and designed the experiments: A.M.-R., J.L.M.-M. and M.V.G.-C.; performed the experiments: A.M.-R., J.L.M.-M., J.H.-L., P.G.-F., E.P.-C., T.C., N.A. and M.V.G.-C.; analyzed the data: A.M.-R., J.L.M.-M. and M.V.G.-C.; contributed reagents/materials/analysis tools: A.M.-R., J.L.M.-M., J.H.-L., P.G.-F., E.P.-C., T.C., N.A. and M.V.G.-C.; wrote the paper: A.M.-R., J.L.M.-M. and M.V.G.-C. All authors have read and agreed to the published version of the manuscript.

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Similar Slow Component of Oxygen Uptake and Ventilatory Efficiency between an Aerobic Dance Session on an Air Dissipation Platform and a Constant-Load Treadmill Test in Healthy Women

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Simple Summary: The evaluation of the kinetics of oxygen uptake is considered an essential practice to analyze the effect of exercise intensity, mainly in endurance exercise. This study aimed to compare the slow component of oxygen uptake, ventilatory efficiency, blood lactate concentration, and the rating of perceived exertion between an aerobic dance session on an air dissipation platform and a constant-load treadmill test. Seventeen young adult and healthy women (aged 23.5 ± 2.2 years) completed three evaluation sessions. In session 1, an incremental test to exhaustion was completed. In sessions 2 and 3, the participants were randomly assigned to the aerobic dance session on an air dissipation platform or to a treadmill test at a constant-load corresponding to the first ventilatory threshold. No significant differences were found between the constant-load treadmill test and aerobic dance session on an air dissipation platform regarding the slow component of oxygen uptake, ventilatory efficiency, and the rating of perceived exertion. Higher blood lactate concentrations were observed in the aerobic dance session on an air dissipation platform than in the constant-load treadmill test. In conclusion, two different exercise modalities elicited similar slow components of oxygen uptake, ventilatory efficiency, and ratings of perceived exertion, even though the blood lactate concentrations were different.

Abstract: There is a lack of evidence about the slow component of oxygen consumption ($\dot{V}O_{2sc}$) and ventilatory efficiency (slope $VE{\cdot}VCO_2{}^{-1}$) during an aerobic dance (AD) session on an air dissipation platform (ADP) despite the key role played in endurance exercises. This research was designed to assess $\dot{V}O_{2sc}$, ventilatory efficiency, and blood lactate concentration by comparing two exercise modes: AD session on an ADP versus treadmill test at a constant-load intensity of the first ventilatory threshold (VT1). In the first session, an incremental treadmill test was completed. In sessions 2 and 3, the participants were randomly assigned to the AD session on an ADP or to a treadmill constant-load test at VT1 intensity to determine their cardioventilatory responses. In addition, their blood lactate levels and ratings of perceived exertion (RPE, CR-10) were evaluated. No significant differences were found between the constant-load treadmill test and AD session on an ADP with respect to $\dot{V}O_{2sc}$, VE $VCO_2{}^{-1}$ slope, and RPE ($p > 0.05$). Higher blood lactate concentrations were observed in an AD session on an ADP than in a constant-load treadmill test at 10 min ($p = 0.003$) and 20 min ($p < 0.001$). The two different exercise modalities showed similar $\dot{V}O_{2sc}$ and $VE{\cdot}VCO_2{}^{-1}$ slope, even though the blood lactate concentrations were different.

Keywords: oxygen uptake kinetics; $VE \cdot VCO_2^{-1}$ slope; cardiorespiratory responses; blood lactate; rating of perceived exertion; cardiopulmonary exercise test

1. Introduction

The evaluation of the kinetics of oxygen uptake ($\dot{V}O_2$) is considered an essential practice to analyze the effect of exercise intensity on so-called endurance exercises [1] and resistance exercises [2] in several populations [3–6]. Specifically, the pulmonary $\dot{V}O_2$ has a tendency to raise beyond 3 min during any constant work rate exercise involving sustained lactic acidosis, and above that of the primary component initiated at exercise onset. This ventilatory response generated in the kinetics of $\dot{V}O_2$ is known as the slow component of $\dot{V}O_2$($\dot{V}O_{2sc}$) [7].

Cardioventilatory function could be altered by various parameters that condition the acute response of the $\dot{V}O_{2sc}$, such as the load intensity, the lactate threshold (LT), and the ventilatory threshold (VT) [2,8]. At exercise intensities below LT and VT, a steady state of $\dot{V}O_2$ has been observed without increasing the $\dot{V}O_{2sc}$ and blood lactate concentration. At exercise intensities above the LT or VT, an increase in the $\dot{V}O_{2sc}$ has been verified depending on the increase in the exercise intensity and the blood lactate concentration. At a load intensity of the LT or the first ventilatory threshold (VT1), a steady state of both the $\dot{V}O_2$ and the blood lactate concentration has been observed, as well as a slight-moderate increase in the $\dot{V}O_{2sc}$, both in endurance exercises and resistance exercises [2,9,10].

Cardiorespiratory performance is also frequently assessed by means of ventilatory efficiency. The relationship between ventilation (VE) and perfusion in the lungs is a key respiratory physiological mechanism to determine ventilatory efficiency in healthy people, athletes [11,12], and in those with respiratory diseases [13]. The VE/perfusion mismatch decreases the efficiency of pulmonary gas exchange, causing a state of hyperpnea and dyspnea that affects ventilatory performance [14]. The slope between the linear relationship of VE and carbon dioxide ($VE \cdot VCO_2^{-1}$ slope) has been frequently used as a prognostic marker of ventilatory efficiency during an incremental test up to the anaerobic or ventilatory threshold [15,16], the ventilatory compensation point [11], in constant-load endurance and resistance exercise tests, and in resistance exercises of moderate and very high intensities [17,18].

As with the $\dot{V}O_{2sc}$, exercise intensity also modulates the ventilatory efficiency response [18]. As exercise intensity increases, ventilation is increased to remove CO_2 and maintain homeostatic control of pH [12], arterial hypoxemia [19], and lactic acidosis [20], thereby conditioning ventilatory efficiency [18]. At a constant-load intensity of the LT, similar to VT1, it has been proposed that both endurance exercises and resistance exercises maintain an efficient $VE \cdot VCO_2^{-1}$ slope in a predominantly aerobic metabolism with a low blood lactate concentration (~2.7 $mmol \cdot L^{-1}$) [17]. It has been suggested that both the $\dot{V}O_{2sc}$ and ventilatory efficiency could be conditioned, at least in part, by the type of exercise [17,21]. The $\dot{V}O_{2sc}$ is higher in cycling compared to running exercises [21], and it even increases to a greater extent in the half-squat exercise compared to the cycle ergometer test at LT intensity [2]. However, the $VE \cdot VCO_2^{-1}$ slope has generated controversy due to the lack of further studies in this regard with which to draw more accurate conclusions. Some studies showed that the $VE \cdot VCO_2^{-1}$ slope is dependent on the mode of exercise [22], whereas others discard this hypothesis [11].

Aerobic dance (AD) classes are a very popular type of exercise worldwide, especially among women. AD is a choreographed activity of moderate to vigorous intensity accompanied by music and perceived as enjoyable [23,24]. Parameters such as $\dot{V}O_2$, heart rate (HR), and blood lactate concentration have been frequently used to determine the exercise intensity during a normal AD session [25]. Recent contributions from our research group have determined that the execution surface in AD activities can influence cardiorespiratory and metabolic responses. Unstable surfaces with a higher elastic component, such as an air dissipation platform (ADP), could increase the blood lactate concentration (~6 mmol·L^{-1}) and cardioventilatory response during an AD session higher than on hard surfaces [26]. This increase in acute cardioventilatory and metabolic responses after the ADP session can be due to a decline in the damping-induced impact forces and an enhance in instability and contact times. From a physiological perspective, greater muscular tissue stimulation is expected in agonist and antagonist muscles [27]. This amplified activation can increase muscle work, causing a higher demand of the anaerobic metabolic pathway compared to a hard surface [28].

Other studies have shown that the type of AD conditions the exercise intensity to a greater degree compared to various intensities on a treadmill [29]. Therefore, it seems that the efficacy of AD exercises depends on the type of dance, the exercise intensity, and the surface of execution.

A steady state of $\dot{V}O_2$ and blood lactate concentration, as well as an adequate ventilatory efficiency with a low blood lactate concentration (~2.7 mmol·L^{-1}), has been observed at a load intensity of the LT or the VT1 in predominantly aerobic metabolism (2, 9, 10, and 17). However, higher cardioventilatory responses and blood lactate concentrations (~6 mmol·L^{-1}) have been verified in an AD session on an ADP compared to a hard surface [26]. Given the differences observed between several exercise modes, the treadmill, and various types of AD, it is plausible to propose that AD session on an ADP could condition the kinetics of $\dot{V}O_2$ by increasing the $\dot{V}O_{2sc}$ and decreasing ventilatory efficiency to a greater extent than a treadmill test at an intensity of VT1 (~3 mmol·L^{-1}), in which aerobic metabolism predominates. However, to the best of our knowledge, the $\dot{V}O_{2sc}$ and ventilatory efficiency during an AD session on an ADP have not been studied to date. This knowledge would allow us to investigate other variables to interpret how the intensity of exercise is modulated in an AD session on an ADP.

The purpose of this study was to assess the $\dot{V}O_{2sc}$, the VE·VCO$_2{}^{-1}$ slope, and blood lactate concentration by comparing a constant speed treadmill test at VT1 loading intensity with an AD test on an ADP in healthy young adult women. We hypothesize that an AD test on an ADP raises the $\dot{V}O_{2sc}$ and the VE·VCO$_2{}^{-1}$ slope to a greater degree than a treadmill trial at VT1 loading intensity

2. Materials and Methods

2.1. Study Design

This is a cross sectional, comparative study. The participants completed three assessment sessions over 21 days in the exercise physiology laboratory. In the first test session, an incremental treadmill trial to exhaustion was completed to assess peak and VT1 cardiorespiratory responses. At the second testing session, which took place one week later, participants were randomly assigned to either the AD test on an ADP or a treadmill trial with a constant speed corresponding to the intensity of VT1. One week later, session 3 was held, in which the participants performed the pending protocol that was not conducted in session 2, and under the same conditions. The objective in sessions 2 and 3 was to determine the cardioventilatory responses for the subsequent analysis of the $\dot{V}O_{2sc}$ and VE·VCO$_2{}^{-1}$ slope. Blood lactate concentration and rating of perceived exertion (RPE, CR-10) produced in sessions 2 and 3 were evaluated. The participants refrained from any type of physical exertion 24 h before starting the evaluation sessions.

2.2. Participants

Seventeen healthy women (23.5 ± 2.2 years, 58.6 ± 6.8 kg, 162.6 ± 0.1 cm, and 22.4 ± 2.5 body mass index) who were lightly physically active or moderate a maximum of 2 to 3 times per week completed the three test session. Participants were familiarized with the experimental procedures (AD and treadmill protocols). The following exclusion criteria were established: (1) any cardiovascular, metabolic, neurological, pulmonary, or orthopedic disorders that could limit exercise performance; (2) being an elite athlete; (3) tobacco or alcohol intake; and (4) the use of any performance-enhancing medication, drug, or supplement. The participants were informed of all experimental tests and signed an informed consent form. The study protocol received the approval of the University Ethics Committee and was carried out in accordance with the principles of the Declaration of Helsinki.

2.3. Treadmill Test

Before the start of the evaluation sessions on a treadmill (TechnoGym, Runrace 1400HC, Forlí, Italy), a 5-min warm-up was carried out at a speed of 5–6 km h^{-1}, followed by 5 min of dynamic joint mobility exercises. Next, the incremental treadmill protocol was started at an initial speed of 5.5 km h^{-1} (1% slope), which was increased by 0.5 km h^{-1} every 30 s, until exhaustion. The constant speed test was performed at VT1 load intensity for 20 min.

2.4. Aerobic Dance Session

Each participant performed an AD session on an ADP. The ADP consists of a platform of one meter in diameter and 20 cm high, which rests on an elastomer that contains air at atmospheric pressure and allows for the entry and exit of air through holes. The air stored in the area produces a rebound effect, lessening the impact and rising instability during movements on the platform. First, a 5-min warm-up on the ADP was performed, followed by 5 minutes of dynamic joint mobility exercises. Subsequently, the main part of the AD test was carried out on an ADP, which lasted 20 min. The AD test was implemented by an experienced trainer to be executed at a constant light to moderate intensity as in a previous study [26].

2.5. Cardiorespiratory Record

In the two sessions on a treadmill and in the AD session on an ADP, respiratory exchange data were recorded using a breath-to-breath open-circuit gas analyzer (Vmax spectra 29, Sensormedics Corp., Yorba Linda, CA, USA), which had been previously calibrated. The following variables were recorded: $\dot{V}O_2$, VE, carbon dioxide production (VCO_2), ventilatory oxygen equivalent ($VE{\cdot}\dot{V}O_2^{-1}$), ventilatory equivalent of carbon dioxide ($VE{\cdot}VCO_2^{-1}$), respiratory exchange rate (RER), partial pressure of oxygen at expiration ($PetO_2$), and partial pressure of carbon dioxide at expiration ($PetCO_2$). HR was controlled every 5 sec by telemetry (RS-800CX, Polar Electro OY, Helsinki, Finland). VT1 was defined as the workload (speed) at which increases occurred in both $VE{\cdot}\dot{V}O_2^{-1}$ and $PetO_2$, with no concomitant increase in $VE{\cdot}VCO_2^{-1}$ [30].

During the constant-load test at an intensity of VT1 on a treadmill and the AD session on an ADP, the kinetics of pulmonary $\dot{V}O_2$ were evaluated. Pulmonary $\dot{V}O_2$ data were recorded during the 2 min prior to the start of the constant test (baseline state). Baseline $\dot{V}O_2$ ($\dot{V}O_{2B}$) was considered to mean the last 60 s before the start of the test. The fundamental kinetics (Phase II) of $\dot{V}O_2$ were determined using the criteria described above and were adjusted to a mono-exponential function, $\dot{V}O_2(t) = \dot{V}O_{2B} + \Delta\dot{V}O_{2FP} \cdot (1 - e^{-(t-TR)/\tau})$ [31], where $\dot{V}O_2(t)$ is the value of pulmonary $\dot{V}O_2$ at any time t of the kinetics of $\dot{V}O_2$, $\dot{V}O_{2B}$ is the value of basal $\dot{V}O_2$, $\Delta\dot{V}O_{2FP}$ is the increase in $\dot{V}O_2$ above the reference values and determines the range of the fundamental phase, and τ is the time constant of the fundamental phase. TR is the delay time. The exponential region of each participant was adjusted individually [32]. To determine the $\dot{V}O_{2sc}$ (Phase III), the data of pulmonary $\dot{V}O_2$ were recorded. Finally, the $\dot{V}O_{2sc}$ was determined in each participant: $\Delta\dot{V}O_{2sc} = \dot{V}O_{2peak} - (\dot{V}O_{2B} + \Delta\dot{V}O_{2FP})$ [32].

2.6. Metabolic Fatigue and Rating of Perceived Exertion

Metabolic fatigue was assessed by means of a transportable lactate apparatus (Lactate Pro LT-1710, Arkray Factory Inc., KDK Corporation, Siga, Japan). For this purpose, blood lactate concentration was quantified in the capillary of the index finger at rest, at 10 min and at the end of the test. The RPE was controlled applying the Borg scale (CR-10) [33] and was assessed in accordance with blood lactate measurements.

2.7. Statistical Analysis

The Shapiro-Wilk test was applied for testing multivariate normality. To apply the statistical treatment, the data were presented as mean, percentages and confidence intervals (95% CI).

A Student's *t*-test for paired samples was utilized to verify statistically significant changes between both experimental sessions (ADP vs. treadmill test). A two-way analysis of variance (ANOVA) for repeated measures was completed to confirm significant differences between an AD session on an ADP and a constant-load treadmill test with respect to blood lactate concentration and RPE. When appropriate, a Bonferroni post hoc adjustment for multiple comparisons was implemented. The magnitude of the response was calculated using the partial eta-squared (ηp^2). Sample size was estimated with $\alpha = 0.05$ (5% probability of type I error) and $1 - \beta = 0.80$ (power 80%). The statistical power (SP) was also calculated using G*Power 3. The Pearson product–moment correlation coefficients were calculated to determine significant relationships between the VE and the VCO_2. SPSS Statistics software package version 25.0 for Mackintosh (SPSS, Chicago, IL, USA) was used for statistical procedures. Statistical significance was set at $p < 0.05$.

3. Results

The data related to the incremental treadmill test are indicated in Table 1.

Table 1. Cardioventilatory data achieved during the incremental treadmill test.

Variable	N	Minimum	Maximum	Mean	SD
HR (beats·min^{-1})	17	173.0	198.0	187.2	7.4
Absolute peak $\dot{V}O_2$ (L·min^{-1})	17	1.7	3.6	2.4	0.5
Relative peak $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	17	30.1	54.8	41.4	7.5
Peak VCO_2 (L·min^{-1})	17	2.0	3.9	2.9	0.5
Peak RER	17	1.1	1.4	1.2	0.1
Peak VE (L·min^{-1})	17	54.7	109.7	84.7	17.0
Peak VE·$\dot{V}O_2{}^{-1}$	17	29.0	47.0	36,5	5.1
Peak VE·$VCO_2{}^{-1}$	17	28.0	36.0	32.5	2.2
Peak Speed (km·h^{-1})	17	9.5	15.0	12.2	1.7
HR at VT1 (beats·min^{-1})	17	127.0	174.0	150.1	13.1
Absolute $\dot{V}O_2$ at VT1 (L·min^{-1})	17	0.6	2.5	1.5	0.5
Relative $\dot{V}O_2$ at VT1 (mL·kg^{-1}·min^{-1})	17	11.1	37.1	25.4	7.2
VCO_2 at VT1 (L·min^{-1})	17	0.5	2.2	1.3	0.4
RER at VT1	17	0.7	1.0	0.9	0.1
VE at VT1 (L·min^{-1})	17	17.9	59.6	37.7	10.4
VE·$\dot{V}O_2{}^{-1}$ at VT1	16	21.0	34.0	25.4	3.6
VE·$VCO_2{}^{-1}$ at VT1	16	24.0	34.0	28.8	3.2
Speed at VT1 (km·h^{-1})	17	5.0	9.0	7.1	1.2

Abbreviations used: HR = heart rate; RER = respiratory exchange rate; SD = standard deviation; VCO_2 = carbon dioxide production; VE = minute ventilation; VE·$VCO_2{}^{-1}$ = ventilatory equivalent of carbon dioxide; VE·$\dot{V}O_2{}^{-1}$ = ventilatory oxygen equivalent; $\dot{V}O_2$ = oxygen uptake; VT1 = first ventilatory threshold.

No significant differences were found between the constant-load treadmill test at VT1 intensity and the AD session on an ADP with respect to the $\dot{V}O_{2sc}$ ($p = 0.642$; Figure 1) and the VE·$VCO_2{}^{-1}$ slope ($p = 0.520$; Figure 2).

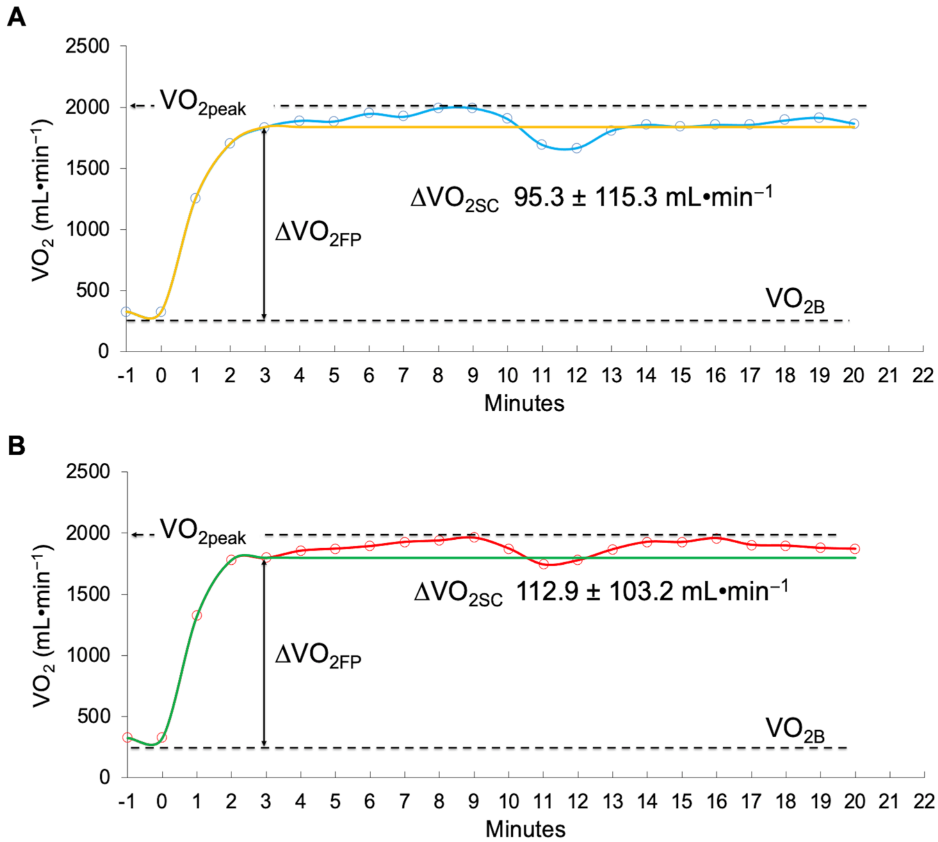

Figure 1. Slow component of oxygen uptake ($\dot{V}O_{2sc}$): (**A**) Aerobic dance on an air dissipation platform (blue line: $\dot{V}O_{2sc}$ of participants; yellow line: $\dot{V}O_{2sc}$ expected at VT_1) (**B**) Constant speed treadmill test at VT1 intensity (red line: $\dot{V}O_{2sc}$ of participants; green line: $\dot{V}O_{2sc}$ expected at VT_1). Abbreviations: ΔVO_{2FP} = increase in oxygen uptake in the fundamental phase; VO_{2B} = baseline oxygen consumption.

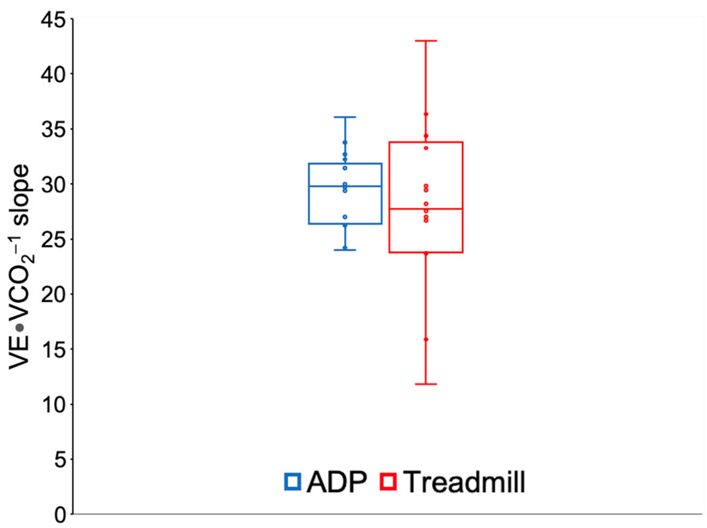

Figure 2. Ventilatory efficiency ($VE \cdot VCO_2^{-1}$ slope) during aerobic dance (AD) exercise on an air dissipation platform (ADP) and constant-load treadmill test at VT1 intensity.

Excellent correlations were verified between the VE and VCO_2 in the constant-load treadmill test (r = 0.93; $p < 0.001$) and in the AD session on an ADP (r = 0.83; $p < 0.001$).

The differences between the constant-load treadmill test at VT1 intensity and the AD session on an ADP concerning the blood lactate concentration and RPE are shown in Table 2.

Table 2. Differences in blood lactate concentration and RPE between an AD session on an ADP and a constant-load treadmill test at VT1 intensity.

	ADP (95% CI)			Treadmill (95% CI)			p^1	p^2	p^3
	Rest	**10 min**	**20 min**	**Rest**	**10 min**	**20 min**	**ES/SP**	**ES/SP**	**ES/SP**
Lactate (mmol·L^{-1})	1.5 *	5.9 $^{\Psi}$	6.5 $^{\#}$	1.5 *	3.8 $^{\delta}$	2.9	**<0.001**	**<0.001**	**<0.001**
	(1.2–1.7)	(4.6–7.4)	(5.2–7.7)	(1.3–1.7)	(3.0–4.6)	(2.3–3.7)	(0.5–0.9)	(0.8–1.0)	(0.6–0.9)
RPE		10.3 (9.8–10.8)	10.7 (10.0–11.4)		10.8 (9.6–12.0)	11.6 (9.9–13.3)	0.300 (0.1–0.2)	**0.034** (0.3–0.6)	0.318 (0.1–0.2)

Abbreviations used: AD—aerobic dance; ADP—air dissipation platform; ES—effect size; RPE—ratio of perceived effort; SP—statistical power; VT1—first ventilatory threshold. p^1 Significant differences for exercise mode × time interaction effect. p^2 Significant differences for time effect. p^3 Significant differences for exercise mode effect. Data are provided as mean and 95% confidence intervals (95% CI). Bonferroni post hoc adjustment for multiple comparisons: $^{\Psi}$ Significant differences compared to 10 min treadmill (p = 0.003). $^{\#}$ Significant differences compared to 20 min treadmill test (p < 0.001). * Significant differences compared to 10 min and 20 min tests (p < 0.001, AD session on an ADP; $p \leq 0.002$, treadmill). $^{\delta}$ Significant differences compared to 20 min treadmill test (p = 0.016).

Regarding the blood lactate concentration, a significant interaction effect (mode·time) was observed ($p = 0.001$, $\eta p^2 = 0.6$, SP = 0.9). Significant time and mode effects were detected ($p < 0.001$, $\eta p^2 = 0.9$, SP = 1.0; $p < 0.001$, $\eta p^2 = 0.6$, SP = 0.9, respectively). The Bonferroni post hoc adjustment determined significantly higher blood lactate concentrations in the AD session on an ADP than in the constant-load treadmill test at 10 min ($p = 0.003$) and 20 min ($p < 0.001$). Concerning the RPE, no significant interaction and mode effects were verified ($p > 0.05$). A significant time effect was found ($p = 0.034$, $\eta p^2 = 0.3$, SP = 0.6).

4. Discussion

Contrary to our study hypothesis, the main finding was that although the AD session on an ADP induced higher blood lactate concentrations than the constant-load treadmill test, both protocols (treadmill versus ADP) elicited similar responses in the $\dot{V}O_{2sc}$, ventilatory efficiency, and RPE in the healthy young adult women.

The results observed with respect to the $\dot{V}O_{2sc}$ (absolute values: 95.3 mL in 20 min; relative values: 4.68 mL·min^{-1}) were slightly lower (not significant) than those verified in the treadmill test (absolute values: 113 mL in 20 min; relative values: 5.65 mL·min^{-1}). In previous studies with samples of similar characteristics, we found slightly higher values in African American women (absolute values: 120 mL in approximately 9 min; relative values: 13.33 mL·min^{-1}) and much higher values in Caucasian women (absolute values: 170 mL in ~8 min; relative values: 21.25 mL·min^{-1}) at an intensity of 25% above the gas exchange threshold in a cycle ergometer test [34]. It is likely that the differences observed can be attributed to the exercise intensity applied in each study and to the fact that the cycle ergometer tends to raise the $\dot{V}O_{2sc}$ to a greater extent than a treadmill at the same relative intensity [21].

Another study found increases in $\dot{V}O_2$ of 599 mL·min^{-1} in women with lupus erythematosus and 540 mL·min^{-1} in healthy sedentary women during a 6-minute walk test on a treadmill at an intensity of 3 MET [35]. Despite being a lower intensity test compared to our study, the $\dot{V}O_2$ rose to a greater extent beyond the third minute to the sixth than during our twenty-minute test, indicating that cardiorespiratory fitness could also be another fundamental element that conditions the $\dot{V}O_{2sc}$ [36]. We did not find a relationship between cardiorespiratory fitness and the $\dot{V}O_{2sc}$ reported in other studies [37].

The physiological mechanisms that influence $\dot{V}O_{2sc}$ are diverse as well as uncertain. The kinetics of $\dot{V}O_2$ showed a similar steady state from the third minute in the AD session and in the treadmill test, justifying the similarity of the exercise intensity in both tests, which were corroborated by a very similar $\dot{V}O_{2sc}$. In theory, the blood lactate concentration should not increase in response to a clearly aerobic metabolism in both experimental conditions. However, the blood lactate concentration increased significantly after the AD session on an ADP compared to the treadmill test, evidencing a transition to increased anaerobic metabolism [38]. In the AD session on an ADP, there was a paradoxical result, since the increase in the blood lactate concentration would indicate an exercise intensity above the LT or anaerobic threshold [39], which in theory should increase the $\dot{V}O_{2sc}$. The fact that the $\dot{V}O_{2sc}$ did not increase could be due, at least in part, to the fact that there was a significant degree of energy contribution from anaerobic sources.

It is likely that the supply of O_2 to active skeletal muscle was deficient, since the intensity of muscle contraction was intense enough to cut off arterial and venous flow, causing other predominantly anaerobic metabolic sources to be activated [40]. In this regard, it is possible that an elastic surface such as an ADP contributed to the increased blood lactate levels. Previous research has shown that elastic or softer surfaces increase blood lactate concentration to a greater extent than hard surfaces, while maintaining a stationary and similar $\dot{V}O_2$ [26,41]. Instability and contact times increase during an AD session on an ADP. The impact forces induced by the damping are reduced, causing greater muscle activation in the agonist and antagonist muscles [27]. This amplified muscle activation could increase muscle work and potentiate a higher demand from the anaerobic sources compared to a hard surface [28]. In addition, a significant part of the energy from the anaerobic sources cannot be quantified by gas exchange [42], which explains, to a certain extent, why an increase in the $\dot{V}O_2$ and $\dot{V}O_{2sc}$ amplitude was not observed. It is likely that the increased lactate production during an AD session would be beneficial to supplying the anaerobic source demands induced by an ADP. More studies will be needed to substantiate such claims.

The increased anaerobic environment produced by the increased blood lactate concentration in the AD session on an ADP would be expected to induce an increase in the $VE{\cdot}VCO_2^{-1}$ slope [18]. The increase in exercise intensity induces an increase in the blood lactate levels, CO_2 levels, and the number of hydrogen ions [H^+]. The accumulation of lactate and [H^+] is mainly due to intracellular glycolysis [43,44], and they are both released into the extracellular fluid [45,46]. In theory, the ventilatory efficiency would decrease as a result of the increasing ventilation required to eliminate the CO_2 produced in order to maintain pH homeostasis, causing a mismatch in the ventilation–perfusion relationship. However, no changes were noted in terms of ventilatory efficiency between both exercise modalities; thus, this mismatch in the ventilation–perfusion relationship did not occur, which is typical as the exercise intensity increases [18]. This confirms that the exercise intensity in both modalities was not high enough to cause this mismatch in the ventilation–perfusion ratio.

Comparing them with other studies with healthy adult women, we found similar values ($VE{\cdot}VCO_2^{-1}$ slope of 28.7) during an incremental protocol on a treadmill [47]. In another study, slightly lower $VE{\cdot}VCO_2^{-1}$ values (24.1) were reported during a cycle ergometer test in healthy adult women [11]. In strenuous high-intensity exercise with blood lactate concentrations close to 18 mmol·L^{-1}, the $VE{\cdot}VCO_2^{-1}$ slope could exceed values of 40 [18].

From a mechanistic perspective, the $VE{\cdot}VCO_2^{-1}$ slope data (Figure 2) showed different variabilities between the treadmill test and the AD session on an ADP. The analysis of the differences between both modes of exercise accounted for the different variances between both groups. In this case, no homogeneity of variances was identified between both groups (homoscedasticity).

Few studies have compared the $VE{\cdot}VCO_2^{-1}$ slopes between different exercises modalities. Our findings showed that two different exercise modalities with similar responses in $\dot{V}O_2$ and the $\dot{V}O_{2sc}$ and different metabolic responses had similar ventilatory efficiency values. Other studies found no difference between treadmill and cycle ergometer tests, although both exercise modalities showed a lower $VE{\cdot}VCO_2^{-1}$ slope compared to a robotics-assisted tilt table [48]. There appears to be a trend towards a similar $VE \cdot VCO_2^{-1}$ slope between different exercise modalities at the same relative intensity [12].

A similar RPE was observed in both exercise modalities, which indicates the enjoyment that the AD session can produce [24].

Several of this study's limitations should be considered. AD is a complex exercise modality for assessing the $\dot{V}O_{2sc}$, since maintaining constant $\dot{V}O_2$ kinetics, unlike the constant-load test (treadmill), depends on the intensity, which is always determined by the AD monitor. Although the kinetics of $\dot{V}O_2$ were similar between both exercise modes, the movements performed in the AD session on an ADP were different from those observed in the treadmill test. This different methodology could have influenced the final results.

5. Conclusions

Our findings indicated that the AD session on an ADP and the treadmill test at a constant-load intensity of VT1 elicited similar $\dot{V}O_{2sc}$, $VE \cdot VCO_2^{-1}$ slope, and RPE values in healthy young adult women, despite the fact that the AD session on an ADP induced higher blood lactate concentrations than the treadmill test.

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Aerobic Dance on an Air Dissipation Platform Improves Cardiorespiratory, Muscular and Cellular Fitness in the Overweight and Obese Elderly

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Simple Summary: Aerobic dance is considered a viable strategy to prevent the effects of aging, mainly in obese and overweight elderly people. This study aimed to evaluate the effects of aerobic dance on an air dissipation platform (ADP) on body composition, oxidative stress and muscular and cardiorespiratory fitness in 32 elderly adults (67.1 ± 3.6) who were divided into 3 groups based on body mass index: healthy (HG), overweight (OWG) and obese (OG). Training program of aerobic dance on an ADP was carried out twice a week for 12 weeks at an intensity of 6–8 on the scale of subjective perception exertion (Borg Scale, CR-10). There was a significant decrease in malondialdehyde concentrations in all experimental groups. OWG and OG significantly improved their peak oxygen uptake. An interaction effect was observed in vertical flight height and power output, during the jump test. HG increased the vertical jump height, and HG and OG improved the power output of the lower extremities. In conclusion, aerobic dance on an ADP may be an effective alternative to lose weight, prevent oxidative stress and improve cardiorespiratory fitness in obese and overweight elderly people.

Abstract: Background: Obesity is a global health problem associated with a high number of comorbidities that decrease functional capacity, especially in elderly people. Aerobic dance is considered a viable strategy to prevent the effects of aging, mainly in obese and overweight elderly people. This study aimed to evaluate the effects of aerobic dance on an air dissipation platform (ADP) on body composition, oxidative stress and muscular and cardiorespiratory fitness in elderly people. Methods: In total, 32 elderly adults (67.1 ± 3.6) were divided into 3 groups based on body mass index: healthy (HG), overweight (OWG) and obese (OG). Training program of aerobic dance on an ADP was carried out twice a week for 12 weeks. Results: OWG ($p = 0.016$) and OG decreased their weight ($p < 0.001$). There was a significant decrease in malondialdehyde concentrations in all experimental groups ($p < 0.05$). OWG and OG significantly improved their peak oxygen uptake ($p < 0.01$). HG increased the vertical jump height ($p < 0.05$), and HG and OG improved the power output of the lower extremities ($p < 0.05$). Conclusions: The aerobic dance on an ADP may be an effective alternative to lose weight, prevent oxidative stress and improve cardiorespiratory fitness in obese and overweight elderly people.

Keywords: obesity; body composition; elderly; oxidative stress; human performance; cardiorespiratory fitness; aerobic dance; health promotion

1. Introduction

Obesity is a global health problem associated with a high number of comorbidities that affect quality of life and decrease functional capacity, especially in elderly people. Globally, the prevalence of obesity in adults increased from 6.4% to 14.9% in women and from 3.2% to 10.8% in men between 1975 and 2014 [1]. Population studies have shown the relationship between a body mass index (BMI) higher than 25 kg/m^2 (especially a BMI $\geq$ 30 kg/m^2) and greater functional impairment [2,3]. In elderly people, BMI $\geq$ 25 kg/m^2 is related to chronic diseases, metabolic syndrome, diabetes [4], frailty [5] and increased mortality [5,6].

At the cellular level, increased concentrations of reactive oxygen and nitrogen species (RONS), combined with the reduction in endogenous antioxidants are common features for both, the aging process and obesity, increasing oxidative stress [7–9]. The imbalance between the antioxidant systems and free radical overproduction leads to cell oxidative damage affecting tissue components such as lipids, proteins or deoxyribonucleic acid (DNA) molecules [10].

Obesity leads to an increase in adipose tissue, triggering the release and storage of lipids in the skeletal muscle. These intramuscular lipids and their derivatives induce a mitochondrial dysfunction characterized by alterations in β-oxidation capacity, therefore, increasing oxidative stress (ROS) and impairing metabolic function [11]. The main products of lipid peroxidation are lipid hydroperoxides where malondialdehyde (MDA) is commonly formed as a secondary by product. It has been described that lipid peroxidation is greater in skeletal muscle mass in obese adults [12]. Several studies have shown that sarcopenia, high BMI and increased MDA concentrations are all parameters [13–15] related to an augmented risk of cardiovascular diseases [16,17] and incidence of atherosclerotic processes involving circulating lipoproteins [10].

Countless studies point to regular physical activity as one of the most beneficial resources for delaying the physiological deterioration induced by aging and obesity [18–20]. Specifically, aerobic dance (AD) is one of the most practiced aerobic activities in the world, mainly in senior centers [21]. AD is characterized by a sequence of impact movements choreographed to the rhythm of the music. Several studies have proposed that AD improves muscular strength, cardiorespiratory endurance, body agility, flexibility [22,23], lower body function [24] and locomotion/agility and balance, thus attenuating risks of falling in elderly adults [25]. AD exercise programs have been shown to reduce body weight, fat mass and cardiovascular disease risks in overweight and obese women [26], as well as improve maximal oxygen uptake (VO_2), decrease MDA levels and enhance antioxidant capacity [27]. From a psychological perspective, AD has been confirmed to have a positive effect on cognition in older people [28].

Exercise programs for the elderly that include unstable surfaces have been proposed to induce improvements in physical capabilities, such as muscle strength, power and balance [29,30], functional mobility, gait performance [19] and appear to be a good alternative to reduce the impact on joints [31]. Unstable surfaces have been shown to be a suitable alternative for improving cardiorespiratory fitness and producing positive changes in body composition in overweight women [32]. In addition, several studies have shown that exercise performed on unstable surfaces can be more intense compared to exercise on the ground [33–35].

Recently, our research group incorporated an air dissipation platform (ADP) in AD sessions. The ADP contains an area that rests on an elastomer with holes through which air flows. The amount of air that remains in the area produces rebound damping, reducing impacts during exercise and increasing instability. In a previous study, we demonstrated that an AD session on an ADP increased metabolic and cardiorespiratory responses compared to a hard surface, maintaining the perception of greater effort and muscle fatigue. [35]. We suggested that an AD exercise program on an ADP carried out 3 d·wk^{-1} for 75 min·wk^{-1} or 20 min·d^{-1} could maintain or improve metabolic and cardiorespiratory fitness, according to the American College of Sports Medicine (ACSM) guidelines [18].

To our knowledge, there are no studies assessing the effects of AD on an ADP on oxidative stress and cardiorespiratory and muscular function in obese or overweight older people. Therefore, this study aimed to investigate the chronic effects of an exercise program of AD performed in an ADP on cardiorespiratory and muscular fitness and oxidative stress in overweight and obese older people.

2. Materials and Methods

2.1. Subsection

The exercise program was explained in detail to the participants in the preliminary meeting. In the first session, all subjects were rigorously evaluated for comorbidities and diseases and their medical history was analyzed. In addition, their level of physical activity was checked up using an international physical activity questionnaire (IPAQ-E) for measurement of physical activity in people over 65 years of age [36].

The AD program in an ADP lasted 12 weeks. Before (pre-test) and after (post-test) the AD program, the same tests were carried out by the same evaluators to determine the effects of the exercise program in an ADP on body composition, oxidative stress and cardiorespiratory and muscular fitness. Previously, a familiarization session was performed of the muscular and cardiorespiratory fitness tests. The participants did not perform any physical effort for 48 h before the tests. The tests and the order of the tests were defined as follows (Figure 1): 1st assessment of body composition, 2nd capillary blood collection, 3rd assessment of muscular fitness (lower extremity strength, upper extremity strength, jump test), 4th assessment of agility and dynamic balance (8 foot UP & Go test) and 5th assessment of cardiorespiratory fitness (YMCA test). A 5 min rest was established between each test.

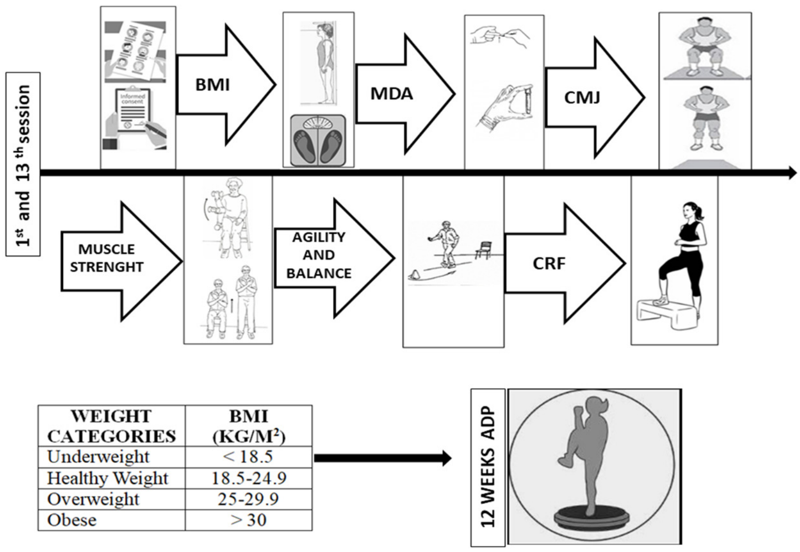

Figure 1. Protocol test. Abbreviations: BMI = body mass index, CMJ = counter movement jump, CRF = cardiorespiratory fitness and MDA = malondialdehyde. The images were selected from the internet (20 September 2021). http://fonamentsgrausuperiordanigoncalves.blogspot.com/p/senior-fitness-test.html; https://www.klipartz.com/es/sticker-png-ouoxs; https://www.makeoverfitness.com/leg-exercise-charts/7906-printable-leg-exercise-chart-for-women; https://mundoentrenamiento.com/salto-vertical-como-aumentarlo/; https://www.pngwing.com; https://www.shutterstock.com/es/search/chemistry+sketches; https://sp.depositphotos.com/vector-images/consentimiento-informado.html.

2.2. Participants

Participants of this study were members of the centers for the elderly in the community of Madrid. In total, 58 healthy older adults between 60 and 78 years old were recruited. Finally, 32 participants (age = 67.1 ± 3.6 years; weight = 67.5 ± 16.6 kg; height = 155.4 ± 6.7 cm; BMI = 27.9 ± 6.2 $kg \cdot m^{2-1}$) were included in this study. In total, 28 women and 4 men were assigned to 3 groups based on BMI according to established guidelines by the World Health Organization [37]: eutrophic (18.5–24.9 kg m^2), overweight (25–29.9 kg/m^2) and obese (≥30 kg/m^2): healthy group (HG, n = 10; men, n = 1), overweight group (OWG, n = 10; men, n = 2) and obese group (OG, n = 12; men, n = 1).

Participants with orthopedic prostheses or implanted pacemaker, cardiovascular neurological, musculoskeletal, infectious and oncological diseases were excluded from the study. In addition, all participants who missed 10% of the exercise sessions in the ADP were excluded from the final data analysis. The participants were informed of all experimental procedures and each participant provided written informed consent to participate in the study. This investigation was approved by the Institutional Review Board (Identification number: 13/2018) according to the principles and policies of the Declaration of Helsinki.

2.3. Body Composition

Body composition was calculated by bioimpedance using the electric Bioimpedance model scale (InBody 3.0, Biospace, Seoul, Korea). The variables assessed were weight, body fat (BF), body fat percentage (% BF), fat-free mass (FFM) and lean mass (LM) [38]. Height was measured with a standard stadiometer, and BMI was calculated as weight (kg)/height (m^2).

2.4. Oxidative Stress

Blood samples for oxidative stress determination were collected by finger pricking. After puncture, blood was immediately collected in EDTA-K2 Microvette tubes (SAR-STEDT, Nümbrecht, Germany). The tubes were centrifuged at 600× g for 15 min (4 °C). To avoid peroxidation amplification, butylated hydroxytoluene (antioxidant) and the iron chelator EDTA were added to fresh plasma samples. Then, plasma was stored at −80 °C until assessment of MDA as determined by thiobarbituric acid-reactive substance concentrations (TBARS), a product of lipid peroxidation, following Yagi's technique with minor modification [39]. Results were expressed in uM compared to a standard curve prepared with MDA.

2.5. Muscular Fitness

After a 5 min general warm-up (movements, joint mobility, push-ups, jumps, etc.), the participants began the assessment of muscle fitness.

2.5.1. Countermovement Jump

The countermovement jump (CMJ) was used to measure the vertical flight height and the power output of the lower extremities on a contact platform (ChronoJump, Bosco System, Barcelona, Spain). Three CMJs were performed at the participant's maximum capacity with a 30 s rest between each jump. The mean values of height and mean power output of the three jumps were used in the subsequent analyses [40].

2.5.2. Arm Curl Test

Sitting, at the signal of the evaluator, the participant performed an elbow flexion–extension (bicep flexion) with both limbs throughout the range of motion as many times as possible for 30 s. The test started with the dominant arm and ended with the non-dominant. A single series was performed and 1 min rest was established between each attempt. A 2 kg dumbbell was used for women and 4 kg for men [41].

2.5.3. Agility and Dynamic Balance

Agility and dynamic balance were assessed using the 8 foot UP & Go test. At the investigator's signal, the participant should get up from the chair and walk 8 feet (2.44 m), turn around and sit back down. Two attempts were executed and the shortest time of the two attempts was recorded [42]. A 3 min rest was applied between attempts.

2.6. Cardiorespiratory Fitness

The cardiorespiratory fitness was assessed using the YMCA step test. At a 30 cm high stride, participants performed 24 steps per minute at a rate of 96 bits per minute for 3 min [43]. Heart rate values were recorded using a polar heart rate monitor (RS-800CX, Polar Electro OY; Kempele, Finland) during the exercise and 1 min after exercise (1 min HBC). Peak oxygen consumption was estimated according to the guidelines established in a previous study by Beutner et al., who established a linear regression model (YMCA model) taking into account age, sex and 1 min HBC. The regression coefficients for each of the variables were: −0.15 for 1 min HBC, −4.2 for the gender variable, −0.38 for the age variable and 78.2 as a constant [44].

2.7. Exercise Program

All sessions were led by the same instructor. Two AD classes on an ADP were conducted per week for 12 weeks (Appendix A, Figure A1). The duration of the classes was 45 min divided into 10 min of warm-up, 30 min of the main part and 5 min of cool down. The AD class consisted of global and combined lower and upper body exercises such as jumps with both feet, knee raises, flexion with elbow extension, kick with shoulder abduction, squats, leg flexion and extension, jumping jacks, scissors, calisthenics, plyometrics etc. The music that accompanied the exercises was selected to mark the right time of transition between the different types of exercise. The exercise changes were performed every 16 s and the intensity of the class was controlled by the Borg rating of perceived exertion (RPE, Borg Scale CR-10) [45] following the guidelines established in previous studies [46]. Upper body exercises consisted of performing elbow flexion–extensions, shoulder abductions–adductions and shoulder flexion–extension with dumbbells and elastic bands simultaneously while dancing to the rhythm of the music. The participants had to perform a high number of repetitions (≈15 repetitions) with light resistance. After 16 s, the muscle group was changed to another upper extremity exercise (Table 1).

Table 1. Summary of characteristics and expected RPE of dance session performed on an air dissipation platform.

Variable/Weeks	1–3	4–8	9–12
Sessions for week	2	2	2
Exercise intensity	moderate	intensity	vigorous
Expected RPE (1–10)	5–6	6–7	7–8

In addition to performing all the exercises on the platform, materials such as dumbbells, rubber bands, maracas, sticks and pikes were also used (Appendix A, Figure A2).

2.8. Statistical Analysis

The Shapiro–Wilk test was used to check the normal distribution of the data, which are reported as means and standard deviation (SD), means and confidence intervals (95% CI). To identify significant differences between the HG, OWG and OG, a general linear model with a two-way analysis of variance (ANOVA) for repeated measures was applied (group × time). When appropriate, a post hoc Bonferroni adjustment was implemented for multiple comparisons. The partial eta-squared (η_p^2) was computed to determine the magnitude of the response to exercise program. The statistical power (SP) was also calculated. All statistical tests were performed using the software package SPSS version 23.0 for Apple Macintosh (SPSS Inc., Chicago, IL, USA). Significance was set at $p < 0.05$.

3. Results

3.1. Body Composition

The data related to body composition are shown in Table 2.

Table 2. Body composition variable.

	Assessment	HG	OWG	OG	P1 for interaction/ES/SP	P2 for time/ES/SP	P3 for group/ES/SP
Participants (n)		10	10	12			
Weight (kg)	Pre †	58.20 (4.21)	68.29 (5.70)	80.16 (9.94)	0.028	0.001	<0.001
	Post †	58.22 (3.57)	67.51 (5.61) *	78.98 (9.54) *	0.23/0.68	0.33/0.95	0.62/1.00
Body mass index ($kg \cdot m^{-2}$)	Pre †	24.23 (1.24)	28.83 (1.13)	32.17 (1.93)	0.121	0.002	<0.001
	Post †	24.16 (0.99)	28.59 (0.87)	31.71 (1.95) *	0.14/0.42	0.30/0.92	0.84/1.00
Fat Mass (kg)	Pre ¥	22.02 (3.28)	26.22 (2.51)	31.65 (4.54)	0.732	0.078	<0.001
	Post ¥	21.72 (2.69)	25.46 (2.17)	31.30 (4.22)	0.02/0.09	0.11/0.42	0.61/1.00
Body Fat (%)	Pre	36.79 (4.29)	38.56 (3.43)	40.78 (6.32)	0.901	0.038	0.180
	Post	36.23 (3.78)	37.74 (3.56)	40.25 (5.98)	0.01/0.06	0.15/0.56	0.12/0.35
Fat-Free Mass (kg)	Pre	37.91 (3.91) $^{\beta}$	41.78 (5.09)	46.72 (9.99)	0.971	0.095	0.030
	Post	38.20 (3.83) $^{\beta}$	42.15 (5.31)	47.13 (9.76)	0.00/0.05	0.10/0.39	0.23/0.67
Lean Mass (kg)	Pre	20.91 (2.70) $^{\beta}$	22.92 (3.01)	25.81 (6.16)	0.401	0.960	0.041
	Post	20.57 (2.33) $^{\beta}$	23.02 (3.19)	26.02 (6.08)	0.07/0.20	0.00/0.05	0.21/0.62
Basal Metabolic Rate ($kcal \cdot day^{-1}$)	Pre	1182.11 (82.28) $^{\beta}$	1276.20 (108.51)	1383.64 (224.23)	0.775	0.155	0.027
	Post	1195.89 (82.62) $^{\beta}$	1281.20 (114.61)	1389.00 (211.44)	0.02/0.09	0.07/0.292	0.24/0.68

Data are provided as mean ± standard deviation (SD). Abbreviations: ES = effect size; HG = healthy group; OG = obesity group; OWG = overweight group; SP = statistical power. P1 = p-value for group × time interaction effect; P2 = p-value for time effect; P3 = p-value for group effect. Bonferroni's multiple comparisons determined: * Significant differences compared to pretest ($p < 0.05$). † Significant differences between groups in pretest (HG vs. OWG, $p \leq 0.018$; HG vs. OG, $p < 0.001$; OWG vs. OG, $p \leq 0.002$) and posttest (HG vs. OWG, $p \leq 0.023$; HG vs. OG, $p < 0.001$; OWG vs. OG, $p \leq 0.002$). ¥ Significant differences between groups in pretest (HG vs. OG, $p < 0.001$; OWG vs. OG, $p = 0.005$) and posttest (HG vs. OG, $p < 0.001$; OWG vs. OG, $p = 0.001$). $^{\beta}$ Significantly lower in HG than OG in pre- and posttest ($p < 0.05$). In weight, an interaction effect (group × time) was detected ($p = 0.028$). The Bonferroni test determined significant differences between groups in the pretest and posttest ($p < 0.05$). The OWG ($p = 0.016$) and OG ($p < 0.001$) decreased their weight after the training program. No interaction effect (group × time) was found in other body composition variables ($p > 0.05$).

3.2. Oxidative Stress

In MDA, an interaction effect (group × time) and a time effect ($p = 0.032$, ES = 0.25, SP = 0.66; $p < 0.001$, ES = 0.70, SP = 1.00, respectively) were verified; however, a group effect was not detected ($p > 0.05$). The Bonferroni post hoc determined a significant decrease in MDA concentrations in the three experimental groups after the training program ($p < 0.05$) (Figure 2).

3.3. Cardiorespiratory Fitness

The data related to cardiorespiratory and muscular fitness are shown in Table 3.

Regarding the estimated VO_{2peak}, an interaction effect (group × time) ($p = 0.008$) was observed. The Bonferroni test determined that the OWG and OG significantly improved their VO_{2peak} ($p = 0.005$ and $p = 0.002$, respectively). No interaction effect (group × time) was detected in the strength of the arms and in the 8 foot UP & Go test ($p > 0.05$). However, an interaction effect (group × time) was observed in vertical flight height ($p = 0.001$) and power output ($p = 0.044$) during the jump test. Bonferroni test determined that only HG increased the vertical jump height after training program ($p < 0.05$). Furthermore, the power output of lower limbs was improved in HG and OG after the training program ($p < 0.05$).

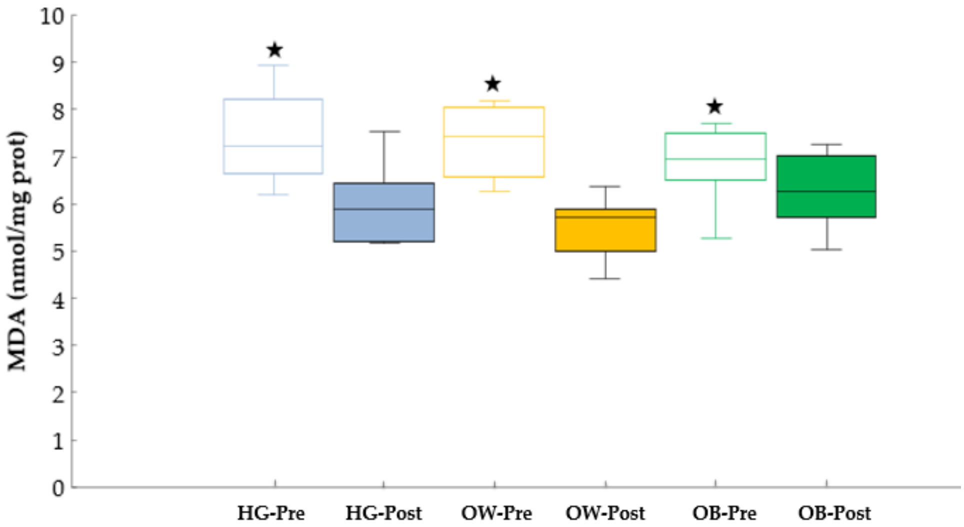

Figure 2. Lipid peroxidation, measured as TBARS concentrations. Abbreviations used: HG = healthy group; MDA = malondialdehyde; OG = obesity group; OWG = overweight group. ★ Significant differences compared to posttest ($p < 0.001$ in HG; $p < 0.001$ in OWG; $p = 0.024$ in OG).

Table 3. Cardiorespiratory and muscular fitness variables.

	Assessment	HG	OWG	OG	P1 for interaction/ES/SP	P2 for time/ES/SP	P3 for group/ES/SP
Participants (n)		10	10	12			
VO_2peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Pre	30.38 (3.62)	28.66 (2.41)	29.45 (2.89)	0.008	0.005	0.763
	Post	29.87 (2.39)	30.13 (3.09) *	30.93 (2.46) *	0.29/0.83	0.24/0.83	0.02/0.09
Strength DA (repetitions)	Pre	21.00 (2.21)	21.60 (3.17)	18.55 (2.54)	0.696	0.003	0.031
	Post	23.20 (2.04)	22.80 (3.91)	20.91 (2.77)	0.03/0.10	0.27/0.87	0.22/0.66
Strength NDA (repetitions)	Pre	21.20 (1.23)	21.80 (3.43)	18.09 (3.11)	0.754	0.001	0.01
	Post	23.00 (2.11)	23.40 (3.95)	20.64 (2.46)	0.02/0.09	0.32/0.94	0.28/0.81
8 foot UP & Go (seconds)	Pre	5.93 (0.49)	6.00 (0.59)	6.12 (0.94)	0.481	0.008	0.786
	Post	5.34 (0.31)	5.72 (0.62)	5.24 (1.77)	0.05/0.17	0.22/0.79	0.02/0.08
Jump height (cm)	Pre	9.21 (2.05)	9.84 (1.79)	11.05 (4.23)	0.001	0.001	0.226
	Post	10.66 (2.10) *	9.93 (2.10)	11.17 (4.53)	0.17/0.95	0.13/0.92	0.04/0.31
Power output (watts)	Pre †	390.64 (66.35)	466.28 (60.33)	554.76 (173.51)	0.044	0.005	<0.001
	Post	418.25 (65.31) *	462.99 (64.41)	577.03 (168.11) *‡	0.08/0.60	0.09/0.82	0.29/0.99

Data are provided as mean ± standard deviation (SD). Abbreviations: DA = dominant arm; ES = effect size; HG = healthy group; NDA = no dominant arm; OG = obesity group; OWG = overweight group; SP = statistical power. P1 = p-value for group × time interaction effect; P2 = p-value for time effect; P3 = p-value for group effect. Bonferroni's multiple comparisons determined: * Significant differences compared to pretest ($p < 0.05$). † Significant differences between experimental groups in pretest ($p < 0.05$). ‡ Significant differences compared to HG ($p < 0.001$) and OWG ($p = 0.001$) in posttest.

4. Discussion

The main finding of this study was that a 12-week AD exercise program on an ADP successfully reduced body weight, decreased lipid peroxidation (MDA) and increased VO_2peak in obese and overweight elderly. Moreover, the OG showed an improvement in balance and agility and also in the strength of both arms over time (pre vs. post). One of the main objectives of an exercise program in obese and overweight people is to lose weight and gain lean mass. Our results indicated that only OWG and OG decreased their weight after the intervention program while HG maintained weight and lean mass. It should be noted that weight loss in elderly may have an effect on reducing lean mass, which could increase the risk of sarcopenia [3,47]. However, no significant changes in lean mass in OWG and OG were detected after the AD program; although aerobic exercise compared to other types of exercise has less effect on lean mass [47,48]. It has been evidenced that weight loss and maintenance of lean mass decrease the risk of developing metabolic diseases, reducing skeletal muscle deterioration and disability, hospitalizations and early mortality [49]. An exercise program of two sessions per week of AD in an ADP for at least 12 weeks could be a sufficient stimulus to reduce weight and maintain lean mass, reducing the risk of metabolic diseases and the deterioration of muscle mass in obese and overweight older people. More studies are needed to corroborate such claims. The role of oxidative stress in the aging process appears mainly related to the decrease in antioxidant systems, and the loss of functionality of other detoxifying systems, causing the accumulation of oxidized lipids, proteins or DNA molecules, negatively impacts on the homeostatic cellular mechanisms [7–9].

The level of lipid peroxidation was similar in all the experimental groups before starting the exercise program. At the end of the AD program, the MDA levels were significantly attenuated. Although MDA levels have not been investigated after an exercise program on an ADP, the results were similar to several studies in which other exercise programs were applied [27,50]. Yu et al. showed that aerobic exercise such as running, cycling and dancing induced lower MDA levels and protective effects against oxidative stress damage in older people [50]. Similar findings were found in obese elderly women after performing an aerobic exercise program for 12 months at an intensity of 60–75% of maximum HR. The authors concluded that aerobic exercise decreases oxidative stress when accompanied by gains in cardiorespiratory fitness [51]. From a physiological perspective, the decrease in oxidative stress may be related to an improvement in mitochondrial function. Mitochondrial dysfunction is one of the characteristics of the aging process inducing an elevated emission of ROS and the activation of apoptotic pathways [52]. It seems that exercise programs could reduce oxidative stress in the elderly and obese people, depending on the type of exercise and the intensity established [53,54]. Previous studies found different levels of lipid peroxidation and TBARS in obese individuals at several types of exercise and intensities [55–57].

One of the purposes of this study was to be able to control exercise intensity on an ADP. Our previous findings demonstrated that exercise on an ADP stimulates a greater cardiorespiratory and metabolic response compared to exercise on a hard surface [35]. The exercise intensity of the sessions was controlled using the Borg scale of 0 to 10. The instructor regularly reported the ranges and intensity changes, following the aforementioned scale, which allowed the control of intensity levels within the ranges of moderate to vigorous intensity (RPE 5 to 8), ensuring that the subjects were not exposed to strenuous efforts [46]. Studies have shown to improve the cardiorespiratory fitness by controlling exercise intensity with RPE [46,58]. OWG and OG increased their VO_{2peak} at the prescribed intensities, demonstrating the efficacy of the exercise program on an ADP. In contrast, HG did not improve their VO_{2peak}, suggesting that the implemented exercise program (2 sessions per week) could be sufficient stimulus to improve VO_{2peak} in overweight and obese older people, but not for older people with a normal weight. Improvements in VO_{2peak} are of crucial relevance to the health of obese and overweight people. Several studies have shown that an increase of 1 MET (3.5 mL/kg/min O_2) in exercise capacity reduced the adjusted risk for mortality in 13% [59] and reduces the risk of mortality or suffering a cardiovascular event by 13–15% [60]. OWG and OG increased ~1.5 mL/kg/min O_2 similar to other AD studies using a mini trampoline [27,61]. Cugusi et al. found a significant increase in VO_{2max} (1.5 mL/kg/min, from 15.4 to 16.9 mL/kg/min,) in overweight women after a 12-week exercise program on a mini trampoline [32].

Van Schoor et al. assumed that the higher physiological demands induced by the mini trampoline could be due to the constant rebounding and instability produced by an elastic surface [61]. This higher physiological demand would imply a greater effort to perform the exercise and maintain balance on an ADP. In addition, soft surfaces can reduce the risk of high-impact joint injuries by improving balance and strength in older people [29,30], especially in obese and overweight people. This suggestion could account for, at least in part, the improvements in agility and balance observed in obese older people. However, the exercise program on an ADP was not adequate stimulus to significantly improve agility and balance in the OWG and HG. Nonetheless, the results of the 8 foot UP & Go test can be considered normal [62]. Contrary to what might be expected, the rebound effect produced by ADP did not improve jumping ability in overweight and obese people despite including plyometric in the AD program. However, HG improved vertical jump ability by demonstrating increased lower extremity strength, consistent with other studies where jump training appears to be more effective in non-obese older people [63].

A twice-weekly AD program on an ADP preserved explosive strength levels in the lower extremities in overweight and obese older people. Preventing loss of muscle strength, as well as cardiorespiratory fitness, is crucial for the elderly to maintain their functional ability to perform activities of daily living independently [59,64,65]. Muscle mass declines by roughly 3–8% per decade after the age of 30 and increases even more after the age of 60 [66,67]; this gradual decrease in muscle mass is accompanied by a simultaneous reduction in strength [68], in muscle performance and a decrease in cardiorespiratory fitness [59,64,69,70]. In addition, as a preventive measure, this type of training with instabilities could improve neuro-muscular and musculoskeletal functions and reduce the risk of falls, using exercises for strength, postural balance, muscle coordination, joint range of motion and spatial orientation with a multi-component approach [29,30].

This study presents some limitations. Some participants did not attend the posttest, which significantly reduced the sample size. The initial sample of 58 participants was reduced to 32 participants at the end of study. Data from participants who failed to complete more than two AD sessions were not considered for the final statistical analysis [46] but they continued to perform the exercise program.

5. Conclusions

In conclusion, a training program of aerobic exercise on an ADP should be considered a viable strategy to positively regulate cardiorespiratory and muscular adaptations and to ameliorate the effects of oxidative stress in obese and overweight older people.

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Appendix A

Figure A1. Session of ADP with the elderly.

Figure A2. The air dissipation platform (ADP), materials such as dumbbells, elastic bands, maracas, sticks and paddles used in the sessions.

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