PROGRAMA DE DOCTORADO EN FISIOTERAPIA

INESTABILIDAD GLOBAL VS. SELECTIVA: RESPUESTA ELECTROMIOGRÁFICA, DE FUERZA Y DE EQUILIBRIO AL TRABAJO ESPECÍFICO DEL PIE Y TOBILLO EN DIFERENTES POBLACIONES.

TESIS DOCTORAL

Presentada por:

Mariana Sánchez Barbadora

Dirigida por:

Dr. Rodrigo Martín San Agustín

Valencia, Febrero de 2025.

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D. Rodrigo Martín San Agustín, Doctor en Fisioterapia por la Universidad de Valencia y Ayudante Doctor del Departamento de Fisioterapia de Universidad de Valencia.

CERTIFICA que el trabajado presentado como Tesis Doctoral por Dña. Mariana Sánchez Barbadora, titulado **INESTABILIDAD GLOBAL VS. SELECTIVA: RESPUESTA ELECTROMIOGRÁFICA, DE FUERZA Y DE EQUILIBRIO AL TRABAJO ESPECÍFICO DEL PIE Y TOBILLO EN DIFERENTES POBLACIONES,** ha sido realizado bajo su dirección y considera que reúne las condiciones apropiadas en cuanto a contenidos y rigor científico para ser presentado a trámite de lectura.

Y para que así conste, expide y firma la presente certificación en Valencia, a 10 de Febrero de 2025.

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"Por la mañana todo ha pasado y me encuentro bien; el largo que ayer dejé a medias es una belleza. ¿Qué ha cambiado? Es uno de tantos enigmas sin respuesta, como porqué escalas o qué haces aquí."

Miriam García Pascual
Bájame una estrella

Índice

Índice de abreviaturas

CAI: Inestabilidad crónica de tobillo (del inglés: *chronic ankle instability*)

FAI: Inestabilidad funcional de tobillo (del inglés: *functional ankle instability*)

GID: Dispositivo global de inestabilidad (del inglés: *global instability device*)

BOSU: del inglés: *Both sides utilized*

SID: Dispositivo específico de inestabilidad (del inglés: *specific instability device*)

BB: Blackboard

tDCS: Estimulación por corriente directa transcraneal (del inglés: *transcraneal direct current stimulation*)

YBT: Test Y-Balance

SHT: Test Side-hop

ET: Test de Emery

EMG: Electromiografía de superficie

RMS: Media cuadrática (del inglés: *root mean square*)

nEMG: Electromiografía normalizada

CS: Puntuación compuesta (del inglés: *composite score*)

Índice

1. Introducción 3
1.1 Objetivos 12
2. Metodología 13
2.1. Diseño y sujetos. 13
2.2. Instrumentos de intervención 15
2.2.1. Dispositivos de inestabilidad 15
2.2.2. tDCS 16
2.3. Variables resultado 17
2.3.1. Electromiografía de superficie 18
2.3.2. Pruebas de estabilidad 19
2.4. Procedimientos 21
2.5. Análisis estadístico. 24
3. Resultados 26
4. Conclusiones 28
5. Bibliografía 29
Anexos 45

Resumen de la tesis

1. Introducción

Las lesiones de tobillo representan una de las afecciones más comunes en la población, tanto en el ámbito general como en el deportivo (Lambers, Ootes, & Ring, 2012). Dentro de ellas, una de las lesiones más frecuentes y que más consultas médicas ocasiona es el esguince de tobillo (Herzog, Kerr, Marshall, & Wikstrom, 2019). Los esguinces de tobillo representan el 25% de todas las lesiones musculoesqueléticas y hasta el 50% de las relacionadas con el deporte (Czajka, Tran, Cai, & DiPreta, 2014). De ellos, los que se producen con mayor frecuencia son los esguinces del ligamento lateral, representando más del 75% de los casos (Herzog et al., 2019), y su mecanismo de lesión suele ser la inversión forzada (van den Bekerom, Kerkhoffs, McCollum, Calder, & van Dijk, 2013). Aunque se considere que su gravedad pueda ser relativamente menor en comparación con otros traumatismos severos como las fracturas, el impacto que tienen en la población no debe subestimarse. Su alta tasa de recurrencia afecta de forma significativa a la calidad de vida, al ámbito laboral y al deportivo, incrementando además el riesgo de desarrollar patologías degenerativas como la artrosis (Herzog et al., 2019; Verhagen, de Keizer, & van Dijk, 1995). En este sentido, los esguinces de tobillo ocasionan entre el 13% y el 22% de todos los casos de osteoartritis de tobillo y el 80% de los casos de osteoartritis postraumática (Herzog et al., 2019).

La relevancia social y económica de esta lesión está justificada por las consecuencias que tiene un esguince de tobillo a corto y largo plazo (Anandacoomarasamy & Barnsley, 2005; Braun, 1999). A nivel individual se limitan las actividades físicas y recreativas, aumenta el sedentarismo y surgen comorbilidades asociadas (Herzog et al., 2019). Se estima, además, que un 20% de los casos derivan en una inestabilidad crónica de tobillo (CAI, por sus siglas en inglés: *chronic ankle instability*), especialmente cuando el abordaje inicial no es el óptimo (Al-Mohrej & Al-Kenani, 2016). En el ámbito deportivo, un esguince de tobillo puede afectar al rendimiento e incluso suponer la baja del deportista (Han, Anson, Waddington, Adams, & Liu, 2015). Finalmente, en el ámbito económico, el coste derivado del tratamiento y la rehabilitación de una lesión tan frecuente representa una elevada cifra anual para los sistemas de salud y las organizaciones deportivas: se estima que los tratamientos médicos y de fisioterapia para esguinces de tobillo en los Estados Unidos alcanzan los 3.52 mil millones de euros anuales (Bielska, Wang, Lee, & Johnson, 2019).

En el seguimiento de los pacientes que sufren un esguince de tobillo, y a pesar de la ausencia de un consenso claro en su clasificación (Delahunt et al., 2010; Thompson et al., 2018), se utilizan diferentes etiquetas según la evolución clínica y funcional tras la lesión. Entre ellas están los pacientes que desarrollan CAI, caracterizada por inestabilidad mecánica, episodios recurrentes de torceduras, sensación de inseguridad y limitaciones funcionales persistentes (P. A. Gribble et al., 2013). Otro grupo está formado por los pacientes con inestabilidad funcional de tobillo (FAI, por sus siglas en inglés: *functional ankle instability*), quienes no presentan inestabilidad mecánica evidente, pero sí déficits en el control neuromuscular y alteraciones propioceptivas (Munn, Sullivan, & Schneiders, 2010). Por último, están los denominados 'copers', individuos que, a pesar de haber sufrido un esguince inicial, no desarrollan inestabilidad significativa gracias a una adecuada respuesta funcional y adaptativa (Wikstrom et al., 2012). Un metaanálisis publicado por Thompson et al. en 2018 destaca esta problemática de nomenclatura, afirmando que solo un 17% de los estudios analizados (13 de un total de 77) habían tenido un criterio claramente definido para etiquetar a sus casos de CAI. Por ello, ante la necesidad de ser rigurosos al crear clasificaciones y sacar conclusiones sobre ellas, deciden acuñar el término de “inestabilidad inespecífica de tobillo” (Thompson et al., 2018).

Un aspecto comúnmente alterado en los perfiles de CAI, FAI o inestabilidad inespecífica es la estabilidad. La estabilidad postural es la capacidad de mantener el cuerpo en equilibrio, asegurando que el centro de masas se mantenga dentro de la base de sustentación. Para lograrlo, es necesario integrar la información sensorial y ejecutar respuestas motoras adecuadas (Williams et al., 2016). Con relación al tobillo, la estabilidad no solo es crucial para prevenir el desarrollo de la patología, sino que también resulta esencial para garantizar una biomecánica eficiente y prevenir tanto recidivas como lesiones en estructuras adyacentes (Doherty, Bleakley, Delahunt, & Holden, 2017; McKeon & Hertel, 2008). Existen dos formas principales de evaluar la estabilidad: mediante pruebas estáticas o dinámicas. Las pruebas estáticas se realizan sobre superficies fijas y estables, mientras que las dinámicas implican movimientos que requieren un cambio en la posición o localización (Goldie, Bach, & Evans, 1989; P. Plisky, Schwartkopf-Phifer, Huebner, Garner, & Bullock, 2021; Sell, 2012). Hay estudios que relacionan el deterioro de la estabilidad estática como factor de riesgo para lesiones de miembro inferior (Baumhauer, Alosa, Renström, Trevino, & Beynnon, 1995; Dolan et al., 2023; McGuine, Greene, Best, & Leverson, 2000; Willems et al., 2005). Sin embargo, la valoración estática puede no ser la más adecuada en población deportista, que generalmente posee mejor capacidad de mantener el equilibrio. En este sentido, deberían ser utilizadas pruebas dinámicas, ya que resultan más desafiantes y se pueden asemejar más a las actividades deportivas (Sell, 2012). Además, se ha visto que la valoración de la estabilidad estática no presenta diferencias entre sujetos con FAI y población sana, mientras que las pruebas dinámicas sí reflejan variaciones significativas (Ross & Guskiewicz, 2004). La estabilidad de tobillo, por tanto, constituye un pilar esencial en el estudio y la intervención terapéutica dentro del ámbito de la fisioterapia, y la elección del método de valoración deberá depender de la población de estudio. En este contexto, la propiocepción, entendida como la percepción de la posición, el movimiento, la fuerza y la vibración, desempeña un papel fundamental, especialmente en actividades que requieren altos niveles de coordinación y control funcional, como las deportivas o el proceso de recuperación tras una lesión (Han, Waddington, Adams, Anson, & Liu, 2016). Se cree que la alteración de la función propioceptiva es el resultado del daño en receptores sensoriales del ligamento del tobillo, lo que disminuye el suministro de mensajes relacionados con el movimiento y la posición de las articulaciones hacia las vías aferentes (Lephart, Pincivero, Giraldo, & Fu, 1997). Un metaanálisis reciente confirma que las personas con CAI tienen un déficit en propiocepción, en particular en la capacidad de percibir el movimiento y la posición de sus articulaciones (Xue, Ma, Li, Song, & Hua, 2021). Esto puede influir negativamente en su capacidad de reacción ante una perturbación, lo que a su vez aumenta el riesgo de nuevas lesiones o episodios de inestabilidad.

Una de las claves para comprender el problema de la recurrencia en los esguinces de tobillo, así como de los casos de CAI o FAI, reside en el rol fundamental de los músculos peroneos: el peroneo largo y el peroneo corto. Su papel es crucial en la estabilización activa del tobillo, y su función óptima depende de su fuerza y tiempo de activación (Arnold, Linens, de la Motte, & Ross, 2009; Hopkins, Brown, Christensen, & Palmieri-Smith, 2009; Vaes, Van Gheluwe, & Duquet, 2001). Por sus diferencias en longitud y posición, la activación de cada uno depende de la posición del tobillo. En particular, el peroneo largo se encarga de la eversión con flexión plantar, mientras que el peroneo corto realiza la eversión con el tobillo a 90º (posición neutra). De hecho, en condiciones normales, los músculos peroneos complementan la función de los ligamentos laterales, y su activación protege a estos ligamentos de posibles daños frente a una torcedura (Glick, Gordon, & Nishimoto, 1976; Kaumeyer & Malone, 1980). Por una parte, se ha visto que uno de los factores que interfieren en el momento que ocurre un esguince de tobillo es el retardo en la activación de estos músculos (Kobayashi, Tanaka, & Shida, 2016), en particular en presencia de fatiga (Rodrigues, Soares, & Tomazini, 2019). A su vez, tras el esguince de tobillo, se suele dar lugar a una alteración de morfología y ángulo de penación del peroneo largo (Yoshida & Suzuki, 2020), perpetuando un círculo vicioso que favorece la recidiva. Por otra parte, las primeras hipótesis sobre la relación entre los músculos peroneos y las inestabilidades de tobillo sugerían una debilidad de estos no solo como como causa, sino también como consecuencia de la lesión (Bosien, Staples, & Russell, 1955). Bosien y Staples fueron los primeros en utilizar métodos manuales para detectar la debilidad de los músculos peroneos en pacientes que habían sufrido esguince de tobillo (Bosien et al., 1955; Staples, 1972). Sin embargo, sus métodos no eran cuantitativos y, por lo tanto, solo podían utilizarse para evaluar la fuerza muscular isométrica, pero no para evaluar la fuerza dinámica ni los efectos del entrenamiento. Poco después, Tropp abordó esta limitación midiendo por primera vez el torque muscular en el tobillo mediante un dinamómetro isocinético, para comprobar si la debilidad muscular y la falta de control postural estaban presentes en pacientes con inestabilidad de tobillo. En su estudio se confirma la hipótesis ya sospechada de que la debilidad de los músculos peroneos está presente en los pacientes con inestabilidad. Además, sugirió que el deterioro muscular se debía a la rehabilitación inadecuada y a la atrofia muscular secundaria (Tropp, 1986). Sin embargo, existe controversia en este sentido. Algunos estudios posteriores no encuentran diferencias significativas en la fuerza muscular entre los tobillos con inestabilidad y los sanos, lo que sugiere que la debilidad muscular no es un factor principal en el desarrollo de la inestabilidad (Arnold et al., 2009; Holmes & Delahunt, 2009; Thomas W. Kaminski & Hartsell, 2002). En este sentido, el estudio desarrollado ya hace 30 años por Baumhauer et al. sugiere un enfoque más indirecto, centrado en el equilibrio muscular y no en la fuerza absoluta de los músculos peroneos. Concluyen que las personas que presentan una mayor incidencia de esguinces de tobillo son aquellas en las que existe un desequilibrio en la fuerza muscular (Baumhauer et al., 1995). Específicamente, destacan como de riesgo valores elevados (>1.00) en la relación fuerza de eversión/fuerza de inversión, así como en la relación fuerza de dorsiflexión/fuerza de flexión plantar. Aunque la idea de que el riesgo de lesión depende de la relación entre agonistas y antagonistas, más que de la fuerza absoluta, represente una valiosa contribución al campo, el hecho de que un mayor riesgo esté asociado con una fuerza de eversión y dorsiflexión superior a la de inversión y flexión plantar puede resultar controvertido. Algunos estudios posteriores, que analizaron los mismos ratios de fuerza en una población similar, no encontraron relación con la tasa de esguinces de tobillo (Beynnon, Murphy, & Alosa, 2002; T. W. Kaminski, Perrin, & Gansneder, 1999), lo que sugiere que el modelo estadístico univariado elegido para el análisis por Baumhauer et al. podría no haber sido el más adecuado, al no considerar otros factores relacionados, como el índice de masa corporal (Eagle et al., 2019). Por tanto, parece ser que, aunque la fuerza de los peroneos puede influir, tiene una elevada importancia el equilibrio muscular y otras causas como los déficits en propiocepción (Thomas W. Kaminski & Hartsell, 2002; Xue et al., 2021). Pese a todo lo anterior, existe un metaanálisis reciente que respalda la influencia del equilibrio dinámico, el tiempo de reacción de los peroneos y los déficits de fuerza de eversión, así como los déficits de propiocepción y equilibrio estático, en la inestabilidad inespecífica del tobillo (Thompson et al., 2018). Este trabajo afirma que, en el tratamiento de la inestabilidad inespecífica del tobillo, los clínicos deben enfocarse en tres aspectos clave: el equilibrio dinámico, el tiempo de reacción y los déficits de fuerza. Todo esto subraya la importancia de diseñar intervenciones que no solo se centren en mejorar la fuerza de los músculos peroneos, sino también en optimizar su velocidad de activación y equilibrar su fuerza en relación con el resto de los músculos. Además, resulta fundamental incluir el entrenamiento del equilibrio dinámico como parte integral de las estrategias de prevención para evitar futuras recidivas.

Los programas de entrenamiento diseñados para mejorar estos factores han demostrado ser efectivos tanto para prevenir lesiones en sujetos sanos como para reducir las recidivas en aquellos con historial previo de esguinces de tobillo (Cruz, Oliveira, & Silva, 2019; de Vasconcelos, Cini, Sbruzzi, & Lima, 2018; Rivera, Winkelmann, Powden, & Games, 2017). Realizar, al menos, 6 semanas de entrenamiento de la estabilidad tras un esguince de tobillo reduce sustancialmente el riesgo de recurrencia en nuevos episodios (McKeon & Hertel, 2008). En este sentido, la prevención se posiciona como una estrategia fundamental en la reducción de la incidencia y recurrencia de los esguinces de tobillo (Anandacoomarasamy & Barnsley, 2005; de Vasconcelos et al., 2018). Para ello, han resultado altamente efectivos los programas de entrenamiento de la estabilidad, que se centran en el fortalecimiento de la musculatura y en el desarrollo del control neuromuscular, haciendo uso frecuentemente de dispositivos de inestabilidad (Cheng, Yang, Cheng, Lin, & Wang, 2010; Rivera et al., 2017; Stanek, Meyer, & Lynall, 2013). Este enfoque no solo mejora la resistencia del tobillo frente a las fuerzas externas, sino que también ayuda a restaurar los patrones adecuados de movimiento y a minimizar el riesgo de lesión.

Los dispositivos de inestabilidad han emergido como una herramienta fundamental en fisioterapia, especialmente en programas de ejercicio terapéutico (Saeterbakken & Fimland, 2013). Se emplean para desafiar el equilibrio, la propiocepción y la fuerza del sujeto, aspectos esenciales en la rehabilitación y mejora del rendimiento (Stanek et al., 2013). Tradicionalmente, se han utilizado dispositivos globales (en adelante GID, por sus siglas en inglés: *global instability devices*) como la Wobble board, la Power board o el BOSU (por sus siglas en inglés: Both Sides Utilized). Estos dispositivos generan inestabilidad en todo el miembro inferior, induciendo una activación generalizada de los músculos estabilizadores (Cheng et al., 2010; Rivera et al., 2017; Silva, Oliveira, Mrachacz-Kersting, Laessoe, & Kersting, 2016; Stanek et al., 2013). Sin embargo, presentan algunas limitaciones: su tamaño y volumen pueden dificultar su uso en ciertas poblaciones o en etapas iniciales de rehabilitación, y no permiten un enfoque específico en estructuras clave del tobillo.

En respuesta a estas limitaciones, han surgido dispositivos de inestabilidad selectiva (en adelante SID, por sus siglas en inglés: *selective instability devices*) que permiten un trabajo más focalizado en el pie y el tobillo. Ejemplos como las *Exercise Sandals*, la *Ankle-Destabilization Boot* y *Ankle-Destabilization Sandal*, el *Stepright Stability Trainer* y el *Mini Stability Trainer* ofrecen un abordaje más específico sobre los músculos peroneos (Alfuth & Gomoll, 2018; Bouillon, Hofener, O'Donnel, Milligan, & Obrock, 2019; Donovan, Hart, & Hertel, 2014, 2015; Forestier & Toschi, 2005; Michell, Ross, Blackburn, Hirth, & Guskiewicz, 2006). Un dispositivo reciente, el Blackboard (BB) (Figura 1), permite configurar la dirección y grado de inestabilidad, adaptándose así a las necesidades individuales de cada paciente o usuario. Esta configurabilidad parece facilitar una progresión controlada en el entrenamiento y un enfoque específico en diferentes estructuras del tobillo, representando una mejora significativa frente a los dispositivos tradicionales.

Figura 1. Blackboard

En los últimos años, la tendencia de trabajar con el pie descalzo para fomentar la apertura de los dedos y una conexión más directa con el suelo ha ganado popularidad, por sus múltiples beneficios (Endo & Miura, 2023; Nigg, 2009; Roth, Neumann, & Tao, 2016). En este contexto, a diferencia de otras herramientas, que al ser demasiado blandas o comprimir el pie pueden limitar su movimiento natural (como la cara blanda del BOSU o el Airex Pad), dispositivos como el BB destacan por permitir una interacción activa con una superficie plana y rígida, facilitando que el pie se mueva activamente de forma libre, descalzo, y en la dirección configurada. Este enfoque no solo podría tener beneficios en la mejora del equilibrio y la estabilidad de tobillo, sino que también podría optimizar la percepción sensorial y favorecer un movimiento más saludable y eficiente (Endo & Miura, 2023).

Los programas de entrenamiento con dispositivos de inestabilidad han mostrado resultados positivos en términos de activación muscular, equilibrio y control del tobillo (Ahern, Nicholson, O'Sullivan, & McVeigh, 2021; Anguish & Sandrey, 2018; Bouillon et al., 2019; Cain, Garceau, & Linens, 2017; Guo et al., 2021; Martínez-Amat et al., 2013; McKeon & Hertel, 2008; Romero-Franco, Martínez-Amat, Hita-Contreras, & Martínez-López, 2014). Las intervenciones que incluyen ejercicios con dispositivos inestables suelen realizarse con frecuencias de tres veces por semana durante períodos de 4 a 8 semanas, mostrando mejoras significativas en la estabilidad de tobillo (Guo et al., 2021; Romero-Franco, Martínez-López, Lomas-Vega, Hita-Contreras, & Martínez-Amat, 2012; Wright & Linens, 2017; Wright, Nauman, & Bosh, 2020). Diversos estudios sugieren que una duración de cuatro semanas de intervención puede ser suficiente para alcanzar beneficios en la estabilidad de tobillo en personas con CAI (Anguish & Sandrey, 2018; Powden, Hoch, Jamali, & Hoch, 2019). En sujetos sanos, también hay evidencia de que intervenciones de tres sesiones semanales durante 4 semanas son efectivas para mejorar la estabilidad dinámica de tobillo (Cuğ, Duncan, & Wikstrom, 2016). Por otro lado, se ha visto que la actividad electromiográfica en músculos de la pierna es generalmente independiente del dispositivo utilizado (Saeterbakken & Fimland, 2013), aunque esto no se relaciona con las diferencias que producen en términos de estabilidad estática (Stanek et al., 2013). A su vez, aumentar progresivamente la dificultad a lo largo de la intervención no genera mejores adaptaciones en la estabilidad que la repetición de sesiones con el mismo nivel de dificultad (Cuğ et al., 2016). Mientras que los dispositivos globales están ampliamente utilizados, los dispositivos selectivos, como el BB, ofrecen un enfoque más localizado que podría igualar los resultados de los primeros en programas de entrenamiento. Por ello, se requiere una mayor investigación para evaluar su impacto en programas específicos de rehabilitación y prevención.

Por último, cabe destacar el potencial de combinar el entrenamiento basado en dispositivos de inestabilidad con otras terapias complementarias. Estas pueden incluir abordajes que potencien la plasticidad neural y mejoren la recuperación de la función neuromuscular, como la terapia manual o el *biofeedback* (Kim & Uhm, 2016; Plaza-Manzano et al., 2016). En este sentido, una de las técnicas emergentes en fisioterapia que podría facilitar el aprendizaje motor y mejorar el control neuromuscular es la estimulación transcraneal por corriente directa (tDCS). Pese a su reciente desarrollo, ya existen algunos estudios probando su eficacia en combinación con intervenciones de ejercicios de pie y tobillo (Bruce, Howard, VAN Werkhoven, McBride, & Needle, 2020; Ma et al., 2020; Xiao et al., 2022), incluso sobre GIDs (Huang, Gao, & Fu, 2024). Sin embargo, los posibles efectos de su combinación con intervenciones específicas con SIDs aún permanecen desconocidos.

Hasta la fecha, diversos programas de ejercicio se han desarrollado para optimizar la prevención y rehabilitación de los esguinces de tobillo (Doherty et al., 2017; Rivera et al., 2017). No obstante, aunque los GIDs han demostrado ser en su mayoría efectivos, no está del todo claro cómo los dispositivos selectivos, como el BB, actúan en comparación con los globales en contextos clínicos y deportivos. Además, no se ha explorado su aplicación en poblaciones específicas ni su combinación con terapias innovadoras como la tDCS.

A partir de lo expuesto anteriormente, surgen tres hipótesis de investigación: (1) la activación muscular en diferentes condiciones de mantenimiento de un apoyo monopodal sobre un SID, específicamente el BB, podría generar activaciones musculares diferentes a las provocadas por los GID, aunque con similitudes en los músculos a los que se dirija su configuración; (2) el entrenamiento específico del pie y tobillo en jugadores y jugadoras recreacionales de fútbol, mediante el uso del BB, podría ser tan eficaz como el mismo entrenamiento realizado con el BOSU, en cuanto a la mejora de la estabilidad dinámica de tobillo; y (3) el uso del BB en una intervención de estabilidad de tobillo en sujetos sanos podría mejorar su estabilidad dinámica de tobillo y su combinación con tDCS podría inducir mejores adaptaciones al potenciar la respuesta neuromuscular del sujeto.

1.1 Objetivos

Los objetivos generales de esta tesis son los siguientes:

1. Comparar la activación electromiográfica del músculo peroneo largo, así como de otros músculos de las extremidades inferiores, durante el mantenimiento de un apoyo monopodal sobre diferentes dispositivos de entrenamiento del equilibrio (BOSU, Wobble Board, Power Board y BB), estando de pie o en posición de semisentadilla.
2. Comparar los efectos de un programa de entrenamiento de 4 semanas utilizando el BOSU o el BB sobre la estabilidad dinámica de tobillo en futbolistas recreacionales jóvenes.
3. Comparar los efectos de un programa de entrenamiento de 4 semanas con el BB, ya sea de forma aislada o combinado con tDCS, sobre la estabilidad dinámica de tobillo en adultos jóvenes físicamente activos.

2. Metodología

2.1. Diseño y sujetos.

Se realizaron tres estudios: un estudio inicial y dos estudios paralelos derivados del primero. El primero y el tercero fueron realizados en la Facultad de Fisioterapia de la Universidad de Valencia por estudiantes voluntarios de la misma, y el segundo se llevó a cabo en las instalaciones del club de fútbol Discóbolo-La Torre A.C. (Valencia), con voluntarios de sus diferentes equipos femeninos y masculinos.

El primer estudio, realizado para cumplir el primer objetivo, fue un estudio descriptivo transversal en el cual se evaluó la activación muscular de 6 músculos de la pierna mediante electromiografía (EMG) en una situación de equilibrio monopodal con la rodilla extendida y en posición semisentadilla monopodal, sobre diferentes dispositivos de inestabilidad. Participaron diez hombres (edad media: 23.40 ± 2.91 años; peso corporal: 79.80 ± 8.42 kg; altura: 177.90 ± 3.07 cm; actividad física semanal: 359.00 ± 211.05 minutos) y diez mujeres (edad media: 22.30 ± 1.06 años; peso corporal: 57.20 ± 11.17 kg; altura: 164.00 ± 6.02 cm; actividad física semanal: 282.00 ± 168.05 minutos) y el protocolo experimental fue aprobado por el Comité de Ética de la Universidad de Valencia (H1544554364247).

El segundo y tercer estudio fueron ensayos clínicos aleatorizados con dos grupos. El segundo estudio, que se diseñó para cumplir el segundo objetivo, se trató de un pre-post en el cual se midió la estabilidad dinámica de tobillo antes y después de una intervención de ejercicios de equilibrio sobre el BB (grupo SID) o sobre el BOSU (grupo GID). Veinte participantes integraron el estudio: el grupo SID estuvo formado por cinco mujeres y cinco hombres (edad media: 23.00 ± 5.68 años; peso corporal: 73.80 ± 18.34 kg; altura: 169.70 ± 8.89 cm), al igual que el grupo GID, formado por otras cinco mujeres y cinco hombres (edad media: 21.00 ± 3.80 años; peso corporal: 65.89 ± 6.79 kg; altura: 168.17 ± 5.25 cm). El protocolo experimental fue aprobado por el Comité de Ética de la Universidad de Valencia (1236358).

En el caso del tercer estudio, elaborado para examinar el tercer objetivo, se siguió un diseño de medidas repetidas. En él se midió la estabilidad dinámica de tobillo antes de comenzar, a las dos semanas, y al acabar una intervención de ejercicios de equilibrio sobre el BB, con o sin la aplicación de tDCS durante la ejecución del entrenamiento (grupo BB+tDCS y grupo BB, respectivamente). Veinte participantes constituyeron la muestra final. El grupo BB estuvo formado por tres mujeres y siete hombres (edad media: 22.40 ± 1.90 años; peso corporal: 75.11 ± 14.15 kg; altura: 173.11 ± 76.56 cm; actividad física semanal: 453.30 ± 177.76 minutos), y el grupo BB+tDCS por cuatro mujeres y seis hombres (edad media: 21.70 ± 2.70 años; peso corporal: 75.50 ± 10.17 kg; altura: 170.00 ± 89.57 cm; actividad física semanal: 396.00 ± 201.89 minutos). El protocolo experimental fue aprobado por el Comité de Ética de la Universidad de Valencia (1491326).

En relación con los criterios de inclusión, los del primer estudio fueron: (a) edad comprendida entre 16 y 35 años, (b) no haber sido sometido a cirugía en la extremidad inferior durante el último año, (c) no tener antecedentes de dolor en tobillos, rodillas o caderas en los dos meses previos a la participación y (d) no haber sufrido esguinces de tobillo en los tres meses previos a la participación. Para el segundo y tercer estudio existieron criterios de inclusión comunes: (a) edad entre 18 y 30 años, (b) no tener antecedentes de dolor o lesión en la extremidad inferior durante el último año y (c) realizar al menos 90 minutos de actividad física semanal.

Un criterio de exclusión específico del primer estudio fue la contraindicación para el uso de electrodos adhesivos debido a lesión de la piel o alergia al adhesivo. Finalmente, existieron criterios comunes de exclusión a los tres estudios: (a) haber participado previamente en programas de mejora del equilibrio o propiocepción y (b) presentar trastornos conocidos del equilibrio como vértigo, alteraciones vestibulares o del sistema nervioso central.

Todos los participantes de los tres estudios firmaron un consentimiento informado previo a su participación. En los casos en que los participantes eran menores de edad, se obtuvo la autorización correspondiente de sus padres o tutores legales, garantizando así el cumplimiento de los principios éticos y legales establecidos para la investigación.

2.2. Instrumentos de intervención

2.2.1. Dispositivos de inestabilidad

2.2.1.1. Blackboard

El BB es un dispositivo diseñado para el trabajo de la estabilidad y de la movilidad específica de pie y tobillo. Su estructura consiste en una plataforma hecha de madera, compuesta por dos tablas planas rectangulares, y varios puntos de apoyo que se consiguen mediante listones semicilíndricos, y que se adhieren a la base mediante velcro (Figura 1). Al ser pequeño, resulta fácilmente transportable, y configurable, lo que ofrece varias ventajas al trabajar con determinadas poblaciones o en momentos determinados del proceso de recuperación o prevención de una lesión. Se trata de un elemento innovador en el campo de la fisioterapia, ya que permite al usuario trabajar descalzo sobre una superficie plana y ancha, con inestabilidad dirigida específicamente hacia el antepié, retropié o ambos, y con diversas variaciones de dificultad entre ellos.

2.2.1.2. Dispositivos de inestabilidad global

<u>BOSU</u>

El BOSU es un dispositivo de inestabilidad compuesto por una semiesfera de goma inflable adherida a una base rígida de plástico (Figura 2-A), lo que permite trabajar con la superficie plana hacia abajo o hacia arriba para variar el enfoque de los ejercicios. Está ampliamente extendido en gimnasios y clínicas de fisioterapia, tratándose del dispositivo más empleado en programas de equilibrio y entrenamiento de la inestabilidad (Laudner & Koschnitzky, 2010).

<u>Wobble Board</u>

El Wobble Board (Figura 2-B) es un dispositivo de inestabilidad formado por una plataforma circular, plana y rígida, que descansa sobre una semiesfera en su base, que queda en contacto con el suelo. Esto genera una superficie inestable que obliga al usuario a mantener el equilibrio mediante la activación de su musculatura estabilizadora. Al igual que el BOSU, permite movimientos en todas direcciones, generando una inestabilidad global en el usuario.

Power board

La Power board (también conocida como Tabla de Freeman o Rocker Board) (Figura 2-C) es un dispositivo de inestabilidad compuesto por una plataforma rectangular rígida situada sobre un semicilindro fijo que queda en contacto con el suelo, que permite movimientos en un solo eje. Se puede utilizar con un pie o ambos y de forma longitudinal o transversal en función de la inestabilidad deseada.

Figura 2. Dispositivos de inestabilidad globales empleados: A) BOSU en sus diferentes posiciones; B) Wobble Board; C) Power Board

2.2.2. tDCS

La tDCS es una técnica no invasiva que utiliza una corriente galvánica de baja intensidad para modular la actividad neuronal en áreas específicas del cerebro. La estimulación se realiza mediante electrodos colocados en el cuero cabelludo, a través de los cuales se aplica una corriente suave (transcraneal), generalmente de 1 a 2 mA. Durante la estimulación se produce una alteración del potencial de membrana de la neurona dependiendo de su polaridad (Bruce et al., 2020; Emadi Andani et al., 2020; Shaheiwola, Zhang, Jia, & Zhang, 2018).

La aplicación puede ser de dos tipos: anódica (cuando la corriente estimula la actividad neuronal, aumentando su excitabilidad) o catódica (cuando la corriente inhibe la actividad neuronal, reduciendo su excitabilidad) (Nitsche & Paulus, 2000; Yavari, Jamil, Mosayebi Samani, Vidor, & Nitsche, 2018). Este tipo de estimulación no provoca dolor ni efectos adversos graves, siendo generalmente bien tolerada por los pacientes (Brunoni et al., 2011). La corriente aplicada puede tener efectos localizados en las áreas del cerebro objetivo, lo que permite influir en las funciones cerebrales relacionadas con el área estimulada (Yavari et al., 2018).

La tDCS se ha explorado principalmente en el ámbito clínico y de investigación, con aplicaciones en diversos trastornos neurológicos y psiquiátricos. Entre sus usos más comunes se encuentra el tratamiento de trastornos como la fibromialgia, la depresión, especialmente en pacientes con depresión no resistente a medicamentos, o el tratamiento del dolor neuropático crónico en miembros inferiores secundario a lesiones de la médula espinal (Lefaucheur et al., 2017). Además, la tDCS se ha utilizado para mejorar la cognición, especialmente en áreas como la memoria, la atención y el aprendizaje (Waters-Metenier, Husain, Wiestler, & Diedrichsen, 2014). La tDCS podría aumentar la plasticidad cerebral, lo que facilitaría el aprendizaje y la adaptación del cerebro a nuevas habilidades o la recuperación de funciones perdidas (Fritsch et al., 2010).

2.3. Variables resultado

La estabilidad del tobillo es una característica que comúnmente se evalúa mediante plataformas de presión y pruebas funcionales (Ross & Guskiewicz, 2004; Sell, 2012). Estas herramientas permiten cuantificar la capacidad de equilibrio y el control neuromuscular antes y después de una intervención, proporcionando datos objetivos sobre la eficacia del entrenamiento (7, 8). Las plataformas de presión proporcionan una información sobre la estabilidad estática del sujeto, mientras que pruebas funcionales como el Y-Balance Test (YBT), el test de Emery (ET), o el Side-Hop test (SHT), ofrecen datos relacionados con la estabilidad dinámica del tobillo. Estas tres pruebas funcionales son empleadas en el segundo estudio, y el YBT y el ET en el tercero.

Otra forma de valorar los cambios que experimenta un sujeto al entrenar sobre plataformas de inestabilidad es la electromiografía de superficie (EMG), empleada en el primer estudio. Se trata de una técnica no invasiva ampliamente utilizada en el campo de la fisioterapia para evaluar y registrar la actividad eléctrica de los músculos durante su contracción (Drost, Stegeman, van Engelen, & Zwarts, 2006). En el contexto de los dispositivos de inestabilidad, la EMG se presenta como un método efectivo para validar su eficacia, ya que permite medir con objetividad el grado de activación muscular que dichos dispositivos generan (Donovan et al., 2015; Laudner & Koschnitzky, 2010; Saeterbakken & Fimland, 2013). Este enfoque contribuye a una comprensión más profunda de los efectos biomecánicos y terapéuticos de estas herramientas, facilitando su aplicación.

En el primer estudio, la variable principal de medición fue la activación muscular de 6 músculos de la pierna (peroneo largo, tibial anterior, sóleo, gastrocnemio medial, recto femoral y glúteo mayor), medida con EMG. En los estudios segundo y tercero, las variables resultado fueron la estabilidad de tobillo medida con el YBT y el ET y, en el caso del segundo estudio, también mediante el SHT.

2.3.1. Electromiografía de superficie

Para colocar los electrodos, se rasuró y limpió la zona con alcohol y se siguieron las pautas recomendadas por SENIAM (Tabla 1). El dispositivo empleado para la recogida de datos fue el MuscleLab 4020e (Ergotest Technology, Stathelle, Noruega). Una vez fijados los electrodos adhesivos Ag/AgCl (BlueSensor N; Ambu Ballerup, Dinamarca) y sensores del aparato, se realizó la medición control en la superficie estable del suelo, la cual fue utilizada como referencia para normalizar los datos obtenidos sobre las plataformas de inestabilidad (Saeterbakken & Fimland, 2013). Después de realizar un ensayo para familiarizarse con cada condición y tomar las mediciones de control en el suelo rígido, los participantes realizaron dos repeticiones de quince segundos en cada dispositivo, con un descanso de dos minutos entre repeticiones (Wahl & Behm, 2008).

Los datos brutos de EMG fueron procesados siguiendo el protocolo descrito por Van den Tillaar y Larsen (2020) (van den Tillaar & Larsen, 2020). Las señales de EMG se digitalizaron a una frecuencia de 1,000 Hz. Posteriormente, se aplicaron filtros de paso alto y paso bajo con frecuencias de corte de 20 Hz y 500 Hz, respectivamente. Las señales filtradas fueron rectificadas, integradas y convertidas en señales de raíz cuadrática media (RMS) utilizando un circuito de hardware (respuesta en frecuencia de 450 kHz, constante de promedio de 12 ms, error total ≤ 0.5 %). La señal de EMG filtrada fue normalizada con respecto a la actividad muscular obtenida durante la medición control (Silva et al., 2016).

De los quince segundos totales recopilados, se descartaron los primeros y últimos cinco segundos de la EMG normalizada (nEMG) para minimizar ajustes posturales o efectos de fatiga. De este modo, se calculó la amplitud de la nEMG durante los 5 segundos centrales de cada ensayo (Wahl & Behm, 2008). Finalmente, se obtuvo el promedio de la nEMG de los dos intentos en cada condición para su posterior comparación.

Tabla 1. Colocación de electrodos según pautas SENIAM.

MÚSCULO	COLOCACIÓN ELECTRODOS
Peroneo largo	¼ de la línea entre cabeza de peroné y maléolo lateral
Tibial anterior	⅓ de la línea entre cabeza de peroné y el maléolo medial
Sóleo	⅔ de la línea entre el cóndilo medial del fémur y el maléolo medial
Gastrocnemio medial	En la zona más prominente del músculo
Recto femoral	½ de la línea entre la espina iliaca anterior superior y la parte superior de la rótula
Glúteo mayor	½ de la línea entre el sacro y el trocánter mayor

2.3.2. Pruebas de estabilidad

2.3.2.1. Y-Balance Test

El YBT es un test que ha demostrado ser muy fiable para evaluar la estabilidad dinámica de un sujeto (P. A. Gribble, Hertel, & Plisky, 2012). Consiste en mantenerse de pie sobre una pierna mientras, con la contralateral, se alcanza el punto más lejano posible en tres direcciones diferentes (en primer lugar hacia anterior, después posteromedial y por último posterolateral) , manteniendo la estabilidad del pie de apoyo (P. A. Gribble et al., 2012; P. J. Plisky, Rauh, Kaminski, & Underwood, 2006). Las tres direcciones están representadas por una línea milimetrada en el suelo, y parten de un punto central en el que se coloca el pie del sujeto. El objetivo del test es alcanzar la mayor distancia posible en cada una de las direcciones sin perder la posición de inicio (apoyo monopodal, pie en completo contacto con el suelo, manos en las caderas) (P. A. Gribble et al., 2012; P. Plisky et al., 2021). Para realizarlo se marcaron mediante tape las líneas en el suelo y se utilizó un goniómetro para asegurarse de los ángulos (90º entre las líneas posteriores y 135º de éstas con respecto a la línea anterior) (Granacher et al., 2014).

Cada participante realizó dos intentos con cada pierna y en cada dirección para familiarizarse con el test, seguidos de tres intentos más que fueron los registrados (Robinson & Gribble, 2008). Se dejó un tiempo de descanso de quince segundos entre intentos de una misma posición y de cinco minutos entre las diferentes direcciones

(Granacher et al., 2014; P. Gribble & Hertel, 2003). Todas las mediciones se realizaron descalzos y con las manos colocadas en las caderas. A su vez, para las mediciones anteriores se colocaba la parte más distal del pie en la intersección de las líneas, y para las mediciones posteriores era el talón el que se colocaba en este punto (P. A. Gribble et al., 2012). Se registraron los valores de los tres últimos intentos para calcular posteriormente el valor medio. A su vez, la distancia recorrida en cada intento se normalizó posteriormente con la longitud de la pierna, para lo cual se midió el miembro inferior de cada sujeto en decúbito supino, tomando como referencia la espina ilíaca anterosuperior y el maléolo medial de la misma pierna (P. Gribble & Hertel, 2003)

Si durante el intento el sujeto no alcanzaba a tocar la línea con el pie móvil, movía el pie de apoyo, soltaba las manos de las caderas, perdía el equilibrio en algún momento apoyando su pie móvil, no mantenía la posición de inicio o final por al menos un segundo o dejaba caer peso sobre el pie móvil en el final del recorrido, no se consideraba un intento válido y se repetía el movimiento (Granacher et al., 2014).

2.3.2.2. Emery test

Tras la medición del YBT se realizó el ET. El ET es un test que ha demostrado ser interesante para medir la estabilidad dinámica de tobillo en sujetos jóvenes (Emery, Cassidy, Klassen, Rosychuk, & Rowe, 2005). Consiste en mantener el equilibrio sobre una pierna el mayor tiempo posible con los ojos cerrados, descalzo y con las manos en las caderas, sobre un Airex Balance Pad (Blasco et al., 2019; Emery et al., 2005). El tiempo máximo establecido para cada intento es de 180 segundos (Hahn, Foldspang, Vestergaard, & Ingemann-Hansen, 1999). Cada participante realizó 3 intentos para, de ellos, calcular posteriormente el valor medio. Se dio un tiempo de prueba de 15 segundos a los sujetos para su familiarización con el cojín (Emery et al., 2005).

2.3.2.3. Side hop test

El SHT es una prueba funcional utilizada para evaluar la estabilidad, fuerza y control neuromuscular del tobillo. Para ejecutarlo, el participante debe realizar 20 saltos monopodales laterales sobre una distancia de 30cm marcada en el suelo, en el menor tiempo posible. Tras un intento que se daba los participantes como familiarización, se realizaron 3 intentos que se registraron con un cronómetro de mano. Se dejaba 1 minuto de descanso entre ellos, y el mejor tiempo fue utilizado para el posterior análisis.

2.4. Procedimientos

Para cumplir los objetivos del primer estudio, tras colocar los electrodos se realizó una familiarización con cada dispositivo y condición y la medición control sobre el suelo. Esta consistió en mantener un apoyo monopodal durante 15 segundos sobre la pierna dominante, con el pie descalzo y las manos en las caderas (Harput, Soylu, Ertan, & Ergun, 2013; Laudner & Koschnitzky, 2010; Wahl & Behm, 2008). A continuación, la misma pauta se llevó a cabo sobre los 4 dispositivos de estudio, con un tiempo de descanso de 2 minutos entre dispositivos y condiciones (Wahl & Behm, 2008). Se les midió tanto con la rodilla en extensión como en posición de semisentadilla monopodal, a 60º de flexión de rodilla (Saeterbakken & Fimland, 2013). Para asegurar la posición articular se utilizó un goniómetro, aunque se permitieron las variaciones propias de ajustar el equilibrio, procurando en todo momento volver a la posición original. El orden de uso de los dispositivos, así como de las posiciones en extensión de rodilla y en semisentadilla, fue aleatorizado. La Power board fue utilizada en su configuración de inestabilidad longitudinal, y el BB en su configuración de retropié inestable y antepié fijo.

Para cumplir los objetivos del segundo estudio, se analizó la estabilidad de tobillo de los sujetos mediante varios test funcionales (YBT, ET, SHT). Tras la toma de datos, se llevó a cabo un plan de ejercicios supervisado por una fisioterapeuta tres veces por semana durante cuatro semanas, justo antes de comenzar sus entrenamientos en el campo de fútbol. Tras ello, se volvió a evaluar la estabilidad con los test funcionales. El plan de ejercicios comenzaba con un calentamiento convencional que comprendía 5 minutos de bicicleta estática y movilidad activa de tobillos (Subasi et al., 2008). A continuación, se llevaba a cabo una serie de ejercicios con el elemento (BOSU o BB) que aleatoriamente le había sido asignado a cada sujeto. El plan de ejercicios establecido fue una modificación del propuesto previamente para el trabajo de propiocepción en deportistas (Romero-Franco et al., 2014), y consistía en la realización de cuatro ejercicios de apoyo monopodal sobre la superficie inestable (Figura 5). La configuración del BOSU en este estudio fue con su base rígida hacia arriba, y el BB se configuró en inestabilidad total (tanto antepié como retropié inestables). Todos los ejercicios se realizaron con un balón medicinal de tres kg de peso.

Figura 3. Plan de ejercicios del segundo estudio. A) Mantener apoyo monopodal durante 30” con el balón medicinal por encima de la cabeza. B) 10 repeticiones de semisentadilla monopodal con el balón medicinal por encima de la cabeza. C) 10 repeticiones de balanceo en flexoextensión de cadera de 45º de flexión a 45º de extensión, con el balón a la altura del pecho. D) 10 pases con su compañera/o mientras se mantiene un apoyo monopodal.

Para cumplir los objetivos del tercer estudio se siguieron unos procedimientos muy semejantes a los del segundo estudio. En primer lugar, se analizó la estabilidad de tobillo de los sujetos mediante los test funcionales YBT y ET. Tras la medición inicial, se llevó a cabo una intervención de ejercicios supervisada por una fisioterapeuta tres veces por semana durante 4 semanas. Tanto a mitad de la intervención (antes de comenzar la séptima sesión), como al acabar la intervención, se volvió a evaluar la estabilidad con los dos test funcionales. La sesión de trabajo de tanto los sujetos del grupo BB+tDCS como de los del grupo BB consistió en 5 repeticiones de mantener el equilibrio sobre el BB de 40 segundos de trabajo y 60 segundos de descanso con su pierna dominante. A su vez, los sujetos del grupo tDCS+BB, recibían la aplicación de la corriente durante el tiempo de duración de la intervención. El dispositivo utilizado para aplicar la corriente fue el EPTE Bipolar System (Ionclinics, Valencia, España). El ánodo se colocaba en la corteza motora contralateral a la pierna dominante, específicamente en el área de representación de la pierna (lateral al vértice Cz, en la línea sagital media), mientras que el cátodo se posicionaba en la región supraorbitaria contralateral (Figura 6) [14,28]. Se utilizaron electrodos de goma dentro de una esponja previamente humedecida con solución salina. También se aplicó gel conductor entre el electrodo y el cuero cabelludo para asegurar el flujo de corriente a través del cabello. Los electrodos tenían una superficie de 35 cm². La estimulación se aplicó durante un total de 10 minutos a una intensidad de 2 mA [28,29]. La configuración del BB para la intervención fue igual que en el segundo estudio, en su configuración de inestabilidad total, con dos listones colocados en el centro de cada plataforma para generar inestabilidad tanto en antepié como en retropié. Como el objetivo de la intervención era el entrenamiento del sujeto, se permitió que eventualmente los bordes del BB contactaran con el suelo o que el sujeto perdiera ligeramente su posición, aunque siempre acumulando los 40 segundos de tiempo de trabajo planteados.

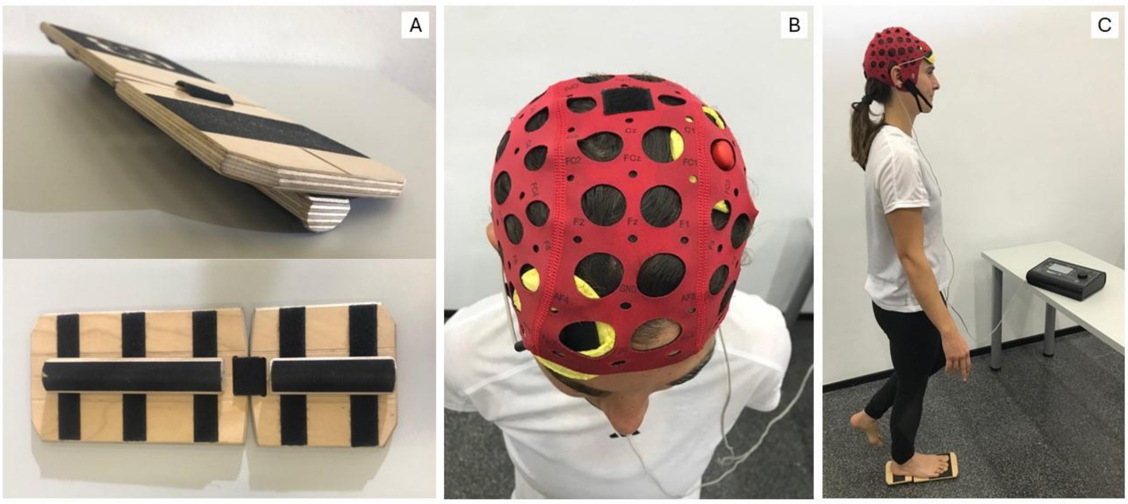

Figura 4. A) Blackboard en su configuración de inestabilidad total. B) Colocación de los electrodos. C) Ejecución del ejercicio en una participante del grupo BB+tDCS.

2.5. Análisis estadístico.

El análisis estadístico de todos los estudios fue realizado con el programa estadístico IBM SPSS Statistics, versión 25, 28 y 29, respectivamente. En el estudio 1 se utilizó adicionalmente el programa MedCalc Statistical Software (MedCalc Software, Mariakerke, Belgium) para la creación de gráficas.

En el análisis estadístico del estudio 1, al tratarse de un estudio descriptivo transversal, se estudiaron los efectos intragrupo. Para analizar específicamente las diferencias en el nEMG del músculo peroneo largo entre distintas superficies inestables se emplearon análisis de varianza (ANOVA) de medidas repetidas con un diseño *split-plot*. Para evaluar los efectos principales de los dispositivos y las condiciones, así como su interacción, en la nEMG del peroneo largo y de los demás músculos, se utilizó un ANOVA de medidas repetidas de dos factores ("dispositivo" y "condición"). Además, en caso de detectar un efecto principal significativo, se aplicaron pruebas t post hoc con correcciones de Bonferroni para establecer las diferencias.

En los estudios 2 y 3, al tratarse de ensayos clínicos controlados aleatorizados con dos grupos, el análisis estadístico se basó en el análisis de la diferencia de medias entre los grupos, así como en el análisis de las diferencias dentro de cada grupo en el tiempo. Las características de los participantes se resumieron como medias (con su desviación estándar) o frecuencias, y las medidas de estabilidad como medias (intervalos de confianza del 95%). Para examinar las diferencias en características demográficas y antropométricas, y las medidas de estabilidad entre grupos en el momento de inicio, se utilizó la prueba *t* de Student para muestras independientes. En el estudio 2 se empleó una ANOVA de medidas repetidas para analizar los efectos del programa de entrenamiento sobre las variables de estabilidad (YBT, ET y SHT), con el factor tiempo como factor intragrupo de dos niveles (pre y post) y el factor grupo como factor entregrupos de dos niveles (SID y GID) En el estudio 3 se realizó también una ANOVA, en este caso con el factor tiempo como factor intragrupo de tres niveles (basal, POST_2W y POST_4W) y el factor grupo como factor entregrupos de dos niveles (BB y BB+tDCS) y así analizar los efectos del programa de entrenamiento sobre las variables de estabilidad (YBT y ET) a lo largo de las 3 mediciones. En ambos estudios, en caso de detectar significancia en los efectos principales o en sus interacciones, se utilizaron post hoc pruebas *t* de muestras relacionadas para comparaciones intra grupo y pruebas *t* de muestras independientes para comparaciones entre grupos.

Otros estadísticos empleados comunes a todos los estudios fueron la *d* de Cohen (60) y η^2 (Eta al cuadrado parcial) para evaluar el tamaño del efecto (61). El nivel de significancia se estableció en $p < 0.05$. La normalidad de las muestras fue evaluada con Shapiro-Wilk o Kolmogorov-Smirnov, y la homogeneidad de varianzas con el test de Levene. Todos los ajustes del error en los análisis post-hoc se realizaron mediante la corrección de Bonferroni.

En relación con el cálculo muestral del primer estudio, aunque no fue realizado, el número de participantes se consideró adecuado en base a estudios similares previos y a la disponibilidad de recursos (Strøm et al., 2016). Los cálculos muestrales del segundo y tercer estudio fueron realizados con el programa G*Power v.3.1.9.2 (Universität Kiel, Germany). El tamaño de la muestra del segundo estudio se calculó en base a un estudio previo (Guo et al., 2021), que reportó diferencias dentro de los grupos para la prueba YBT debido a una intervención con un tamaño del efecto de 1.2. Sin embargo, para adoptar un enfoque conservador, se utilizó un tamaño del efecto de 0.7, con un poder estadístico de 0.9 y un nivel alfa de 0.05. Este cálculo indicó que se requería un mínimo de 19 participantes, el cual fue redondeado a 20 para facilitar la homogeneidad del grupo. Para el tercero, se tomó como referencia el artículo de Ma et al. (2020), que informó un tamaño del efecto de $\eta^2 = 0{,}096$ para la interacción tiempo x grupo en el YBT. Con un nivel alfa de 0,05 y una potencia de 0,85, se determinó un tamaño muestral de 20 participantes (Ma et al., 2020).

3. Resultados

Los resultados del primer estudio confirman la hipótesis de que el BB, configurado para generar inestabilidad del retropié, induce niveles de activación del peroneo largo similares a los logrados con GIDs como el BOSU, el Wobble board o el Power board. Por el contrario, se observaron diferencias significativas en otros músculos de la pierna, donde el BB presentó menores niveles de activación en comparación con los GIDs. Estas diferencias sugieren que el BB, al focalizar la inestabilidad específicamente en el retropié, puede reducir la demanda muscular general mientras mantiene un estímulo adecuado en el peroneo largo. Además, se identificaron diferencias importantes según la posición corporal: en la posición de rodilla extendida se observó una activación significativamente mayor en el sóleo, el recto femoral y el glúteo mayor en comparación con la posición en semisentadilla. La interacción entre dispositivo y condición fue particularmente relevante para el recto femoral y el glúteo mayor, donde el BB mostró activaciones más bajas en varias combinaciones de dispositivo y postura. En conjunto, estos hallazgos destacan la capacidad del BB para modular la activación muscular según el contexto, ofreciendo una herramienta potencialmente útil para entrenamientos más específicos de peroneo largo y menos demandantes para el resto de los músculos.

Los resultados del estudio 2 indican que tanto el BOSU como el BB son herramientas efectivas para mejorar la estabilidad dinámica de tobillo, logrando mejoras similares en diferentes parámetros relacionados con esta habilidad en ambos grupos de intervención. Los resultados destacan que ambos métodos, a pesar de sus diferencias en la generación de inestabilidad, pueden provocar adaptaciones significativas en el YBT, aunque ninguno de ellos logró mejorías en el ET o el SHT. Ambos métodos resultaron efectivos para mejorar el alcance posteromedial, posterolateral y el sumatorio en el YBT, lo que sugiere que incluso dispositivos que focalizan la inestabilidad en un solo plano, como el BB, pueden lograr adaptaciones comparables a las obtenidas con dispositivos más globales como el BOSU. Este hallazgo es relevante para usuarios y clínicos que buscan personalizar las intervenciones de estabilidad de tobillo según las necesidades específicas de cada contexto o situación deportiva.

Los hallazgos principales del tercer estudio demostraron que el programa de ejercicios de estabilidad haciendo uso del BB fue efectivo para mejorar la estabilidad dinámica, pero la adición de tDCS no ofreció beneficios adicionales al grupo BB+tDCS. Estas mejoras fueron evidentes tanto a las 2 como a las 4 semanas de intervención, siendo algo más pronunciadas en el grupo BB+tDCS. Las mejoras significativas se evidenciaron en múltiples parámetros del YBT, incluidas las direcciones posteromedial y posterolateral, así como en el *composite score* (CS), lo que resalta la eficacia del programa. Además, estas mejoras superaron los valores mínimos detectables de cambio, confirmando que las adaptaciones observadas no fueron casuales, sino que representaron un cambio genuino en el desempeño. También se observaron avances en el ET, consolidando la utilidad del programa en la mejora de la estabilidad dinámica. Cabe destacar que, aunque la tDCS ha mostrado potencial en otras áreas de la rehabilitación, su combinación con este tipo de entrenamiento no proporcionó beneficios significativos adicionales en esta población. Estos resultados subrayan la importancia y la eficacia de los dispositivos de inestabilidad como herramientas independientes en programas de rehabilitación y prevención de lesiones de tobillo, ofreciendo una base sólida para su implementación práctica en contextos deportivos y clínicos. Sin embargo, se necesita más investigación para explorar formas de optimizar la integración del tDCS en este tipo de intervenciones.

4. Conclusiones

1. La activación muscular del peroneo largo fue similar en todos los dispositivos y condiciones estudiadas. En cambio, la activación del resto de músculos dependió del dispositivo o condición, siendo, en general, superior en los GIDs que en el BB.

2. En futbolistas recreacionales, un programa de entrenamiento con el BB fue efectivo para mejorar la estabilidad dinámica de tobillo, logrando beneficios comparables a los obtenidos con un programa de inestabilidad usando el BOSU.

3. La implementación de un programa de entrenamiento con el BB mejoró la estabilidad dinámica de tobillo en jóvenes activos. Sin embargo, combinarlo con tDCS no ofreció beneficios adicionales en comparación con realizarlo de forma aislada.

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Anexos

Categorización de los artículos presentados en la tesis doctoral

Artículo	Revista	Factor de impacto (según JCR)	Área temática	Ranking	Cuartil
I	PeerJ	2.3	Multidisciplinary sciences	48/134	Q2
II	Journal of Functional Morphology and Kinesiology	2.6	Sport sciences	31/127	Q1
III	Applied Sciences	2.5	Engineering, Multidisciplinary	44/181	Q1

JCR: Journal Citation Reports (2023).

ARTÍCULO I

Sánchez-Barbadora, M., Cuerda-Del Pino, A., González-Rosalén, J., Moreno-Segura, N., Escriche-Escuder, A., & Martín-San Agustín, R. (2022). Differences in lower limb muscle activation between global and selective instability devices in single-leg stance in healthy active subjects. PeerJ, 10, e13317. doi: 10.7717/peerj.13317

PeerJ

Differences in lower limb muscle activation between global and selective instability devices in single-leg stance in healthy active subjects

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ABSTRACT

Background. Balance and strength training are frequent strategies to address lower limb injuries, including ankle injuries, which are usually performed in single-leg stance on global instability devices, producing generalized muscular activation of the lower limb. In this context, new specific instability devices arise from the need to selectively work the ankle, specifically the peroneus longus. This study aimed to compare the EMG muscle activation of the peroneus longus, as well as other lower limbs muscles, in a single-leg stance on different balance training devices (BOSU, wobble board, power board, and Blackboard) in standing or squatting positions.
Methods. Twenty healthy recreationally trained subjects participated in the study. Subjects performed three repetitions of 15 s (one for familiarization and two for measurement) in standing and squatting positions on the floor, BOSU, wobble board, power board, and Blackboard. Surface electromyography (EMG) was used to record activity of the peroneus longus, soleus, gastrocnemius medialis, tibialis anterior, rectus femoris, and gluteus maximus.
Results. The main outcome was that no differences were found for the peroneus longus normalized EMG, neither between devices ($p = 0.09$) nor between conditions ($p = 0.11$), nor in the interaction between them ($p = 0.16$). For the normalized EMG of the other muscles, there were multiple differences between devices and conditions. Of the devices studied, the Blackboard was the one that implied a lower activation of the lower limb muscles and a lower degree of instability, activating the peroneus longus similarly to global instability devices. The BOSU and wobble board achieved high levels of EMG muscle activation for most muscles of the lower limbs. Therefore, they should be considered as potential devices for work in highly unstable conditions or when high activation levels are sought.

Subjects Kinesiology, Sports Injury, Rehabilitation, Sports Medicine
Keywords Electromyography, Peroneus, Ankle, Balance

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INTRODUCTION

Ankle injury is among the most common pathologies treated in primary care and emergency services, involving approximately 25% of all injuries of the musculoskeletal system and 50% of all sports-related injuries (*Czajka et al., 2014*). This injury, characterized by excessive stretching or tearing of the ankle ligaments, is usually acute. However, some studies quantify the incidence of residual symptoms after acute ankle sprain at between 40 and 50% (*Gerber et al., 1998*; *Konradsen et al., 2002*; *Van Rijn et al., 2008*; *Hubbard-Turner & Turner, 2015*). Among these residual symptoms, we can find lateral ankle pain with long evolution times, caused by ankle instability (better known as Chronic Ankle Instability, CAI) or other differential causes (*Gerber et al., 1998*; *Konradsen et al., 2002*; *Van Rijn et al., 2008*; *Hubbard-Turner & Turner, 2015*).

In this regard, EMG muscle activation of the peroneus longus (Pero-L) and brevis, in particular, has shown to be delayed following sprains and in the presence of fatigue (*Keles et al., 2014*; *Rodrigues, Soares & Tomazini, 2019*). Likewise, changes are found in the morphology and pennation angle of Pero-L in chronic ankle instability (*Yoshida & Suzuki, 2020*). According to the findings of a previous study, Pero-L plays an important role in the eversion and plantarflexion of the ankle (*Mendez-Rebolledo et al., 2021*). Therefore, a tailored Pero-L approach may be essential to manage and prevent ankle injury (*Han & Ricard, 2011*; *Thompson et al., 2018*). In turn, since ankle inversion/eversion is accompanied by hip axial rotation during single-leg stance (primarily characterized by inter-joint coordination) (*Liu et al., 2012*), training of other muscles involved in both ankle and hip movements is also essential.

Considering the previous, exercise therapy is one of the main approaches used to treat and prevent the recurrence of ankle sprains (*Doherty et al., 2017*) and CAI (*McKeon & Hertel, 2008*). In particular, balance and strength training performed in single-leg stance have proven to be effective in improving proprioception, neuromuscular control, and sensorimotor system (*Gauffin, Tropp & Odenrick, 1988*; *Lazarou et al., 2018*; *Hall et al., 2018*; *Vuurberg et al., 2018*). Balance training is frequently approached through training in conditions of instability. This training is characterized by exercises performed with devices or postures challenging postural control. Unlike traditional strength training, this approach has previously shown to facilitate the recruitment of muscle fibers for maintaining body stability. In addition, a fundamental aspect of balance training is the progression in the exercises using, for example, platforms with different levels of stability (*Borreani et al., 2014*).

The most popular balance training methods include devices such as BOSU, wobble board (WB), or power board (PB) (*Saeterbakken & Fimland, 2013*; *Strøm et al., 2016*), which have traditionally been used as exercise therapy for ankle rehabilitation and injury prevention. These global instability devices have proven to be very demanding in the inversion-eversion movement (*Strøm et al., 2016*). However, they do not allow their modification to progress or adapt to the difficulty of the exercise, and the structure of the foot to be worked cannot be selectively determined. Therefore, they produce a generalized muscle activation of the entire lower limb (*Silva et al., 2016*). This fact contrasts with the effect of selective devices such as the Mini Stability Trainer (Ludwig ARTZT GmbH, Germany), which produces different muscle activations of the lower limb muscles depending on whether the forefoot or rearfoot is destabilized (higher activation of most of the lower limb muscles when the forefoot is destabilized) (*Alfuth & Gomoll, 2018*).

With the intention of directly addressing the application of forefoot or rearfoot instability, additional selective balance training alternatives have been developed, also finding differences in the activation of the muscles of the lower limbs using specific forefoot or rearfoot destabilization procedures (*e.g.*, Exercise Sandals (*Michell et al., 2006*), Ankle-Destabilization Boot and Ankle-Destabilization Sandal (*Forestier & Toschi, 2005*; *Donovan, Hart & Hertel, 2014*; *Donovan, Hart & Hertel, 2015*), or StepRight Stability Trainer (*Bouillon et al., 2019*)). Most of these devices focus directly on the ankle joint, specifically on the Pero-L (*Forestier & Toschi, 2005*; *Donovan, Hart & Hertel, 2014*; *Donovan, Hart & Hertel, 2015*; *Bouillon et al., 2019*). However, some of them have the disadvantage of being excessively complex or bulky, not configurable to progress in the rehabilitation process, or not easily portable. Others, such as the device investigated by *Alfuth & Gomoll (2018)*, have improved configurability (*e.g.*, select instability direction) and portability aspects but remain limited in terms of progression in complexity. In this sense, a recently developed device known as Blackboard Training (BB) has been designed in which instability direction and degree settings can be adjusted by the user. This characteristic could favor the progression in complexity and activate specific ankle muscles.

In this context, the study of how selective and standard devices specifically activate the muscles related to the kinematics of the ankle is required. According to a previous study, comparisons of the surface electromyography (EMG) signal across different exercises may provide insight into muscular force production, despite some limitations (*Vigotsky et al., 2017*). In turn, in balance training, muscle activity has been used as an indicator of the intensity produced by the instability of the device used (*Strøm et al., 2016*). Thus, previous authors have suggested the importance for a clinician of distinguishing between the different devices concerning perturbation potential (*i.e.,* ability to produce kinematic alterations through instability) and intensity (*Strøm et al., 2016*) or between different positions that affect these as well (*e.g.*, standing or squat position) (*Wahl & Behm, 2008*).

However, although some of these selective instability devices have been analyzed in terms of the EMG muscle activation produced (*Forestier & Toschi, 2005*; *Donovan, Hart & Hertel, 2014*; *Donovan, Hart & Hertel, 2015*; *Alfuth & Gomoll, 2018*; *Bouillon et al., 2019*), to date there are no studies comparing the EMG muscle activity produced by one of them against multiple global instability devices.

The main hypothesis of this study is that balance training using a selective device as BB results in differences in the activity of lower limb muscles compared with global instability devices, since these are devices with different perturbation potential. In this sense, it is hypothesized that BB configured for anteversion instability of the rearfoot produces similar Pero-L muscle EMG activation that global instability devices but lower in other lower limb muscles.

Therefore, the main aim of this study was to compare the EMG muscle activation of the Pero-L as well as other lower limbs muscles in a single-leg stance on different balance training devices (BOSU, WB, PB, and BB) in standing or squatting positions.

MATERIALS & METHODS

Study design

In this observational study, the activation of the Pero-L, soleus, gastrocnemius medialis (Gastr-M), tibialis anterior (Tib-A), rectus femoris (Rect-F), and gluteus maximus (Glut-M) muscles was measured in a single day of testing. Performance conditions registered were standing and squatting positions on the floor, BOSU, WB, PB, and BB. Both standing and squat positions were proposed to compare the level of muscle activation between four instability systems.

Subjects

Twenty healthy recreationally trained participants, ten males (mean age: 23.40 ± 2.91 years; body mass: 79.80 ± 8.42 kg; stature: 177.9 ± 3.07 cm; weekly physical activity: 359.00 ± 211.05 min) and ten females (mean age: 22.30 ± 1.06 years; body mass: 57.20 ± 11.17 kg; stature: 164.00 ± 6.02 cm; weekly physical activity: 282.00 ± 168.05 min), were recruited through a call for volunteers by the Faculty of Physiotherapy at the University of Valencia. All participants performed exercise; three times per week and practiced activities such as running, swimming, cycling, or general strength training (*Martín-San Agustín et al., 2018*). For inclusion, participants had to be between 18 and 30 years old, have no history of lower limb injury or pain during the year preceding the study and had to perform at least 90 min of physical activity per week. The established exclusion criteria were the contraindication of the use of adhesive electrodes either due to injury or adhesive allergy, to have previously participated in some balance improvement or lower limb proprioception program, or presenting any known balance disorder, such as vertigo, or vestibular or central nervous system alterations. All participants had to provide written informed consent and complete a basic information form prior to data collection, which included demographic (age and sex) and anthropometric measures (height and weight). The experimental protocol was approved by the Ethics Committee of the University of Valencia (Spain) (H1544554364247).

Procedures

EMG muscle activity was registered with the participants first on the floor and then on the various devices. All measurements were made in both standing and squatting positions, as previous authors have suggested differences in activation for leg and trunk musculature between positions (*Wahl & Behm, 2008*). The order of measurements in standing and squatting positions, as well as that of the different devices, was randomized. Participants performed three single-leg standings (0° of knee extension) and three single-leg squats (60° of knee flexion) trials on the dominant leg using one stable control (rigid floor) and four unstable devices (Fig. 1). While the initial range of motion (0° or 60°) was established with

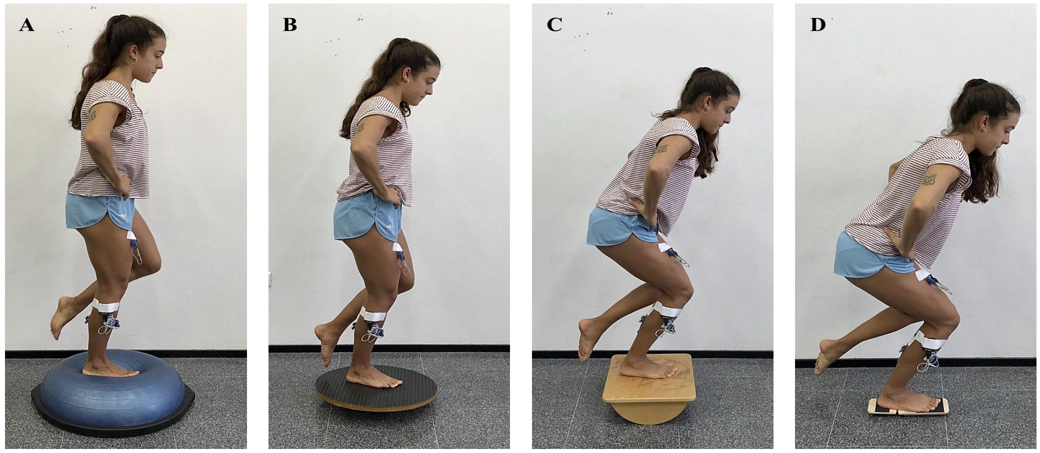

Figure 1 **Different conditions of measurement of the EMG. Single-leg standing on BOSU (A) and on WB (B) and single-leg squat on PB (C) and on BB (D).**
Full-size DOI: 10.7717/peerj.13317/fig-1

a goniometer, the subjects could make small variations of the range of motion to balance against instability during the maintenance of the single-leg standing or squat.

Devices used were BOSU, with the bladder side up, WB, PB, oriented in the sagittal plane, and BB, with its instability in the rearfoot. Previously, device instability requirements have been described regarding the number of unstable dimensions and the magnitude of contact with the floor. While PB was only unstable in 1 dimension (front–back position), BOSU and WB were unstable in 2 dimensions. In turn, BOSU has a larger support base than the WB, so theoretically, it would be considered less unstable than the WB (*Saeterbakken & Fimland, 2013*).

Moreover, the BB is a device designed for single-leg stability training, consisting of two wooden boards connected by a strap. Its base has a Velcro surface on which half-cylinder-shaped wooden slats can be freely placed (Fig. 2). In this study, the slats were positioned so that the forefoot was fixed and the hindfoot remained unstable, with the slat placed longitudinally in the center of the board. Thus, although BB solo was only unstable in one dimension, the support base was the lowest of all devices. The foot was placed central to the platform for the first three unstable devices. For the Blackboard, the tuberosity of the fifth metatarsal was taken as a reference, which coincided with the spacing between the two wooden boards.

Participants were barefoot with their eyes open as this is the most common methodology in similar studies (*Laudner & Koschnitzky, 2010*; *Harput et al., 2013*; *Alfuth & Gomoll, 2018*). Initially, the knee of the supporting leg was straight for the standing measurements, and at 60° of flexion measured with a goniometer for the squat measurements (*Wahl & Behm, 2008*), with their hands placed on their hips. After a trial to become familiar with each condition and taking the control measurements on the rigid floor, participants performed two repetitions of 15 s, with 2 min rest between them, on each device (*Wahl & Behm, 2008*). The trial was considered unacceptable if the participant left the device,

Figure 2 **Selective instability device: Blackboard Trainer.**
Full-size DOI: 10.7717/peerj.13317/fig-2

displaced it from its usual location during the measurement or touched the floor with the contralateral foot (*Alfuth & Gomoll, 2018*).

Surface EMG was used to record the activity of the Pero-L, soleus, Gastr-M, Tib-A, Rect-F, and Glut-M by MuscleLab 4020e (Ergotest Technology, Stathelle, Norway). The skin was shaved and cleaned with alcohol. The recommendations of the SENIAM project (*Hermens et al., 2000*) were followed to apply the pre-gelled Ag/AgCl EMG electrodes

Figure 3 Electrode placement. The circles with a cross indicate the place of placement of the electrodes.
Full-size DOI: 10.7717/peerj.13317/fig-3

(BlueSensor N; Ambu Ballerup, Denmark). After placing them (Fig. 3 shows the electrode placement), the examiner performed a manual muscle testing procedure by palpating the muscle belly and verifying accurate electrode location. The raw EMG signals were processed as previously described in *Van den Tillaar & Larsen (2020)*. Specifically, raw EMG signals were sampled at 1,000 Hz. Then, the signals were high pass and low pass filtered with a cutoff frequency of 20 Hz and 500 Hz, and subsequently rectified, integrated, and converted to root-mean-square (RMS) signals using a hardware circuit network (frequency response 450 kHz, averaging constant 12 ms, total error ± 0.5%). The filtered EMG signal was normalized to the muscle activity obtained from the floor trial (*Silva et al., 2016*).

Of the total 15 s collected, the initial and final 5-second periods of normalized EMG (nEMG) were discarded to minimize postural adjustments or fatigue. Thus, nEMG amplitude over the central 5-second period was calculated for each trial (*Wahl & Behm, 2008*). nEMG mean of the two attempts in each condition was calculated and used for the subsequent comparison.

Statistical analysis

SPSS Statistics 25 (IBM Corporation, Chicago, Illinois, USA) was used to perform all statistical analyses. Descriptive statistics of each variable (including means, 95% confidence

Table 1 Mean EMG (μV) of the six muscles, 95% confidence interval (CI), and standard deviation (SD) in stable surface (floor) during standing and squat monopodal position.

Condition	Peroneus longus	Soleus	Gastrocnemius medialis	Tibialis anterior	Rectus femoris	Gluteus maximus
	Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)
Standing	63.65; 46.81–80.49 (8.05)	32.43; 24.68–40.17 (3.70)	49.23; 37.26–61.19 (5.72)	51.43; 37.18–65.67 (6.81)	8.25; 5.09–11.41 (1.51)	7.28; 5.06–9.49 (1.06)
Squat	71.28; 52.48–90.07 (8.98)	42.05; 30.96–53.14 (5.30)	24.38; 16.67–32.08 (3.68)	76.10; 53.80–98.40 (10.65)	39.23; 21.63–56.82 (8.41)	18.98; 13.65–24.30 (2.54)

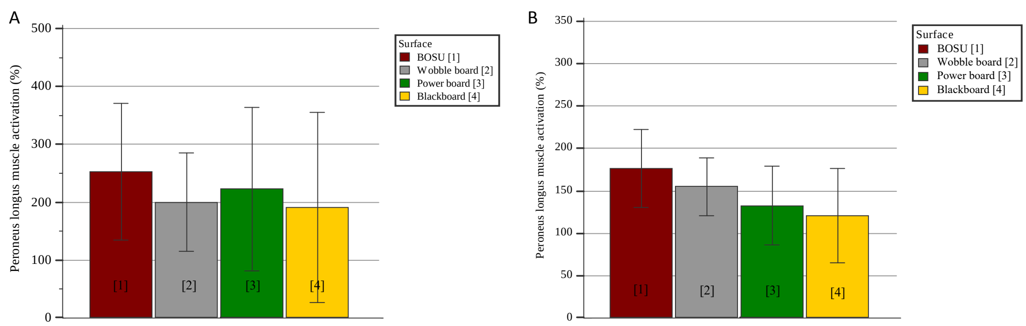

Figure 4 Peroneus longus muscle activation (nEMG) in different unstable surfaces in (A) standing and (B) squat monopodal position (mean and 95% CI).

Full-size DOI: 10.7717/peerj.13317/fig-4

intervals, and standard deviations) were defined. To determine differences in Pero-L nEMG for all different unstable surfaces, as well as in the rest of the muscles, repeated-measures split-plot analyses of variance (ANOVAs) were used.

For the nEMG of Pero-L, as well as for the other muscles, a two-way repeated-measures ANOVA was used to determine differences between devices, conditions, and the interaction between devices and conditions, in a similar way to what was done in previous studies (*Martín-San Agustín et al., 2021*). Additionally, in the case of detecting a significant main effect, post hoc t tests with Bonferroni corrections were applied to establish the identity of the differences. The level of significance was set at $p < 0.05$. The effect size was assessed using η^2 (partial-Eta squared) where 0.01 $<\eta^2<$ 0.06 was considered a small effect, 0.06 $<\eta^2<$ 0.14 a medium effect, while $\eta^2>$ 0.14 was considered a large effect (*Cohen, 1977*).

RESULTS

Table 1 shows the absolute EMG values (μV) for each muscle by condition on the floor.

Figure 4 and Table 2 show the nEMGs for Pero-L and the other muscles, respectively. Regarding the comparisons for the Pero-L nEMG (Fig. 4), there were no differences either between devices ($p = 0.09$; $\eta^2 = 0.12$) or between conditions ($p = 0.11$; $\eta^2 = 0.12$), nor in the interaction between them ($p = 0.16$; $\eta^2 = 0.09$).

For the nEMG of the remaining muscles, there were multiple differences between devices regardless of the condition (Table 2); soleus ($p = 0.01$; $\eta^2 = 0.46$), Gast-M ($p = 0.01$; η^2

Table 2 **Difference in nEMG of each muscle by device and condition*.**

Muscle	Condition	BOSU (%)	WOBBLE BOARD (%)	POWER BOARD (%)	BLACKBOARD (%)	Inter-device differences†
		Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)	Mean; 95% CI (SD)	
Gluteus maximus	Standing	456.31; 263.01–649.60 (92.35)	403.96; 256.86–551.07 (70.28)	349.01;218.30–479.72 (62.45)	186.74; 132.89–240.59 (25.73)	WB-BB
	Squat‡	273.95; 124.41–423.48 (71.44)	211.68; 169.80–253.56 (20.01)	196.70; 153.67–239.74 (20.56)	189.81; 135.11–244.51 (26.13)	
Rectus femoris	Standing	452.12; 295.21–609.02 (74.96)	493.65; 268.62–718.67 (107.51)	308.83; 193.32–424.34 (55.19)	165.34; 102.91–227.76 (29.82)	BO-BB; WB-BB; PB-BB
	Squat‡	221.00; 133.50–308.49 (41.80)	176.62; 100.54–252.70 (36.35)	149.05; 110.77–187.33 (18.29)	123.57; 88.07–159.06 (16.96)	
Tibialis anterior	Standing	294.52; 194.03–395.02 (48.01)	328.90; 180.12–477.69 (71.09)	277.54; 151.74–403.34 (60.11)	158.65; 58.75–258.55 (47.73)	BO-BB; WB-BB; PB-BB
	Squat	257.00; 153.66–360.34 (49.38)	226.28; 165.00–287.57 (29.28)	196.16; 139.01–253.31 (27.31)	137.57; 99.81–175.33 (18.04)	
Gastrocnemius medialis	Standing	205.24; 147.70–262.78 (27.49)	216.49; 134.62–298.36 (39.12)	133.85; 105.86–161.83 (13.37)	118.08; 94.13–142.03 (11.44)	BO-PB; WB-PB
	Squat	227.09; 167.64–286.54 (28.40)	252.52; 173.04–332.00 (37.97)	147.03; 90.47–203.58 (27.02)	166.99; 73.10–260.88 (44.86)	
Soleus	Standing	252.12; 184.79–319.45 (32.17)	256.24; 181.36–331.11 (35.77)	180.33; 141.11–219.55 (18.74)	143.44; 99.60–187.27 (20.94)	BO-PB; BO-BB; WB-PB; WB-BB
	Squat‡	204.98; 145.98–263.98 (28.19)	197.06; 134.45–259.67 (29.91)	114.83; 90.54–139.13 (11.61)	118.14; 81.50–154.78 (17.51)	

Notes.
*All values of devices are expressed in percent (normalized by EMG's floor) † Abbreviations (BO = BOSU; WB: wobble board; PB = power board; BB = blackboard) indicate statistical significance ($p \leq 0.05$). ‡ Differences between conditions ($p \leq 0.05$). SD = standard deviation; CI = confidence interval.

= 0.26), Tib-A ($p = 0.01$; $\eta^2 = 0.33$), Rect-F ($p = 0.01$; $\eta^2 = 0.32$), and Glut-M ($p = 0.02$; $\eta^2 = 0.22$), all of them associated with large effect sizes. In particular, BOSU produced a greater activation of soleus and Gast-M (p's values = 0.01) than PB and of soleus, Tib-A, and Rect-F (p's values = 0.01) than BB. In addition, muscle activation achieved by WB was greater than PB-based activation for soleus and Gastr-M (p's values = 0.01), and greater than BB-based activation for soleus, Tib-A, Rect-F, and Glut-M (p's values = 0.01). Finally, activation of Tib-A and Rect-F (p's values = 0.01) was larger with PB than with BB.

In terms of comparisons between conditions (Table 2), standing position was associated with a higher activation of soleus (208.1% *versus* 158.7%; $p = 0.01$), Rect-F (354.9% *versus* 167.5%; $p = 0.01$), and Glut-M (349.0% *versus* 218.0%; $p = 0.04$) as compared to the squat position. Finally, a significant interaction between device and condition was observed for Rect-F ($p = 0.03$; $\eta^2 = 0.18$) and Glut-M ($p = 0.01$; $\eta^2 = 0.22$). In post hoc analysis, in Rect-F nEMG, differences were found both in standing position between BB and the other devices (lower activation in BB compared to BOSU, WB, and PB) (p's range = 0.01 to 0.03) and in squat position between BB and BOSU ($p = 0.03$), with lower values for BB. Otherwise, in Glut-M nEMG, only significant differences (p's values = 0.01) in standing position were found between BB and the other devices (lower activation in BB compared to BOSU, WB, and PB).

DISCUSSION

Our results support our initial hypothesis that BB configured for anteversion instability of the rearfoot produces a similar Pero-L activation to that obtained with global instability devices but less for other lower limb muscles. Thus, the main finding was that there were no differences between the nEMG of Pero-L between BB and BOSU, WB and PB, but, depending on the muscle, lower values were found for BB in soleus, Tib-A, Rect-F, and Glut-M than those global instability devices. Additionally, differences were found between standing or squat positions in soleus, Rect-F, and Glut-M muscle activation.

As far as we know, this is the first study comparing several global balance training devices with a selective instability device. On the one hand, the main result observed was that there are no differences in Pero-L muscle activation between devices. Accordingly, Pero-L levels of activation on the four different surfaces (BOSU, WB, PB, BB) were about 150% (squat) and 200% (standing) of muscle activation on the floor, this being consistent with the results reported for other selective (*Alfuth & Gomoll, 2018*) and global (*Harput et al., 2013*; *Strøm et al., 2016*) instability devices. This finding could be due to the fact that an instability involving pronosupination of the calcaneus is enough to achieve similar levels of activation to those obtained by overall balance devices.

On the other hand, activation differences were noted for other limb muscles (*e.g.*, soleus, Gastr-M, Tib-A, Rect-F, and Glut-M) between global and selective devices. Compared to PB and BB, BOSU and WB increased activation in around 100% in the lower leg muscles, the Rect-F and the Glut-M. Furthermore, BB-based activation levels in other muscles were around 100%–200% lower than those produced by global devices. The present study shows a trend whereby BOSU and WB generate greater instability than PB, which may be plausible bearing in mind the axis of movement of each device. Both BOSU and WB are multidirectional, while the PB only generates instability in one plane (sagittal in the case of this study). In addition, other studies have analyzed a different PB configuration (*e.g.*, with the instability in the coronal plane), likewise obtaining a similar Rect-F activation on PB, on BOSU and on WB (*Saeterbakken & Fimland, 2013*). Still, since PB destabilizes the ankle in a global movement of flexion/extension, the instability is not as specific as that achieved by BB and produces greater muscle activation of the Rect-F and Tib-A.

Despite the importance of results obtained, this study has also several limitations. First, population studied includes only healthy participants, so its results cannot be extrapolated to a pathological population. Thus, further research is needed on this device in pathological subjects. Secondly, measurements were taken in single-leg stance only, while other authors have carried out similar studies recording the muscle activation produced in the performance of various exercises (*Wahl & Behm, 2008*; *Saeterbakken & Fimland, 2013*; *Harput et al., 2013*). However, being the first study developed with the inclusion of the BB device, we believe that the results could be a starting point for future research work on this device, further featuring dynamic movements and interventions with different exercises. Finally, the study of a larger number of leg muscles would allow a better understanding of muscle response on a selective instability device. In the same way, the inclusion for comparison of some of the selective instability devices previously studied would be interesting.

The comparison between selective and global instability devices carried out in this study might serve as a guide in the progression of an ankle rehabilitation or injury prevention program, using muscle activity as an indicator of the degree of instability and intensity produced by the devices. As previously mentioned, an alteration caused in the rearfoot elicits a similar electromyographic response (activation) of the Pero-L while causing less activation of the remaining lower limb muscles compared to global instability devices. This could indicate that the device that implies a lower intensity for the entire lower limb is the BB without losing activation of the Pero-L. This may be desirable in the initial stages of ankle rehabilitation, in which the reinforcement of the tensile stress mechanisms that support the lateral ligaments of the ankle is considered important (*Bleakley et al., 2019*), which could be achieved by the activation of the Pero-L. Likewise, since the association between peroneal muscle fatigue and sprain is clear (*Rodrigues, Soares & Tomazini, 2019*), the use of selective instability devices such as the BB may be useful in the early stages in the prevention of ankle injuries, being part of strengthening programs. In contrast, BOSU or WB might be the selected devices for overall lower limb training, generating higher levels of muscle activation than PB or BB. To progress these programs in terms of intensity and degree of instability, it would be recommended to incorporate global instability devices in later phases, first PB and later BOSU and WB.

CONCLUSIONS

According to the results obtained in healthy subjects, Pero-L activation seems to be similar on all the devices included and in the analyzed conditions. For the other muscles, each device produces a different level of activation. Thus, the BB elicits a similar electromyographic response (activation) of the Pero-L while causing less activation of the remaining muscles measured in this study. This could be useful in ankle injury prevention training programs, or perhaps in early stages of a rehabilitation process. PB would be a good device to progress in intensity, and finally, due to its high levels of activation for most muscles of the lower limb, the BOSU or WB should be included as instability training devices if the desire is for more functional training of the lower extremity rather than isolation of the stabilizing muscles of the ankle joint.

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Mariana Sánchez-Barbadora and Alba Cuerda-Del Pino conceived and designed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Javier González-Rosalén conceived and designed the experiments, prepared figures and/or tables, and approved the final draft.
- Noemi Moreno-Segura performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Adrian Escriche-Escuder conceived and designed the experiments, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Rodrigo Martín-San Agustín performed the experiments, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

The experimental protocol was approved by the Ethics Committee of the University of Valencia (Spain) (H154455436424).

Data Availability

The following information was supplied regarding data availability:

The raw measurements are available in the Supplemental File.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.13317#supplemental-information.

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ARTÍCULO II

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Effects of an Instability Training Program Using Global Versus Selective Instability Devices on Dynamic Balance and Ankle Stability in Young Amateur Soccer Players

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Abstract: Background/Objectives: Both Sides Utilized it is one of the most employed global instability devices (GID), but it is difficult to progress and select a particular foot structure. In this sense, the Blackboard has been created as selective instability device (SID). The aim of this study is to compare the effects of both devices on balance and ankle stability. **Methods**: The study was designed as a randomized controlled clinical trial. Twenty healthy amateur soccer players were divided into two groups: GID and SID. Both performed balance training (4-weeks, 3 days/week). Ankle balance and stability were assessed. Paired *t*-tests were used to analyze the pre-, post-, and between-groups differences. **Results**: No differences were found between the groups. Significant intra-group changes were found in both groups for posterolateral balance and summation. Moreover, posteromedial balance increased in the GID group. No changes were found in ankle stability results. **Conclusions**: A balance intervention using GID or SID is effective in improving general and posterolateral balance. Moreover, the GID intervention improved posteromedial balance.

Keywords: instability; ankle; soccer players; instability devices

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1. Introduction

Sport injuries are one of the main concerns of soccer players and their coaching staff [1,2]. Ankle sprains are one of the most common injuries in this sport [3,4] due to the fact that soccer requires sudden stops and pivoting that lead to a situation of muscle and central fatigue [5–7]; this results in ankle inversion during plantar flexion, or ankle internal rotation in an inverted position, which most commonly leads to ankle sprain [8]. In addition, sprains have a high recurrence in soccer, leading to pathological laxity, residual pain, and sensorimotor deficits in the ankle, which could cause stability alterations known as chronic ankle instability [3,9]. In this sense, numerous efforts have been made to find alternatives to reduce the incidence and recurrence of ankle sprains. However, the exercise protocols designed to date are still not completely effective since the incidence rates of ankle sprains remain high. Studies that deal with exercises or balance devices that could produce changes in ankle stability and, consequently, reduce injury rates, are still necessary.

The current clinical approach to acute and chronic ankle sprains includes strengthening, balance, and proprioception exercises, such as single -leg stance, restoration of postural control exercises, and coordination tasks [3,4,9–11]. These techniques focus on ankle stability training to achieve good dynamic balance. This means the ankle should be able to withstand the presence of forces that would normally alter the state or condition and be capable of returning to an initial state after the disturbance [12]. Maintaining balance is a complex process that not only depends on the integrity of the musculoskeletal and proprioceptive system, but the visual and vestibular systems also play a relevant role [13]. Therefore, therapeutic strategies that take all this into account could be relevant in ankle sprain prevention.

Previous evidence suggests that muscle strength training programs could improve the activation of the ankle proprioceptors, allowing the automation of balance tasks [10]. It is explained that being strong allows athletes to focus on other aspects of the sport, due to the reduction in central fatigue and, consequently, the risk of injury [10]. Nevertheless, programs that include strategies to improve strength, proprioception, vestibular, and visual components could be an effective alternative given the complete work done on all the components of the balance system. In this sense, training on unstable surfaces has been shown to offer greater benefits than training on stable surfaces [14–17]. There are many devices that allow for stability training such as Both Sides Utilized (BOSU®), balance boards, pads, soft mats, air cushions, or tilting platforms [3,18,19]. Generally, all of these tools are considered global instability devices (GIDs) as the direction and intensity of the instability cannot be selected and adjusted by the user [14].

The most commonly employed GID, having become increasingly popular over the past years, is BOSU®. BOSU® combines a solid round base with an inflatable air chamber, and although it highly demands inversion-eversion movements, other movements such as plantarflexion or dorsalflexion could compensate for the lack of balance [14]. However, this device presents some limitations such as the difficulty in progression, the lack of specificity in the foot and ankle structure trained, and the difficulty in portability of the device. In this context, a not yet widely studied device has been designed to overcome these limitations. This is the Blackboard Training, which is a selective instability device (SID) that has demonstrated that it could improve muscle activation of the peroneus longus during single-leg stance, at least as much as other GIDs (including BOSU®), finding no differences between devices [20]. These findings may suggest that the use of the SID to improve functional ankle balance in athletes' ankle sprain preventive programs could be effective, at least as those produced by GIDs, but a clinical comparison has not yet been conducted. If this were the case, the inclusion of Blackboard in ankle instability prevention programs could facilitate the development of the exercises, the progression of the difficulty, the selection of the specific movements worked on, and the portability of the device, making it easier to incorporate this training in multiple environments.

Thus, the aim of this study was to compare the effects of a 4-week balance training program using GIDs or SIDs on functional dynamic balance and functional ankle stability in young healthy amateur soccer players.

2. Materials and Methods

2.1. Study Design and Participants

The present study was a randomized controlled clinical trial. The randomization process was as follows: of the total number of teams with young soccer players, two teams were randomly selected, one female and one male. Then, a random selection of players who participated in a 4-week balance training program was made within each team. Subsequently, the selected subjects were randomly allocated into two groups: GID balance training (i.e., with a BOSU®) and SID balance training (i.e., with Blackboard). The randomization and allocation were performed using the sealed envelope method. Participants were recruited from the Discobolo-La Torre A.C. (Valencia, Spain) with the mediation of the coaches. All participants were informed about the purpose and content of the study and gave their written informed consent to participate in the project. All procedures were approved by the Ethics Committee of the University of Valencia (register number 1236358) and complied with the requirements listed in the 1975 Declaration of Helsinki and its amended version of 2024.

A total number of 20 amateur soccer players made up the study sample. The inclusion criteria were (I) aged between 16 and 35 years, (II) no lower limb surgery during the last year prior to participation, (III) no history of pain in either ankle, knees, or hips during the two months prior to participation, and (IV) not having sprained either ankle for at least three months prior to participation. Those who had participated in lower limb balance and proprioception programs or had suffered balance alterations such as vertigo, vestibular, or central disorders were excluded from the study.

2.2. Procedures

Before the intervention, sociodemographic (age, gender, and dominant leg), anthropometric (height, weight, and leg length), dynamic balance, and ankle stability data were collected. Dynamic balance and ankle stability were also measured at the end of the intervention. To measure leg length, participants were placed in a supine position, and a measurement was taken from the anterior superior iliac spine to the internal malleolus of the same leg.

Firstly, for assessing dynamic balance, the three-direction modified Star Excursion Balance Test (mSEBT) and Emery Test were employed.

The mSEBT consists of standing on one leg while reaching with the contralateral leg to the farthest possible point in three different directions (anterior, posteromedial, and posterolateral) [21,22]. Adhesive tape was employed to delimit two lines forming a 90-degree angle, and a third line forming a 135-degree angle with respect to the others. Five-millimeter increments were marked on the tape to facilitate measurements [23]. The distance reached in each attempt was normalized with the leg length. Each participant was allowed to make two attempts with each leg and in each direction to practice [24]. Then, three more attempts were performed [25]. A 15-second rest time was allowed between attempts of the same position [23], and five minutes between the different directions [23,24]. All measurements were made barefoot and with hands placed on the hips. For the anterior measurements, the most distal part of the foot was placed at the intersection of the lines, while for the posterior measurements, the heel was aligned with this point [24]. The last three attempts were recorded to calculate the average value. Attempts were discarded in cases of failure to touch the line with the mobile foot, the support foot being moved, hands being released from the hips, loss of balance at some point while resting the mobile foot, failure to maintain the start or end position for at least one second, or supporting the weight on the moving foot at the end of the movement; such attempts were not considered valid and the movement was repeated [23]. The mSEBT has demonstrated excellent inter- and intra-rater reliability [21,26].

For the Emery Test, subjects were required to maintain a single-leg stance on an Airex® Balance Pad, with their eyes closed, barefoot, and with their hands placed on their hips [27,28]. The knee of the supporting leg was slightly flexed (at about 30°), and the contralateral knee was at 45° of flexion. The subjects were asked to remain as stable as possible for a maximum time of 180 s [29]. The remaining time of those 180 s minus the time achieved was given as rest time. Three attempts were performed, and the best time obtained was recorded. A handheld stopwatch was used to measure the subjects' hold position. Before starting the measurements, the subjects were allowed to familiarize themselves with the test for 15 s [28]. When the subjects released their hands from their hips, touched the ground with the contralateral leg, moved the support foot, moved the Airex® Balance Pad from its original position, or opened their eyes, it was considered a loss of balance and the test was repeated [23,28].

Secondly, to assess functional ankle stability, the Side Hop Test was employed to challenge the mediolateral stability of the ankle joint through dynamic inversion and eversion movements, producing a high demand on the peroneus longus muscle [30]. The test consists of jumping laterally on one leg 30 cm delimited by two lines marked on the ground [31,32]. Participants performed 10 repetitions barefoot (a total of 20 jumps) in the shortest possible time. Each participant made three attempts with each leg, with 1-min rests. The best time for each leg was registered. One repetition was allowed before starting for practice. The time was measured with a stopwatch [31,33]. The test was considered failed if the subject touched or crossed the line with their support foot or if the contralateral leg contacted the ground [31].

Finally, a familiarization session identical to the exercise session of the training program was performed. Regarding the intervention, both groups completed a 5-min conventional warm-up, which included stationary cycling and active ankle mobility exercises. Ankle training was then carried out with the different devices (BOSU® or Blackboard).

On the one hand, the BOSU® is a device that combines a solid round base with an inflatable air chamber, simulating a split Swiss ball. Both parts can be used to work stability in a different way [14], demanding the inversion-eversion movement. On the other hand, the Blackboard is another device designed for stability training that consists of two wooden boards joined together by a tape. Its base has a Velcro surface where you can freely place half -cylinder wooden slats. Depending on the position where they are placed, one or another type of instability training is generated. Both devices are illustrated in Figure 1.

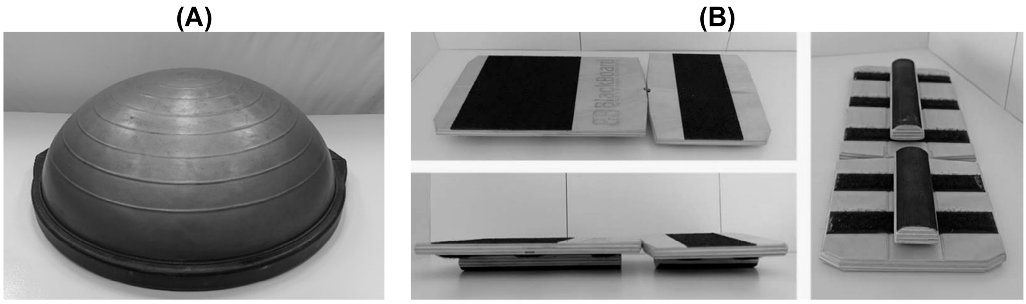

Figure 1. Balance training devices employed. (**A**) BOSU® Balance Training; (**B**) Blackboard Training.

The exercise plan was a modified version of the previously proposed plan published by Romero-Franco et al. for proprioception training in athletes [33]. It consisted of four single-leg stance exercises on an unstable surface. All the exercises were performed on the BOSU® in its inverted position or on the Blackboard with the two slats placed centrally (i.e., generating mediolateral instability).

The exercises were the same for both groups and were performed with a 3-kg medicine ball, with the only difference being the unstable surface device [33]. These exercises were as follows: (1) A 30-s series of maintaining the single-leg stance position with an extended knee and hip, holding the ball with the arms stretched out above the head; the free leg was kept at 90° hip and knee flexion. (2) A series of 10 repetitions where the subject was asked to move from the supporting-leg hip and knee starting position to a 90° knee flexion squat, keeping the ball above their head and maintaining the other leg with the knee and hip at about 90° flexion. (3) A single series of 10 repetitions where the subject started with full limb extension of the supporting leg and the ball held with both hands at chest height; from this position, subjects were asked to bring the free leg from 45° hip extension to 45° hip flexion. (4) 10 passes between the subject and a partner where the participants started with a total extension of the supporting limb and the ball held in both hands in front of them at chest height, and their free leg flexed 90° at the hip and knee. A 2-min rest between exercises was allowed. These exercises are illustrated in Figure 2.

The stability training program was performed over a period of four weeks, with three weekly sessions using BOSU® or Blackboard at their soccer club before their usual training and under the supervision of a physical therapist. In total, 12 sessions were completed.

Figure 2. Exercises performed during the balance training sessions. (**A**) Single-leg stance hold. (**B**) Single-leg half-squats. (**C**) Single-leg stance with the contralateral leg balancing from 45° flexion to 45° extension. (**D**) Passes with a partner while maintaining a single-leg stance.

2.3. Statistics

All statistical analyses were carried out using IBM SPSS Statistics software (Version 28.0, IBM Corp., Armonk, NY, USA). Participant characteristics were summarized as means (SD) or frequencies, and stability measures as means (95% confidence intervals (CIs)). The normality of distribution for stability measures was verified using the Shapiro–Wilk test. Unpaired *t*-tests were used to examine the differences in demographic and anthropometric characteristics, and stability measures at baseline between groups. The effects of the balance training program on stability measures were analyzed in separate 2 (Group: SID, GID) × 2 (Time: pre, post) ANOVA with repeated measures on "Time". The effect size was evaluated with η^2 (Partial Eta squared), where $0.01 < \eta^2 < 0.06$ constitutes a small effect, $0.06 < \eta^2 < 0.14$ a medium effect, and $\eta^2 > 0.14$ a large effect [34]. Where significant main or interaction effects were detected, post hoc *t*-tests with Bonferroni corrections were used (paired for within-group comparisons and unpaired for between-group comparisons). Significance was set at $p < 0.05$ and Cohen's d was also calculated to evaluate the effect size ($d < 0.2$: trivial, 0.2–0.5: small, 0.5–0.8: medium, and >0.8: large) [34].

The sample size was calculated based on a previous study [35], which reported within-group differences for the YBT due to an intervention with an effect size of 1.2. However, to adopt a conservative approach, we estimated our sample size using an effect size of 0.7, with a statistical power of 0.9 and an alpha level of 0.05. This calculation indicated that a minimum of 19 participants was required, which we rounded up to 20 to facilitate group homogeneity.

3. Results

A total of 20 participants (9 women and 11 men) made up the final sample. Clinical and demographic variables are depicted in Table 1. No significant differences were found between groups.

Table 1. Descriptive characteristics of the participants.

	SID Group (n = 10)	GID Group (n = 10)
Age (years)	23.0 (5.68)	21.0 (3.80)
Sex (women/men)	5/5	4/6
Height (cm)	169.70 (8.89)	168.17 (5.25)
Weight (kg)	73.80 (18.34)	65.89 (6.79)
Dominant leg (right/left)	5/5	9/1
Right leg length (cm)	88.40 (4.70)	87.39 (3.05)
Left leg length (cm)	89.10 (4.64)	88.11 (3.19)

Data are expressed as mean (standard deviation); mm: millimeters; kg: kilograms. SID: selective instability device; GID: global instability device.

In relation to dynamic balance measured with the mSEBT (Table 2), mSEBT-A showed neither a significant main effect for time nor group-time interaction, while mSEBT-PM, mSEBT—PL, and mSEBT—∑ showed a significant main effect for time (p = 0.001; η^2 =0.54, p < 0.001; η^2 = 0.60, and p = 0.001; η^2 = 0.54) although not for the group × time interaction was observed. Post hoc analyses revealed a significant increase of 0.14 m in mSEBT-PM in both groups and of 0.16 m and 0.21 m in the mSEBT—PL for SID and GID groups, respectively. Regarding mSEBT—∑, it improved 0.13 m in the SID group and 0.10 m in the GID group.

Table 2. Differences within and between groups for dynamic balance measured using the mSEBT and Emery Test.

	SID Group (n = 10)			GID Group (n = 10)			SID-GID
	PRE	POST	p (d) *	PRE	POST	p (d) *	p (η^2)
mSEBT − A	0.69; 0.65–073 (0.02)	0.72; 0.63–0.82 (0.04)	0.889	0.72; 0.63–0.81 (0.04)	0.72; 0.64–0.80 (0.04)	0.484	0.389 (0.05)
mSEBT—PM	0.92; 0.80–1.04 (0.05)	1.06; 0.99–1.12 (0.03)	0.013 (3.40)	0.96; 0.85–1.07 (0.05)	1.10; 0.97–1.22 (0.05)	0.013 (−2.80) *	0.987 (0.01)
mSEBT—PL	1.06; 0.96–1.16 (0.04)	1.22; 1.11–1.34 (0.05)	0.014 (−3.53) *	1.06; 0.93–1.19 (0.06)	1.27; 1.16–1.38 (0.05)	0.003 (−3.80) *	0.564 (0.02)
mSEBT—∑	0.90; 0.81–0.99 (0.04)	1.03; 0.96–1.1 (0.03)	0.006 (−3.68) *	0.90; 0.83–0.96 (0.03)	0.99; 0.92–1.07 (0.03)	0.024 (−3.00) *	0.629 (0.02)
EMERY TEST	5.47; 2.05–8.9 (1.45)	11.44; 4.02–18.86 (3.14)	0.093	5.76; 3.95–7.58 (0.74)	5.03; 3.93–6.13 (0.45)	0.327	0.094 (0.19)

Data are expressed as mean; 95% confidence interval (standard deviation). mSEBT: three-directions modified Star Excursion Balance Test; SID: selective instability device; GID: global instability device. mSEBT-A: three-direction modified Star Excursion Balance Test anterior; mSEBT-PM: three-direction modified Star Excursion Balance Test posteromedial; mSEBT-PL: three-direction modified Star Excursion Balance Test posterolateral; mSEBT—∑: three-direction modified Star Excursion Balance Test Summation. n = sample size; p = p-value; d = Cohen's d; η^2 = partial eta squared; * = significant change.

In terms of the results obtained in the Emery Test (Table 2) and the Side Hop Test (Table 3), neither showed a significant main effect for time nor group-time interaction.

Table 3. Differences within and between groups for ankle stability measured using the Side Hop Test.

	SID Group (n = 10)			GID Group (n = 10)			SID-GID
	PRE	POST	p	PRE	POST	p	p (η^2)
SIDE HOP TEST	10.05; 7.87–12.23 (0.92)	9.17; 6.43–11.91 (1.16)	0.292	9.63; 7.8–11.46 (0.75)	8.96; 7.1–10.82 (0.76)	0.212	0.827 (0.01)

Data are expressed as mean; 95% confidence interval (standard deviation). SID: selective instability device; GID: global instability device. n = sample size; p = p-value; d = Cohen's d; η^2 = partial eta squared.

4. Discussion

To the best of our knowledge, the present study is the first aimed at comparing the effects of a 4-week (12 sessions) balance training program using GIDs or SIDs on dynamic balance and ankle stability in amateur soccer players. The main findings of this study were that both balance training programs improved several parameters related to dynamic balance without differences between groups, suggesting that both methods could achieve improvements in dynamic balance. By contrast, functional ankle stability did not improve after either of the two interventions.

The most relevant finding is that the equal improvements obtained by both interventions (BOSU® and Blackboard device) in balance could lead to more specific training in athletes. Thus, while the instability produced by the BOSU is indiscriminate across all planes of movement, the Blackboard allows the instability to be directed toward the chosen plane for the objective, in this case, the mediolateral. Consequently, the dynamic balance evaluated by means of the mSEBT improved in both groups, regardless of using GID or SID. This could suggest that instability directed toward inversion-eversion movement could alone be enough to generate adaptations from more global and bulky devices, achieving improvements in dynamic balance.

Our findings for the GID group are similar to those obtained in previous studies, such as that by Cuğ et al., who carried out a similar BOSU-based 4-week exercise program (12 sessions) in healthy athletes [36]. They also achieved improvements in dynamic balance following their intervention as evaluated by the mSEBT, particularly in the posteromedial- and posterolateral-reach directions of the test. They also found differences in the anterior-reach direction, which did not occur in our case. This may be attributed to the chosen intervention approach, as they directly addressed hopping in their exercises, which could influence performance in the anterior-reach direction of the mSEBT. Nevertheless, based on a previous study where it was shown that the activation of the peroneus longus muscle was similar on the Blackboard as on the BOSU, we decided to focus the intervention on specific mediolateral plane instability. Thus, to our knowledge, this is the first time that the effects of an SID intervention on dynamic balance in an athletic population have been studied. Since dynamic balance improved similarly in both groups of amateur soccer players, we consider that our proposal is an interesting starting point, and future studies could apply this program for injury prevention, mainly ankle sprains, or address the potential benefits of including SID training in rehabilitation schemes for chronic or acute ankle instability.

In terms of functional ankle stability, unexpectedly, no changes were observed in either of the groups. While ankle stability is multifactorial, we expected that instability training would have a positive effect on it, but this was not the case. This may be due to a ceiling effect since all the participants were young, sporty, and healthy subjects and, therefore, the probability of improvement is low. In this regard, research by Linens et al. found a cut-off score of 12.88 that discriminates between people with and without postural instability, and in our sample, the mean values at baseline were 10.05 for the SID group and 9.63 for the GID group; accordingly, when a population group is already at optimal values, obtaining a significant improvement will be more complex [37].

On the other hand, this study shows that an improvement in balance does not always imply an improvement in ankle stability. This may be explained by the fact that balance relates to the ability to maintain a stable and controlled posture, while ankle stability refers specifically to the ability of the ankle joint to resist excessive movement and avoid injury. Therefore, the exercise program implemented in the present study may be more focused on improving general balance than on improving stability, where other components such as strength, proprioception, specific neuromuscular control of muscles and ligaments, coordination, and movement technique, may enjoy greater benefits. Therefore, given the multifactorial origin of ankle stability, an approach focused on an analysis of the athlete's specific deficiencies could be more effective than a generalized protocol, to obtain significant improvements in healthy athletes.

4.1. Implications for Practice and Research

Our study has important clinical applications. Our findings suggest a possible beneficial use of this exercise program with BOSU® or Blackboard to preventively improve dynamic balance in healthy young amateur soccer players, which could potentially reduce their risk of ankle sprains. Additionally, considering our findings with similar improvements for both GID- and SID-based balance programs, this could imply that the Blackboard could serve as an alternative to the BOSU®, which is the most commonly used GID within the sports field, as the chosen instability device in these programs. For this reason, since the Blackboard is more portable and smaller than the BOSU®, it could facilitate its use and implementation, allowing athletes to use it regularly within their sports practice. On the other hand, the Blackboard as an SID allows for a wide range of instability settings, being able to configure its direction and intensity depending on how the slats are placed. Thus, this study promotes the implementation of a program and tool that can be used in future studies using different configurations or applied to different populations.

4.2. Strengths and Limitations of the Study

This study had several strengths. First, our experimental protocol was similar to previous work, which facilitated comparison [33]. In addition, the tests used to measure the changes produced by the intervention have been widely used in the literature. Second, we are the first to propose a program using SID to improve the balance of amateur soccer players. Since SIDs have the advantage of being more portable, cheaper, and configurable than GIDs, we consider that multiple athletes can benefit from the use of this type of instability device. Moreover, it could even be used as a device for autonomous training of the athlete due to its portability.

Despite the relevant findings, this study is not without limitations. First, the population studied included only healthy young amateur soccer players; therefore, the results cannot be extrapolated to a pathological population or to other sports. as previously mentioned, obtaining significant improvement was challenging. Secondly, only two instability devices were employed, and other devices may have been more demanding in terms of balance and ankle stability, but this was outside the objectives of the study, as the aim was to compare the effectiveness of a relatively new SID such as the Blackboard with the most used GID, the BOSU®. Thirdly, due to the nature of the study design, the low availability of the soccer players (given that they were not professional teams and because of their work schedules), the available sample size has been small. Therefore, future studies with a larger sample size should be carried out. Fourth, the exercise program proved to be not very demanding in producing adaptations in ankle stability in healthy subjects, which might have been different if hopping exercises had been included in the intervention. Fifth, the study includes soccer players of both genders who continued their regular training alongside the intervention, which could induce adaptations in balance too and make it difficult to analyze the isolated effects of the interventions. future studies should include a control group. Considering the above and having demonstrated the effectiveness and safety in healthy individuals, it could be interesting to apply this protocol in the recovery of subacute sprains and chronic ankle instability to analyze the results in pathological amateur soccer players, where improvements in ankle stability could be higher.

5. Conclusions

In conclusion, according to the results obtained from healthy amateur soccer players, a balance intervention using either the BOSU® or the Blackboard unstable surfaces is effective for improving general and posterolateral balance. Moreover, BOSU® intervention improved posteromedial balance. By contrast, there were no differences between groups and no changes in ankle stability after either intervention. Thus, subject to further research, this type of intervention could be beneficial in ankle injury prevention and sprain rehabilitation programs for amateur soccer players, especially the Blackboard, which could be implemented on soccer fields and in installations due to its easy portability. Moreover, both interventions could be implemented in gym programs to improve ankle balance and stability, extrapolating these results not only to soccer players but also to other types of athletes.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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ARTÍCULO III

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Article

The Effects of a Balance Training Program With and Without Transcranial Direct Current Stimulation on Dynamic Balance in Recreationally Active Young Adults: A Randomized Controlled Trial

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Featured Application: This study supports instability-based training as a standalone method for improving balance and encourages further research to refine transcranial direct current stimulation (tDCS) protocols.

Abstract: (1) Background: Dynamic balance plays a crucial role in maintaining ankle stability and preventing injuries, particularly in active individuals. Instability devices are commonly utilized to enhance ankle strength and stability, and there is growing interest in integrating these tools with novel modalities, such as transcranial direct current stimulation (tDCS), to maximize benefits. This study aimed to compare the effects of a 4-week balance training program performed on a selective instability device alone or combined with tDCS on dynamic balance in recreationally active young adults. (2) Methods: Twenty participants were randomized into two groups: one performing balance exercises on the Blackboard device and another combining the exercises with tDCS. Dynamic balance was measured at baseline, midway, and post-intervention using the Y-Balance Test and the Emery Test. (3) Results: Both groups showed significant improvements in balance performance, with increased reach distances and stability times ($p = 0.001$ and $p = 0.04$, respectively), after 4 weeks. However, the addition of tDCS did not yield additional benefits over balance training alone ($p > 0.05$). (4) Conclusions: These findings underscore the value of instability device-based balance training for enhancing dynamic balance while questioning the utility of tDCS as a combined therapy in healthy individuals.

Keywords: transcranial direct current stimulation; balance; instability devices; ankle injuries

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1. Introduction

Ankle balance deficits represent a significant issue in the health field as they are closely associated with an increased risk of ankle sprains [1]. Proprioception plays a crucial role in maintaining balance and joint stability, and its impairment can reduce the body's capacity to sense joint position and movement, leading to instability and a heightened risk of re-injury [2]. These deficits often result in chronic ankle instability (CAI), which negatively impacts individuals' quality of life and functional capacity [3]. A contributing factor during an ankle sprain is the delayed activation of the peroneal muscles in the presence of fatigue [4]. Additionally, following an ankle sprain, morphological changes and alterations in the pennation angle of the peroneus longus often occur [5], perpetuating a vicious cycle that promotes recurrence. This highlights the need for interventions aimed not only at addressing the acute injury but also at preventing future recurrences through strengthening and functional re-education. Given the high incidence of ankle sprains linked to balance deficits, it is essential to explore effective training methods to enhance balance and prevent injuries.

Various training methods have been proposed to enhance balance and decrease the risk of ankle injuries [6]. Among these, instability devices have demonstrated particular effectiveness in strengthening and stabilizing the ankle, as these devices challenge the neuromuscular system, thereby improving proprioception and balance [7]. In this regard, recent evidence suggests a transition toward smaller and more portable devices, known as selective instability devices [8], which can offer similar benefits for ankle balance training when compared to larger, heavier, and less portable global instability devices (e.g., the widely used Both Sides Utilized (BOSU)®) [9]. An example of such a device is the Blackboard (BB), a configurable wooden device composed of two interconnected boards with independent movement. Its bottom surface features Velcro, allowing the user to freely place half-cylinder slats, thereby directing the instability to specific areas of the foot (e.g., the forefoot, rearfoot, or targeted pronation/supination movements).

To optimize the process of balance training, recent research has explored the combination of exercise-based programs with additional therapeutic modalities to enhance training outcomes [10–12]. One emerging modality in this context is transcranial direct current stimulation (tDCS), a non-invasive low-intensity galvanic current neuromodulation technique that has shown promising results in enhancing motor learning by modulating primary motor cortex excitability (M1) [13]. This is particularly relevant since individuals with CAI exhibit reduced cortical excitability in M1, altered somatosensory cortex activation in response to joint loading, and increased reliance on visual and planning areas during simple movement execution compared to uninjured controls [14,15]. Clinical interventions targeting these neural alterations, such as tDCS interventions, could play an important role in ankle balance training programs. In healthy participants, anodal tDCS over the M1 leg area has shown effectiveness in promoting balance performance in a dynamic balance task relative to sham tDCS [16], as confirmed as well in the systematic review and meta-analysis by De Moura (2019) [17]. tDCS delivers low-amplitude electrical currents to modulate cortical excitability, facilitating neural plasticity and enhancing the capacity for skill acquisition [18,19].

While its application in motor learning and rehabilitation is relatively novel, preliminary research suggests that tDCS can optimize training outcomes when combined with the performance of specific tasks [20,21]. In fact, the application of tDCS over M1 has proven effective in enhancing motor learning both within and across sessions, in addition to improving the consolidation of this learning. This occurs in both healthy individuals and patients with motor impairments [22,23]. In this sense, tDCS has been combined with global instability devices such as the BOSU®, resulting in improvements in dynamic balance, proprioception, and functionality [24–26]. However, to the best of our knowledge, no previous studies have compared the combination of tDCS with selective instability devices. Given their key advantage of high configurability, which makes them suitable for use in different clinical contexts, and the potential of tDCS to facilitate motor learning through its effects on cortical excitability, we believe it is of interest to examine the effects of tDCS combined with training programs using this type of device. This approach could provide valuable insights into strategies for enhancing dynamic balance training in healthy individuals, which could hold considerable potential for the prevention of ankle injuries.

Therefore, the present study aimed to compare the effects of a 4-week balance training program on a selective instability device alone or combined with tDCS on dynamic balance in recreationally active young adults.

2. Materials and Methods

2.1. Design

This study was designed as a repeated measures randomized clinical trial. Participants were randomly divided into two groups: one that only performed a balance exercise intervention on the BB instability device (BB group), and another that followed the balance exercise intervention using the instability device combined with the application of tDCS (BB + tDCS group).

During the first session, a blinded physiotherapist assessed the single-leg dynamic balance of each participant's dominant leg using the Y-Balance Test (YBT) and the Emery Test (ET). Participants performed the intervention with their dominant leg, with or without tDCS depending on the group, three times a week for four weeks. Midway through the intervention, prior to the seventh session, a second measurement (POST_2W) of both variables was taken. Finally, after completing the 12 exercise sessions, dynamic balance was measured again (POST_4W).

2.2. Participants

Twenty healthy volunteers who were recreationally active (engaging in 1–5 h of moderate physical activity 3–4 days per week) were initially enrolled in this study and all of them finished the intervention [27]. Table 1 shows their demographic data and clinical characteristics. Inclusion criteria required participants to be between 18 and 30 years old; to engage in at least 90 min of physical activity per week; and to have had no lower limb injury or pain in the year prior to this study, including a history of ankle sprains, CAI, or functional ankle instability, as these factors are important in causing ankle balance deficits. On the one hand, the absence of CAI was assessed using the Cumberland Ankle Instability Tool in its Spanish adaptation, which is validated to assess unilateral CAI [28]. Thus, to be included in this study, participants had to have a score of 30 on this questionnaire, which is related to the absence of CAI and normal stability [28]. On the other hand, functional ankle instability, which has been defined as a tendency for the foot to give way or a disabling loss of reliable static and dynamic support of a joint [29], was assessed by means of six dichotomous questions regarding participants' self-reported feeling of instability, a method that has shown good reliability [29]. All participants had to answer no to all 6 questions to be included. Exclusion criteria included prior participation in any lower limb balance or proprioception improvement program and the presence of any known balance disorders, such as vertigo or vestibular or central disturbances. All participants provided written informed consent. This study was conducted between November 2022 and January 2023. Participants were recruited through a call for volunteers at the Faculty of Physiotherapy at the University of Valencia (Spain) and the experimental protocol was approved by the Ethics Committee of the same University (1491326).

Table 1. Characteristics of the participants.

	Blackboard Group (*n* = 10)	Blackboard + tDCS Group (*n* = 10)
Age (years)	22.4 (1.9)	21.7 (2.7)
Sex (women/men)	3/7	4/6
Height (cm)	173.11 (76.56)	170.0 (89.57)
Weight (kg)	75.11 (14.15)	75.50 (10.17)
Dominant leg (right/left)	8/2	9/1
Minutes activity	453.3 (177.76)	396.0 (201.89)

Data are expressed as mean (standard deviation).

2.3. Procedures

The YBT, a modified version of the Star Excursion Balance Test, was employed to measure dynamic balance [30,31]. Participants stood on one leg and reached as far as possible in three directions (anterior, posteromedial, and posterolateral) with the contralateral leg. Adhesive tape marked the directions on the floor, with increments of 5 mm for precise measurement [32]. The distances reached were normalized to leg length, measured from the anterior superior iliac spine to the medial malleolus [33]. Each participant performed four practice attempts followed by three recorded attempts per leg and direction, with 15 s rests between attempts and 5 min rests between directions [32]. For further data analyses, the mean of the three attempts was used for each leg in each of the three directions and a composite score (CS) was calculated as the summation of the three directions, divided by three times the leg length, and multiplied by 100. Measurements were taken barefoot, with hands placed on hips. Invalid attempts (e.g., moving the supporting foot or removing hands from hips) were repeated [30].

The ET was also used to assess dynamic balance. Participants stood on one leg on an Airex® Balance Pad (AIREX®, Sins, Switzerland), barefoot with eyes closed and hands on hips, aiming to maintain stability for up to 180 s [34,35]. The remaining time of those 180 s minus the time achieved was given as rest time. A 15 s familiarization trial was allowed before registered measurements. The supporting leg was slightly flexed at the knee (approximately 30°), and the contralateral leg at 45° [34]. The best time from three attempts was recorded, and trials were repeated if balance was lost [32,35].

2.4. Intervention

After a familiarization period consisting of 2–3 repetitions of a single-leg stance for 20 s on the instability device, participants performed the balance exercise session [36]. This session consisted of five repetitions of 40 s of work and 60 s of rest with their dominant leg [37], and this was repeated three times a week for four weeks, based on previous research [24,38].

The instability device chosen for the intervention was the BB (Blackboard, Cologne, Germany), which has been shown to be as effective as other conventional devices in activating the peroneus longus muscle [8]. This device allows for specific instability configurations according to the user's needs. As in a previous study, the maximum instability setting was chosen (Figure 1A), inducing instability in both the forefoot and rearfoot [9].

While the BB group performed the balance intervention on the device, the BB + tDCS group performed the same intervention while receiving a tDCS treatment. The device used to apply the current was the EPTE Bipolar System (Ionclinics, Valencia, Spain). The anode was placed on the motor cortex contralateral to the dominant leg (C3/C4), specifically in the leg representation area (lateral to the vertex Cz, on the mid-sagittal line), while the cathode was positioned on the contralateral supraorbital region (Figure 1B) [18,39]. Rubber electrodes were used inside a sponge previously moistened with saline solution.

Conductive gel was also applied between the electrode and the scalp to ensure current flow through the hair. The electrodes had a surface area of 35 cm^2. Stimulation was applied for the duration of the exercise session, simultaneously (Figure 1C), for a total of 10 min at an intensity of 2 mA [19,39].

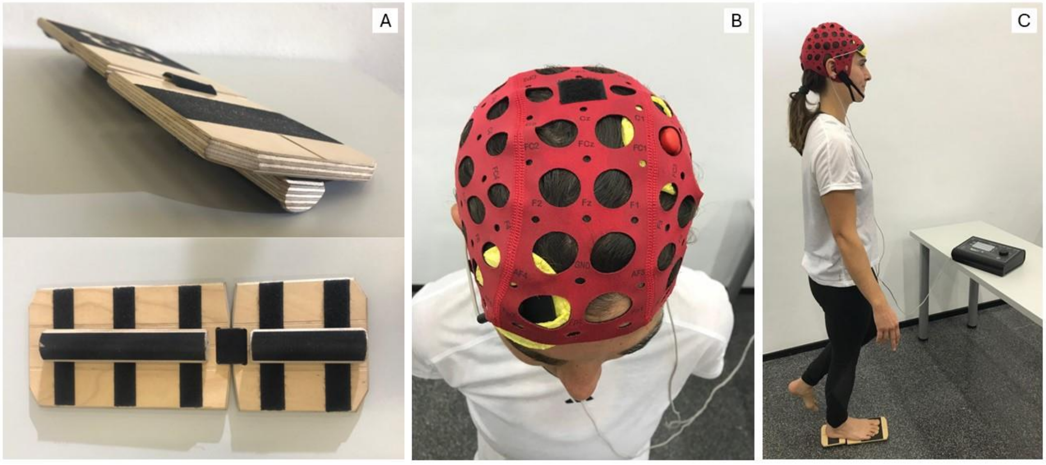

Figure 1. (**A**) Blackboard instability device; (**B**) position of the tDCS electrodes; (**C**) combined therapy applied.

2.5. Statistics

All statistical analyses were carried out using IBM SPSS Statistics software (version 29.0, IBM Corp, Armonk, NY, USA). Participant characteristics were summarized as means (SD) or frequencies and stability measures as means (95% confidence intervals (CIs)). The normality of distribution for stability measures was verified using the Shapiro–Wilk test. Unpaired *t*-tests were used to examine the differences in demographic and anthropometric characteristics, and stability measures at baseline between groups. The effects of the balance training program on stability measures were analyzed in separate 2 (group: BB, BB + tDCS) × 3 (time: baseline, POST_2W, and POST_4W) ANOVA with repeated measures on "Time". The effect size was evaluated with η^2 (partial Eta-squared), where $0.01 < \eta^2 < 0.06$ constitutes a small effect, $0.06 < \eta^2 < 0.14$ a medium effect, and $\eta^2 > 0.14$ a large effect [40]. Where significant main or interaction effects were detected, post hoc t-tests with Bonferroni corrections were used (paired for within-group comparisons and unpaired for between-group comparisons). Significance was set at $p < 0.05$ and Cohen's d was also calculated to evaluate the effect size (d < 0.2: trivial, 0.2–0.5: small, 0.5–0.8: medium, and >0.8: large) [40].

The sample size calculation was based on a previous study [25], which reported an effect size of $\eta^2 = 0.096$ for the time x group interaction in the YBT. With an alpha level of 0.05 and a power of 0.85, we determined a sample size of 20 participants.

3. Results

A total of 20 participants made up the final sample. Their characteristics are depicted in Table 1. No significant differences were found between groups.

In relation to the balance measures, no group–time interactions were observed for any of the tests; instead, a significant main effect for time was found for the posteromedial, posterolateral, and CS YBT measurements, as well as in the Emery Test. Post hoc analyses revealed a significant increase in both groups at the end of the intervention for the posteromedial, posterolateral, CS, and Emery Test variables. In addition, these YBT variables also increased in the BB group at two weeks after the start of the intervention. Complete information is shown in Table 2.

Table 2. Differences within and between groups for dynamic balance measured using the Y-Balance Test and Emery Test.

	Blackboard Group			Blackboard + tDCS Group			Group Differences
	Baseline	**POST_2W**	**POST_4W**	**Baseline**	**POST_2W**	**POST_4W**	***p*** **(η^2)**
YBT—A	0.63 (0.05)	0.65 (0.05)	0.64 (0.05)	0.65 (0.07)	0.66 (0.06)	0.67 (0.05)	0.507 (0.04)
YBT—PM *(η^2 = 0.57)	0.85 (0.19)	0.96 (0.21) †(d = 0.54)	0.98 (0.17) †(d = 0.72)	0.80 (0.10)	0.84 (0.14)	0.89 (0.11) †(d = 0.86)	0.101 (0.14)
YBT—PL *(η^2 = 0.40)	0.94 (0.16)	0.99 (0.14) †(d = 0.33)	1.01 (0.14) †(d = 0.47)	0.89 (0.10)	0.90 (0.12)	0.94 (0.11) †(d = 0.48)	0.375 (0.06)
YBT—CS (%) *(η^2 = 0.60)	80.89 (11.45)	86.53 (11.71) †(d = 0.49)	88.08 (10.66) †(d = 0.64)	78.12 (8.33)	79.84 (10.26)	83.36 (8.61) †(d = 0.59)	0.128 (0.13)
EMERY (s) *(η^2 = 0.23)	13.15 (6.91)	12.91 (7.33)	17.45 (7.98) †(d = 0.58)	13.78 (8.60)	16.28 (7.41)	18.81 (7.85) †(d = 0.61)	0.799 (0.02)

Data are expressed as mean (standard deviation). YBT-A: Y-Balance Test anterior; YBT-PM: Y-Balance Test posteromedial; YBT-PL: Y-Balance Test posterolateral; YBT-CS: Y-Balance Test composite score. * Significant main effect for time. † Significant change in relation with baseline.

4. Discussion

This study aimed to compare the effects of a 4-week balance training program, performed in isolation or combined with tDCS, on functional dynamic balance in recreationally active young adults. Two main findings can be highlighted: first, the balance exercise program established in this study was effective in improving dynamic balance; and second, combining it with 10 min of tDCS did not yield additional benefits compared to performing the program alone. These findings have important implications for designing effective and efficient ankle training and injury prevention programs.

The significant improvements in the YBT and ET outcomes observed in both groups underscore the effectiveness of the balance training program in enhancing dynamic balance. Notably, in addition to the differences in the posteromedial and posterolateral directions of the YBT, the improvement observed in the CS is noteworthy. Both the BB and BB + tDCS groups achieved CS improvements of over 7% and 5%, respectively, exceeding the minimum detectable change recently established by Foldager et al. for this YBT component [41], thus indicating a genuine and meaningful change attributable to the intervention. According to the literature, a CS below 89.6% is associated with a higher risk of lower extremity injury in American football players [42]. While Plisky et al. highlight the importance of considering this threshold within population-specific contexts [31], our findings are particularly interesting, as participants demonstrated significant improvements, progressing closer to this critical threshold. Additionally, the absence of changes in the anterior component of the YBT following the intervention aligns with the findings of a previous study comparing the effects of a balance training program on dynamic balance using the BB and BOSU devices [9]. This may be attributed to the specific instability characteristics of the BB device, which predominantly induces movement in the frontal plane while offering limited demands in the sagittal plane. Moreover, we observed that the anterior component of the YBT largely depends on the dorsiflexion movement, which appears to be insufficiently addressed by the balance training interventions used in both the aforementioned study and the present one. In summary, the observed improvements in the YBT outcomes in the posteromedial and posterolateral directions can be attributed to the specific demands of the BB device, which challenges the participants' ability to stabilize in the frontal plane.

Furthermore, the improvements in the performance of the ET (4.30 s and 5.03 s for the BB and BB + tDCS groups, respectively) are noteworthy. Although the ET is not widely used for balance assessment in adults, its reliability in adolescent populations [35], combined with the relatively young average age of our participants, justified its inclusion in this study. Notably, our findings align with those of Blasco et al., who reported similar results in healthy young adults after a nine-session balance training intervention using various instability devices [34]. In addition, their study concluded that the degree of instability participants trained with was not a determining factor in the balance improvements achieved. This aligns with the findings of our study, where the observed gains likely resulted from the use of a selective instability device. This device was not excessively unstable but appeared to provide the right amount of instability to induce effective adaptations. The improvement in ET performance likely reflects the participants' enhanced ability to manage balance challenges induced by the selective instability of the BB device, which could optimize neuromuscular coordination and rapid stabilization during dynamic tasks.

However, the lack of additional improvements in the BB + tDCS group compared to in the BB group raises important considerations. In fact, the BB group demonstrated earlier gains in both the YBT and ET (at the second week) that were not observed in the combined group. Given prior evidence suggesting that M1 stimulation can modulate motor function, we expected different results. Nevertheless, our findings did not confirm these expectations. On the other hand, more recent systemic reviews have reported non-significant effects of anodal or cathodal tDCS on postural control and balance in healthy individuals [43]. However, it is important to note that the studies included in their analysis applied tDCS over the cerebellum, whereas our protocol targeted M1. Despite its interesting applications in fields such as pain management, chronic syndromes (e.g., fibromyalgia), or psychological conditions like depression [44], the use of tDCS remains controversial in the context of motor learning. In this sense, several factors may explain this lack of benefits of the tDCS protocol in this study. Firstly, the similarity in outcomes at the fourth week suggests that the balance exercises alone may have reached a ceiling effect, meaning further improvements were limited regardless of the addition of tDCS. It is plausible that if this protocol were applied to a clinical population where balance is much more impaired, such as patients with CAI or post-stroke patients, the differences between the intervention groups could be more pronounced [45,46]. For instance, Bruce et al. found that a combined intervention of 4 weeks of eccentric ankle training and tDCS improved dynamic balance in individuals with CAI [24]. Secondly, it must be emphasized that the duration of the tDCS application was set to 10 min to match the duration of the balance exercise session, as it was designed to be administered simultaneously. By contrast, most clinical trials employing similar configurations and intensity (2 mA) applied tDCS for 20 min, so longer interventions in combination with longer balance training programs might be more effective. However, it is important to note that a longer duration alone may not guarantee better results. For example, Xiao et al. applied tDCS for 20 min in combination with foot exercises and observed no significant differences in balance compared to foot exercises alone [38]. Therefore, while extending the duration of tDCS might be beneficial, it may not be the primary limiting factor in this study. Thirdly, another reason that could explain these unexpected results is that the addition of tDCS might have imposed a cognitive overload on participants. Balance exercises demand focused attention and concentration to efficiently engage the musculoskeletal and neurological motor control systems [47]. Therefore, the concurrent application of tDCS may have distracted the brain from efficiently processing the sensory stimuli needed to maintain balance, especially in those individuals with lower working memory capacity [48,49].

In relation to clinical implications, the findings of this study highlight the efficacy of a balance training program on a selective instability device for improving dynamic balance. Notably, the significant gains observed in the BB group just two weeks after the baseline assessment indicate that the balance program chosen is potentially suitable. These improvements on dynamic balance could play a significant role in preventing ankle injuries, further emphasizing the value of the improvements achieved with the exercise intervention using the specific instability device. Balance training on unstable devices is a cost-effective, accessible, and efficient method for improving dynamic balance. An interesting aspect of this program is the use of an innovative, configurable instability device, which differs from conventional instability devices by specifically targeting the foot and ankle. This ankle-specific approach minimizes the need for additional attention to other body regions, potentially making it an efficient tool for improving balance. Additionally, the results suggest that the inclusion of tDCS may not provide sufficient additional benefits to justify its use in healthy, recreationally active individuals, given the minimal improvements observed in the BB + tDCS group and the logistical and equipment demands associated with its application. However, this finding is a valuable insight into the use of tDCS in the context of motor learning in healthy subjects, which can help clinicians refine their practice (e.g., by avoiding the allocation of resources to an apparently ineffective intervention).

Despite its contributions, this study is not without limitations. The small sample size may limit the generalizability of the findings, and the relatively short intervention duration may not reflect the potential long-term benefits of tDCS. In addition, while improvements were observed in the CS of the YBT, the reference values reported in the literature were not fully achieved. This could be due to the intervention's duration or intensity, or to the notably low baseline performance of both groups. However, as previously discussed and to the best of our knowledge, no reference values have been specifically established for a young, physically active population not engaged in a particular sport. Therefore, it would be misleading to assume that our studied population is failing to meet a certain threshold and thus at a higher risk of lower limb injuries based solely on comparisons with other populations. Lastly, the tDCS protocol selected for this study may not have been the optimal choice for combination with a balance training program on a selective instability device in healthy individuals. Nevertheless, given the lack of prior research in this area, we encourage future studies to refine the duration and intensity of tDCS sessions to maximize their benefits in this context when combined with exercise. Although there are already some studies that analyze the effects of adding tDCS to relatively short-duration exercise interventions (2–6 weeks) [24–26,38], longer studies with follow-up assessments would be necessary to fully understand how this stimulation affects motor learning in participants. It is also important to recognize that if exercise alone produces strong effects, tDCS may not be the most effective complementary therapy for enhancing ankle dynamic balance, at least in the short term. Instead, its application may be more suitable for pathological populations who cannot adhere to demanding exercise programs.

The results of the present study partially align with previous studies that have explored the combination of tDCS with specific motor control strategies [38,43]. However, our study is the first to analyze its effect alongside a specific instability device, opening new research avenues regarding the use of more configurable and adaptable tools for specific needs. On the one hand, despite the apparent absence of benefits of integrating tDCS into the training program, enhancing motor learning by neuromodulation strategies remains an area of growing interest. Future research should focus on how different instability devices, in combination with tDCS, may influence neuromuscular control and balance training outcomes, exploring different protocols of application. For example, the efficacy of this combination in simpler tasks or in populations whose baseline condition allows for a greater margin of improvement, such as older adults, remains unknown. Additionally, optimizing tDCS parameters (i.e., stimulation duration and its application at different stages of motor learning) could further maximize its benefits. In the sports field, using selective instability devices alongside neuromodulation strategies could provide an innovative tool for injury prevention and neuromuscular performance enhancement in athletes. Finally, future research should also explore the long-term adverse effects of the technique, since they remain partially unknown. On the other hand, the efficacy of the training program provides valuable insights into the specific approach of ankle dynamic balance training. This can contribute to clinical practice by optimizing treatment times and achieving effective results in ankle injury prevention by improving subjects' dynamic balance.

5. Conclusions

In conclusion, this study reinforces the efficacy of instability device-based balance training in enhancing ankle dynamic balance, while questioning the added value of combining this approach with tDCS in recreationally active healthy young adults. These findings emphasize the utility of instability devices as standalone tools for ankle dynamic balance improvement and suggest that further research is needed to optimize the use of tDCS in this context.

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