UNIVERSIDAD DE JAÉN

FACULTAD DE CIENCIAS DE LA SALUD
DEPARTAMENTO DE CIENCIAS DE LA SALUD

TESIS DOCTORAL

ESTABILIDAD Y PROPIOCEPCIÓN EN ATLETISMO

PRESENTADA POR:
NATALIA ROMERO FRANCO

DIRIGIDA POR:
DR. D. ANTONIO MARTÍNEZ AMAT
DR. D. EMILIO J. MARTÍNEZ LÓPEZ

JAÉN, 2 DE DICIEMBRE DE 2013

ISBN 978-84-8439-852-3

A mi familia

DEPARTAMENTO DE CIENCIAS DE LA SALUD

FACULTAD DE CIENCIAS DE LA SALUD

UNIVERSIDAD DE JAÉN

ESTABILIDAD Y PROPIOCEPCIÓN EN ATLETISMO

STABILITY AND PROPRIOCEPTION IN ATHLETICS

Natalia Romero Franco

Directores de Tesis

Dr. D. Antonio Martínez Amat

PhD

Profesor Contratado Doctor

Universidad de Jaén

Dr. D. Emilio J Martínez López

PhD

Profesor Titular

Universidad de Jaén

Jaén, 02 de Diciembre de 2013

Profesor Dr. Antonio Martínez Amat
Profesor Contratado Doctor
Departamento de Ciencias de la Salud

Profesor Dr. Emilio J Martínez López
Profesor Titular
Departamento de Didáctica de la Expresión Musical, Plástica y Corporal.

Universidad de Jaén

AUTORIZACIÓN DE LOS DIRECTORES DE LA TESIS PARA SU PRESENTACIÓN

El Dr. Antonio Martínez Amat y el Dr. Emilio J Martínez López como Directores de la Tesis Doctoral titulada "*Estabilidad y Propiocepción en Atletismo*" *,* realizada por Doña. **Natalia Romero Franco** en el Departamento de Ciencias de la Salud **autorizan su presentación a trámite** dado que reúne las condiciones necesarias para su defensa.

Lo firmo, para dar cumplimiento a los Reales Decretos 56/2005 y 778/98, en Jaén a 7 de Mayo de 2013.

Dr. D. Antonio Martínez Amat Dr. D. Emilio J Martínez López

Departamento de Ciencias de la Salud

Paraje Las Lagunillas, s/n – Edificio B3 - 23071 – Jaén

Tel. (+34) 953.21.18.51 - Fax (+34) 953 21 29 43

ÍNDICE DE CONTENIDOS (INDEX OF CONTENTS)

LISTA DE PUBLICACIONES (LIST OF PUBLICATIONS)

I. **Romero-Franco N**, Martínez-López EJ, Lomas-Vega R, Hita-Contreras F, Martínez-Amat A. Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *The Journal of Strength & Conditioning Research.* 2012; 26(8), 2071-2077.

II. **Romero-Franco N**, Martínez Amat A, Martínez-López EJ. Effects of the proprioceptive training in Sprinters. *Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*. 2013; 13(51), 437 – 451.

III. **Romero-Franco N**, Martínez-López EJ, Lomas-Vega R, Hita-Contreras F, Osuna-Pérez C, Martínez-Amat A. Short-term effects of proprioceptive training with unstable platform on the stabilometry of athletes. *The Journal of Strength & Conditioning Research*. 2013; 27(8), 2189-2197.

IV. **Romero-Franco N**, Martínez-Amat A, Hita-Contreras F, Martínez-López EJ. Short-term effects of a proprioceptive training session with unstable platform on the monopodal stabilometry of athletes. *Journal of Physical Therapy Science*, *in press.*

V. **Romero-Franco N**, Martínez-López EJ, Osuna-Pérez MC, Hita-Contreras F; Martínez-Amat A. Postural stability and subsequent sports injuries during indoor-season of athletes. *Journal of Physical Therapy Science, in press.*

VI. **Romero-Franco N**, Martínez-López EJ, Hita-Contreras F, Martínez-Amat A. Indoor-season changes on the stabilometry of sprinters and middle-distance runners. *Submitted.*

VII. **Romero-Franco N**, Martínez-López EJ, Hita-Contreras F, Lomas-Vega R, Martínez-Amat A. Effects of an anaerobic lactic training session on the postural stability of athletes. *Submitted.*

VIII. **Romero-Franco N**, Martínez-López EJ, Hita-Contreras F, Lomas-Vega R, Martínez-Amat A. Effects of anaerobic lactic training on knee proprioception of athletes. *Submitted.*

RESUMEN

En el contexto deportivo, las lesiones suponen un gran coste económico y requieren el cese temporal e incluso definitivo de la actividad deportiva, mermando el rendimiento de todo deportista. Es necesaria una estrategia de prevención primaria para optimizar los recursos económicos y evitar abandonos deportivos. Esta profilaxis comprende la evaluación del deportista y la elaboración de programas de entrenamiento para mejorar las capacidades alteradas que ponen en riesgo al atleta.

Numerosos investigadores afirman que la lesión deportiva está muy relacionada con la propiocepción debido a su importancia en la estabilidad postural del atleta y en el correcto reconocimiento de la posición y el movimiento corporal. Innumerables investigaciones hasta la fecha han reportado deterioros propioceptivos tras lesiones deportivas que se mantienen incluso después de que el atleta se reincorpore a su nivel de actividad física. Sin embargo, también algunos autores han encontrado alteraciones propioceptivas previas al acontecimiento lesivo, anotando que factores propios del entrenamiento pueden producir alteraciones propioceptivas.

El objetivo general de esta Tesis Doctoral fue analizar la influencia del tipo, la intensidad y el volumen de entrenamiento en la estabilometría de atletas tanto a medio – largo plazo (artículos II y II y VI) como a corto plazo (artículos III y IV, VII y VIII). Al mismo tiempo, se analizó la influencia de la estabilidad postural en la aparición de lesiones (artículo V) y se diseñó un programa de entrenamiento para mejorar la estabilometría y otras habilidades motoras (artículos I y II), teniendo en cuenta los efectos inmediatos de ese entrenamiento (artículos III y IV).

Los principales resultados de la Tesis sugieren que: a) Tras seis semanas de entrenamiento propioceptivo, los atletas mejoran la estabilidad postural y el control de centro de gravedad, además de producir moderadas mejoras en la potencia de salto vertical, aunque estas mejoras no se transfieren a mayor velocidad de carrera. b) Una única sesión de entrenamiento propioceptivo deteriora de forma inmediata la estabilidad postural bipodal de atletas, sin embargo mantiene constantes los valores de estabilidad monopodal. c) Los atletas con mayores valores de dispersión del centro de presiones en apoyo bipodal o un posicionamiento medio-lateral del centro de presiones más alejado del eje de ordenadas en apoyo monopodal son más propensos a lesionarse en el periodo de entrenamiento subsequente. d) Los atletas muestran peores valores estabilométricos en los periodos de entrenamiento con mayor carga de trabajo y estos valores mejoran con menor carga y mayor intensidad de entrenamiento, sin influencia de la modalidad de carrera de los atletas. Sin embargo, los velocistas tienen una mejor estabilidad postural monopodal en plano anteroposterior comparado con los medio-fondistas. e) Una sesión de entrenamiento láctico deteriora de forma inmediata la estabilidad postural y la propiocepción de los atletas. Aunque treinta minutos después este deterioro se mantiene en la estabilidad postural, tras 24 horas, existe una mejora de los valores estabilométricos basales.

En síntesis, los resultados de la presente Tesis Doctoral muestran que la estabilidad y la propiocepción son parámetros clave en la prevención de lesiones de atletas. A medio-largo plazo, éstos se modifican con el volumen e intensidad de entrenamiento y se benefician del trabajo en superficie inestable. A corto plazo, los entrenamientos de alta intensidad constituyen una situación de potencial riesgo lesivo. A nivel de rendimiento deportivo, es necesaria la realización de trabajos futuros para

aclarar si las mejoras obtenidas con el entrenamiento propioceptivo son transferibles al terreno deportivo.

Entrenadores y fisioterapeutas han de valorar los condicionantes que deterioran y benefician los parámetros propioceptivos con el fin de mitigar el riesgo lesivo al que se exponen los atletas diariamente.

Palabras clave: Propiocepción. Estabilidad postural. Lesiones. Atletas.

SUMMARY

In the context of sports, injuries mean a great economical impact and require a temporary or even a final cease of the physical activity, reducing every athlete's performance. A primary preventive strategy is needed to optimize economical resources and avoid sports abandonment. This prophylaxis should include an evaluation of athletes and the addition of preventive training programs to improve the altered capacities that expose athletes to risks.

Many authors affirm that sports injuries are closely related to proprioception due to its role in the postural stability, the correct sense of position and effective body movement. Investigations to date have reported proprioceptive damages after sports injuries, that remain even after athletes have returned to their physical activity level. However, some authors have also found proprioceptive alterations prior to sports injury, by noting that factors from training may produce proprioceptive variations.

The overall purpose of this Thesis was to analyze the short-term (papers III and IV, VII and VIII) and medium and long-term effects (papers I and II, and VI) of type, intensity, and volume of training on stabilometry of athletes. Also, we analyzed effects of postural stability on subsequent sports injuries (paper V) and designed a proprioceptive training program to improve stability and other motor skills (papers I and II), by taking into account the short-term effects of the proprioceptive training of athletes (papers III and IV).

The main findings and conclusions are: a) Six weeks of proprioceptive training improve postural stability and control of gravity center of athletes, and also produce moderate improvements in jump power, which is non-transferrable to a faster race. b) A proprioceptive training session deteriorates immediately the bipodal postural stability of athletes, however maintains stabilometric values on monopodal support. c) Athletes showing higher center-of-pressure spread on bipodal support and a mediolateral center-of-pressure position further from axis of ordenates on monopodal support are more prone to injuries in subsequent training period. d) Athletes show worse postural stability in training periods with a higher volume of workload, and it improves in periods with a low-volume, high intensity workload. The athletic variety do not have any influence on these differences, but sprinters display better anteroposterior monopodal stability compared with middle-distance runners. e) A lactic training session deteriorates immediately the postural stability and proprioception of athletes. Although after thirty minutes the stabilometric deterioration remains, 24 hours later, stability is better than basal level.

In short, the findings of this Thesis highlight that proprioception and postural stability are essential parameters to prevent injuries in track and field athletes. In the medium to -long term, these parameters might be modified due to volume and intensity of training, and be benefited from proprioceptive training on unstable platforms. In the short-term, high intensity trainings involves potential risks. With respect to sports performance, future research is needed to clear if improvements from proprioceptive training are transferable to performance.

Coaches and physiotherapists should evaluate all conditioning aspects which deteriorate or improve proprioception to mitigate injury risk to which athletes are exposed in every training session.

Keywords: Proprioception. Postural stability. Injuries. Athletes.

ABREVIATURAS (ABBREVIATIONS)

AAE	Absolute Angular Error
ACL	Anterior Crossed Ligament
Area	Area covered by CoP movement
Areal	Area covered by CoP movement on left-leg stance
Arear	Area covered by CoP movement on right-leg stance
CMJ	Counter Movement Jump
CoP	Center of Pressure
EMG	Electromiografía
JPS	Joint Position Sense
LCA	Ligamento Cruzado Anterior
Length	Length covered by CoP movement
Lengthl	Length covered by CoP movement on left-leg stance
Lengthr	Length covered by CoP movement on right-leg stance
RAE	Relative Angular Error
SEBT	Star Excursion Balance Test
SJ	Squat Jump
SNC	Sistema Nervioso Central

Speed Speed of CoP movements

Speedl Speed of CoP movements on left-leg stance

Speedr Speed of CoP movements on right-leg stance

VAE Variable Angular Error

Xmean Values mean of CoP movements of mediolateral plane

Xmeanl Values mean of CoP movements of mediolateral plane on left-leg stance

Xmeanr Values mean of CoP movements of mediolateral plane on right-leg stance

Ymean Values mean of CoP movements of anteroposterior plane

Ymeanr Values mean of CoP movements of anteroposterior plane on right-leg stance

Ymeanl Values mean of CoP movements of anteroposterior plane on left-leg stance

INTRODUCCIÓN (INTRODUCTION)

El rendimiento máximo en atletismo depende directamente de la aplicación de programas de entrenamiento que son cada vez más sofisticados. Gracias a las aportaciones de las ciencias aplicadas al deporte, se conocen los efectos de los cambios en intensidad, volumen y tipología de entrenamiento y la adecuación de los descansos para restaurar el equilibrio biológico, consiguiendo una planificación con la que el organismo se adapta a la carga de trabajo[62].

Sin embargo, las lesiones deportivas afectan directamente a la capacidad de rendimiento del deportista en su totalidad[106, 151]. Lesión deportiva es un término no consensuado que ha implicado extensos debates entre los distintos autores puesto que al definirla se pueden tener en cuenta diferentes circunstancias como son la interrupción de la práctica deportiva, la forma súbita o insidiosa de presentación (aguda o por uso repetitivo) o la evolución del cuadro (aguda, subaguda o crónica)[131]. En esta Tesis se ha tomado como referencia el término atribuido por Kolt et al. (1999) en el que define la lesión como "*el daño corporal que obliga al deportista a abandonar o modificar una o más sesiones de entrenamiento, competición o ambos*"[82]. De acuerdo con la definición mencionada, la lesión deportiva puede condicionar el rendimiento del atleta[11].

Estudios de prevalencia calculan que la tasa de lesiones deportivas en la población general es de 15,4 por 1000 personas, siendo el 5,2% la frecuencia promedio de lesiones deportivas en atletas[59]. El 20% de las lesiones deportivas corresponde a fracturas o daños a órganos internos y el 80% restante afecta a músculos, tendones, ligamentos y articulaciones, siendo generalmente la rodilla la región más afectada, seguida del tobillo y el hombro[124, 170]. Una revisión de estudios del 2007 reportó que el

37% de los atletas profesionales sufrían lesiones deportivas, de las que el 55% eran en miembros inferiores y de ese porcentaje, el 25% eran de rodilla[158]. Como dato importante, el 40% de los atletas que se lesionan, presentan una lesión previa en el mismo sitio[131]. Además, las acciones explosivas son las más lesivas para los deportistas[138].

A nivel económico, los estudios describen un coste anual medio de un billón de dólares destinado a lesiones deportivas[127]. La NCAA contabilizó entre 3 y 5 millones de lesiones anuales en Estados Unidos en la temporada deportiva 2000-2001, destacando las distensiones musculares, los esguinces y las contusiones, siempre más frecuentes en el periodo competitivo que en el de entrenamiento[10]. En el ámbito nacional, escasa documentación muestra el impacto económico que las lesiones ocupan en el panorama deportivo. Un informe del Instituto de Análisis Económico y Empresarial de Andalucía del año 2008 describió que las lesiones deportivas producían un gasto mensual medio de 36,1 millones de euros[5]. Si tenemos en cuenta que en estos datos no se incluían los tratamientos en ámbito privado a los que acuden muchos deportistas, hablamos de un gasto muy elevado, puesto que según un estudio realizado por el Consejo Superior de Deportes en ese mismo año, a nivel nacional, sólo el 8,9% de los deportistas hacen uso de los servicios sanitarios de las federaciones deportivas[96].

La prevalencia de lesiones deportivas y su impacto económico requieren estrategias de prevención que reduzcan su incidencia, disminuyendo y/o eliminando los principales factores de riesgo[106].

Para ello, es preciso el conocimiento de los mecanismos que predisponen a la lesión, así como aquellos que se mantienen deficitarios una vez que el atleta se reincorpora al entrenamiento.

SISTEMA SENSORIOMOTOR: propiocepción y propioceptores

Todos los mecanismos fisiológicos intrínsecos propios del sistema nervioso que permiten el control del cuerpo se unen en el término *sistema sensoriomotor*. Éste incluye los sistemas fisiológicos neurosensores y neuromusculares, así como las señales aferentes, eferentes y los componentes de integración central y de procesamiento que mantienen la estabilidad articular funcional[53]. Aunque está compuesto por todo tipo de receptores, el control óptimo del movimiento y la postura dependen de la *propiocepción*[94].

La propiocepción fue definida por primera vez en 1906 por Sherrington como "*el sentido de la posición que adoptan las partes corporales de uno mismo*". El término propiocepción se refiere estrictamente a la información procedente de los receptores específicos que contribuye a las sensaciones conscientes e inconscientes del sentido muscular, el equilibrio postural y la estabilidad articular[93]**.** Estos receptores específicos, los *propioceptores*, son los detectan las variaciones de tensión y longitud muscular y tendinosa y las variaciones de posición, velocidad y aceleración de las articulaciones e informan sobre los cambios que se producen en el organismo y en su entorno en todo momento. Con frecuencia, los autores no consideran a las terminaciones nerviosas libres de la piel como receptores propioceptivos, sin embargo, algunas investigaciones han afirmado la contribución de estos receptores a la sensibilidad propioceptiva[132].

Además de los receptores propioceptivos musculoesqueléticos, articulares y las terminaciones libres, se encuentran los receptores propioceptivos vestibulares localizados en el oído interno. Estos informan de la posición de la cabeza (receptores estáticos) y de su movimiento (receptores dinámicos). También serán fundamentales en la propiocepción del miembro inferior[28].

Por otra parte, los propioceptores se encuentran especializados de acuerdo a la información que captan y transportan hasta el sistema nervioso central. Una vez allí, la información es enviada a distintos nivel de integración para su procesamiento en médula espinal, corteza sensorial, ganglios basales, tronco del encéfalo o cerebelo[28, 61, 105].

La propiocepción y los propioceptores conforman el sistema propioceptivo, que es determinante para el rendimiento, la prevención y la recuperación de lesiones en deporte[95].

PROPIOCEPCIÓN Y EFERENCIAS MOTORAS

En función de los niveles de integración y procesamiento central de la información propioceptiva, las eferencias motoras serán diferentes, abarcando desde niveles básicos procesados inconscientemente (reflejos), hasta movimientos más complejos que determinan el mejor gesto deportivo[149].

Reflejos y control motor

Además de analizar los propios reflejos, varias investigaciones han evaluado el nivel de actividad muscular a través de electromiografía (EMG) en condiciones distintas. Existen estudios que han descrito mayor activación muscular en EMG durante el entrenamiento de la fuerza en condiciones de inestabilidad, donde la propiocepción juega un importante rol[7, 8, 47, 103]. Este incremento de la actividad muscular podría compensar la inestabilidad provocada para conseguir que el centro de gravedad se mantenga dentro de la base de sustentación y evitar una caída[57].

Esta activación muscular a nivel inconsciente regula el reclutamiento muscular y la frecuencia de impulsos para conseguir una correcta coordinación intramuscular, a la vez que coactiva agonistas y antagonistas para obtener la coordinación intermuscular. Por tanto, la información propioceptiva es crucial en la estabilización articular y la correcta ejecución de movimientos[93].

Además, el control articular acorde al medio externo también es regulado por los mecanismos de feedback y feedforward[120]. Los componentes dinámicos neuromusculares (propioceptivos) incluyen la anticipación (información previa/ feedforward) y la retroalimentación (feedback) para un correcto control motor[9, 162].

El feedback juega un papel muy importante en el desarrollo de las destrezas motrices puesto que el sujeto es informado sobre las consecuencias de sus respuestas motoras. En el caso del feedback propioceptivo, es el mecanismo por el cual el sujeto conoce su posición corporal en el tiempo y en el espacio en todo momento. Cuando se produce una perturbación inesperada, los mecanorreceptores de la cápsula articular, ligamentos, tendones, músculos y piel la perciben e informan de esta señal a centros superiores. El SNC elabora una respuesta motora para contrarrectar el cambio y mantener la estabilidad[120].

El feedforward, que es desarrollado previo al movimiento, activa los músculos circundantes a la articulación antes de la carga excesiva, para absorber la fuerza y disminuir la tensión en los ligamentos. Por ello, depende en gran medida de las experiencias previas del deportista. Este mecanismo corresponde a un plan motor anticipatorio para mantener la estabilidad, pero ahora ante perturbación previstas o aprendidas[120].

Además, el feedforward tiene gran relevancia en el control y la estabilidad postural[9], de la cual hablaremos en el siguiente apartado por su importante relación con el sistema propioceptivo. Se ha evidenciado que el SNC reconoce movimientos y perturbaciones y actúa a través de acciones musculares anticipatorias para minimizar sus efectos[101, 122, 123, 154]. Hay evidencia de la capacidad del cerebro para la anticipación y reconocimiento de movimientos a través de EMG, encontrando incluso relación entre los músculos antigravitacionales y los antagonistas de un movimiento determinado del brazo[3, 9 25, 45]. La anticipación también se ha estudiado añadiendo perturbaciones directamente sobre el sujeto o su base de sustentación, existiendo anticipaciones musculares desde 50 hasta 100 milisegundos desde distintos músculos[3, 25]. Por lo que la anticipación o mecanismo de feedforward cumple un importante papel en el control postural.

Estabilidad postural

La estabilidad postural es una función compleja que supone el mantenimiento de la proyección vertical del centro de gravedad en la base de sustentación[155]. Para ello, señales desde el sistema propioceptivo, sistema visual y vestibular se integran en los pedúnculos cerebelosos, donde el huso neuromuscular es la primera fuente propioceptiva que ayuda a mantener la postura erguida. Por tanto, la propiocepción es un componente clave en la consecución de la estabilidad postural, siendo esta la razón por la que la estabilometría es uno de los métodos que más se utilizan actualmente para valorar la estabilidad postural y una manifestación importante de la capacidad propioceptiva. Esta misma justificación da sentido a la realización de trabajo con superficie inestable como entrenamiento propioceptivo más efectivo en la recuperación, prevención y rendimiento deportivos[76].

Además de la información procedente de los propioceptores, el mantenimiento postural es conseguido gracias a la "rigidez" proporcionada por la actividad muscular alrededor del tobillo (teoría del péndulo invertido)[99, 100, 122]. La integración de los reflejos tónicos posturales del nivel medular se encargan de conservar la estabilidad del tobillo y con ello, la estabilidad postural. Por tanto, mientras estamos de pie, hay múltiples balanceos posturales que son también contrarrestados por la actividad muscular, la cual ayuda a mantenernos dentro de los límites de la base de sustentación y evitar así la caída[118].

Esto supone que la estabilidad postural sea un proceso de restablecimiento continuo de equilibrio y que la actitud postural nunca sea adquirida de forma definitiva[31, 41, 72]. En primer lugar, existen movimientos cardíacos y de líquidos y contracciones musculares respiratorias que inducen movimientos continuos de balanceo corporal[31]. Además, el cuerpo se somete a constantes deformaciones, lo cual contribuye a modificar su estado de descanso siendo necesario el continuo mantenimiento del equilibrio. Sin embargo, Bouisset and Duchene afirman que las deformaciones resultantes de los movimientos de respiración son débiles y no son los únicos responsables del balanceo postural[20], sino que los movimientos respiratorios son parcialmente contrarrestados por desplazamientos pequeños angulares del tronco inferior y los miembros inferiores[72]. También, De Luca et al., especificaron que el sistema neuromuscular es incapaz de mantenerse en tensión constante y esta es la causa esencial del balanceo postural en la postura erecta[41].

La estabilidad postural puede ser cuantificada midiendo los desplazamientos del centro de gravedad o del centro de presiones, usualmente a través de estabilometría[29].

El test más frecuente en laboratorios para determinar la estabilidad postural es la monitorización del movimiento del centro de presiones durante una duración específica mientras el atleta se mantiene en apoyo bipodal o unipodal y con ojos abiertos o cerrados lo más inmóvil posible. El gold stándar es la medición del movimiento del centro de presiones en plataforma de fuerzas, aunque muy frecuentemente esta medida es llevada a cabo a través de plataformas baropodométricas o de presiones por su menor coste. En cualquiera de los casos, el mínimo desplazamiento del centro de presiones será indicador de buena estabilidad postural[76]. Por ello, las variables que se obtengan siempre indicarán una mejor estabilidad postural cuanto más bajos sean sus valores. Las variables que es posible obtener tras un test estabilométrico son innumerables, sin embargo, a nivel clínico y práctico, las que más se utilizan en el ámbito de la investigación son las siguientes:

Variables que definen el recorrido del centro de presiones: Longitud, velocidad y superficie del recorrido del centro de presiones.

Variables que definen la posición del centro de presiones: Xmedia, referida al balanceo del centro de presiones en el plano mediolateral; Ymedia, referida al balanceo del centro de presiones en el plano anteroposterior. En este caso y de forma excepcional, estas variables indicarán una mejor estabilometría cuanto más cercano a cero sea el valor que muestren.

Además de esas, se pueden encontrar otras: RMS (Root Mean Squared)= es el valor cuadrático medio del recorrido del centro de presiones ; RMSX= valor cuadrático medio en el plano mediolateral; RMSY= valor cuadrático medio en el plano anteroposterior;

DeltaX= desviación mediolateral del centro de presiones; DeltaY= desviación anteroposterior del centro de presiones; LFS=Longitud en función de superficie, indicando el camino que recorre el centro de las presiones por unidad de superficie, orientando sobre la energía gastada por el sujeto para controlar su equilibrio[23].

En el tratamiento de la estabilidad postural cabe mencionar el *equilibrio dinámico* como el mantenimiento de la estabilidad postural durante la realización de una tarea, por lo que podría considerarse una parte de la estabilidad postural. Su evaluación es llevada a cabo con diversa metodología, entre la que cabe destacar el Sistema de Equilibrio BIODEX[27], el Star Excursion Balance Test (SEBT) o prueba funcional de equilibrio de excursión en estrella[81, 143] o la contabilidad de contactos en el suelo durante una tarea en plataforma inestable durante 30 segundos[76]. El sistema de equilibrio Biodex es una herramienta que puede ser utilizada para realizar test, así como para el propio entrenamiento del equilibrio tanto en superficie estable como inestable. Se compone de 5 programas de evaluación y entrenamiento. Entre ellos están los límites de estabilidad, como programa que evalúa y entrena el control postural multidireccional y que puede ser realizado también en su versión en dinámico, el test de riesgo de caídas, el test de estabilidad postural bipodal y unipodal y el test de integración sensorial del equilibrio. La fiabilidad de este sistema ha sido mostrada en estudios anteriores[27]. El SEBT es un test funcional que evalúa el equilibrio unilateral y que es llevado a cabo con el participante de pie en medio de un cuadrícula de 1.83-m × 1.83-m formada por tape en el suelo y compuesta por 8 líneas que se extienden en forma de estrella, con una angulación de 45º desde el centro de la cuadrícula. Estas líneas se nombran de acuerdo a la dirección y el sentido con respecto a la pierna apoyada anterolateral (AL), anterior

(A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), y lateral (L)[33]. Su fiabilidad ha sido determinada en estudios previos[67].

Sentido de posición articular y Kinestesia

El sentido de posición articular y la kinestesia son importantes componentes de proprioceptivos. El sentido de posicionamiento articular es la consciencia sobre la posición articular y el movimiento corporal, lo cual es posible gracias a la entrada de aferencias recogidas por los propioceptores[68] hasta la corteza somatosensorial, donde es procesada para hacer consciente el sentido de la posición articular y la motricidad articular[93]. En 1976, Gandevia y McCloskey observan por primera vez que el huso muscular contribuye de forma significativa al sentido de la posición de la articulación de la falange distal del dedo medio. Por ello, es un componente propioceptivo vital en el funcionamiento articular necesario para la coordinación y estabilización de la articulación[30]. Tanto es así que algunos autores han reportado con sus estudios, la importancia de la agudeza propioceptiva en la función de articulaciones como la rodilla y en el rendimiento del deportista[125].

El principal método para la evaluación de la consciencia de posicionamiento articular se ha llevado a cabo a través del *Joint Position Sense* (JPS) o test de posiciomiento articular. El JPS es definido clínicamente como la habilidad del sujeto para reconocer una posición articular y más tarde reproducirla de forma activa o pasiva [98, 161]. Su metodología puede variar dependiendo de los objetivos, posibilidades y estructuras a evaluar. La realización de forma activa ha mostrado mayor validez debido a que los receptores musculares como es el huso neuromuscular, son los primeros y más importantes contribuyentes a la información propioceptiva[79]. Con un test activo a diferencia de la forma pasiva, estos receptores son potencialmente estimulados, por lo que la medición propioceptiva será más real al testar a los receptores musculares como lo más importantes contribuyentes propioceptivos. Paillard y Brouchon informaron que el test activo es más preciso por la existencia de contracción muscular, sin embargo en el test pasivo los receptores musculares están más silentes y los errores de posicionamiento son mayores[132].

La metodología del JPS se compone de sistemas muy sofisticados que van desde electrogoniómetros y sistemas completamente automatizados[97], hasta incluso sistemas electromagnéticos de control de movimiento[165]. Pero también pueden ser empleados sistemas más económicos que emplean la colocación de marcadores en las articulaciones y cámaras de vídeo con la posterior digitalización y análisis de la imagen para determinar el fallo en los distintos intentos de reposicionamiento articular. Ambas metodologías han demostrado fiabilidad en su ejecución en miembro inferior[130 14, 44], en miembro superior[46] e incluso en la totalidad de la columna vertebral[110, 165].

Otro componente vital en la propiocepción y en el correcto funcionamiento articular es el sentido de movimiento del miembro o también llamado *kinestesia*, con el que el sujeto detecta el movimiento de cualquier zona corporal[71], a diferencia de la propiocepción que detectaba la posición de la misma. Su evaluación suele ser llevada a cabo a través de la medición del umbral en el que el sujeto es capaz de detectar el movimiento pasivo, de tal modo que su afectación aumentará los valores de dicho umbral, indicando una deteriorada capacidad de detección del movimiento. Con frecuencia, la metodología de este tipo de test se compone de electrogoniómetros motorizados encargados de movilizar la articulación del sujeto a una velocidad de

5º/segundo. La fiabilidad de este método de evaluación ha sido mostrada en estudios previos[2, 44].

PROPIOCEPCIÓN Y FATIGA

La fatiga afecta a la mayor parte de las capacidades y aptitudes del deportista, incluyendo la propiocepción. Como ejemplo, ante la fatiga, el control neuromuscular activo del miembro inferior disminuye y puede aumentar la angulación en valgo de la rodilla. Esta situación incrementa la tensión de los ligamentos de la rodilla y el riesgo lesivo[38, 69, 70].

La fatiga es un proceso provocado por una estimulación o esfuerzo prolongados, en el que la fuerza del atleta se reduce hasta un 50% en pocos segundos, debido a la contracción máxima de varios músculos[152]. De particular interés es la fatiga periférica muscular, que se define como la incapacidad de mantener un nivel de fuerza después de un uso intenso y/o prolongado del músculo, lo cual conlleva una ineficacia contráctil y la afectación de la función muscular[85]. Sin embargo, ambos tipos de fatiga, central y periférica, ponen en marcha mecanismos de compensación a nivel bioquímico y metabólico para mantener la función corporal debido a que las aferencias propioceptivas llegan al sistema nervioso central tergiversadas. Esta alteración de información aferente dificulta la elaboración de respuestas motoras adecuadas[121]:

A nivel de activación muscular, la fatiga produce cambios en el reclutamiento motor y en los niveles de activación muscular[50, 124]. Se han detectado retrasos en la coativación muscular y disminución del control motor que incrementan la inestabilidad articular[64]. Este elentecimiento progresivo de las señales en EMG inducido por la fatiga muscular puede ser cuantificado en tiempo y frecuencia de las señales percibidas[16, 173].

A nivel de estabilidad postural, la fatiga incrementa los valores de balanceo postural de los deportistas[133], aunque la duración de esta afectación varía con el protocolo de fatiga aplicado[36, 43, 91, 133 92 159 24 111 133 164 54 119, 175]. Mello et al., en 2009 afirmaron que la fatiga resultante tras un test de consumo máximo de oxígeno deterioraba la estabilidad postural[119]. Otros autores estudiaron los efectos de otros protocolos de fatiga como competiciones de fútbol, triatlones o carrera prolongada. Todos describieron que la fatiga deteriora la propiocepción[24, 54, 133, 163]. También existen autores que describen los efectos de la fatiga tras protocolos de ejercicios locales isocinéticos. Entre los hallazgos, destacan que la fatiga en cuádriceps y después en tríceps sural deterioran más la estabilidad postural[17].

La fatiga también afecta al mecanismo de feedforward durante el proceso de mantenimiento postural**.** Allison y Henry observaron que tras un protocolo de fatiga, los músculos del tronco tardaban más en activarse para compensar el movimiento de uno de los brazos[3]. Similares resultados hallaron Mello et al., en 2007, quienes describieron que el gemelo se contrae aproximadamente un segundo antes de que se produzca el movimiento del centro de presiones. Este periodo de latencia es mayor que en movimientos controlados conscientemente, por lo que el feedforward juega un papel importance en el balanceo postural[118].

A nivel de consciencia de posición articular, numerosas investigaciones han descrito que la fatiga deteriora la agudeza del reposicionamiento articular de los deportistas[36, 90, 145]. La mayoría de los autores emplearon protocolos de fatiga local con cicloergómetros y mostraron que la extenuación local aumentaba los errores cometidos por los deportistas durante el posicionamiento activo y pasivo[30]. Otros investigadores usaron protocolos de fatiga general como partidos de fútbol o balonmano a nivel competitivo, triatlones, entrenamientos de running o ciclismo e incluso pruebas controladas de esfuerzo en laboratorio[145 36, 129]. Todas las investigaciones reportaron que la fatiga deterioraba la capacidad de reposicionamiento articular, aunque la duración de la afectación varió considerablemente con el protocolo de fatiga empleado[36, 145].

Todas las alteraciones propioceptivas que la fatiga ocasiona aumentan el riesgo de lesión de los deportistas[86, 87, 157] y disminuyen su rendimiento debido a la mayor ineficacia y coste energético del gesto deportivo[30].

Algunos autores describen los déficits de procesamiento central de las señales propioceptivas como el principal responsable de estas alteraciones motoras. Otros responsabilizan a las propias señales propioceptivas que están tergiversadas a nivel periférico. Por tanto, es unánime que la fatiga altera las respuestas motoras, aunque existe controversia sobre el origen de este deterioro[121].

PROPIOCEPCIÓN Y LESIONES EN EL DEPORTE

Lesión → deterioro propioceptivo

Numerosos investigaciones han descrito alteraciones propioceptivas tras una lesión, que deterioran las respuestas motoras y facilitan la consecución de recidivas y/o nuevas lesiones[51, 55, 65, 83, 140].

A nivel de estabilidad postural, se ha evidenciado de forma muy concluyente el aumento en los niveles de balanceo postural en los sujetos con lesiones previas de tobillo en deportista[1, 104 89]. Sin embargo, la permanencia en el tiempo de esta afectación estabilométrica no está aun consensuada, abarcando etapas desde las 2 semanas de afectación[66] hasta incluso los 2 meses. Incluso hay estudios que hablan de una afectación estabilométrica bilateral tras un esguince, sugiriendo una afectación neuromuscular central hasta incluso 21 días después del acontecimiento lesivo[51]. También existe evidencia de otras lesiones además de las referentes al tobillo como es la rotura de ligamento cruzado anterior (LCA), después de la cual el atleta presenta déficit en la estabilidad postural una vez recuperado, mostrándose además como factor predictor de una lesión de LCA secundaria[140].

En el reposicionamiento articular, ha sido demostrado que los sujetos con lesiones previas articulares, muestran un deterioro en la capacidad de reposicionamiento articular pasivo[21] y activo, déficit que puede prolongarse hasta los 6 meses[58]. También, Witchalls et al., (2013) mostraron que los atletas con inestabilidad crónica de tobillo mostraban un proceso de aprendizaje propioceptivo más lento en un test de discriminación de movimiento que evaluaba la sensibilidad propioceptiva[179].

También, la atrofia muscular tras una lesión deteriora la detección del movimiento corporal y aumenta el periodo de latencia entre la captación de ese estímulo y la respuesta motora del atleta. Esta afectación propioceptiva cambia la representación de actividad cortical[137], de tal modo que los deportistas sanos necesitan menos tiempo para detectar el estímulo y preparan antes la respuesta al mismo[153].

Deterioro propioceptivo → lesión

También, algunos autores han descrito deterioros propioceptivos previos a la lesión[112, 143, 177], debido a que existen factores de riesgo que deterioran la información propioceptiva, como la edad, el género, la deshidratación, el frío, algunas enfermedades o la fatiga[24, 32, 146, 148]. Este deterioro propioceptivo podría impedir al organismo elaborar respuestas motoras adecuadas, aumentando el riesgo lesivo[127, 131]. Sin embargo, existe controversia entre los autores debido a la disparidad de resultados hallados[76, 127].

A nivel de estabilidad postural, algunos estudios que evaluaron la estabilometría al inicio de la temporada de jugadores de baloncesto, determinaron un mayor balanceo postural como predictor de esguinces de tobillo durante el resto de la temporada[112, 143, 177]. Varios autores sugieren que estabilidad postural deteriorada puede predecir lesiones posteriores debido a una estrategia de control neuromuscular alterada[177 171, 183]. Esta estrategia sería la responsable de que aumentaran las fuerzas intersegmentales de las articulaciones, aumentando así las fuerzas aplicadas en ligamentos, tendones y musculatura[127].

Lo mismo ocurre con la estabilidad dinámica, en cuyo estudio Plisky (2006) analizó esta variable al comienzo de la temporada de jugadores de baloncesto a través del SEBT. Los autores concluyeron que era un método fiable cuya incorporación al inicio de la temporada podría ser útil en la predicción y detección de jugadores con riesgo lesivo[143].

A nivel de sentido de posición articular, hay pocos estudios que hayan evaluado el reposicionamiento articular de forma prospectiva. Payne et al., (2000) afirmaron que un déficit en el sentido de posicionamiento articular en el tobillo durante la primera semana del periodo competitivo podría ser usado como predictor de lesiones de tobillo durante el periodo competitivo[141]. También, hay autores que han descrito el déficit en el sentido articular de una articulación como predictor de lesión articular a otro nivel. Zazulak, en 2007, determinó un deterioro en el reposicionamiento activo del tronco como predictor de lesiones de rodilla en mujeres atletas, aunque no en hombres[182].

PROPIOCEPCIÓN Y DEPORTE

La evidencia científica dota de gran importancia a los parámetros propioceptivos como herramientas de predicción y de prevención lesiva. En este sentido, el deporte es un gran protagonista debido a la destacada evidencia existente sobre la práctica deportiva como principal método de mejora de la calidad de los inputs propioceptivos y las respuestas motoras. Se ha demostrado que el calentamiento previo a la práctica deportiva mejora la sensibilidad propioceptiva y el funcionamiento del sistema propioceptivo en general[12, 39, 56]. También, una revisión de estudios del 2013 mostró que el entrenamiento de fuerza y de propiocepción y la combinación de ambos reducían la incidencia de lesiones, aunque no ocurría lo mismo tras el entrenamiento con estiramientos[88].

A pesar del potencial riesgo lesivo al que se exponen los atletas diariamente por la estimulación excesiva de los propioceptores durante el acto deportivo y el consecuente deterioro propioceptivo transitorio, el intento de compensación de ese deterioro pone en marcha un aumento en la sensibilización de los propioceptores. Estos mecanismos han permitido la obtención de beneficios a partir de la realización de la actividad física y el deporte a todos los niveles[175].

Al igual que ocurre a niveles metabólicos y bioquímicos y en las capacidades básicas, a nivel propioceptivo y de las eferencias motoras también se consiguen progresos con la práctica deportiva:

En referencia al nivel de activación muscular, los deportistas muestran mejores valores de reclutamiento muscular que los no deportistas, de tal modo que los músculos se activan antes, se coactivan mejor y se produce una mejor estabilización[78, 115].

En cuanto a la estabilidad postural, como consecuencia de distintos niveles de actividad física, los no deportistas muestran peores valores que los deportistas[40, 76] y son más dependientes de la visión para la consecución de la estabilidad postural que los deportistas[37, 135, 117]. También, ha sido estudiada la estabilidad postural en los deportistas de la misma modalidad y distinto nivel competitivo, mostrando aquellos altamente entrenados mejor estabilidad postural y estabilidad dinámica que los de menor nivel[26, 37, 117, 135, 136]. Además, muchos autores han investigado la estabilidad postural en deportes como fútbol, baloncesto, judo, danza y personas activas[4, 22], mostrando que los gimnastas muestran mejor estabilidad postural, debido a que éstos trabajan más el equilibrio en sus entrenamientos y dominan más la estabilidad postural[40, 76]. Estos datos indican que los parámetros propioceptivos dependen de la especificidad y el nivel de actividad física[181 70, 154, 162]. También, Melnikova et al., (2013) reportaron que la estabilidad postural de atletas se deteriora menos tras un protocolo de ejercicio aeróbico intenso que en los no atletas. Además, la mejor recuperación de la frecuencia cardíaca de los atletas también contribuyó a este menor deterioro, como ya referían estudios previos[31, 116].

A nivel de reconocimiento de la posición articular, los deportistas poseen un sentido de posición articular más fino y agudo que los no deportistas, lo cual mejora la funcionalidad articular[126]. También, los deportistas detectan mejor el movimiento corporal y reaccionan más rápido a ese estímulo que los no deportistas[153].

EL ENTRENAMIENTO PROPIOCEPTIVO

La relación entre la propiocepción y las lesiones en el deporte ha conducido a muchos investigadores al diseño de entrenamientos para mejorar las capacidades propioceptivas de los deportistas y aumentar su control motor[49, 114, 172, 178].

El entrenamiento propioceptivo pretende acortar las respuestas motoras ante situaciones no aprendidas o imprevistas. Para ello, se reproducen situaciones de perturbación ante las que el individuo aprenderá respuestas motrices y se preparará para cuando éstas lleguen de forma natural y espontánea[76].

En el entrenamiento propioceptivo suele estar presente el entrenamiento del equilibrio como componente de control motor, cuyo objetivo es estimular los receptores propioceptivos para adaptar al máximo la cápsula y los ligamentos articulares ante la aparición de cargas en distintos sentidos y direcciones. Por tanto, se consigue una reacción más rápida ante desequilibrios por parte de los músculos, o al menos, éstos pueden llegar a su pico máximo de activación en menos tiempo[102]. Además, esta introducción de perturbaciones es la mejor vía para crear adaptaciones, más allá del hecho de mantener el equilibrio[76]. Cuando hablamos de perturbación hacemos referencia a cualquier estímulo físico que altera su estado de equilibrio. Introduciéndolas en el trabajo conseguimos un control postural, no sólo de la extremidad inferior sino del cuerpo en su totalidad, puesto que se controla por una interacción compleja de acciones musculares anticipatorias y preparatorias que se producen a lo largo de todo el cuerpo[120]. De hecho, se ha observado que el SNC crea una base estable para el movimiento de las articulaciones inferiores mediante la coactivación de los músculos del tronco, concretamente los multífidos y el transverso del abdomen[73]. Esto hace que haya un mejor control del movimiento y un menor riesgo lesivo[120].

Entrenamiento propioceptivo con plataformas inestables

En el entrenamiento propioceptivo, las plataformas inestables son una forma sencilla de trabajo que además de comprometer al sistema propioceptivo, también implica al visual y al vestibular. Aunque el empleo de Swiss ball en la rehabilitación y prevención de lesiones ya estaba presente en los años de la II Guerra Mundial[13], una reciente revisión ha desvelado que el entrenamiento propioceptivo a través del trabajo del equilibrio es una de las medidas más efectivas en la prevención de lesiones, especialmente de rodilla y tobillo, así como en el tratamiento del dolor de espalda[120].

Sin embargo, hay que tener en cuenta que, cómo cualquier tipo de trabajo, necesita una progresión racional y adecuada determinada por varios parámetros. En primer lugar y teniendo en cuenta que las mejoras van a ser similares a los ejercicios que el atleta realice, es aconsejable la realización de movimientos y ejercicios específicos de la modalidad del deportista[181]. Basándonos en la intensidad del ejercicio y en la progresión en la activación muscular, lo óptimo será el comienzo sobre superficie estable, apoyo bipodal y con ojos abiertos, para ir avanzando progresivamente en dificultad sobre superficie inestable, apoyo unipodal y ojos cerrados, acompañado de movimientos con cargas adicionales y/o perturbaciones externas[19]. La progresión dependerá de la adaptación de cada deportista[76].

A pesar de los beneficios derivados del entrenamiento propioceptivo, este tipo de trabajo debe ser considerado un componente adicional del entrenamiento del deportista y no así un sustitutivo de otro tipo de trabajo. Se ha demostrado que el trabajo de fuerza realizado en condiciones de inestabilidad aumenta hasta un 40,2% la actividad de los músculos del tren inferior implicados. Este aumento provocado para compensar la inestabilidad incluida con la superficie inestable, hace que la producción de fuerza disminuya hasta un 59,6%[8], lo cual reduce su mejora considerablemente y con ello, la capacidad de salto y de sprint[34].

Sin embargo, cuando el trabajo con superficie inestable se lleva a cabo como complemento del entrenamiento y no como sustitutivo, ha demostrado inducir mejoras claras en multitud de capacidades motoras. La incorporación del entrenamiento de equilibrio ha mostrado mejoras en el salto vertical y ejercicios de agilidad como el descenso de montaña con ski en eslalon o el shuttle run[76]. Sin embargo, los estudios que mostraron estos hallazgos no informaban de qué porcentaje de mejora era debido al entrenamiento de equilibrio o al entrenamiento base de los deportistas, por tanto, es importante la incorporación de trabajos futuros con el fin de dilucidar el origen real de las mejoras en las habilidades motoras de los deportistas y el porcentaje de protagonismo del entrenamiento propioceptivo[76].

Adaptaciones al entrenamiento propioceptivo

Todos los beneficios derivados del entrenamiento propioceptivo son obtenidos gracias a una serie de adaptaciones que dan explicación a los hallazgos que se testan en las mediciones en campo, como son las mejoras en estabilidad postural[180], salto vertical[80] y agudeza en el reposicionamiento articular[35, 76].

Según una revisión llevada a cabo por Hrysomallis en 2011[76], en la consecución de las mejoras en las diferentes habilidades motoras, tienen que ver distintas adaptaciones a nivel fisiológico:

Por una parte, se producen adaptaciones neuromusculares dentro de las cuales cabe destacar las modulaciones selectivas de la secuencia de activaciones de los músculos del tobillo ante situaciones potencialmente lesivas. Para desarrollar esas adaptaciones en el tobillo, los estudios llevados a cabo emplearon un disco inestable que reproducía los mecanismos lesivos en esa lesión, además de inhibir los músculos que facilitan el mecanismo lesional en la misma estructura articular. Con ello se comprueba que el hecho de intentar conducir al atleta a los mecanismos de lesión, hará que se adapten a dicha situación y desarrollen capacidades para reducir el riesgo lesivo en ese movimiento[76].

También se producen adaptaciones neurales específicas a la tarea realizada tanto a nivel espinal como supraespinal, lo cual explicaría la teoría de Yasuda y otros autores con la que sugieren la mejora específica conseguida a los ejercicios realizados durante el entrenamiento propioceptivo en plataforma inestable[181]. Estas adaptaciones son las siguientes:

- Con el entrenamiento propioceptivo en plataforma inestable, se produce una supresión del reflejo muscular de estiramiento durante las tareas posturales, disminuyendo así gran parte de los movimientos desestabilizadores[167].
- La inhibición del reflejo muscular de estiramiento mejora la co-contracción agonista-antagonista aumentando la estabilidad articular frente a posibles perturbaciones, además de aumentar la estabilidad postural[102].
- Las tareas específicas disminuyen la excitabilidad cortical, lo cual mejora la estabilidad postural[167].

- El entrenamiento propioceptivo en plataforma inestable ha mostrado una activación del recto femoral durante el aterrizaje después de un salto, aumentando la optimización músculo – tendinosa y la rigidez articular. Todo ello favorece la disminución de la fase de amortización en el ciclo de estiramiento – acortamiento muscular y por tanto, en las acciones de excéntrico – concéntrico, o lo que es lo mismo, en el trabajo pliométrico. Este mecanismo explicaría las mejoras reportadas en la bibliografía en cuanto al salto vertical con contramovimiento[80].

- Se han reportado incrementos en el "*rate of force development*", que hace referencia al desarrollo de la fuerza y que daría sentido a las mejoras en salto vertical[76].

A nivel central también se producen adaptaciones de tal modo que el SNC es capaz de llevar a cabo ajustes posturales según la información que se almacene desde experiencias motrices previas. Por lo que, al entrenar con perturbaciones y movimientos inesperados estamos provocando estímulos para que el SNC afine los ajustes posturales según los requerimientos de la situación. Si a esto le añadimos una mejora en la rapidez de esos ajustes, la lesión será más difícil que acontezca[6, 76, 120].

Esta mejora en el campo de la profilaxis de lesiones deportivas se sustenta gracias a que el entrenamiento propioceptivo modifica el patrón de activación muscular, siendo más rápida la reacción muscular ante un desequilibrio. Esto supone una mejora del control del movimiento, lo que disminuye el riesgo de lesión en las acciones realizadas[102]. Por otro lado, se consigue una mejor estabilidad articular que además de prevenir lesiones, hace que el atleta pueda desarrollar mayor potencia en el movimiento, lo cual suele comportar una mejora de su rendimiento[178].

En base a estos argumentos, el entrenamiento propioceptivo tiene 3 justificaciones importantes:

- Rehabilitación completa de la lesión.
- Prevención de lesiones y recidivas.
- Mejora del rendimiento[150].

Entrenamiento propioceptivo en la Rehabilitación de Lesiones

El entrenamiento propioceptivo como terapia complementaria en el proceso de rehabilitación de lesiones es una indicación muy frecuente que ha estado siempre ligada la Fisioterapia[94]. La principal razón es que el deterioro de la información propioceptiva inducido tras una lesión, supone pérdidas en la eficacia del movimiento y por tanto, un factor de riesgo ante la aparición de una recidiva o incluso una nueva lesión. La realización de ejercicios propioceptivos para mejorar o restaurar el control neuromuscular ante una lesión, se basa en que ligamentos, músculos, articulaciones y piel contienen propioceptores y una lesión de éstos alteraría la información que llega al Sistema Nervioso Central, siendo necesaria la restauración neurológica para la total recuperación. En base a los mencionados argumentos, Lephart et al. reportaron que el entrenamiento propioceptivo es crucial en la recuperación de lesiones[93].

Además, ante una situación de lesión en la que hay una alteración propioceptiva, el organismo desarrolla nuevos modelos de activación muscular de forma preventiva, que a veces no son suficientes. En este sentido, la creación de mecanismos automáticos para prevenir la lesión en situaciones de riesgo lesivo es el principal objetivo del entrenamiento propioceptivo, de tal modo que los patrones musculares deben anticiparse a la existencia de cargas lesionales. Por ello, en este tipo de trabajo se busca una repetición de una tarea para que el patrón de activación sea aprendido y puesto en práctica con mayor rapidez ante la situaciones comprometidas similares. Por ello, la especificidad del estímulo que se trabaje es fundamental para conseguir las adaptaciones deseadas[167]. Gracias a estos mecanismos, la evidencia del entrenamiento propioceptivo en la completa rehabilitación de lesiones y en la disminución así de las recidivas posteriores, se ha puesto de manifiesto en multitud de estudios. Verhagen et al., en 2004 llevaron a cabo un estudio en el que un grupo de jugadores de vóley-bol integraron en su rutina de entrenamiento un programa de entrenamiento propioceptivo en superficie inestable, mientras que otro grupo de jugadores similares de vóley-bol siguió con su rutina normal de trabajo. Los hallazgos mostraron que hubo una reducción significativa en la aparición de esguinces de tobillo en aquellos jugadores del grupo que realizó los ejercicios propioceptivos y que tenían una historia de esguinces recurrentes, aunque no hubo resultados significativos en aquellos jugadores sin lesiones previas[172]. Similares resultados fueron hallados por Hupperets et al., en 2008 y revisados por De Vries et al., en 2006 cuando estudiaron los efectos del entrenamiento propioceptivo en la recurrencia de lesiones de tobillo[42, 77]. Otros autores como Kynsburg et al., (2010) estudiaron los mecanismos propioceptivos que llevan a esa reducción lesiva. Para ello, integraron un programa de ejercicios propioceptivos a un grupo de jugadores de balonmano de élite a su rutina de entrenamiento y midieron el JPS del tobillo un día antes y 20 meses después. Estos autores hallaron mejoras significativas, concluyendo que la mejora del JPS es una de las claves por las que se disminuye el número de lesiones[84].

Entrenamiento propioceptivo en la Prevención de Lesiones

Además del posible daño propioceptivo posterior a una lesión, se ha evidenciado la existencia de alteraciones propioceptivas previas a la aparición de la lesión, incluso en deportistas sin lesiones anteriores, lo cual supondría un riesgo lesivo a tener en cuenta. Por ello, el entrenamiento propioceptivo ha sido incorporado más recientemente a las rutinas de entrenamientos de muchos deportistas a modo de prevención primaria, con el fin de compensar los deterioros propioceptivos que suponen un alto riesgo lesivo para los deportistas, incluso sin haber sufrido lesiones previas.

En esta dirección, cada vez son más los autores que diseñan estudios prospectivos con el fin de evaluar la importancia de esos deterioros en futuras lesiones. Mc Guine et al. (2006), evaluaron la estabilidad postural de jugadores de baloncesto durante las dos primeras semanas de la temporada y registraron las lesiones de los jugadores durante el resto de la temporada. Los resultados hallados permitieron describir el balanceo postural de estos deportistas como predictor lesivo, de tal modo que aquellos que tenían valores más altos de balanceo del centro de presiones al inicio de la temporada, mostraron mayor número de lesiones a largo plazo[113]. Similares fueron los resultados encontrados por Wang et al., en 2006, quienes correlacionaron lesiones de tobillo con peores valores de estabilidad postural en el plano mediolateral[177], al igual que habían hecho Tropp et al. unos años antes, en 1984[171] o Trojian and McKeag, que correlacionaron la estabilidad monopodal con esguinces de tobillo en 2006[170].

Además de la evaluación propioceptiva previa para conocer su importancia como factor de riesgo lesivo, numerosas investigaciones intentan diseñar protocolos de entrenamiento que compensen estas alteraciones y se reflejen en una disminución lesiva significativa. Sin embargo, los trabajos llevados a cabo sólo habían reportado reducción de lesiones significativa como prevención secundaria[77], es decir, para evitar recidivas una vez acontecida la lesión. Ninguno, para nuestro conocimiento, había hallado resultados significativos sobre el entrenamiento propioceptivo como estrategia de prevención primaria[48]. En 2010, Elis et al., realizaron un estudio en jugadores de baloncesto sin historia de esguinces o lesiones previas, a los que aplicaron un protocolo de ejercicios propioceptivos como parte de su rutina de entrenamiento, a la vez que un grupo similar de jugadores de baloncesto se limitó a realizar sólo su rutina. Los datos de este estudio reportaron una diferencia significativa en la aparición de lesiones entre ambos grupos, de tal modo que se contabilizaron 7 lesiones en el grupo que realizó el programa propioceptivo frente a las 22 lesiones que acontecieron en el grupo que no lo llevó a cabo[49].

Entrenamiento propioceptivo en el Rendimiento Deportivo

El entrenamiento propioceptivo también ha sido investigado en el terreno deportivo por su supuesto potencial en la mejora de la técnica deportiva debido a la información que proporciona sobre la posición y el movimiento corporal[13]. Por ello, muchos autores han analizado su repercusión en diferentes capacidades que marcan el rendimiento deportivo[160, 180].

Algunos estudios han demostrado mejoras en el equilibrio tanto dinámico como estático como beneficio para el rendimiento puesto que la optimización estabilométrica supone una base más estable desde la que realizar los movimientos deportivos complejos[178]. Mattacola et al. (1997), Gioftsidou et al. (2006), Marshall and Murphy (2006) o Yaggie and Campbell (2006) obtenían mejoras significativas en equilibrio en diferentes modalidades deportivas[60, 103, 108, 180]. Parece ser que cuando ciertos reflejos aparecen en determinadas situaciones inesperadas, pueden desarrollarse de forma correcta equilibrándonos ante una situación de inestabilidad, o de forma incorrecta desequilibrándonos aún más. Con el entrenamiento propioceptivo se tienden a eliminar estos últimos, llevándose a cabo una respuesta óptima[166].

También, Lephart et al., en el 2000 afirmaron que la propiocepción permite mantener mejor la estabilidad de rodilla durante la fase estática haciendo que esta articulación actúe de forma coordinada y precisa. Esa estabilidad suponía una mejora en la efectividad del movimiento de la articulación transfiriéndose a mejoras muy funcionales, como la mejora de la velocidad de la marcha[93]. Y es que la efectividad del movimiento depende de la facilitación de agonistas e inhibición de antagonistas que proporcionan los receptores propioceptivos[176]. Por tanto, la propiocepción es muy importante en los movimientos comunes que realizamos diariamente y especialmente, en los movimientos deportivos que requieren una coordinación especial[109].

Por ello y puesto que el entrenamiento propioceptivo tiene una transferencia positiva de cara a acciones nuevas similares a los ejercicios que hemos practicado, podría tener una gran transferencia en el campo de la mejora de la técnica, aunque hasta la fecha no ha sido evidenciado.

A nivel de mejora en la fuerza, se ha observado un incremento al inicio de una acción isométrica resultando beneficioso en la fuerza explosiva[63]. También, se han reportado incrementos en las señales propioceptivas y fuerza muscular específica, así como mejoras significativas en el tiempo de reacción[180] y en la agilidad[76, 156].

Otros muchos trabajos, a pesar de haber reportado mejoras estabilométricas y propioceptivas, no han conseguido producir mejoras claras en las habilidades más importantes en deportistas con la inclusión de entrenamiento propioceptivo en la rutina de entrenamiento como la carrera de velocidad[74, 180]. Sin embargo, se han observado cambios e incluso mejoras en la capacidad de salto[18, 107, 128, 156, 168]. Boccolini et al., (2013) reportó que tras 12 semanas de entrenamiento en superficie inestable – 2 sesiones semanales de 30 minutos –jugadores de baloncesto juniors mejoraron la potencia de salto –CMJ – además de la estabilidad postural monopodal y bipodal[18]. Taube et al., (2007) y Myer et al, (2006) encontraron similares resultados en atletas[128, 168].

PROBLEMA DE INVESTIGACIÓN (RESEARCH PROBLEM)

Planteamiento del problema

La documentada presencia de lesiones en el contexto deportivo y el elevado gasto que éstas inducen dota de gran relevancia la necesidad de la puesta en marcha de programas de prevención que impidan y/o disminuyan la aparición de lesiones en el deporte, a la vez que controlen los factores de riesgo más importantes. En la bibliografía se define la importancia de la evaluación propioceptiva y la realización de entrenamiento propioceptivo tras el acontecimiento lesivo, a modo de prevención secundaria. Sin embargo, existe controversia en cuanto a su efectividad como estrategia de prevención primaria. Asimismo, aunque se ha evidenciado la influencia del entrenamiento en la propiocepción del deportista, queda por descubrir qué tipos de entrenamientos son los que más afectan a la capacidad propioceptiva, poniendo en un potencial riesgo lesivo al atleta. Por otra parte, hay varias investigaciones que evalúan de forma prospectiva a jugadores de baloncesto y de fútbol, pero casi ninguno que analice a atletas[112, 113, 171].

En base a lo anterior, se han formulado las siguientes preguntas de investigación: ¿existen diferencias propioceptivas entre los atletas en función del tipo y volumen entrenamiento que lleven a cabo tanto a medio-largo plazo (Artículos I, II y VI) como a corto plazo (Artículos III, IV, VII y VIII)? e ¿influyen estas diferencias en la posterior aparición de lesiones (Artículo V)?

OBJETIVOS

General:

El objetivo general de esta Tesis Doctoral fue analizar la influencia del tipo, la intensidad y el volumen de entrenamiento en la estabilometría de atletas tanto a medio – largo plazo (artículos II y II y VI) como a corto plazo (artículos III y IV, VII y VIII). Al mismo tiempo, se analizó la influencia de la estabilidad postural en la aparición de lesiones (artículo V) y se diseñó un programa de entrenamiento para mejorar la estabilometría y otras habilidades motoras (artículos I y II), teniendo en cuenta los efectos inmediatos de ese entrenamiento (artículos III y IV).

Específicos:

- Analizar los efectos de un programa de entrenamiento propioceptivo con superficie inestable en la estabilidad postural y en el rendimiento deportivo de atletas velocistas (**Artículos I y II**).

- Examinar los efectos a corto plazo de una sesión de entrenamiento propioceptivo con superficie inestable en la estabilidad postural bipodal y monopodal de atletas **(Artículos III y IV).**

- Estudiar la estabilometría de atletas y su influencia en la posterior aparición de lesiones deportivas **(Artículo V)**.

- Describir los cambios estabilométricos de atletas velocistas y fondistas durante la temporada de pista cubierta y comparar la estabilometría de atletas velocistas y fondistas durante la temporada de pista cubierta **(Artículo VI)**.

- Analizar los efectos de una sesión de entrenamiento anaeróbico láctico en la estabilidad postural y en la propiocepción de atletas **(Artículos VII y VIII)**.

AIMS

Overall:

The overall purpose of this Thesis was to analyze the short-term (papers III and IV, VII and VIII) and medium and long-term effects (papers I and II, and VI) of type, intensity and volume of training on stabilometry of athletes. We also analyzed the effects of the postural stability on subsequent sports injuries (paper V) and designed a proprioceptive training program that improves stability and other motor skills (papers I and II), by taking into account the short-term effects of the proprioceptive training in athletes (papers III and IV).

Specific:

- To analyze the effects of proprioceptive training on the postural stability, strength and speed of sprinters **(Papers I and II)**.
- To examine the short-term effects of a proprioceptive training session with unstable platforms on the bipedal and monopodal postural stability of athletes **(Papers III and IV).**
- To study the effects of postural stability on subsequent sports injuries of athletes **(Paper V)**.
- To describe the stabilometric differences in every training period of the indoor-season and compare the postural stability of sprinters with middle-distance runners **(Paper VI)**.

- To analyze the short-term effects of a lactate-accumulation training session on postural stability and proprioception of athletes **(Papers VII and VIII)**.

RESULTADOS (RESULTS)

- Tras 6 semanas de entrenamiento propioceptivo, los sujetos experimentales obtuvieron valores de balanceo mediolateral más cercanos al eje de ordenadas que los controles (-1,1 ± 4,3 mm vs 2,6 ± 2,8 mm, p = 0,010) y (- 0,78 ± 4,31 mm vs 2,30 ± 2,74 mm, p=0,010) y mayor control de centro de gravedad hacia posterior y hacia la derecha (p = 0,026 y p = 0,041, respectivamente). Además, el grupo experimental alcanzó mayor altura en SJ (p = 0.032) y en CMJ (p = 0,047) que el grupo de Control **(Artículos I y II)**.

- Tras una sesión de 30 minutos entrenamiento propioceptivo, los sujetos experimentales mostraron en apoyo bipodal un incremento de los valores de longitud (p=0,045) y velocidad (p=0,022) y del posicionamiento mediolateral (p<0,001) del recorrido del centro de presiones, el cual fue más lejano al eje de ordenadas que los sujetos controles (p=0,009). En apoyo monopodal, los sujetos experimentales presentaron valores más bajos de longitud y velocidad del recorrido del centro de presiones (p=0,030 y p=0,021 respectivamente) y valores más centrados de posicionamiento mediolateral y anteroposterior (p=0,005 y p=0,009, respectivamente) que los sujetos controles. Además, el grupo experimental mostró valores estabilométricos constantes mientras que los controles sufrieron contínuas fluctuaciones en todas las variables de apoyo monopodal **(Artículos III y IV)**.

- Los atletas con valores más altos en longitud y velocidad del centro de presiones en apoyo bipodal (p=0,005 y p=0,009, respectivamente) y un posicionamiento mediolateral más alejado del eje de ordenadas en apoyo monopodal (p=0.041) eran más propensos a sufrir lesiones en el periodo de entrenamiento consecutivo **(Artículo V)**.

- Los atletas presentaron los valores más elevados de longitud y velocidad del centro de presiones durante el periodo de volumen, seguido del precompetitivo. Además, los atletas de mediofondo presentaban valores de posicionamiento anteroposterior más alejados del eje de abcisas que los velocistas en apoyo monopodal izquierdo y derecho (p=0,005 y p=0,030, respectivamente) **(Artículo VI)**.

- Tras una sesión de entrenamiento láctico, los atletas presentaban un incremento inmediato en la longitud y velocidad del recorrido del centro de presiones en apoyo bipodal (p_s<0,001) y monopodal (longitud izquierdo y derecho: p=0,004 p=0,038; velocidad izquierdo y derecho: p=0,015 y p=0,015, respectivamente) y un posicionamiento anteroposterior del apoyo izquierdo más alejado del eje de abcisas (p=0,01), además de un mayor error angular absoluto en el reposicionamiento de la rodilla que el grupo control (p=0,001). Los atletas continuaban mostrando valores estabilométricos elevados en apoyo bipodal tras 30 minutos (p=0,013), sin embargo 24 horas más tarde presentaban un descenso de estos valores por debajo de la línea base (p=0,046) **(Papers VII y VIII)**.

DISCUSIÓN (DISCUSSION)

El objetivo general de esta Tesis Doctoral fue analizar la influencia del tipo, la intensidad y el volumen de entrenamiento en la estabilometría de atletas tanto a medio – largo plazo (artículos II y II y VI) como a corto plazo (artículos III y IV, VII y VIII). Al mismo tiempo, se analizó la influencia de la estabilidad postural en la aparición de lesiones (artículo V) y se diseñó un programa de entrenamiento para mejorar la estabilometría y otras habilidades motoras (artículos I y II), teniendo en cuenta los efectos inmediatos de ese entrenamiento (artículos III y IV).

Los **artículos I y II** analizaron los efectos de seis semanas de entrenamiento propioceptivo con superficies inestables y mostraron que los atletas mejoraron la estabilidad postural y la potencia de salto.

Las mejoras estabilométricas se mostraron en consonancia con estudios previos, que realizaron programas de entrenamiento propioceptivo en superficie inestable de entre 6 y 10 semanas de duración, realizando dicho entrenamiento entre 3 y 5 veces en semana y 10 – 20 minutos cada vez. Sin embargo, nosotros sólo hallamos mejoras en el balanceo postural mediolateral, como ocurría en el estudio de Biec y Kunzkinsky en jugadores de fútbol[15]. Contrario a estos hallazgos, Paterno encontró que la estabilidad unipodal mejoraba el balanceo postural anteroposterior tras un programa de entrenamiento propioceptivo de 10 semanas en jugadoras de fútbol[139]. Ante esta disimilitud entre resultados, los autores sugieren un tipo de estrategia estabilizadora que difiere según las perturbaciones que el atleta recibe y por tanto, con el tipo de ejercicios y material utilizado en el programa de entrenamiento, así como el tipo de atletas[75, 175]. También, los atletas mejoraron el control del centro de gravedad, apoyando así los resultados del estudio de Mattacola et al. en 1997[108], quien encontró mejoras en la misma variable de estabilidad dinámica.

Por otra parte, en el **artículo II** encontramos una tendencia de mejora en la potencia de salto vertical que se sitúa en la misma línea que estudios previos[107, 128, 168]. Taube et al., (2007), Myer et al., (2006) y Boccolini et al., (2013) reportaron mejoras en salto vertical tras un programa de entrenamiento propioceptivo en atletas, mujeres atletas y jugadores de baloncesto juniors, respectivamente[107, 128, 168]. También Ziegler et al. (2002) y Kean et al. (2006) reportaron mejoras de salto tras un programa de ejercicios propioceptivos en mujeres activas[80, 184], similares al estudio de Simek et al., (2007) realizado en hombres activos[156]. Sin embargo, que la muestra estuviera compuesta por deportistas jóvenes o personas activas pudo haber condicionado los resultados. En contraste, en el estudio de Yaggie and Campbell, los atletas no mejoraron el salto tras un programa de entrenamiento propioceptivo. Además, en este estudio los atletas no mejoraron el "shuttle run" como variable de agilidad en carrera, aunque sí la estabilidad postural[180]. Estos hallazgos concuerdan parcialmente con los resultados de nuestras investigaciones, en las que los atletas no mejoraron la velocidad de carrera pero sí la estabilidad postural.

De forma general, muy pocas investigaciones hasta la fecha han mostrado mejoras claras en la capacidad de salto de deportistas tras entrenamiento propioceptivo[18, 168], aunque sí tendencias o cambios favorables[107, 156]. Además, el entrenamiento propioceptivo no ha mostrado mejoras en las variables directas de rendimiento como la velocidad y la agilidad. Sin embargo, basándonos en las mejoras halladas por Boccolini et al., (2013) en la potencia de salto de jugadores de baloncesto tras 12 semanas de entrenamiento propioceptivo[18], la tendencia favorable encontrada en nuestro artículo II podría ser un atisbo de mejoras futuras si el entrenamiento propioceptivo se continuase en el tiempo.

Según los artículos I y II, el entrenamiento propioceptivo mejora la estabilidad, lo cual podría prevenir lesiones de acuerdo al **artículo V**, de carácter prospectivo y donde la estabilidad postural era significativamente peor en los atletas que se lesionaban posteriormente. Este estudio sigue la línea de las escasas investigaciones prospectivas que describieron la estabilidad como parámetro indicador de lesiones posteriores. Wang et al., en 2006 y McGuine et al., en 2000 analizaron las semanas iniciales de la temporada de jugadores de baloncesto, identificando el balanceo postural mediolateral y las variables que definen el recorrido del centro de presiones respectivamente, como predictores de lesiones de tobillo y pie posteriores[177 112]. Del mismo modo, Trojian y McKeag en 2006, lograron correlacionar un deterioro de la estabilidad unipodal con lesiones de tobillo y pie en deportistas[170].

En base a los hallazgos de los artículos I, II y V, podemos afirmar que los deportistas que incluyen trabajo propioceptivo en su rutina de entrenamiento mejoran la estabilidad postural, la cual es una diana para la prevención primaria de lesiones.

Por ello, es importante describir los periodos de entrenamiento que más deterioran la estabilidad postural de los atletas y actuar con vehemencia en esas etapas. Con este objetivo se diseñó el **artículo VI,** cuyos hallazgos han permitido conocer que los atletas muestran un mayor deterioro estabilométrico en el periodo de volumen seguido del precompetitivo, ambos como periodos de entrenamiento con más carga de trabajo y entrenamiento poco específico. Estos resultados mejoraban al cambiar al periodo competitivo, más intenso y específico. Aunque los atletas mostraban la mejor estabilidad postural de la temporada de invierno en el periodo más general, en la pretemporada. Los estudios que analizan los efectos del entrenamiento en la estabilidad postural muestran la misma línea que nuestro artículo VI. Perrin et al. en el 2002, concluyeron que entrenamientos más generales podían contribuir a un desarrollo de adaptaciones sensitivomotoras transferibles a la estabilidad postural de los deportistas[142]. Del mismo modo, nuestro estudio muestra la mejor capacidad estabilométrica en pretemporada, donde los ejercicios son muy generales. Por otro lado, la bibliografía muestra que atletas del mismo deporte pero mayor nivel e intensidad competitiva, tienen mejor estabilidad postural[134, 135]. También, la estabilidad postural cambia entre deportistas, representando los gimnastas los deportistas con mejor capacidad estabilométrica y sugiriendo una adaptación por parte de entrenamiento más específico. Ambas conclusiones apoyarían al estudio de Thorpe and Ebersole, quienes afirmaron que la estabilidad es sensible a la etapa de entrenamiento en el que se encuentre el atleta e induce adaptaciones corporales inducidas según la intensidad y el volumen de entrenamiento[169]. En apoyo a la bibliografía, nuestros resultados muestran que la estabilidad postural mejora al pasar de los periodos de más carga de entrenamiento (volumen y precompetitivo) al periodo competitivo, compuesto por entrenamientos muy intensos y específicos.

Sin embargo, también hemos de tener en cuenta que los periodos centrales de la temporada, en los que se ha observado mayor deterioro estabilométrico en nuestro artículo VI (volumen y precompetición) son los que más carga de trabajo sustentan y por tanto mayor nivel de fatiga, la cual debe ser considerada por su demostrada relación con la estabilidad[32, 36, 54, 111]. Estos periodos contienen la mayor parte del trabajo láctico de la temporada, el cual induce un alto daño muscular. Por ello, los **artículos VII y VIII** se diseñaron para analizar los efectos a corto plazo del entrenamiento láctico en la propiocepción y estabilidad del atleta. Los resultados mostraron que esta tipología de entrenamiento deteriora la estabilometría y el posicionamiento articular de la rodilla de forma inmediata. Estos hallazgos son afines a innumerables estudios que han evaluado los efectos a corto plazo de protocolos de ejercicios extenuantes, mostrando siempre un deterioro estabilométrico[24, 36, 64, 133] y en la capacidad de reposicionamiento articular tanto miembro inferior como superior e incluso columna vertebral[36, 90, 144, 147]. Voight et al., sugieren que los husos musculares se desensibilizan y son incapaces de enviar la información propioceptiva al sistema nervioso de forma eficaz. Consecuentemente, el reconocimiento posicional y la estabilidad postural se deterioran[174]. Además, el artículo VIII muestra que el deterioro estabilométrico contínua 30 minutos más tarde. Por lo que, de acuerdo a los resultados de nuestro artículo V, el atleta se encuentra en una situación de potencial riesgo lesivo post-entrenamiento. Por otra parte, este mismo artículo muestra que la estabilometría mejora incluso los valores basales 24 horas después del trabajo láctico. Este hallazgo podría ser justificado por las adaptaciones que los deportistas experimentan con la actividad física y que los dotan de una mejor capacidad estabilométrica en comparación con los no deportistas[4, 52, 92]. Por tanto, sería interesante analizar los efectos de diferentes metodologías de entrenamiento en la propiocepción de los deportistas.

En base a los resultados de los artículos I y II, V, VI, VII y VIII, los periodos de entrenamiento de volumen y pre-competición se presentan como etapa diana en la que incluir el entrenamiento propioceptivo para mejorar la estabilidad y prevenir lesiones posteriores.

Por otra parte, para que los deportistas incluyan el entrenamiento propioceptivo como complemento de su rutina de trabajo, los **artículos III y IV** analizaron los efectos inmediatos del entrenamiento propioceptivo en la estabilidad postural. Los hallazgos mostraron que el entrenamiento propioceptivo reporta un mantenimiento o "congelación" inmediata de los valores en la estabilometría monopodal, pero al mismo tiempo deteriora la estabilometría bipodal. La justificación de estos resultados podría radicar en la fatiga resultante del ejercicio propioceptivo intenso al que se sometieron, aunque al no ser determinada mediante medición, la fatiga no es concluida como causa sino a modo de sugerencia. Probablemente y de acuerdo a la revisión de Hrysomallis en 2011, los atletas no hicieron un entrenamiento propioceptivo con una secuencia progresiva[76], lo que pudo dificultar la mejora estabilométrica. También, la sesión propioceptiva que los atletas realizaron consistió en ejercicios monopodales, lo cual pudo mejorar los parámetros monopodales debido a la especificidad del entrenamiento y no los bipodales[181].

Nuestros artículos III y IV aportaron nueva evidencia sobre los efectos agudos del entrenamiento propioceptivo, sin embargo, sería interesante incorporar una muestra de atletas con experiencia en trabajo propioceptivo para descartar que la progresión de la secuencia no haya condicionado los resultados.

En general, los hallazgos mostrados en los distintos trabajos de esta Tesis muestran que los atletas que realizan entrenamiento propioceptivo mejoran la estabilidad postural, lo cual puede impedir lesiones posteriores. Considerando una dosis y progresión adecuada, la mejor etapa para realizar el entrenamiento propioceptivo se corresponde con los periodos de más carga y trabajo de la temporada puesto que la estabilidad está más deteriorada. Además, el entrenamiento láctico constituye una situación de potencial riesgo lesivo, puesto que altera la estabilidad y el reconocimiento articular de forma inmediata. A nivel de rendimiento deportivo, el entrenamiento propioceptivo mejora la potencia de salto de forma moderada, aunque no se transfiere en mejoras más funcionales.

Entrenadores y fisioterapeutas han de valorar los condicionantes que mejoran y deterioran la propiocepción para mitigar el riesgo lesivo de los deportistas.

CONCLUSIONES

- Seis semanas de entrenamiento propioceptivo mejoran la estabilidad postural y el control de centro de gravedad en velocistas, además de producir moderadas mejoras en la potencia de salto vertical, aunque estas mejoras no se transfieren a mayor velocidad de carrera **(Artículos I y II)**.

- Una sesión de entrenamiento propioceptivo deteriora de forma inmediata la estabilidad postural bipodal de atletas, sin embargo mantiene constantes los valores de estabilidad monopodal **(Artículos III y IV)**.

- Los atletas que presentan mayores valores de dispersión en apoyo bipodal o posicionamiento medio-lateral en apoyo monopodal del centro de presiones son más propensos a lesionarse en el periodo de entrenamiento subsequente **(Artículo V)**.

- Los atletas muestran peores valores estabilométricos en los periodos de entrenamiento con mayor carga de trabajo y estos valores mejoran con menor carga y mayor intensidad de entrenamiento, sin influencia de la modalidad de carrera de los atletas. Sin embargo, los velocistas tienen una mejor estabilidad postural monopodal en plano anteroposterior comparado con los medio-fondistas **(Artículo VI)**.

- Una sesión de entrenamiento láctico deteriora de forma inmediata la estabilidad postural y la propiocepción de los atletas. Treinta minutos después este deterioro se mantiene en la estabilidad postural, aunque tras 24 horas, existe una mejora de los valores estabilométricos basales **(Artículos VII y VIII)**.

CONCLUSIONS

- Six weeks of proprioceptive training improve postural stability and control of gravity center of athletes, and also produce moderate improvements in jump power, which is untransferable to a faster race **(Papers I and II)**.

- A proprioceptive training session immediately deteriorates the bipodal postural stability of athletes, however maintains stabilometric values on monopodal support **(Papers III and IV)**.

- Athletes showing worse postural stability – higher center-of-pressure spread on bipodal support and a mediolateral center-of-pressure position further from axis of ordenates on monopodal support – are more prone to injuries in subsequent training period **(Paper V)**.

- Athletes show worse postural stability in training periods with a higher volume of workload, and it improves in periods with a low-volume, high intensity workload. The athletic variety does not have any influence on these differences, although sprinters display better anteroposterior monopodal stability compared with middle-distance runners **(Paper VI)**.

- A lactic training session deteriorates immediately the postural stability and proprioception of athletes. Although after thirty minutes the stabilometric deterioration remains, 24 hours later, stability is better than basal level **(Papers VII and VIII)**.

AGRADECIMIENTOS (ACKNOWLEDGEMENTS)

Después de haber transcurrido días, semanas, meses y años desde que escribí la primera palabra destinada a esta Tesis, casi estoy a punto de plasmar la última, aunque no sin antes acordarme de todas las personas que me han acompañado y ayudado en este largo y arduo camino.

Mis padres, siempre dispuestos a hacer un hueco en el sofá a la niña del inseparable ordenador y a esperarme todo el tiempo del mundo después de un día de mediciones.

Mis hermanos, que de forma peculiar, siempre mostraron su orgullo por la hermana más "frikie" y cabezona de la familia.

Victoria y José Miguel, que me hicieron sentir siempre como una más de la familia.

Mis tutores de Tesis, Antonio y Emilio. Antonio, por el apoyo mostrado desde el día en que le propuse mi proyecto y por su aliento cuando las cosas parecía que se torcían. Emilio, por su incansable empeño en enseñarme y aportarme nuevos puntos de vista, fuera el día y la hora que fuera.

Fidel, Cati y Rafa, por sus aportaciones y disponibilidad ante cualquier duda, proyecto o trabajo, por loco que pareciera.

Pedro, con su perspectiva diferente y refrescante que avivó el fuego de la ilusión en cada trabajo. También por aportarme el cambio que sin duda necesitaba y ponerle la guinda a este gran pastel.

Una guinda portuguesa que le ha dado el toque de color, no sólo a esta Tesis, sino también a mí misma. Una estancia de 3 meses en la ciudad del vino, de la que gente amable y del trabajo bien hecho. Filipe, quien facilitó mi comienzo y me hizo reir después de cada entrenamiento. Joana, por su atención desde el primer email y su muestra de hospitalidad en cada palabra y gesto. Al gran profesor Oliveira, por su tiempo y sus innovadoras aportaciones y perspectivas a la investigación y por prestarse a trabajar desde el primer día con "la menina española de Jaén". A Paulo Colaço, por su colaboración y aportes como profesor, investigador y entrenador. Y a Jorge Mota, por tener tiempo siempre para acordarse de mí, a pesar de ir siempre "volando" para atendernos a todos.

No puedo olvidarme de todos los entrenadores que mostraron su apoyo y ofrecieron su tiempo para que este sueño pudiera hacerse realidad. Y los propios atletas, por mostrarme la mejor de sus sonrisas aunque no tuvieran aliento "por mi culpa".

Y por supuesto, a tí, por acompañarme desde el minuto cero, por ayudarme en cada medición, respondiendo siempre aunque no te lo pidiera. Por estar siempre ahí, demostrándome que se puede y que nunca hay que rendirse. Gracias por poner la luz a este camino y gracias por cogerme la mano cada vez que tropezaba.

A todos, muchas gracias.

BIBLIOGRAFÍA (REFERENCES)

1. Akbari M, Karimi H, Farahini H, Faghihzadeh S. Balance problems after unilateral lateral ankle sprains. *Journal of Rehabilitation Research & Development.* 2006;43(7):819-824.

2. Allegrucci M, Whitney S, Lephart S, Irrgang J, Fu F. Shoulder kinesthesia in healthy unilateral athletes participating in upper extremity sports. *Journal of Orthopaedic and Sports Physical Therapy.* 1995;21:220-220.

3. Allison GT, Henry SM. The influence of fatigue on trunk muscle responses to sudden arm movements, a pilot study. *Clinical Biomechanics.* 2002;17(5):414-417.

4. Ambegaonkar JP, Caswell SV, Winchester JB, Shimokochi Y, Cortes N, Caswell AM. Balance comparisons between female dancers and active nondancers. *Research Quarterly for Exercise & Sport.* 2013;84(1):24-29.

5. Andalucía, Instituto de Análisis Económico y Empresarial. Actividad económica del deporte en Andalucía 2008. 2010.

6. Anderson K, Behm DG. The impact of instability resistance training on balance and stability. *Sports Medicine.* 2005;35(1):43-53.

7. Anderson K, Behm DG. Trunk muscle activity increases with unstable squat movements. *Canadian Journal of Applied Physiology.* 2005;30(1):33-45.

8. Anderson KG, Behm DG. Maintenance of EMG activity and loss of force output with instability. *The Journal of Strength & Conditioning Research.* 2004;18(3):637-640.

9. Aruin A, Latash M. Directional specificity of postural muscles in feed-forward postural reactions during fast voluntary arm movements. *Experimental Brain Research.* 1995;103(2):323-332.

10. Association NCA. Injury surveillance system. *Washington: NCAA.* 2002.

11. Bahr R, Maehlum S. *Lesiones deportivas: diagnóstico, tratamiento y rehabilitación*: Editorial Medica Panamericana; 2007.

12. Bartlett MJ, Warren PJ. Effect of warming up on knee proprioception before sporting activity. *British Journal of Sports Medicine.* 2002;36(2):132-134.

13. Behm DG, Anderson K, Curnew RS. Muscle force and activation under stable and unstable conditions. *The Journal of Strength & Conditioning Research.* 2002;16(3):416-422.

14. Benjaminse A, Sell TC, Abt JP, House AJ, Lephart SM. Reliability and precision of hip proprioception methods in healthy individuals. *Clinical Journal of Sport Medicine.* 2009;19(6):457-463.

15. Biec E, Kuczynski M. Postural control in 13-year-old soccer players. *European Journal of Applied Physiology.* 2010;110(4):703-708.

16. Bigland-Ritchie B, Johansson R, Lippold OC, Woods JJ. Contractile speed and EMG changes during fatigue of sustained maximal voluntary contractions. *Journal of Neurophysiology.* 1983;50(1):313-324.

17. Bizid R, Margnes E, François Y, et al. Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *European Journal of Applied Physiology.* 2009;106(3):375-380.

18. Boccolini G, Brazzit A, Bonfanti L, Alberti G. Using balance training to improve the performance of youth basketball players. *Sport Sciences for Health.* 2013;9(2):37-42.

19. Borreani S, Calatayud J, Martin J, Colado JC, Tella V, Behm D. Exercise intensity progression for exercises performed on unstable and stable platforms based on ankle muscle activation. *Gait & Posture.* 2013 [Epub ahead of print].

20. Bouisset S, Duchêne J-L. Is body balance more perturbed by respiration in seating than in standing posture? *NeuroReport.* 1994;5(8):957-960.

21. Boyle J, Negus V. Joint position sense in the recurrently sprained ankle. *Australian Journal of Physiotherapy.* 1998;44(3):159-163.

22. Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic Training.* 2007;42(1):42-46.

23. Bricot B. Postura normal y posturas patológicas. *Revista del Instituto de Posturología y Podoposturología.* 2008;1(2):1-13.

24. Brito J, Fontes I, Ribeiro F, Raposo A, Krustrup P, Rebelo A. Postural stability decreases in elite young soccer players after a competitive soccer match. *Physical Therapy in Sport.* 2012;13(3):175-179.

25. Brown JE, Frank JS. Influence of event anticipation on postural actions accompanying voluntary movement. *Experimental Brain Research.* 1987;67(3):645-650.

26. Butler RJ, Southers C, Gorman PP, Kiesel KB, Plisky PJ. Differences in soccer players' dynamic balance across levels of competition. *Journal of Athletic Training.* 2012;47(6):616-620.

27. Cachupe WJC, Shifflett B, Kahanov L, Wughalter EH. Reliability of Biodex Balance System Measures. *Measurement in Physical Education and Exercise Science.* 2001;5(2):97-108.

28. Cambisaca C. *Influencia de los ejercicios propioceptivos en la prevención de las lesiones de rodilla en los jugadores de fútbol del equipo de la ESPE entre los 18-25 años de edad en el periodo Oct - Abril del 2008*. [Thesis]. Sangolqui: Escuela Politécnica del Ejército, 2008.

29. Caron O, Gelat T, Rougier P, Blanchi JP. A comparative analysis of the center of gravity and center of pressure trajectory path lengths in standing posture: an estimation of active stiffness. *Journal of Applied Biomechanics.* 2000;16(3):234-247.

30. Carpenter JE, Blasier RB, Pellizzon GG. The effects of muscle fatigue on shoulder joint position sense. *The American Journal of Sports Medicine.* 1998;26(2):262-265.

31. Conforto S, Schmid M, Camomilla V, D'Alessio T, Cappozzo A. Hemodynamics as a possible internal mechanical disturbance to balance. *Gait & posture.* 2001;14(1):28-35.

32. Corbeil P, Blouin JS, Begin F, Nougier V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. *Gait & Posture.* 2003;18(2):92-100.

33. Cote KP, Brunet ME, Gansneder BM, Shultz SJ. Effects of Pronated and Supinated Foot Postures on Static and Dynamic Postural Stability. *Journal of Athletic Training.* 2005;40(1):41-46.

34. Cressey EM, West CA, Tiberio DP, Kraemer WJ, Maresh CM. The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. *The Journal of Strength & Conditioning Research.* 2007;21(2):561-567.

35. Cuğ M, Ak E, Özdemir RA, Korkusuz F, Behm DG. The effect of instability training on knee joint proprioception and core strength. *Journal of Sports Science and Medicine.* 2012;11:468-474.

36. Changela PK, Selvamani K. A Study to Evaluate the effect of Fatigue on Knee Joint Proprioception and Balance in Healthy Individuals. *Indian Journal of Physiotherapy and Occupational Therapy-An International Journal.* 2013;7(1):213-217.

37. Chapman DW, Needham KJ, Allison GT, Lay B, Edwards DJ. Effects of experience in a dynamic environment on postural control. *British Journal of Sports Medicine.* 2008;42(1):16-21.

38. Chappell JD, Herman DC, Knight BS, Kirkendall DT, Garrett WE, Yu B. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *The American Journal of Sports Medicine.* 2005;33(7):1022-1029.

39. Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of comprehensive warm-up programs on proprioception, static and dynamic balance on male soccer players. *PloS one.* 2012;7(12):51568.

40. Davlin CD. Dynamic balance in high level athletes. *Perceptual and motor skills.* 2004;98:1171-1176.

41. De Luca CJ, LeFever RS, McCue MP, Xenakis AP. Control scheme governing concurrently active human motor units during voluntary contractions. *The Journal of Physiology.* 1982;329:129-142.

42. De Vries J, Krips R, Sierevelt I, Blankevoort L, van Dijk C. Interventions for treating chronic ankle instability. *Cochrane Database of Systematic Reviews.* 2006;4.

43. Derave W, De Clercq D, Bouckaert J, Pannier JL. The influence of exercise and dehydration on postural stability. *Ergonomics.* 1998;41(6):782-789.

44. Deshpande N, Connelly DM, Culham EG, Costigan PA. Reliability and validity of ankle proprioceptive measures. *Archives of Physical Medicine and Rehabilitation.* 2003;84(6):883-889.

45. Dietz V, Kowalewski R, Nakazawa K, Colombo G. Effects of changing stance conditions on anticipatory postural adjustment and reaction time to voluntary arm movement in humans. *The Journal of Physiology.* 2000;524(2):617-627.

46. Dover G, Powers ME. Reliability of joint position sense and force-reproduction measures during internal and external rotation of the shoulder. *Journal of Athletic Training.* 2003;38(4):304.

47. Drinkwater EJ, Pritchett EJ, Behm DG. Effect of instability and resistance on unintentional squat-lifting kinetics. *International Journal of Sports Physiology and Performance.* 2007;2(4):400-413.

48. Eils E. The role of proprioception in the primary prevention of ankle sprains in athletes: review article. *International Journal of Sports Medicine.* 2003;4(5):1-9.

49. Eils E, Schröter R, Schröder M, Gerss J, Rosenbaum D. Multistation proprioceptive exercise program prevents ankle injuries in basketball. *Medicine and Science in Sports and Exercise.* 2010;42(11):2098-2105.

50. Esposito F, Orizio C, Veicsteinas A. Electromyogram and mechanomyogram changes in fresh and fatigued muscle during sustained contraction in men. *European Journal of Applied Physiology and Occupational Physiology.* 1998;78(6):494-501.

51. Evans T, Hertel J, Sebastianelli W. Bilateral deficits in postural control following lateral ankle sprain. *Foot & Ankle International.* 2004;25(11):833-839.

52. Fanquin A, Melo SIL, Pires R. Comparação do equilíbrio entre atletas que treinam com calçado, descalços e não atletas. *Congreso Brasileiro de Biomecânica*. Brasil; 2005.

53. Fort Vanmeerhaeghe A, Romero Rodriguez D. Rol del sistema sensoriomotor en la estabilidad articular durante las actividades deportivas. *Apunts. Medicina de l'Esport.* 2013;48(178):69-76.

54. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *Journal of Athletic Training.* 2008;43(5):456-463.

55. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *The Journal of Bone and Joint Surgery British Volume.* 1965;47(4):678-685.

56. Friemert B, Bach C, Schwarz W, Gerngross H, Schmidt R. Benefits of active motion for joint position sense. *Knee Surgery, Sports Traumatology, Arthroscopy.* 2006;14(6):564-570.

57. García PLR. *Ejercicio físico en salas de acondicionamiento muscular: bases científico-médicas para una práctica segura y saludable*: Ed. Médica Panamericana; 2008.

58. Garn SN, Newton RA. Kinesthetic awareness in subjects with multiple ankle sprains. *Phys Ther.* 1988;68(11):1667-1671.

59. Garrick G, Requa R. The epidemiology of foot and ankle injury in sports. . *Clin Sports Med.* 1988;7:29-36.

60. Gioftsidou A, Malliou P, Pafis G, Beneka A, Godolias G, Maganaris CN. The effects of soccer training and timing of balance training on balance ability. *European Journal of Applied Physiology.* 2006;96(6):659-664.

61. Gowitzke BA, Milner M. *El cuerpo y sus movimientos. Bases científicas*: Paidotribo; 1999.

62. Granell JC, Cervera VR. *Teoría y planificación del entrenamiento deportivo:* Paidotribo; 2006.

63. Gruber M, Gollhofer A. Impact of sensorimotor training on the rate of force development and neural activation. *European Journal of Applied Physiology.* 2004;92(1-2):98-105.

64. Hassanlouei H, Arendt-Nielsen L, Kersting UG, Falla D. Effect of exercise-induced fatigue on postural control of the knee. *Journal of Electromyography & Kinesiology.* 2012;22(3):342-347.

65. Hertel J. Functional instability following lateral ankle sprain. *Sports Med.* 2000;29(5):361-371.

66. Hertel J, Buckley W, Denegar CR. Serial testing of postural control after acute lateral ankle sprain. *Journal of athletic training.* 2001;36(4):363.

67. Hertel J, Miller S, Denegar C. Intratester and intertester reliability during the Star Excursion Balance Tests. *Journal of Sport Rehabilitation.* 2000;9(2):104-116.

68. Hertel JN, Guskiewicz KM, Kahler DM, Perrin DH. Effect of lateral ankle joint anesthesia on center of balance, postural sway, and joint position sense. *Journal of Sport Rehabilitation.* 1996;5:111-119.

69. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *The American Journal of Sports Medicine.* 2005;33(4):492-501.

70. Hewett TE, Zazulak BT, Myer GD, Ford KR. A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *British Journal of Sports Medicine.* 2005;39(6):347-350.

71. Hiemstra LA, Lo IK, Fowler PJ. Effect of fatigue on knee proprioception: implications for dynamic stabilization. *The Journal of orthopaedic and sports physical therapy.* 2001;31(10):598-605.

72. Hodges P, Gurfinkel V, Brumagne S, Smith T, Cordo P. Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Experimental brain research.* 2002;144(3):293-302.

73. Hodges PW. Core stability exercise in chronic low back pain. *Orthopedic Clinics of North America.* 2003;34(2):245-254.

74. Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of Neuromuscular Training on Proprioception, Balance, Muscle Strength, and Lower Limb Function in Female Team Handball Players. *Clinical Journal of Sport Medicine.* 2004;14(2):88-94.

75. Horak FB. Postural control. *Encyclopedia of Neuroscience*: Springer; 2009:3212-3219.

76. Hrysomallis C. Balance ability and athletic performance. *Sports Med.* 2011;41(3):221-232.

77. Hupperets MD, Verhagen EA, Van Mechelen W. The 2BFit study: is an unsupervised proprioceptive balance board training programme, given in addition to usual care, effective in preventing ankle sprain recurrences? Design of a randomized controlled trial. *BMC musculoskeletal disorders.* 2008;9(1):71.

78. Hutton R, Atwater S. Acute and Chronic Adaptations of Muscle Proprioceptors in Response to Increased Use. *Sports Medicine.* 1992;14(6):406-421.

79. Kandel ER, Schwartz JH, Jessell TM. *Principles of neural science.* Vol 4: McGraw-Hill New York; 2000.

80. Kean CO, Behm DG, Young WB. Fixed foot balance training increases rectus femoris activation during landing and jump height in recreationally active women. *Journal of Sports Science and Medicine.* 2006;5:138-148.

81. Kinzey SJ, Armstrong CW. The reliability of the star-excursion test in assessing dynamic balance. *The Journal of Orthopaedic and Sports Physical Therapy.* 1998;27(5):356-360.

82. Kolt GS, Kirkby RJ. Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. *British Journal of Sports Medicine.* 1999;33(5):312-318.

83. Konradsen L. Factors Contributing to Chronic Ankle Instability: Kinesthesia and Joint Position Sense. *Journal of Athletic Training.* 2002;37(4):381-385.

84. Kynsburg A, Pánics G, Halasi T. Long-term neuromuscular training and ankle joint position sense. *Acta Physiologica Hungarica.* 2010;97(2):183-191.

85. Latash ML, Yee MJ, Orpett C, Slingo A, Nicholas JJ. Combining electrical muscle stimulation with voluntary contraction for studying muscle fatigue. *Archives of Physical Medicine and Rehabilitation.* 1994;75(1):29-35.

86. Lattanzio PJ, Petrella RJ. Knee proprioception: a review of mechanisms, measurements, and implications of muscular fatigue. *Orthopedics.* 1998;21(4):463-470.

87. Lattanzio PJ, Petrella RJ, Sproule JR, Fowler PJ. Effects of fatigue on knee proprioception. *Clinical Journal of Sport Medicine.* 1997;7(1):22-27.

88. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *British Journal of Sports Medicine.* 2013. [Epub ahead of print].

89. Leanderson J, Wykman A, Eriksson E. Ankle sprain and postural sway in basketball players. *Knee Surgery, Sports Traumatology, Arthroscopy.* 1993;1(3-4):203-205.

90. Lee HM, Liau JJ, Cheng CK, Tan CM, Shih JT. Evaluation of shoulder proprioception following muscle fatigue. *Clinical biomechanics (Bristol, Avon).* 2003;18(9):843-847.

91. Lee Pendergrass T, Moore JH, Gerber JP. Postural control after a 2-mile run. *Military Medicine.* 2003. [Epub ahead of print].

92. Lepers R, Bigard AX, Diard JP, Gouteyron JF, Guezennec CY. Posture control after prolonged exercise. *European Journal of Applied Physiology and Occupational Physiology.* 1997;76(1):55-61.

93. Lephart SM, Fu FH. *Proprioception and neuromuscular control in joint stability*: Human Kinetics Champaign, IL; 2000.

94. Lephart SM, Pincivero DM, Giraido JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *The American Journal of Jports Medicine.* 1997;25(1):130-137.

95. Lephart SM, Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sports Medicine.* 1998;25(3):149-155.

96. Lera-López F, Rapún-Gárate M, Aguirre-Zabaleta J. Análisis y evaluación económica de la participación deportiva en España [Analysis and economic evaluation of sports participation in Spain]. *Madrid: Consejo Superior de Deportes.* 2008.

97. Lönn, Crenshaw, Djupsjöbacka, Johansson. Reliability of position sense testing assessed with a fully automated system.

98. Lönn J, Crenshaw AG, Djupsjöbacka M, Pedersen J, Johansson H. Position sense testing: Influence of starting position and type of displacement. *Archives of Physical Medicine and Rehabilitation.* 2000;81(5):592-597.

99. Loram ID, Kelly SM, Lakie M. Human balancing of an inverted pendulum: is sway size controlled by ankle impedance? *The Journal of Physiology.* 2001;532: 879-891.

100. Loram ID, Lakie M. Human balancing of an inverted pendulum: position control by small, ballistic-like, throw and catch movements. *The Journal of Physiology.* 2002;540: 1111-1124.

101. Loram ID, Maganaris CN, Lakie M. Active, non-spring-like muscle movements in human postural sway: how might paradoxical changes in muscle length be produced? *The Journal of Physiology.* 2005;564(1):281-293.

102. Lloyd DG. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *Journal of Orthopaedic & Sports Physical Therapy.* 2001;31(11):645-654.

103. Marshall P, Murphy B. Changes in muscle activity and perceived exertion during exercises performed on a swiss ball. *Applied Physiology, Nutrition, and Metabolism.* 2006;31(4):376-383.

104. Martín-Casado L, Aguado X. Review of the repercussions of ankle sprains on postural balance. *Apunts. Medicina de l´Esport.* 2011;46:97-105

105. Martín-Cuenca E. Fundamentos de fisiología. *Madrid: Thomson.* 2006.

106. Martínez LC. Revisión de las estrategias para la prevención de lesiones en el deporte desde la actividad física. *Apunts. Medicina de l'Esport.* 2008;43(157):30-40.

107. Matavulj D, Kukolj M, Ugarkovic D, Tihanyi J, Jaric S. Effects of plyometric training on jumping performance in junior basketball players. *The Journal of Sports Medicine and Physical Fitness.* 2001;41(2):159-164.

108. Mattacola CG, Lloyd JW. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: a single-case design. *Journal of Athletic Training.* 1997;32(2):127-135.

109. McArdle W, Katch F, Katch V. Fundamentos de fisiología del ejercicio. 2ªEdición. *Mardrid: McGrawHill-interamericana.* 2004.

110. McGlashen K, Ashton-Miller JA, Green M, Schultz AB. Trunk positioning accuracy in the frontal and sagittal planes. *Journal of Orthopaedic Research.* 1991;9(4):576-583.

111. McGregor SJ, Armstrong WJ, Yaggie JA, et al. Lower extremity fatigue increases complexity of postural control during a single-legged stance. *Journal of NeuroEngineering and Rehabilitation.* 2011;8:43.

112. McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine.* 2000;10(4):239-244.

113. McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. *The American Journal of Sports Medicine.* 2006;34(7):1103-1111.

114. McLeod TC, Armstrong T, Miller M, Sauers JL. Balance improvements in female high school basketball players after a 6-week neuromuscular-training program. *Journal of Sport Rehabilitation.* 2009;18(4):465-481.

115. Medina JM, Valovich McLeod TC, Howell SK, Kingma JJ. Timing of neuromuscular activation of the quadriceps and hamstrings prior to landing in high school male athletes, female athletes, and female non-athletes. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology.* 2008;18(4):591-597.

116. Mel'nikov AA, Savin AA, Emel'ianova LV, Vikulov AD. [Postural stability during static strain before and after submaximal aerobic bycycle test in athletes]. *Fiziologiia Cheloveka.* 2012;38(2):66-72.

117. Mel'nikova AA, Savin AA, Emel'ianova LV, Nikolaev R, Vikulov AD. [Comparative analysis of the regulation of vertical posture in athletes of different sports qualifications]. *Fiziologiia Cheloveka.* 2011;37(5):113-119.

118. Mello RG, Oliveira LF, Nadal J. Anticipation mechanism in body sway control and effect of muscle fatigue. *Journal of Electromyography & Kinesiology.* 2007;17(6):739-746.

119. Mello RG, Oliveira LF, Nadal J. Effects of maximal oxygen uptake test and prolonged cycle ergometer exercise on sway density plot of postural control. *Conference proceedings: IEEE Engineering in Medicine & Biology Society.* 2009;2009:1351-1354.

120. Micheo W, Baerga L, Miranda G. Basic principles regarding strength, flexibility, and stability exercises. *PM&R.* 2012;4(11):805-811.

121. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The effect of local and general fatigue on knee proprioception. *Arthroscopy.* 2004;20(4):414-418.

122. Morasso PG, Sanguineti V. Ankle muscle stiffness alone cannot stabilize balance during quiet standing. *Journal of Neurophysiology.* 2002;88(4):2157-2162.

123. Morasso PG, Schieppati M. Can muscle stiffness alone stabilize upright standing? *Journal of Neurophysiology.* 1999;82(3):1622-1626.

124. Moritani T, Muro M, Nagata A. Intramuscular and surface electromyogram changes during muscle fatigue. *Journal of Applied Physiology.* 1986;60(4):1179-1185.

125. Muaidi QI, Nicholson LL, Refshauge KM. Proprioceptive Acuity in Active Rotation Movements in Healthy Knees. *Archives of Physical Medicine and Rehabilitation.* 2008;89(2):371-376.

126. Muaidi QI, Nicholson LL, Refshauge KM. Do elite athletes exhibit enhanced proprioceptive acuity, range and strength of knee rotation compared with non-athletes? *Scandinavian Journal of Medicine & Science in Sports.* 2009;19(1):103-112.

127. Murphy DF, Connolly DA, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine.* 2003;37(1):13-29.

128. Myer GD, Ford KR, Brent JL, Hewett TE. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *The Journal of Strength & Conditioning Research.* 2006;20(2):345-353.

129. Nagy E, Toth K, Janositz G, et al. Postural control in athletes participating in an ironman triathlon. *European Journal of Applied Physiology.* 2004;92(4-5):407-413.

130. Olsson L, Lund H, Henriksen M, Rogind H, Bliddal H, Danneskiold-Samsøe B. Test–retest reliability of a knee joint position sense measurement method in sitting and prone position. *Advances in Physiotherapy.* 2004;6(1):37-47.

131. Osorio JA, Rodríguez MPC, Arango E, Giraldo SP, Ching ICG. Lesiones deportivas. *Iatreia.* 2007;20(2):167-177.

132. Paillard J, Brouchon M. Active and passive movements in the calibration of position sense. *The Neuropsychology of Spatially Oriented Behavior.* 1968:37-55.

133. Paillard T. Effects of general and local fatigue on postural control: a review. *Neuroscience & Biobehavioral Reviews.* 2012;36(1):162-176.

134. Paillard T, Costes-Salon C, Lafont C, Dupui P. Are there differences in postural regulation according to the level of competition in judoists? *British Journal of Sports Medicine.* 2002;36(4):304-305.

135. Paillard T, Noe F. Effect of expertise and visual contribution on postural control in soccer. *Scandinavian Journal of Medicine & Science in Sports.* 2006;16(5):345-348.

136. Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic Training.* 2006;41(2):172-176.

137. Pap G, Machner A, Nebelung W, Awiszus F. Detailed analysis of proprioception in normal and ACL-deficient knees. *The Journal of Bone and Joint Surgery British Volume.* 1999;81(5):764-768.

138. Pastre CM, Carvalho Filho G, Monteiro HL, Netto Júnior J, Padovani CR. Lesões desportivas no atletismo: comparação entre informações obtidas em prontuários e inquéritos de morbidade referida. *Revista Brasileira de Medicina do Esporte.* 2004;10:01-08.

139. Paterno MV, Myer GD, Ford KR, Hewett TE. Neuromuscular training improves single-limb stability in young female athletes. *Journal of Orthopaedic & Sports Physical Therapy.* 2004;34(6):305-316.

140. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *The American Journal of Sports Medicine.* 2010;38(10):1968-1978.

141. Payne MW, Petrella RJ. Viscosupplementation effect on proprioception in the osteoarthritic knee. *Archives of Physical Medicine and Rehabilitation.* 2000;81(5):598-603.

142. Perrin P, Deviterne D, Hugel F, Perrot C. Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait & Posture.* 2002;15(2):187-194.

143. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy.* 2006;36(12):911-919.

144. Reimer Iii RC, Wikstrom EA. Functional fatigue of the hip and ankle musculature cause similar alterations in single leg stance postural control. *Journal of Science and Medicine in Sport.* 2010;13(1):161-166.

145. Ribeiro F, Gonçalves G, Venâncio J, Oliveira J. A fadiga muscular diminui a sensação de posição do ombro em andebolistas. *Revista Portuguesa de Ciências do Desporto.* 2008;8:271-276.

146. Ribeiro F, Moreira S, Neto J, Oliveira J. Is the deleterious effect of cryotherapy on proprioception mitigated by exercise? *International Journal of Sports Medicine.* 2013;34(5):444-448.

147. Ribeiro F, Mota J, Oliveira J. Effect of exercise-induced fatigue on position sense of the knee in the elderly. *European Journal of Applied Physiology.* 2007;99(4):379-385.

148. Ribeiro F, Oliveira J. Effect of physical exercise and age on knee joint position sense. *Archives of Gerontology and Geriatrics.* 2010;51(1):64-67.

149. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *Journal of athletic training.* 2002;37(1):71.

150. Rodríguez DR, Fajardo JT. *Prevención de lesiones en el deporte: Claves para un rendimiento de portivo óptimo*: Ed. Médica Panamericana; 2010.

151. Roi GS. Vuelta a la competición tras una lesión atlética: la rehabilitación deportiva global. *Apunts: Medicina de l'esport.* 2010;45(167):5.

152. Rothwell J, Lennon S. Control of human voluntary movement: Elsevier; 1994.

153. Salles JI, Cossich VR, Amaral MV, et al. Electrophysiological correlates of the threshold to detection of passive motion: an investigation in professional volleyball athletes with and without atrophy of the infraspinatus muscle. *BioMed Research International.* 2013;2013:634891.

154. Shumway-Cook A, Woollacott MH. *Motor control: theory and practical applications.* Vol 157: Williams & Wilkins Baltimore:; 1995.

155. Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research Into Clinical Practice*: Lippincott Williams & Wilkins; 2007.

156. Šimek S, Milanović D, Jukić I. The effects of proprioceptive training on jumping and agility performance. *Kineziologija.* 2008;39(2):131-141.

157. Skinner HB, Wyatt MP, Hodgdon JA, Conard DW, Barrack RL. Effect of fatigue on joint position sense of the knee. *Journal of Orthopaedic Research.* 1986;4(1):112-118.

158. Sousa JP, Cabri J, Donaghy M. Case research in sports physiotherapy: A review of studies. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine.* 2007;8(4):197-206.

159. Springer BK, Pincivero DM. The effects of localized muscle and whole-body fatigue on single-leg balance between healthy men and women. *Gait & Posture.* 2009;30(1):50-54.

160. Stanton R, Reaburn PR, Humphries B. The effect of short-term Swiss ball training on core stability and running economy. *The Journal of Strength & Conditioning Research.* 2004;18(3):522-528.

161. Stillman BC. An investigation of the clinical assessment of joint position sense. 2000.

162. Stroeve S. Learning combined feedback and feedforward control of a musculoskeletal system. *Biological Cybernetics.* 1996;75(1):73-83.

163. Surenkok O, Isler A, scedil, et al. Effect of knee muscle fatigue and lactic acid accumulation on balance in healthy subjects. *Isokinetics and Exercise Science.* 2006;14(4):301-306.

164. Susco TM, Valovich McLeod TC, Gansneder BM, Shultz SJ. Balance Recovers Within 20 Minutes After Exertion as Measured by the Balance Error Scoring System. *Journal of Athletic Training.* 2004;39(3):241-246.

165. Swinkels A, Dolan P. Regional Assessment of Joint Position Sense in the Spine. *Spine.* 1998;23(5):590-597.

166. Tarantino F. Propiocepción: Introducción Teórica. 2009.

167. Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiologica (Oxford, England).* 2008;193(2):101-116.

168. Taube W, Kullmann N, Leukel C, Kurz O, Amtage F, Gollhofer A. Differential reflex adaptations following sensorimotor and strength training in young elite athletes. *Int J Sports Med.* 2007;28(12):999-1005.

169. Thorpe JL, Ebersole KT. Unilateral balance performance in female collegiate soccer athletes. *The Journal of Strength & Conditioning Research.* 2008;22(5):1429-1433.

170. Trojian TH, McKeag DB. Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine.* 2006;40(7):610-613.

171. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sports Exerc.* 1984;16(1):64-66.

172. Verhagen E, van der Beek A, Twisk J, Bouter L, Bahr R, van Mechelen W. The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *The American Journal of Sports Medicine.* 2004;32(6):1385-1393.

173. Viitasalo JT, Komi P. Signal characteristics of EMG during fatigue. *European Journal of Applied Physiology and Occupational Physiology.* 1977;37(2):111-121.

174. Voight ML, Hardin JA, Blackburn TA, Tippett S, Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *Journal of Orthopaedic & Sports Physical Therapy.* 1996;23(6):348-352.

175. Vuillerme N, Hintzy F. Effects of a 200 W-15 min cycling exercise on postural control during quiet standing in healthy young adults. *European Journal of Applied Physiology.* 2007;100(2):169-175.

176. Wahl MJ, Behm DG. Not all instability training devices enhance muscle activation in highly resistance-trained individuals. *The Journal of Strength & Conditioning Research.* 2008;22(4):1360-1370.

177. Wang HK, Chen CH, Shiang TY, Jan MH, Lin KH. Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Archives of Physical Medicine and Rehabilitation.* 2006;87(6):821-825.

178. Willardson JM. Core stability training: applications to sports conditioning programs. *The Journal of Strength & Conditioning Research.* 2007;21(3):979-985.

179. Witchalls JB, Waddington G, Adams R, Blanch P. Chronic ankle instability affects learning rate during repeated proprioception testing. *Physical Therapy in Sport.* 2013. [Epub ahead of print].

180. Yaggie JA, Campbell BM. Effects of balance training on selected skills. *The Journal of Strength & Conditioning Research.* 2006;20(2):422-428.

181. Yasuda T, Nakagawa T, Inoue H, Iwamoto M, Inokuchi A. The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. *European Archives of Oto-Rhino-Laryngology.* 1999;256:27-32.

182. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. The effects of core proprioception on knee injury: a prospective biomechanical-epidemiological study. *The American Journal of Sports Medicine.* 2007;35(3):368-373.

183. Zech A, Hubscher M, Vogt L, Banzer W, Hansel F, Pfeifer K. Balance training for neuromuscular control and performance enhancement: a systematic review. *Journal of Athletic Training.* 2010;45(4):392-403.

184. Ziegler LP, Gibson MH, McBride JM. Proprioceptive training improves vertical jump performance in untrained women. *NSCA Conference* Las Vegas; 2002.

I

EFFECTS OF PROPRIOCEPTIVE TRAINING PROGRAM ON CORE STABILITY AND CENTER OF GRAVITYCONTROL IN SPRINTERS

N Romero-Franco, EJ Martínez-López, R Lomas-Vega, F Hita-Contreras, A Martínez-Amat

Journal of Strength and Conditioning Research

Aug 2012

Effects of Proprioceptive Training Program on Core Stability and Center of Gravity Control in Sprinters

Natalia Romero-Franco,[1] Emilio Martínez-López,[2] Rafael Lomas-Vega,[1]
Fidel Hita-Contreras,[1] and Antonio Martínez-Amat[1]

[1]Department of Health Sciences, University of Jaén, Jaén, Spain; and [2]Department of Didactics of Musical, Plastic and Corporal, University of Jaén, Jaén, Spain

Abstract

Romero-Franco N, Martínez-López EJ, Lomas-Vega R, Hita-Contreras F, and Martínez-Amat A. Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *J Strength Cond Res* 26(8): 2071–2077, 2012—The purpose of this study was to determinate the effect of a 6-week specific-sprinter proprioceptive training program on core stability and gravity center control in sprinters. Thirty-three athletes (age = 21.82 ± 4.84 years, height = 1.76 ± 0.07 m, weight = 67.82 ± 08.04 kg, body mass index = 21.89 ± 2.37 kg·m^{-2}) from sprint disciplines were divided into a control (n = 17) and experimental (n = 16) groups. A 30-minute proprioceptive training program was included in the experimental group training sessions, and it was performed for 6 weeks, 3 times each week. This program included 5 exercises with the BOSU and Swiss ball as unstable training tools that were designed to reproduce different moments of the technique of a sprint race. Stability with eyes open (EO) and eyes closed, postural stability, and gravity center control were assessed before and after the training program. Analyses of covariance (α = 0.05) revealed significant differences in stability in the medial-lateral plane with EO, gravity center control in the right direction and gravity center control in the back direction after the exercise intervention in the experimental athletes. Nevertheless, no other significant differences were demonstrated. A sprinter-specific proprioceptive training program provided postural stability with EO and gravity center control measures improvements, although it is not clear if the effect of training would transfer to the general population.

Key Words proprioception, athletics, postural stability, gravity center, Swiss ball

Address correspondence to Antonio Martínez Amat, amamat@ujaen.es.

26(8)/2071–2077

Journal of Strength and Conditioning Research

Introduction

In the last 2 decades, proprioception has been considered an irreplaceable tool in the rehabilitation of muscle injuries. Restoring neuromuscular control after a muscle injury by means of proprioceptive exercises performance is based on the fact that the ligaments have proprioceptors and any damage on these structures would change the afferent information, requiring a neurological restoration to obtain a complete recovery (9). If there is no complete restoration and the sense of proprioception is damaged, it provides wrong information to the central nervous system, which cannot be managed, producing uncontrolled and fast body movements. This situation increases the risk of injury and affects the stability of the subject (26). It has been shown that proprioception is affected by age, gender, injuries, environmental temperature, dehydration conditions, and exhausting exercises (10,17). Fatigue caused by these exhausting exercises is considered as a predisposing factor to muscle injury, and it usually appears in sports competition (20). This situation produces disturbances that displace the gravity center outside the base of support and is necessary to activate the stabilizing muscles to correct these alterations and restore the normal postural balance (14,25). Because of this, in recent years, proprioception has also become one of the most important techniques in the prevention of muscle injuries (2,7).

The effectiveness of proprioceptive exercises has been occasionally studied (8,11,21) providing significant improvements in core stability in athletes of different sports. This training is often included in exercise routines by using unstable platforms. Besides, this stability increase has been confirmed to provide a basis to obtain a higher strength output (27).

According to previous research studies, some controversy exists between the consulted authors, and there is no clear relationship between proprioceptive training and improvement in athletic performance.

To address this problem, the purpose of this study was to demonstrate the effect of a sprinter-specific proprioceptive training program with unstable platforms, using the Swiss ball

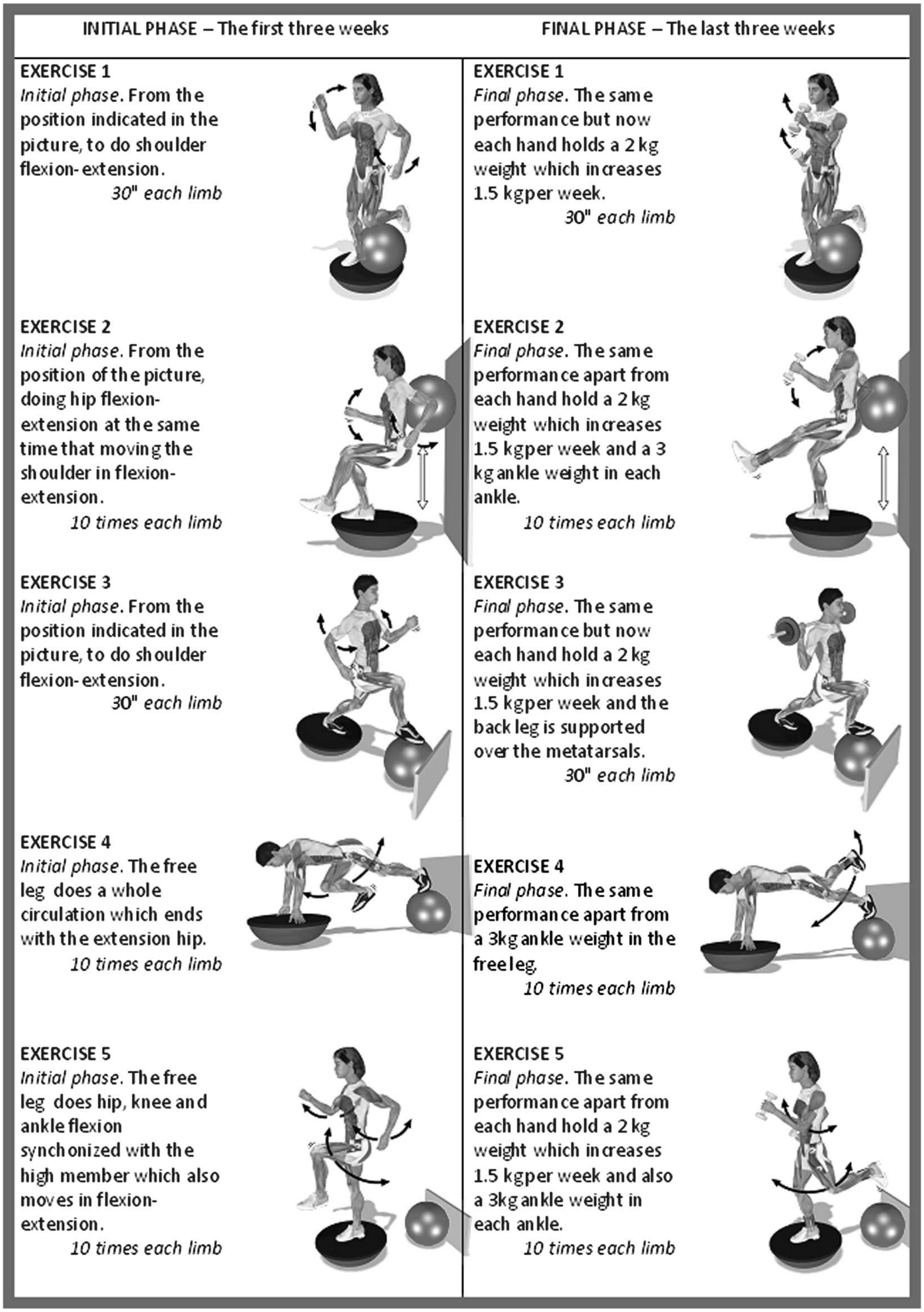


Figure 1. Instructions and exercises to do in the 6-week specific-sprinter proprioceptive training program.

and BOSU as main training tools, on eyes open (EO) and eyes closed (EC) postural stability and sprinters gravity center control. It was hypothesized that a proprioceptive training would improve the stability and the gravity center control of sprinters.

Methods

Experimental Approach to the Problem

A quasiexperimental, pretest-posttest control group design was used in this study. The intervention consisted of the implementation of a sprinter-specific 6-week proprioceptive exercises program in a group of sprinters. These sprinter-specific exercises tried to reproduce the different moments of the technique of a sprint race to perform the propioceptive practice in the same position that the athletes had to compete. Each week, this program was repeated on 3 days, concretely every Monday, Wednesday, and Friday. It was carried out from September to October, which is the preseason period in which none of the athletes were participating in competitions, and all of them were training their aerobic capacity and strength. The training program was divided into 2 different phases of 3 weeks, respectively. The first one was an initial phase, which took place from September 13 to October 3, and the sprinter-specific exercises were performed without additional weight. The last one was the final phase, which took place from October 4 to October 21 and the sprinter-specific exercises were performed with additional weight (Figure 1). The control group had a shorter duration training program because no proprioceptive training was included in it. To avoid influencing the results, the training of the control group and the experimental group took place in the mornings and in the afternoons, respectively. Preintervention and postintervention tests included stabilometric tests with open eyes and closed eyes, postural stability test, and gravity center control test. The dependent variables were all the measures from the 3 tests. The independent variable was the sprinter-specific training program.

Subjects

Thirty-three male sprinters (age = 21.82 ± 4.84 years, height = 1.76 ± 0.07 m, weight = 67.82 ± 08.04 kg, body mass index = 21.89 ± 2.37 kg·m^{-2}) from sprint disciplines (100-, 200-, 400-, and 110- and 400-m hurdles) voluntarily participated in the study. The athletes were divided into 2 groups by means of a simple random probability sampling: group 1 (control) consisted of 17 subjects (age = 21.18 ± 4.47 years, height = 1.75 ± 0.02 m, weight = 65.3 ± 9.79 kg, body mass index = 21.27 ± 2.65 kg·m^{-2}). This group simply continued with their daily workout routine. Group 2 (experimental) consisted of 16 subjects (age = 22.5 ± 5.12 years, height = 1.77 ± 0.06 m, weight = 70.5 ± 4.44 kg, body mass index = 22.33 ± 3.15 kg·m^{-2}). This group added a sprinter-specific proprioceptive exercise protocol to their routine training. No athlete had ever performed any proprioceptive training before. All the subjects were informed of the risks and signed

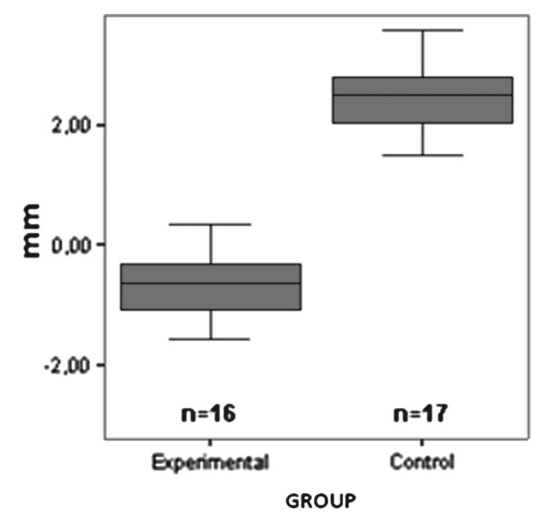


Figure 2. Real picture of exercise 2–initial phase.

the informed consent form. According to the standards of the Declaration of Helsinki, parents or legal guardian signed the informed consent form in the case of underaged athletes (rev. 2008).

Procedures

Stability Test with Eyes Open and Closed. An EPS Baropodometric platform was used (Bologna, Italy). Reliability of this test has been shown in earlier studies (4). All the athletes were asked to stand on both feet on the baropodometric platform with EO and ECEC for 52 seconds each one to allow the study of visual and vestibular influences on sway parameters. This test measures the mean center of pressure position in

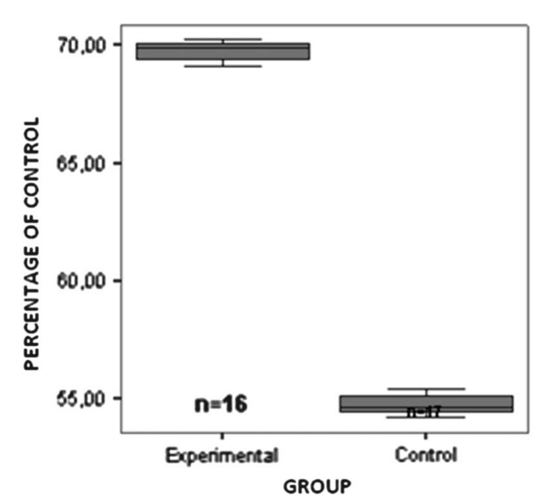


Figure 3. Real picture of exercise 1–final phase.

TABLE 1. Summary of eyes open results after 6 weeks of the proprioceptive training program in both groups.*

Variable	Experimental (*N* = 16)	Control (*N* = 17)	Significance	Eta square
XEO (mm)	−0.78 ± 4.31	2.30 ± 2.75	0.010†	0.203
DEO (mm)	90.04 ± 19.71	105.82 ± 23.12	0.073	0.103
SpEO (mm·s^{-1})	1.79 ± 0.39	2.14 ± 0.52	0.065	0.109
YEO (mm)	−1.12 ± 6.79	2.88 ± 4.76	0.151	0.067
SEO (cm^2)	0.62 ± 0.35	0.90 ± 0.62	0.216	0.051
RombergS	1.05 ± 0.59	0.74 ± 0.46	0.099	0.088
RombergSp	0.89 ± 0.09	0.93 ± 0.09	0.249	0.044
RombergD	1.23 ± 0.30	1.26 ± 0.22	0.891	0.001

*XEO = mean position center of pressure in the medial-lateral plane with eyes open; YEO = mean position center of pressure in the anterior-posterior plane with eyes open; DEO = distance covered by the center of pressure with eyes open; SpEO = speed of center of pressure movement with eyes open; SEO = surface covered by the center of pressure with eyes open; RombergS = Romberg index about surface; RombergSp = Romberg index about speed; RombergD = Romberg index about distance.
†Statistical significance ($\alpha > 0.05$).

the medial-lateral plane (*X*) and posteroanterior plane (*Y*). It also measures the surface covered by the center of pressure (S), the speed of the center of pressure movement (Sp), the distance covered by the center of pressure (D) and the Romberg index about surface (RombergS), about speed (RombergSp), and about distance (RombergD).

Postural Stability. Postural stability measurement was carried out in the Biodex Balance System (BBS; Biodex Medical Systems, Shirley, NY, USA). The BSS is a multiaxial tilting platform that allows the examiner to objectively measure the ability of a subject to maintain dynamic postural stance on a platform through the use of stabilometry (1,19). Schmitz and Arnold (19) examined the intrarater reliability of the Biodex Stability System and reported an intraclass correlation coefficient value of 0.82 for total stability, using a stability test. The variables measured are General Stability (Gs), medial-lateral stability (Ml), and anteroposterior stability (Ap). Measures were obtained from three 20-second trials where participants were asked to maintain an upright standing position on the surface of BBS.

Gravity Center Control. The BBS was used for this test. This test is designed to challenge the user to move through a movement pattern consistent with the sway envelope. The sway envelope is that area a person can move their gravity center within their base of support. It is approximated from vertical as 8° to one side, 8° to the other and 8° forward and 4° back. Scoring is shown as a percentage and reflects the directional accuracy of the movement to the blinking targets time counts up. The variables obtained are general gravity center control (ControlGC) and this control in the right

TABLE 2. Summary of control gravity center results after 6 weeks of proprioceptive training in both groups.*

Variable	Experimental (*N* = 16)	Control (*N* = 17)	Significance	Eta square
CG control (%)	53.63 ± 14.40	48.18 ± 13.38	0.270	0.103
Front (%)	52.44 ± 17.81	57.88 ± 13.98	0.339	0.031
Back (%)	69.75 ± 18.20	54.71 ± 17.68	0.026†	0.154
Right (%)	63.31 ± 17.15	49.71 ± 23.87	0.041†	0.132
Left (%)	56.31 ± 21.36	61.00 ± 22.63	0.545	0.002
Front right (%)	58.94 ± 21.83	52.06 ± 20.34	0.357	0.015
Front left (%)	60.31 ± 18.17	50.88 ± 20.65	0.173	0.054
Back right (%)	51.75 ± 16.47	53.71 ± 17.55	0.743	0.000
Back left (%)	52.19 ± 24.12	46.24 ± 18.74	0.437	0.047

*CG control = general gravity center control; front = gravity center control in the front direction; back = gravity center control in the back direction; right = gravity center control in the right direction; left = gravity center control in the left direction; front right = gravity center control in the front-right direction; front left = gravity center control in the front-left direction; back right = gravity center control in the front-right direction; back left = gravity center control in back-left direction.
†Statistical significance ($\alpha > 0.05$).

(Right), left (Left), back (Back), front (Front), front-left (Front-left), front-right (Front-right), back-left (Back-left), and back-right (Back-right) directions.

Training Program. The training protocol was performed 3 d·wk^{-1} and for 30 minutes each session. The training program consisted of 5 sprinter-specific proprioceptive exercises (Figure 1). Some real pictures of these exercises are shown in Figures 2 and 3.

Statistical Analyses

Data were analyzed using SPSS for Windows, version 17; SPSS, Inc., Chicago, IL, USA. Analyses of covariance were used to study the influence of a proprioceptive program in the stability of athletes, using basal measurement values (pretreatment) as a covariate. Eta square was used to measure the effect sizes. Significance was determined at $p < 0.05$.

Results

A descriptive study of all the variables throughout absolute frequency distribution (*N*) and basic measures summarized as mean, *SD*, and *SEM* was performed. All the variables showed a normal distribution and were comparable at baseline.

Variables of the Stability Test with Eyes Open and Closed

Table 1 shows the mean of the variables measured in the stability test with EO. In the medial-lateral plane of the center of pressure with EO (XEO) mean position (Figure 2), -1.1 ± 4.3 mm was obtained by the experimental group compared with the control group value of 2.6 ± 2.8 mm, showing statistical differences ($p = 0.010$).

The remaining variables showed nonstatistically significant differences though the center of pressure distance with EO (DEO), the center of pressure speed with EO (SpEO), and the Romberg index about the surface oscillation (RombergS) differences were of borderline significance.

Figure 4. Mean position of the center of pressure in the medial-lateral plane for the eyes open test (XEO) after 6 weeks of proprioceptive training program in both groups.

Figure 5. Gravity center control in the back direction after 6 weeks of proprioceptive program in both groups.

Postural Stability Variables

None of this test variables revealed significant differences.

Variables of Gravity Center Control

Table 2 shows the mean scores of the test variables after 6 weeks of the proprioceptive training program. The control of the position of the gravity center in the posterior direction presented significant differences ($p = 0.026$) with a score of $69.5 \pm 18.2\%$ from the experimental group and $54.7 \pm 17.7\%$ obtained by the control group. Statistically significant differences appeared ($p = 0.041$) controlling the position of the gravity center in the right direction (Right) when comparing both experimental and control groups (63.3 ± 17.2 vs. $49.7 \pm 23.9\%$, respectively). Nonsignificant differences were observed in the remaining variables.

Discussion

The purpose of this study was to analyze in sprinters the effect of a proprioceptive training program with a Swiss ball and BOSU on postural stability with open and closed eyes and gravity center control. This training program was performed for 6 weeks, from September 13 to October 21, 2010, 3 d·wk^{-1}. The training program was divided into 2 phases: an initial phase, which took place the first 3 weeks where the sprinter-specific exercises were performed without additional weight, and a final phase, which took place the last 3 weeks where the sprinter-specific exercises were performed with additional weight (Figure 1). The training program was divided into these 2 phases in keeping with the training principle of progression, which says that only the gradual increase of the loads improves the physical capacity (13). Previous research studies have shown that proprioceptive training produced stability improvements with 6- to 10-week programs, with 10- to 20-minute sessions, 3–5 d·wk^{-1} (3,11,16,22–24). With this methodology, some interesting findings have been observed in our study. First of all, some improvements on open eyes stability tests were observed, in keeping with Stanton et al. (21) and Schibeck et al. (18) who found that proprioceptive training improved core stability in sportsmen. In this study, as shown in Figure 4, the stability with EO in the medial-lateral plane (XEO) showed that reaching statistical significance because of the mean position of the center of pressure is more centrally situated in the experimental group than in the control group. Second, because in the present investigation the differences shown in the medial-lateral plane were not found in the anterior-posterior plane (YEO), these data support the notion of the priority of the medio-lateral plane in stability strengthening as was suggested by Bieć and Kuczynski (5) whose study produced similar results with young soccer players, with an important medial-lateral plane improvement, which was not observed in the anterior-posterior plane (YOE). On the other hand, in this study favorable tendencies were observed in most of the variables of this same test: The distance from the center of pressure with EO (DEO) and the speed in covering this distance (SpEO) was improved in the experimental group, and these differences were very close to statistical significance as shown in Table 1. This finding supports those of other studies in which the wrong proprioceptive information could lead to purposeless body movements with a postural instability increase, which could explain these differences (27).

Another interesting finding pertained to the use of vision to stabilize as done in the experimental group compared with in the control group; however, no significant differences were determined. According to one study that stated that the Romberg index was useful for identifying damaged proprioception, in this study, this finding determined the proprioceptive system conditions to be in favor of the experimental group (6).

In this study, we observed that gravity center control improvements in the back and right directions in the experimental group resulted from a 6-week proprioceptive training program, as shown in Table 2. This improvement in the back direction in the experimental group compared with that in the control group is shown in Figure 5. These differences support the earlier work of Mattacola et al. (12), who reported gravity center control improvements as measures of dynamic balance thanks to a proprioceptive training over the Freeman balance board. No significant changes were observed in the rest of the gravity center control measures in the present investigation.

In summary, the results of this study suggest that a 6-week sprinter-specific proprioceptive training program using the Swiss ball and BOSU unstable platforms as the main training tools slightly improves core stability and some dynamic parameters such as gravity center control.

Practical Applications

These data denote that specific BOSU and Swiss ball proprioceptive training programs provide postural stability and certain gravity center control improvements. Although these results are applicable to this specific study population (sprinters), previous research studies have shown stability improvements that result from BOSU and Swiss ball training and the guarantee that these training tools can contribute to sports injury prevention (9,11).

According to the results observed in this research, this kind of specific-sprinter exercises under instability could be incorporated as a part of warming-up activities in the athlete specific training sessions to achieve a better postural stability and gravity center control, which could improve the efficiency in the athlete's running technique as a long-term objective.

For further research, a larger sample size and more experience are recommended. Different age ranges and competitive levels and female sample population inclusion should be an interesting option to consider.

Acknowledgments

The authors would like to thank the Andalusian Sports Medicine Centre and the University of Jaen for the collaboration in the study. They would also like to thank all the athletes who participated in the research.

References

1. Arnold, BL and Schmitz, RJ. Examination of balance measures produced by the Biodex stability system. *J Athl Train* 33: 323–327, 1998.
2. Avalos, C and Berrio, J. Evidencia del trabajo propioceptivo en la prevención de lesiones deportivas. Dissertation, University of Antioquia, Colombia, 2007.
3. Bahr, R, Lian, O, and Bahr, IA. A two fold reduction in the incidence of acute ankle sprain in volleyball after introduction of an injury prevention program: A prospective cohort study. *Scand J Med Sci Sports* 7: 172–177, 1997.
4. Bauer, CM, Gröger, I, Rupprecht, R, Tibesku, CO, and Gasssmann, KG. Reliability of static posturography in elderly persons. *Z Gerontol Geriatr* 43: 245–248, 2010.
5. Bieć, E and Kuczynski, M. Postural control in 13-year-old soccer players. *Eur J Appl Physiol* 110: 703–708, 2010.
6. Douglas, JL. The Romberg sign and early instruments for measuring postural sway. *Semin Neurol* 22: 409–418, 2002.
7. Emery, CA, Cassidy, JD, Klassen, TP, Rosychuk, RJ, and Rowe, BH. Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: A cluster randomized controlled trial. *Can Med Assoc J* 172: 749, 2005.
8. Gioftsidou, A, Malliou, P, Pafis, G, Beneka, A, Godolias, G, and Maganaris, CN. The effects of soccer training and timing of balance training on balance ability. *Eur J Appl Physiol* 96: 659–664, 2006.
9. Griffin, L. Neuromuscular training and injury prevention in sports. *Clin Orthop Relat Res* 409: 53–60, 2003.
10. Ju, Y-Y, Wnag, C-W, and Cheng, KH-Y. Effects of fatiguing movement versus passive repetitive movement on knee proprioception. *Clin Biom* 25: 708–712, 2010.
11. Matsusaka, N, Yokoyama, S, Tsurusaki, T, Inokuchi, S, and Okita, M. Effect of ankle disk training combined with tactiles stimulation to the leg and foot on functional instability of the ankle. *Am J Sports Med* 29: 25–30, 2001.

12. Mattacola, CG and Lloyd, JW. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: A single case design. *J Athl Train* 32: 127–135, 1997.
13. Matviev, LP. *La Periodización en el Entrenamiento Deportivo*. Madrid, Spain: INEF, 1987.
14. Norwood, TJ, Anderson, SG, Gaetz, MB, and Twist, PW. Electromyographic activity of the trunk stabilizers during stable and unstable bench press. *J Strength Cond Res* 21: 343–347, 2007.
15. Paterno, MV, Myer, GD, Ford, KR, and Hewett, TE. Neuromuscular training improves single-limb stability in young female athletes. *J Orthop Sports Phys Ther* 34: 305–316, 2004.
16. Pintsaar, A, Brynhldsen, J, and Tropp, H. Postural corrections after standardised perturbations of single limp stance: Effects of training and orthotic devices in patients with ankle instability. *Br J Sports Med* 30: 151–155, 1996.
17. Ribeiro, F and Oliveira, J. Aging effects on joint proprioception: The role of physical activity in proprioception reservation. *Eur Rev Aging Phys Act* 4: 71–76, 2007.
18. Schibek, JS, Guskiewicz, KM, Prentice, WE, Mays, S, and Davis, JM. The effect of core stabilization training on functional performance in swimming. Master's thesis, University of North Carolina, Chapel Hill, 2001.
19. Schmitz, R and Arnold, B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex stability system. *J Sport Rehabil,* 7: 95–101, 1998.
20. Skinner, HB, Wyatt, MP, and Hodgdon, JA. Effect of fatigue on joint position sense of the knee. *J Orthop Surg Res* 4: 112–118, 1986.
21. Stanton, R, Reaburn, PR, and Humphries, B. The effect of short-term Swiss ball training on core stability and running economy. *J Strength Cond Res* 18: 522–528, 2004.
22. Stasinopoulos, D. Comparison of three preventive methods in order to reduce the incidence of ankle inversion sprains among female volleyball players. *Br J Sports Med* 38: 182–185, 2004.
23. Tropp, H, Ekstrand, J, and Gillquist, J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sports Exerc* 16: 64–66, 1984.
24. Verhagen, EA, Van Mechelen, W, and De Vente, W. The effect of preventive measures on the incidence of ankle sprains. *Clin J Sport Med* 10: 291–296, 2000.
25. Wahl, MJ and Behm, DG. Not all instability training devices enhance muscle activation in highly resistance-trained individuals. *J Strength Cond Res* 22: 1360–1370, 2008.
26. Yaggie, JA and Campbell, BM. Effects of balance training on selection skills. *J Strength Cond Res* 20: 422–428, 2006.
27. Yasuda, T, Nakagawa, T, Inoue, H, Iwamoto, M, and Inokuchi, A. The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. *Eur Arch Otorhinolaryngol* 256: 27–32, 1999.

II

EFFECT OF PROPRIOCEPTIVE TRAINING ON SPRINTERS

N Romero-Franco, A Martínez-Amat, EJ Martínez-López

Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte
Sept 2013

Romero-Franco, N.; Martínez-Amat, A. y Martínez-López, E.J. (2013) Efecto del entrenamiento propioceptivo en atletas velocistas / Effect of the proprioceptive training in sprinters. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 13 (51) pp. 437-451. Http://cdeporte.rediris.es/revista/revista51/artefecto393.htm

ORIGINAL

EFFECT OF PROPRIOCEPTIVE TRAINING ON SPRINTERS

EFECTO DEL ENTRENAMIENTO PROPIOCEPTIVO EN ATLETAS VELOCISTAS

Romero-Franco, N.[1]; Martínez-Amat, A.[2] & Martínez-López, E.J.[3]

[1]Physiotherapist. Master in Investigation and Teach in Physical Activity and Health Sciences. University of Jaen. Spain. narf52@gmail.com
[2]PhD Professor. Health Sciences Falculty. University of Jaen. Spain. amamat@ujaen.es
[3]PhD Titular Professor. Humanities and Education Faculty. University of Jaen. Spain. http://www4.ujaen.es/~emilioml/ emilioml@ujaen.es

Spanish-English translator: Carlos Pérez carlosperez77@gmail.com

Authors would like to thank the collaboration of Andalusian Sports Medicine Center in the present study. Also to be gratefull to all athletes and their coatches for taking part in our investigation.

Código UNESCO / UNESCO code: 2406.04 Biomecánica / Biomechanic
Clasificación Consejo de Europa / European Council Clasification: 3. Biomecánica del deporte / Sports Biomechanic

Recibido 18 de junio de 2011 **Received** June 18, 2011
Aceptado 2 de octubre de 2012 **Accepted** October 2, 2012

ABSTRACT

Proprioceptive training is becoming increasingly integrated in sports performance, but its effects in the are under study in the present paper are still not well-known. The present study was aimed at determining the effect of six weeks of proprioceptive training on the balance, strength, and speed of sprinters. A total 33 medium-level sprinters were divided into two groups: a control group (17 subjects) and an experimental group (16 subjects). The training program in the latter group included 30 minutes a day of proprioceptive training using BOSU® and Swiss balls. Before and after the training program, stabilometry tests were completed for the horizontal (X) and vertical (Y) planes, as well as squat jumps, counter movement jumps, and a 30-meter sprint. An analysis of variance and covariance revealed a beneficial impact on postural balance in the experimental group, as well as moderate increases in jump power with no impact on the speed of sprinters.

KEY WORDS: Proprioception; speed; strength; postural stability; Swiss ball; performance.

RESUMEN

El trabajo propioceptivo está cada vez más integrado en el entrenamiento deportivo, sin embargo sus efectos en este ámbito son poco conocidos. El propósito de este estudio fue determinar el efecto de 6 semanas de entrenamiento propioceptivo sobre el equilibrio, fuerza y velocidad de atletas velocistas. Participaron 33 atletas velocistas de nivel medio que fueron clasificados en dos grupos: *control* (n=17) y *experimental* (n=16). El grupo experimental incluyó en su sesión de entrenamiento un programa propioceptivo de 30 minutos/día utilizando BOSU® y Swiss ball. Antes y después del programa se realizaron test de estabilometría en plano transversal (X) y sagital (Y), squat jump, counter-movement jump y carrera de velocidad de 30 m. El análisis de varianza y covarianza reveló efectos de mejora en el equilibrio postural de los atletas experimentales, así como incrementos moderados en la potencia de salto, que no se tradujeron en mejora de los resultados de velocidad de los atletas.

PALABRAS CLAVE: Propiocepción; velocidad; fuerza; estabilidad postural; swiss ball; rendimiento.

INTRODUCTION

Speed in athletics is particularly influenced by the amplitude and frequency of all body movements (Cometti, 2002). To improve both parameters, training must include muscle contractions at maximum intensity, correct biomechanical movements, and good stability in order to focus and maximize strength in movements (Cosio-Lima et al., 2003; Lin et al., 2007). In response to the stability factor, it has been shown that in unstable conditions force is considerably decreased (Marshall y Murphy, 2006), due to the fact that an accurate and precise contraction requires that the nervous system receives adequate information about the location and position from receptors in muscles, ligaments, joints, and skin (Behm et al., 2002 y 2003). This is called proprioception and helps perceiving conscious and unconscious sensations of muscle sense, postural balance and joint stability (Lephart & Fu, 2000).

It has been proven that athletes who cope with continued fatigue and disturbances that alter the proprioceptive system by sending distorted proprioceptive information suffer biomechanical alterations and lose movement efficiency (Yasuda et al., 1999). Authors agree that during racing, the neuromuscular spindle is the proprioceptive receptor which is responsible for movement execution, posture and maintenance of muscle tone. (Fitzpatrick et al., 1994; Ganong, 2004). It is therefore the only receptor that can be modified by the Central Nervous System through proprioceptive training (Ashton-Miller et al., 2001).

Based on this statement, and thanks to proprioceptive training and the consequent modification of neuromuscular spindles as the main proprioceptive receptors, improvements have been found in the strength of athletes at the start of an isometric action (Gruber & Gollhofer, 2004). In addition, biomechanical performance has been perfected in movements similar to the ones carried out in proprioceptive training (Ashton-Miller et al., 2001; González et al., 2011) and an increased muscle recruitment has been gained during contractile activity in exercises on an unstable platform (Behm et al., 2002, 2003; Marshall & Murphy, 2005; Anderson & Behm, 2005).

Despite previous findings in other athletes, there is little scientific evidence supporting the benefits of including proprioceptive training in the training routine of sprinters. In recent years, proprioceptive training initiatives have been undertaken using equipment such as BOSU® and Swiss balls (Stanton et al., 2004; Wahl & Behm, 2008).

The addition of proprioceptive work to athletic training has provided an important improvement in new ways of training, and in proprioceptive afferents reflected in performance such as reaction time and specific muscle strength, as well as in more stability and in the prevention of common injuries like ankle sprain (Gruber & Gollhofer, 2004; Yaggie & Campbell, 2006; Laudner & Koschnitzky, 2010). However, there are still many aspects of proprioceptive training which must be adjusted, like the type, volume and intensity of exercises.

Based on these arguments, the purpose of the present study was to analyze the effects of proprioceptive training in the balance, strength and speed of sprinters. Authors have hypothesized that proprioceptive training with BOSU® and Swiss balls as unstable platforms would increase postural balance of athletes, improving the effectiveness of lower-body muscle contraction and decreasing the time required to run the 30-meter distance.

METHODS

A quasi-experimental, pre-test-post-test control group design was used in this study. A six-week sprinter-specific proprioceptive exercise program was implemented. The study was carried out during September and October of 2010, at a time when all participant athletes were training in a pre-season period and their training consisted mainly of aerobic capacity and strength exercises.

Participants

Thirty-three medium-level male sprinters from the *Unicaja* athletic club of Jaén (age = 21.82 ± 4.84 years, height = 1.76±0.07 m, weight = 67.82±08.04 kg, body mass index = 21.89±2.37 kg_m^2), with a record that allows them to compete in regional-level events. All athletes belonged to sprint disciplines (100m, 200m, 400m, as well as 110m and 400m hurdles). All athletes with less than one year of experience and/or all those who had previously practiced proprioceptive training were excluded. Athletes were divided into two groups by means of simple random probability sampling. The control group comprised 17 subjects (age = 21.18 ±4.47 years, height = 1.75±0.02 m, weight = 65.3±9.79 kg, body mass index = 21.27±2.65 kg_m^2). This group simply continued with their daily workout routine. The experimental group, which comprised 16 subjects (age = 22.5 ± 5.12 years, height =1.77 ± 0.06 m, weight = 70.5±4.44 kg, body mass index =22.33±3.15 kg_m^2), added a sprinter-specific proprioceptive exercise protocol to their routine training.

Material

Six Swiss balls, 75 cm in diameter, six BOSU® Balance Trainers, six pairs of adjustable-weight dumbbells to fit the physique of the athlete and six pairs of three kg ankle weights were used for proprioceptive training purposes. A system of two OMRON® (Japan) photo-electrical cells and their receptors were place at the start line and the 30-meter line in order to measure running speed. In addition, an Ergo Tester Globus® (Italy) contact platform was used for jump measurements, as well as an EPS ® (Italy) baropodometric platform, which was used for the medial-lateral and anteroposterior stability tests.

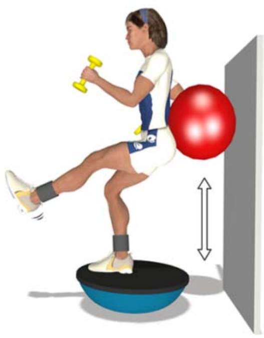
Procedure

This study was carried out during the months of September and October 2010, at a time when all athletes were training in a pre-season period with no competitions. Before taking part in the study, all subjects were briefed on how to correctly execute the tests and exercises, and were informed of the risks. Informed consent was obtained from all subjects. According to the standards of the World Medical Association Declaration of Helsinki of 1975 (2008 version), parents or legal guardians signed the informed consent form in the case of underage athletes.

Intervention: proprioceptive training

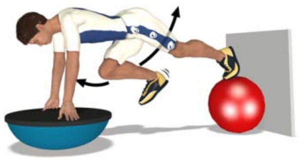
The specific proprioceptive program was carried out three times per week during six weeks. Every proprioceptive training session took approximately thirty minutes, and included five proprioceptive exercises in each of the initial and final phases. The first phase of each exercise was carried out for the first three weeks. The second one (final phase) of each exercise was carried out for the last three weeks and consisted of the same exercises with the addition of weights to increase the intensity of exercises (figure 1). The correct execution of proprioceptive exercises and their intensity were supervised by a fitness specialist and a physical therapist with a specialization in sports injuries. To ensure the best supervision, subjects were divided into groups of ten to twelve athletes.

Athletes in the control group were asked not to include changes in their training routines and inform about any medication taken during the six weeks of the intervention period.

INITIAL PHASE – First three weeks	FINAL PHASE – Last three weeks
EXERCISE 1 *Initial phase*. From the position indicated, flex-extend shoulder. *30" for each limb.* 	**EXERCISE 1** *Final phase.* Same exercise but now each hand holds a 2 kg weight which increases by 1.5 kg every week. *30" for each limb.* 
EXERCISE 2 *Initial phase.* From the position indicated, flex-extend hip and shoulder simultaneously. *Repeat 10 times for each limb.* 	**EXERCISE 2** *Final phase*. Same exercise but now each hand holds a 2 kg weight which increases by 1.5 kg every week, and a 3 kg weight is attached to each ankle. *Repeat 10 times for each limb.* 
EXERCISE 3 *Initial phase.* From the position indicated, flex-extend shoulder . 30" for *each limb* 	**EXERCISE 3** *Final phase.* Hold the indicated position with a 10 kg bar which increases by 2 kg every week. The back leg is supported over the metatarsals. *30" for each limb.* 

EXERCISE 4
Initial phase.
The free leg does a whole circulation which ends with hip extended.

Repeat 10 times for each limb.

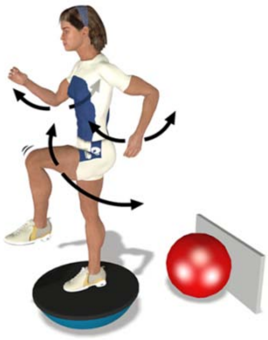


EXERCISE 4
Final phase.
Same exercise, but now with a 3 kg ankle weight in the free leg.

Repeat 10 times for each limb.

EXERCISE 5
Initial phase.
The free leg performs a hip, knee and ankle flexion synchronized with the high member which moves in flexion-extension.

Repeat 10 times for each limb.



EXERCISE 5
Final phase.
Same exercise but now each hand holds a 2 kg weight which increases by 1.5 kg every week and a 3kg weight is attached to each ankle.

Repeat 10 times for each limb.

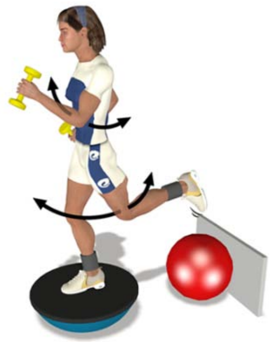


Figure 1. Proprioceptive training program [created by the authors].

Measurement of results

All athletes undertook a plyometric test of squat jump (SJ) and counter movement jump (CMJ), a stabilometry and a 30-meter speed race with and without starting blocks before and after the intervention period. Before every test, all athletes performed a 30-minute warm-up, which included 10 minutes of light running and 20 minutes of stretching, progressive acceleration, unloaded full squats, and progressive height jumping.

Squat jump

This test was performed to measure the explosive strength of lower limbs in all subjects (Cressey et al., 2007). Athletes were instructed to perform a vertical jump from a position of knees bent at 90º, straight torso and hands on the waist, without countermovement and without help from the arms. Test was done three times on the contact platform with a two-minute rest between repetitions. The best try was registered.

Counter movement jump

This test was performed to measure the explosive strength of lower limbs in all subjects (González et al., 2006). Athletes performed the jump from an initial upright position with hand on the waist and a countermovement in which knees became bent at 90º. When jumping, knees had to be extended up to 180° without hyperextending the hips. Test was done three times on the contact platform with a two-minute rest between repetitions. The best try was registered.

Stabilometry

This test was performed to analyze the postural stability of subjects in the anteroposterior (Y) and the medial-lateral plane (X) according to the path described by the center of pressure (Hoffman & Payne, 1995). These stabilometric parameters inform about the mean position of the center of pressure in the medial-lateral path, in the case of variable X, and in the anteroposterior path in the case of variable Y. All athletes were positioned on the baropodometric platform with a between-heels separation of five cm and the feet forming a 30º angle. In this position, athletes had to remain motionless for 52 seconds. This routine was carried out twice: the first one with open eyes and the second one with closed eyes. FootChecker 4.0 (Italy) was the software used to analyze results.

30-meter race

A speed race was performed to analyze the acceleration and maximum speed of all subjects (Ronnestad et al., 2008, Mehmet et al., 2009). The test required running 30 meters at maximum speed on the track. Two photoelectrical cells and their receptors were placed at the start and the 30-meter lines. All athletes had two tries. The first race was performed without starting blocks, from a semi-upright position with a more advanced standing foot and the contralateral hand resting on the ground. A countermovement from that position was not allowed. The second race was performed with starting blocks. A three-minute rest separated both races.

Statistical analysis

A Student's *t*-test for independent samples was used in the initial intra-group comparison. We performed a descriptive analysis of the data, an analysis of variance ANOVA 2 (group) x 2 (time), with a Bonferroni confidence interval adjustment and analysis of covariance (ANCOVA). A Kolmogorov-Smirnov test was used to adjust the normal distribution. Jump measurement, postural stability and the 30-meter speed race were used as dependent variables, and the type of training as independent variable. We used the Pearson correlation analysis to evaluate the relationship between dependent variables. Significance level was determined at $p<0.05$ for all the statistical tests. Data were analyzed using SPSS for Windows, version 19; SPSS, Inc., Chicago.

RESULTS

Table 1 shows the descriptive statistical analysis for the before-training results. All variables had a normal distribution. Statistically significant differences between groups were found in the 30-meters speed race and the stabilometric variable X (*p* = 0,014 y *p* = 0,038, respectively).

Table 1. Descriptive data (mean and standard deviation) of all variables before and after six weeks of proprioceptive training.

efore-training Measures			
Variables (before)	**Experimental (n=16)**	**Control (n=17)**	**P value**
X (mm)	1,83 ± 4,85	-1,88 ± 5,01	0,038*
Y (mm)	0,76 ± 5,51	3,31 ± 6,11	0,220
30 m ST (sec.)	4,31 ± 0,13	4,51 ± 0,28	0,014*
30 m CT (sec.)	4,44 ± 0,12	4,58 ± 0,29	0,091
CMJ (m)	0,45 ± 0,06	0,41 ± 0,07	0,087
SJ (m)	0,42 ± 0,05	0,39 ± 0,06	0,094
Measures after six weeks of a proprioceptive training program			
X (mm)	-0,78 ± 4,31	2,30 ± 2,74	0,010*
Y (mm)	-1,10 ± 6,83	2,89 ± 4,78	0,076
30 m ST (seg.)	4,33 ± 0,12	4,39 ± 0,21	0,118
30 m CT (seg.)	4,40 ± 4,51	4,57 ± 0,27	0,072
CMJ (m)	0,46 ± 0,06	0,40 ± 0,07	0,047*
SJ (m)	0,44 ± 0,02	0,38 ± 0,07	0,032*

X (mm) = Postural stability in the medial-lateral plane (X)
Y (mm) = Postural stability in the anteroposterior plane (Y)
30 m WoutSB (sec.) = 30 meters race without starting blocks
30 m WSB (sec.) = 30 meters race with starting blocks
CMJ (m) = Counter Movement Jump
SJ (m) = Squat Jump
*Statistically significant differences ($p < 0.05$)

Variance analysis in the mean height of SJ shows that the experimental group performed higher jumps in after-training measurements (mean = 0,44 ± 0,02 m) than the control group (mean = 0,38 ± 0,07 m), (p = 0,032) (figure 2). Similar results were shown by variance analysis in the after-training measurement of the mean height of CMJ, where the experimental group reached higher values (mean = 0,46 ± 0,06 m) than the control group (mean = 0,40 ± 0,07 m) (*p* = 0,047).

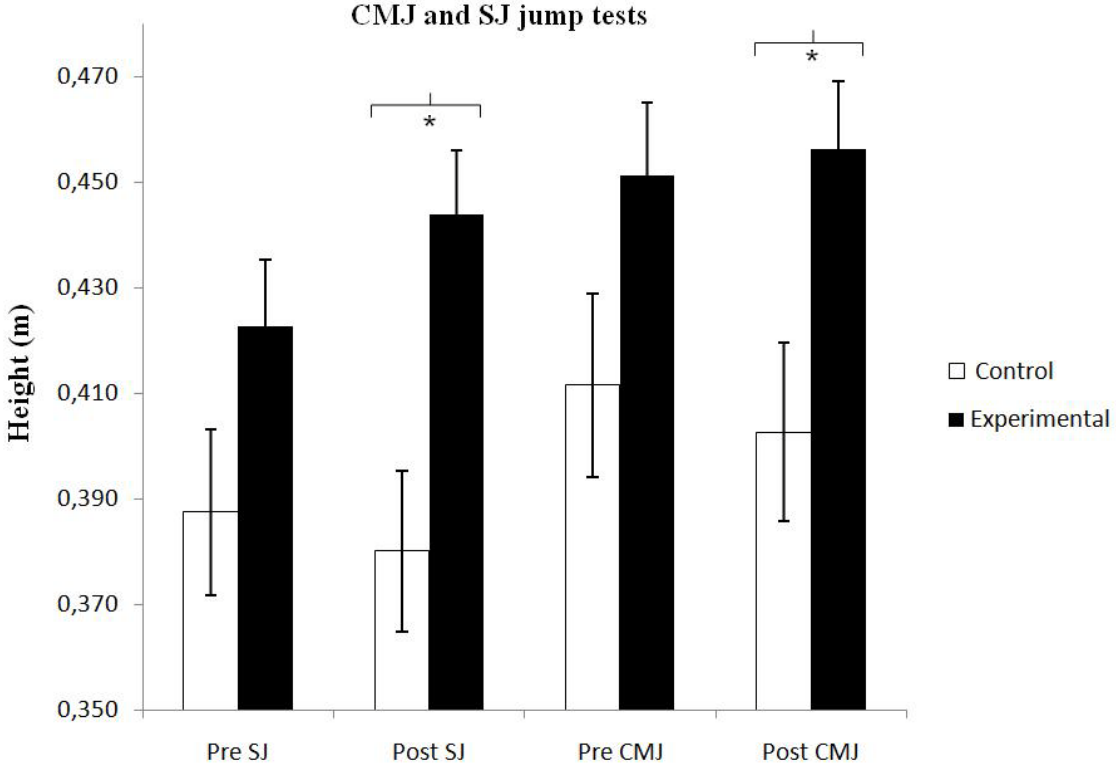


Figure 2. Graphic representation of the before- and after-training for the experimental and control groups for the squat jump (SJ) and counter movement jump (CMJ) tests.* *p* < 0,05.

On the other hand, two of the six study variables (variable X and the 30-meter speed race without starting blocks) showed statistically significant differences in the before-training measures between both groups. To equalize the initial differential effect, an covariance analysis (ANCOVA) was carried out, where before-training measures of both variables were included as covariate. This analysis showed significant differences for variable X (*p* = 0,010) favorable to the experimental group (mean = - 0,78 ± 4,31) with regard to the control (mean = 2,30 ± 2,74; figure 3). No significant differences were apparent in the analysis of the 30-meter race without starting blocks (*p* = 0,118). No main effect or interaction effect were found in the analysis of the 30-meter race with starting blocks.

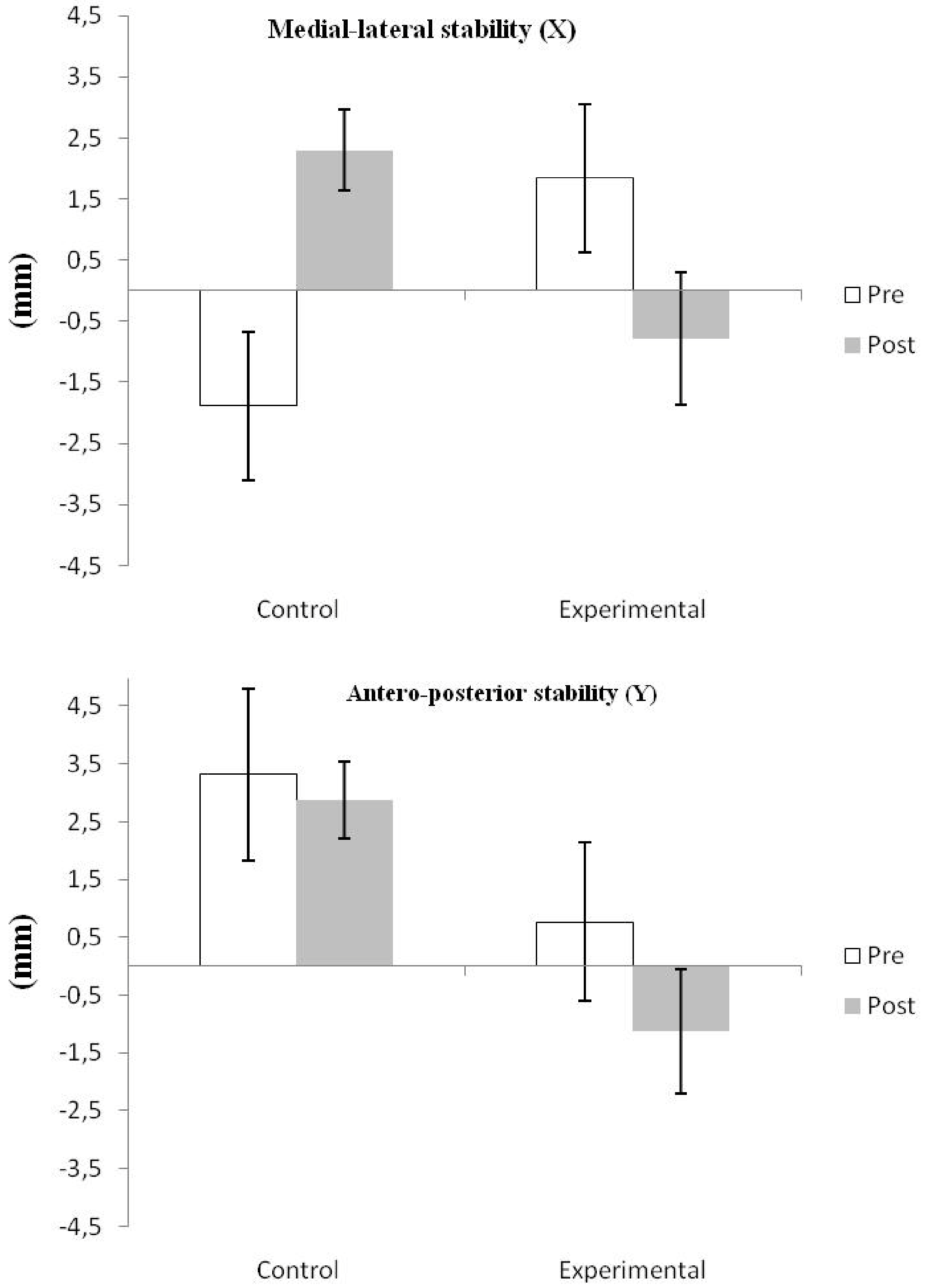


Figure 3. Graphic representation of the before- and after-training results in postural stability according to the path described by the center of pressure.

High statistically significant associations between before-training measurements of the 30-meter race with starting blocks and without starting blocks became apparent in the correlation analysis (r = 0,62, p < 0,05), and particularly so in after-training measures (r = 0,86, p < 0,01). Besides, correlations between SJ and CMJ jumps were really high in before-training measurements (*r* = 0,88, *p* < 0,001) and after-training measurements (*r* = 0,89, *p* < 0,001).

DISCUSSION AND CONCLUSIONS

The purpose of the present study was to analyze the effect of six weeks of proprioceptive training with Swiss balls and BOSU® balls in the sports performance of sprinters. Stabilometric, SJ and CMJ plyometric tests, as well as a 30-meters speed race with and without starting blocks were carried out. The reliability of the 30 meters speed race and plyometric tests as physical condition and performance was reported by Martín et al. (2001). The intervention program was tolerated by all athletes and no sign of health deterioration or injury was detected by the end of the study.

Stabilometric results showed significant differences in the medial-lateral plane (X) with an improvement from the experimental group, although no differences were found in anteroposterior plane (Y). These results agree with those of Schibek et al. (2001), Stanton et al. (2004), Gioftsidou et al. (2006), Yaggie & Campbell (2006), Huang & Lin, (2010) and Romero-Franco et al. (2012), whose surveys showed significant improvements in the postural balance of athletes after performing a training program which included proprioceptive work as the main exercise. Similar results were reported by Bieé & Kuczinsky, (2010) in soccer players, who showed medial-lateral stabilometric improvements, but not anteroposterior ones. The explanation of these results might lie in the length of the program, as Hoffman & Payne, (1995) reported anteroposterior stabilometric measurements in addition to the medial-lateral ones after ten weeks of proprioceptive training.

Plyometric tests analysis found improvements in SJ and CMJ jumps for the experimental group. Similar results were shown by Cressey et al. (2007), who found improvements in the jump of those athletes who had included proprioceptive work on unstable platforms in their training routines, although these results were also present in the group including proprioceptive work on stable platforms. In addition, the present study found a decrease in the statistical limit of the height of jumps for the control group but not for the experimental group. To explain these findings, it should be taken into account that proprioceptive training might have a mitigating effect in the decline of the explosive force of athletes. This could be a long-term benefit, given the fact that the training in the pre-season period, when the present study was carried out, mainly comprised aerobic capacity and strength work, which have been considered counterproductive for jump power and race speed (Baechle & Earle, 2007).

On the other hand, a 30-meter speed race was chosen as a standard to test the maximum speed of athletes (García-López et al., 2001; Cometti, 2002; Fernández et al., 2007). No significant differences were found in speed results after proprioceptive training. Similar results were reported by Cressey et al. In 2007, after ten weeks of proprioceptive training, where both groups, who carried out proprioceptive work on unstable platform and who carried out the same work on stable platform improved from their before-training measurements, although the stable training group had a higher percentage of improvement in a 40- yard test (3,9% from a 1,8% for the unstable platform group). In contrast with our results, Yaggie & Campbell showed in 2007 that a proprioceptive training program improved the reaction capacity of athletes, which is considered a fundamental parameter for the 30-meters speed race. An improvement in this parameter should have been reflected in the results of the present study. The difference between results could be explained by the presence of aerobic resistance, which decreases the maximum racing speed (Baechle & Earle, 2007). This could therefore mask certain improvements in these parameters.

Despite these findings, the present study had important limitations. The authors consider that sample size was enough to obtain optimal results, due to the fact that some parameters such as the Y stabilometric variable and the 30-meter speed race with starting blocks were at the statistical limit. There would have probably been statistically significant differences with a larger size sample. The duration of the intervention time was another great limitation, as it might not have allowed full adaptation of the athletes to the proprioceptive training. A complete adaptation might have been reflected in more notable improvements in the speed and jump variables.

Based on the previous information, it can be concluded that six weeks of proprioceptive training program (three days/week) comprising specific exercises for sprinters improves the medial-lateral postural balance of athletes. The proprioceptive training through Swiss balls and BOSU balls moderately increases jump power, although these improvements are not transferred to a faster racing speed. For further studies, we recommend extending the intervention period to at least twelve weeks, as well as including athletes from different competition levels and age ranges. A wider range of exercises for sprinters might also be beneficial in future research.

REFERENCES

Anderson, K. y Behm, D.G. (2005). Trunk muscle activity increases with unstable squat movements. *Canadian Journal* of *Applied Physiology*, 30: 33-45.

Ashton-Miller, J.A., Wojtys, E.M., Huston, L.J., Fry-Welch, D. (2001). Can Proprioception Really Be Improved by Exercises? *Clinical Orthopaedics and Related Research, 9(3), 128-136*.

Asociación Médica Mundial. Declaración de Helsinki de la Asociación Médica Mundial. Principios éticos para las investigaciones médicas en seres humanos. [Internet]. 2008 [citado 15 Abr 2011]. Disponible en: http://www.wma.net/s/ethicsunit/ helsinki.htm

Baechle, T.R. y Earle, R.W. (2007). *Principios del entrenamiento de la fuerza y del acondicionamiento físico*. Madrid: Panamerica.

Bauersfeld A. (1983). Studien zu ausgewählten Probleme des Schnelligkeit. *Wissenschaftliches Zeitschrift er DHFK,* 24 (3), 45-64.

Behm, D.G., Anderson, K., Currnew, R.S. (2002). Muscle force and activation under stable and unstable conditions. *Journal of Stregth and Conditional Research,* (*16), 416-422.*

Behm, D.G., Leonard, A., Young, W., Bonsey, A., Mackinnon, S. (2003). Trunk muscle EMG activity with unstable and unilateral exercises. *Canadian Journal of Applied Physiology, (28)30*, 326-341.

Bieé, E. y Kuczynski, M. (2010). Postural control in 13-year-old soccer players. *European Journal of Applied Physiology, (110), 703-708.*

Cometti, G. (2002). El entrenamiento de la velocidad. Barcelona: Editorial Paidotribo.

Cosio-Lima, L.M., Reynolds, K.L., Winter, C., Paolone, V., Jones, M.T. (2003). Effects of Physioball and Conventional Floor Exercises on Early Phase Adaptations in Back and Abdominal Core Stability and Balance in Women. *Journal of Strength and Conditional Research, 17(4), 721-725.*

Cressey, E.M., West, C.A., Tiberio, D.P., Kraemer, W.J., Maresh, C.M. (2007). The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. *Journal of Stregth and Conditional Research, 21(2), 561-567.*

Fernández, J.C., Beas, M.A., Martín, F.J., Reina, A. (2007). Fatiga y rendimiento en la velocidad y salto. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte*, *7(26), 99-110.* http://cdeporte.rediris.es/revista/revista26/artfatiga50.htm

Fitzpatrick, R. y McCloskey, D.I. (1994). Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. *The Journal of Physiology,* (478), 173–186.

Ganong, W. (2004). Fisiología médica. México: Editorial El manual moderno.

García-López, J., Villa, J.G., Morane, J.C., Moreno, C. (2001). Influencia del entrenamiento de pretemporada en la fuerza explosiva y velocidad de un equipo profesional y otro amateur de un mismo club de fútbol. *Apunts. Rendimiento y Entrenamiento, (63), 46-52.*

Gioftsidou, A., Malliou, P., Pafis, G., Beneka, A., Godolias, G., Maganaris, C.N. (2006). The Effects of Soccer Training and Timing of Balance Training on Balance Ability. *European Journal of Applied Physiology, 96(6), 659-664.*

González, G., Oyarzo, C., Ficsher, M., De La Fuente, M.J., Diaz, V., Berral, F.J. (2011). Entrenamiento específico del balance postural en jugadores juveniles de fútbol*. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 10(41), 95-114.* Http://cdeporte.rediris.es/revista/revista41/artentrenamiento192.htm

González, J.M., Machado, L., Navarro, F.J., Vilas-Boas, J.P. (2006). Acute affects of strenght training from heavy loads and static stretching training on squat jump and countermovement jump. *Revista internacional de Ciencias del Deporte, 2(4), 47-56.*

Gruber, M. y Gollhofer, A. (2004). Impact of sensorimotor training on the rate of force development and neural activation. *European Journal of Applied Physiology, (92), 98-105.*

Hoffman, M. y Payne, V.G. (1995). The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopaedic & Sports Physical Therapy, 21(2), 90-93.*

Huang, P.Y. y Lin, C.F. (2010). Effects of balance training combined with plyometric exercises in postural control: application in individuals with funtional ankle instability*. Department of Physical Therapy, Medical College, Tainan City, Taiwan. Vol. 31.*

Laudner, K.G. y Koschnitzky, M.M. (2010). Ankle muscle activation when using the Both Side Utilized (BOSU) balance trainer. *Journal of Strength and Conditional Research, 24(1), 218-222.*

Lephart, S.M. y Fu, F.H. (2000) *Proprioception and neuromuscular control in joint stability*. Champaign: Human Kinetics.

Lin, D.H., Lin, Y.F., Chai, H.M., Han, Y.C., Jan, M.H. (2007). Comparison of proprioceptive functions between computerized proprioception facilitation exercise and closed kinetic chain exercise in patients with knee osteoarthritis. *Clinical Rheumatology*, *26: 520–528*.

Mattacola, C.G. y Lloyd, J.W. (1997). Effects of a 6-Week Strength and Proprioception Training Program on Measures of Dynamic Balance: a Single Case Design. *Journal of Athletic Training, 32(2), 127-135.*

Marshall, P., Murphy, B. (2006). Changes in muscle activity and perceived exertion during exercises performed on a swiss ball. *Applied Physiology, Nutrition* and *Metabolism, 31: 376-383.*

Marshall, P., Murphy, B. (2005). Core stability exercises on and off a Swiss Ball. *Archives of Physical Medicine and Rehabilitation, 86(2), 242-249.*

Martín, R., Fernández, M., Veiga, J.V., Otero, X.J., Rodríguez, F.A. (2001). Fiabilidad de las pruebas de fuerza en salto vertical y velocidad de carrera en escolares de 6 a 8 años*. Apunts. Rendimiento y Entrenamiento, (63), 40-45.*

McArdle, W.D., Katch, F.I., Katch, V.L. (2004). *Fundamentos de fisiología del ejercicio*. Madrid: McGraw –Hill.

Mehmet, K., Alper, A., CoÇkun, B., Caner, A. (2009). Relationship among jumping performances and sprint parameters during maximum speed phase in sprinters. *Journal of strength and condition Research, (23), 2272-2279.*

Romero-Franco, N., Martínez-López, E., Lomas-Vega, R., Hita-Contreras, F., Martínez-Amat, A. (2012). Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *Journal of Strength and Conditioning Research, 26(8), 2071-2077.*

Ronestad, B., Kvammen, N., Sunde, A., Raastad, T. (2008). Short-term effects of strength and plyometric training on sprint and jump performance in proffesional soccer players. *Journal of Strength and Conditioning Research, (22), 773 – 788.*

Schibek, J.S., Guskiewicz, K.M., Prentice, W.E., Mays, S., Davis, J.M. (2001). The effect of core stabilization training on functional performance in swimming. *Master´s thesis, University of North Carolina, Chapel Hill.*

Stanton, R., Reaburn, P.R., Humphries, B. (2004). The effect of short-term swiss ball training on core stability and running economy. *Journal of Stregth and Conditional Research, 18(3), 522-528.*

Vance, A., Ferrigno, L., Brown, E., Murray, D.P. (2007). *Entrenamiento de velocidad, agilidad y rapidez*. Badalona: Paidotribo.

Wahl, M.J. y Behm, D.G. (2008). Not all instability training devices enhance muscle activation in highly resistance-trained individuals. *Journal of Stregth and Conditional Research, 22(4), 1360-1370*
Weinek, J. (1986). *Functional Anatomy in Sports*. Chicago: Year Book Medical Publishers.
Wilmore, J.H. y Costill, D.L. (2007). *Fisiología del esfuerzo y el deporte.* Barcelona: Paidotribo.
Yaggie, J.A. y Campbell, B.M. (2006). Effects of balance training on selection skills. *Journal of Stregth and Conditional Research, 20(2), 422-428.*
Yasuda, T., Nakagawa, T., Inoue, H., Iwamoto, M. (1999). The role of labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. *European Archives of Oto-Rhino-Laryngology, (256), 27-32.*

Referencias totales / Total references: 40 (100%)

Referencias propias de la revista / Journal's own references: 2 (5%)

III

SHORT-TERM EFFECTS OF PROPRIOCEPTIVE TRAINING WITH UNSTABLE PLATFORM ON ATHLETES'STABILOMETRY

N Romero-Franco, EJ Martínez-López, R Lomas-Vega, F Hita-Contreras, MC Osuna-Pérez, A Martínez-Amat

Journal of Strength and Conditioning Research
Aug 2013

Short-term Effects of Proprioceptive Training With Unstable Platform on Athletes' Stabilometry

Natalia Romero-Franco,[1] Emilio. J. Martínez-López,[2] Rafael Lomas-Vega,[1]
Fidel Hita-Contreras,[1,3] M. Catalina Osuna-Pérez,[1] and Antonio Martínez-Amat[1,3]

Departments of [1]Health Sciences; [2]Didactics of Musical, Plastic and Corporal, University of Jaén, Jaén, Spain; and [3]Institute of Biopathology and Regenerative Medicine, Department of Anatomy and Embryology, Faculty of Medicine, University of Granada, Granada, Spain

Abstract

Romero-Franco, N, Martínez-López, EJ, Lomas-Vega, R, Hita-Contreras, F, Osuna-Pérez, MC, and Martínez-Amat, A. Short-term effects of proprioceptive training with unstable platform on athletes' stabilometry. *J Strength Cond Res* 27(8): 2189–2197, 2013—The purpose of this study was to determine the short-term stabilometric effects of proprioceptive training in athletes by using a BOSU ball and a Swiss ball as unstable platforms. Thirty-seven athletes from a variety of disciplines were divided into a control group ($n = 17$) and an experimental group ($n = 20$). Both performed a warm-up, and in addition, the experimental group carried out a proprioceptive exercise session after the warm-up. Proprioceptive exercise session consisted of six 25-minute exercise sessions with the BOSU ball and the Swiss ball as unstable platforms. Bipedal stabilometry was assessed before the training session (M_0), immediately after training (M_1), 30 minutes later (M_2), 1 hour after training (M_3), 6 hours after training (M_4), and 24 hours after training (M_5). Analysis of variance ($\alpha = 0.05$) revealed significant differences immediately after training (M_1) in speed ($p = 0.022$) and length covered by the center of pressure ($p = 0.021$) in the experimental group. These differences were even more acute 6 hours later (M_4; $p = 0.021$). In fact, the same group exhibited significant differences in mediolateral position after 30 minutes (M_2; $p = 0.001$) compared with the baseline measure and the control group. Apart from these, no other significant differences were found. A proprioceptive exercise session using a BOSU ball and a Swiss ball as unstable platforms induced short-term negative effects on the stabilometry of athletes. Likewise, an immediate trend to improvement was apparent in the stabilometry of the control group after the warm-up.

Key Words Swiss ball, BOSU, postural control, proprioception, immediate effects

Introduction

Proprioception refers to the conscious and unconscious perception of postural balance, muscle sense, and joint stability (15). Proprioceptive training has the potential of improving sports improves technique because of the information it provides about the situation of the body as a whole (4,5,31). Previous studies showed medium- and long-term improvements through proprioceptive training with unstable platforms in static balance (11,25,26), gravity center control (25), effectiveness of joint movement (16), and strength parameters, such as an improvement in the onset of isometric action (13) in athletes.

Despite the benefits of proprioceptive training shown by previous research, there is no unanimous agreement in the literature regarding the association between proprioceptive training and sports performance in athletes. Lephart et al. (16) found improvements in stability and coordination of the knee after a proprioceptive exercise session, which implied greater effectiveness of the knee joint movement. This effectiveness was measured according to gait speed. Stanton et al. (27), however, found that although better stabilometry and body weight reduction were induced by a 6-week proprioceptive training program in athletes, their running technique was not improved. Likewise, Yaggie and Campbell (30) reported that proprioceptive training with unstable platforms improves proprioceptive inputs, which results in better specific strength and neuromuscular adaptation of postural control, but no significant differences were described in vertical jump. Finally, Gruber and Gollhofer (13) reported that the onset of isometric action was improved. Based on these results, their authors suggested that proprioceptive training might be beneficial for the explosive force of athletes. Despite this suggestion, Cressey et al. (8) did not observe significant differences in explosive force tasks

Address correspondence to Antonio Martínez-Amat, amamat@ujaen.es.

27(8)/2189–2197

Journal of Strength and Conditioning Research

(such as vertical jump). However, stabilometric findings were reported by Gioftsidou et al. (11), who found that a 12-week proprioceptive training program improved balance ability in sports people, and by Romero-Franco et al. (25), whose study showed improvement of postural stability and gravity center control after a 6-week proprioceptive training program.

Furthermore, few studies in the literature have assessed the short-term effects of proprioceptive exercise sessions, and they have been centered on analyzing the effects of proprioceptive training right after performance. Concerning this specific topic, during the last decade, several studies have reported that muscle activity was increased in electromyography (EMG) after proprioceptive exercise (2,4,5,17,19,21,22,28). Accordingly, muscle demand was immediately increased (18,19). Anderson and Behm (2) found that the activity of upper lumbar, lumbosacral erector spinae, abdominal muscles, and soleus muscles was increased while the athletes squatted in unstable conditions. Similar findings were reported by Vega-García et al. (28), Rodd et al. (24), and Behm et al. (4,5) who also reported that the maximum isometric force was reduced by 60% in exercises carried out on a Swiss ball as unstable platform. Likewise, Marshall and Murphy (19) reported an increase in the activity of abdominal muscle during exercises in which the instability was higher by putting some body parts out of the support base. Based on these results, it is suggested that right after proprioceptive training, muscle activity increases to compensate for the instability and to help keep the center of gravity over the base of support, thus preventing falls, which is a neuromuscular adaptation to gain a better postural control (7).

Despite the considerablenumber of studies that have assessed the short-term effects of proprioceptive training, it must be noted that all of them were focused on strength parameters (2,4,5,17,18,19,21,24,28). Thus, stabilometric data are left out even when these variables are directly related to medium- and long-term postural control because of proprioceptive training (11,13,16,25,26). Accordingly, the limitation of these studies on short-term effects was the lack of assessment of the stabilometric parameters: although they suggested that muscle activity was increased to gain postural balance, they did not analyze this potential improvement on stability (7).

To our knowledge, no study to date has evaluated the short-term effects of a proprioceptive exercise session on stabilometric measures. So far, studies have only looked into the assessment of medium- and long-term effects in stabilometric parameters (11,15,20,25–27), and the immediate effects of proprioceptive training are therefore not well known yet.

After revising previous studies, and considering the stabilometric improvements caused by proprioceptive training (11,15,20,25–27) and its immediately subsequent muscle activation (1,2,4,5,17,18,19,21,22,24,28), we hypothesized that proprio ceptive training will induce immediate improvements on the stabilometry of athletes and that such improvements will decrease until their normalization after 24 hours (something to take into account for the planning of further training). Based on the preceding arguments, the goal of our research was to determine the short-term effects that a proprioceptive exercise session with a BOSU and a Swiss ball as unstable platforms would have on the stabilometry of athletes. More precisely, our study evaluated the effects of a proprioceptive exercise session on the bipedal postural stability of athletes during the first 24 hours after a proprioceptive exercise session.

Methods

Experimental Approach to the Problem

The study had a quasi-experimental design with a control group, and it took 24 hours to complete. Six measurements were taken to analyze all stabilometric changes induced by a proprioceptive exercise session. The measurements were M_0 (before training), M_1 (immediately after training), M_2 (30 minutes after training), M_3 (1 hour after training), M_4 (6 hours after training), and M_5 (24 hours after training). Under randomized conditions, a group of athletes (experimental group) performed a 25-minute free warm-up followed by a 25-minute proprioceptive exercise session on an unstable platform (Swiss and BOSU ball). Meanwhile, the control group only performed the 25-minute free warm-up. Tests took place in February 2012, in the transitional period of the season for all athletes, where their training mostly consisted in aerobic work and strength exercises (12). The study was timed on different days because of schedule restrictions. Training started at 11 AM, and all athletes were instructed to sleep at least 8 hours the night before. Days and venues were different for the control and experimental groups to avoid them finding out which group they belonged to.

Subjects

Thirty-seven athletes from all athletic disciplines of the UNICAJA JAEN athletic club (Spain) voluntarily took part in the study. Athletes were between 17 and 33 years of age, and they were excluded if they had ever performed any proprioceptive training before or if they had any injuries at the time of data collection. Athletes were divided into 2 groups by simple random probability sampling: the "control group" composed of 17 athletes who performed a 25-minute free warm-up and the "experimental group" composed of 20 athletes who carried out a 25-minute proprioceptive exercise session in addition to the previous 25-minute free warm-up (Table 1). Research design was approved by the Ethics Committee of the University of Jaén, and written informed consent was obtained from each subject before participation according to the standards of the Declaration of Helsinki (rev. 2008). Parental consent was given for athletes under the age of 18.

Procedures

Baseline characteristics of the participants (Table 1) were initially collected by means of self-administered questionnaires in the presence of well-trained interviewers. A 100 g–130 kg precision digital weight scale (Tefal, Ecully Cedex, France)

TABLE 1. Sociodemographic and antropometric characteristics.*

Variable	All ($n = 37$) Mean	All SD	Control ($n = 17$) Mean	Control SD	Experimental ($n = 20$) Mean	Experimental SD	p
Age (y)	21.22	4.60	21.12	4.85	21.30	4.50	0.906
Height (m)	1.74	0.07	1.72	0.07	1.75	0.07	0.246
Weight (kg)	63.68	11.69	61.29	12.87	65.70	10.48	0.259
BMI ($kg \cdot m^{-2}$)	20.95	2.71	20.46	2.78	21.36	2.65	0.322
Years_training	7.08	4.47	6.29	4.16	7.75	4.71	0.330
Days_training	5.08	0.76	4.88	0.78	5.25	0.72	0.145
Gender							
Female	12	32.43%	7	41.18%	5	25.00%	0.925
Male	25	67.57%	10	58.82%	15	75.00%	
Mode							
Runner	17	45.95%	8	47.06%	9	45.00%	0.901
Jumper	17	45.95%	8	47.06%	9	45.00%	
Launcher	3	8.11%	1	5.88%	2	10.00%	
Student							
Yes	25	67.57%	14	82.35%	11	55.00%	0.077
No	12	32.43%	3	17.65%	9	45.00%	
Studies							
Primary	12	32.43%	5	29.41%	7	35.00%	0.904
Secondary	9	24.32%	4	23.53%	5	25.00%	
University	16	43.24%	8	47.06%	8	40.00%	

*Quantitative variables are shown in mean and *SD*. Categorical variables are shown in frequencies and percentages. The p values are from Student's *t*-test and chi-square tests, respectively. BMI = body mass index; Years_training = number of experience years in the sport; Days_training = periodicity of training sessions every weeks.

TABLE 2. Test-retest reliability of data.*

Variable	Intraclass correlation	95% Confidence interval	p
Ymean	0.792	0.425 to 0.925	0.002‡
Xmean	0.593	−0.124 to 0.853	0.041†
DeltaX	0.772	0.371 to 0.918	0.003‡
DeltaY	0.770	0.366 to 0.917	0.003‡
Area	0.495	−0.396 to 0.817	0.092
Length	0.721	0.230 to 0.899	0.007‡
Speed	0.720	0.226 to 0.899	0.008‡
RMS	0.744	0.294 to 0.908	0.005‡
RMSX	0.832	0.537 to 0.939	<0.001§
RMSY	0.527	−0.305 to 0.829	0.072
RMSX2	0.723	0.235 to 0.900	0.007‡
RMSY2	0.337	−0.831 to 0.760	0.210

*Interclass correlation coefficients obtained by repeated-measures analysis of variance. Ymean = mean antero-posterior position; Xmean = mean mediolateral position; DeltaX = mediolateral rate covered by the center of pressure in mediolateral plane; DeltaY = mediolateral rate covered by the center of pressure in antero-posterior plane; Area = Area covered by center of pressure; Length = Length covered by center of pressure; Speed = Speed of center of pressure; RMSY and RMSY2 = Root mean squared amplitude of the CoP in antero-posterior direction; RMSX and RMSX2 = Root mean squared amplitude of the CoP in mediolateral direction.
†Differences between groups of the same mean $p < 0.05$.
‡Differences between groups of the same mean $p < 0.01$.
§Differences between groups of the same mean $p < 0.001$.

and a t201–t4 Asimed adult height scale (Asimed, Valencia, Spain) were used to obtain weight and height, respectively.

In addition, before commencement, all athletes were taught about the correct execution of tests and training. Then, all athletes were subject to a bipedal stabilometry test (M_0). After the test, all athletes performed a 25-minute free warm-up. In addition to this, the experimental group undertook a 25-minute proprioceptive exercise session with unstable platforms. At the end of the warm-up (control group) and at the end of the proprioceptive exercise training (experimental group), the second bipedal stabilometry (M_1) was carried out. The third stabilometry was carried out 30 minutes after training (M_2), the fourth 1 hour after training (M_3), the fifth 6 hours after training (M_4), and the sixth and last 24 hours after training (M_5). Participants were asked not to engage in any physical activity until the end of the study.

Bipedal Stabilometry. A Freemed baropodometric platform (Rome, Italy) and FreeStep v.1.0.3 software (Rome, Italy) were used to measure stabilometric parameters. The platform's surface is 555 × 420 mm, with an active surface of 400 × 400 mm and 8-mm thickness. All athletes were asked to stand on both feet over the baropodometric platform for 51.2 seconds. This test measures the center of pressure (CoP) position in the mediolateral plane (Xmean) and antero-posterior plane (Ymean). It also measures the area covered by the CoP, the speed of movement of the CoP, and the length covered by the CoP. Besides, the root mean squared amplitude of the CoP in mediolateral (RMSX) and antero-posterior (RMSY) directions (in millimeters) were reported. Other measures were the CoP rate in the antero-posterior direction (DeltaY) and in the mediolateral direction (DeltaX). The reliability of data is shown in Table 2.

Proprioceptive Exercise Session. The duration of the training session was 25 minutes. Six BOSU and Swiss balls and six 3-kg medicinal balls were used for the training. The proprioceptive exercise session used 6 Swiss and BOSU ball exercises (Figure 1). The correct performance of the exercises was carefully supervised by a fitness specialist and a sports physiotherapist, who worked with groups of 6 athletes.

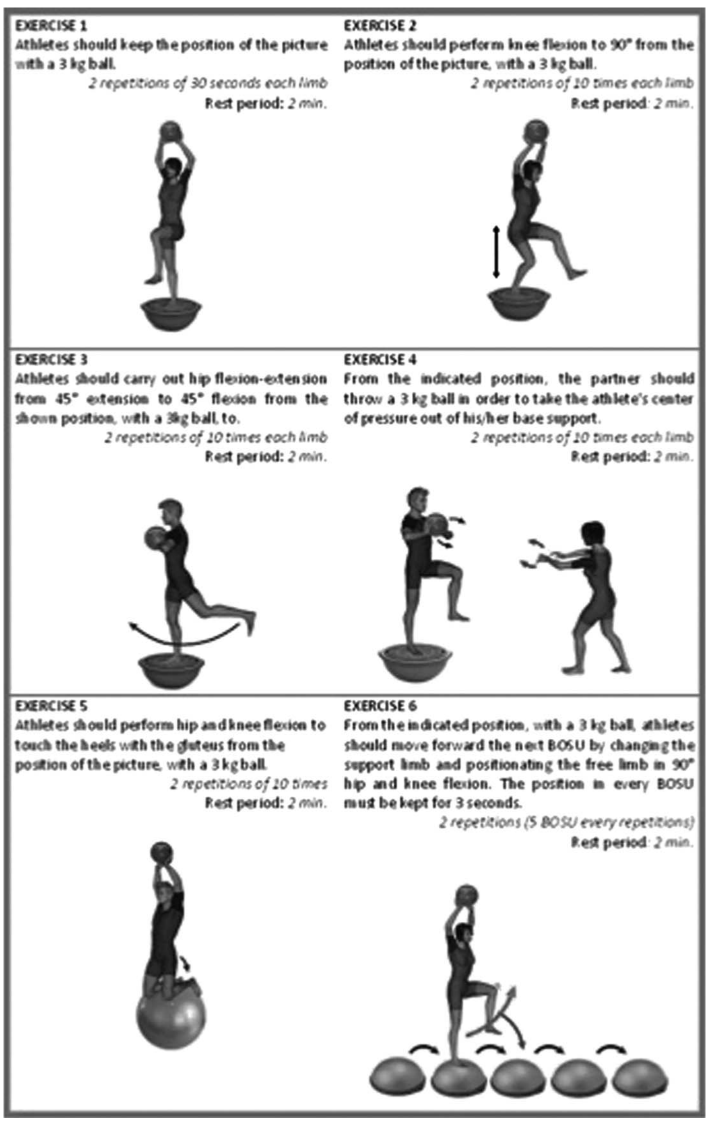


Figure 1. Proprioceptive training program performed by athletes.

Statistical Analyses

Mean and *SD* were included in the data description in continuous variables and frequencies. Nonetheless, percentages were included in categorical variables.

A Kolmogorov-Smirnov test was used to adjust the normal distribution of quantitative variables. For the demographic and morphological variables, a Student's *t*-test for independent samples was used in continuous variables and a chi-square test was used for categorical variables. The general linear model for repeated measures was used to assess the effect of the intervention groups, with time and intervention group as intra- and inter-subject variables, respectively (repeated-measures analysis of variance [ANOVA]). For the variables that showed significant baseline differences, the basal measures (pretreatment) were used as covariate. A Bonferroni test was used for paired comparisons, and significance was determined at $p < 0.05$. Data were analyzed using SPSS for Windows (version 17; SPSS, Inc., Chicago, IL, USA) and MedCalc 12.1 (Mariakerke, Belgium).

Results

Length, speed, area covered by CoP, and RMS are shown in Table 3. The covariance analysis (adjusted for pretreatment) for length and speed measures showed a group effect ($p = 0.021$ and 0.022, respectively). More specifically, the experimental group exhibited higher values of length and speed compared with the control group in M_1 ($p = 0.045$). These differences were higher in M_4 ($p = 0.009$). No significant differences were shown between groups in the rest of length and speed measures. No significant intra- and inter-group effects were found in area and RMS ($p > 0.05$).

In Table 4, mean results and *SD* of the area covered by the CoP in the XY plane are shown (RMSX, RMSX2, RMSY, and RMSY2). The repeated-measures ANOVA analysis showed no main group effects for any variables ($p = 0.260$ for the largest). Although a main time effect was found in RMSY2

TABLE 3. Mean values of length, speed, and area covered by the center of pressure and root mean squared.*

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta^2
Length (mm)†						
Pre	383.33	60.70	326.79	57.76	Group 0.021	0.147
Post$_{0Min}$‡	352.65	82.90	342.31	77.88		
Post$_{30Min}$	431.72	182.54	360.11	84.41	Time 0.089	0.223
Post$_{1H}$	350.10	38.56	375.30	98.52		
Post$_{6H}$§	348.02	82.64	372.31	102.77	Group × time 0.669	0.071
Post$_{24H}$	348.12	88.03	360.51	98.61		
Speed (mm)†						
Pre	89.47	14.20	76.25	12.98	Group 0.022	0.144
Post$_{0Min}$‡	82.44	19.23	80.54	18.17		
Post$_{30Min}$	100.46	39.79	85.40	20.84	Ttime 0.106	0.212
Post$_{1H}$	81.54	7.90	87.78	21.93		
Post$_{6H}$‡	78.06	19.48	83.93	23.03	Group × time 0.669	0.066
Post$_{24H}$	80.96	21.42	83.15	22.41		

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta^2
Area (mm)						
Pre	74.91	49.25	51.52	34.40	Group 0.159	0.056
Post$_{0Min}$	59.09	47.41	69.56	85.21		
Post$_{30Min}$	169.35	286.43	61.14	53.71	Time 0.094	0.252
Post$_{1H}$	143.68	139.38	95.67	107.89		
Post$_{6H}$	102.78	75.28	87.93	70.77	Group × time 0.230	0.191
Post$_{24H}$	74.11	67.84	101.99	112.11		
RMS (mm)†						
Pre	0.40	0.06	0.35	0.06	Group 0.216	0.045
Post$_{0Min}$	0.38	0.09	0.38	0.07		
Post$_{30Min}$	0.57	0.49	0.38	0.08	Time 0.475	0.104
Post$_{1H}$	0.38	0.05	0.41	0.12		
Post$_{6H}$	0.37	0.08	0.71	1.36	Group × time 0.500	0.100
Post$_{24H}$	0.39	0.08	0.39	0.09		

*Length = Length covered by center of pressure; Area = Area covered by center of pressure; Speed = Speed of center of pressure; RMS = Root mean squared; Eta^2 = Eta square, a measure of the magnitude of the treatment effect; Pre = measures before the training session; Post$_{0Min}$ = measures just after the training session; Post$_{30Min}$ = measures 30 minutes after the training session; Post$_{1H}$ = measures after 1 hour after the training session; Post$_{6H}$ = measures 6 hours after the training session; Post$_{24H}$ = measures 24 hours after the training session.

†Repeated-measured analysis of variance test adjusted for baseline measurement (pretreatment).

‡Differences between groups of the same mean $p < 0.05$.

§Differences between groups of the same mean $p < 0.001$.

TABLE 4. Root mean squared in antero-posterior and mediolateral planes.*

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta²
RMSX (mm)						
Pre	0.30	0.06	0.37	0.46	Group 0.942	0.000
$Post_{0Min}$	0.29	0.07	0.30	0.06		
$Post_{30Min}$	0.45	0.46	0.32	0.14	Time 0.658	0.096
$Post_{1H}$	0.28	0.04	0.32	0.12		
$Post_{6H}$	0.29	0.06	0.30	0.07	Group × time 0.546	0.117
$Post_{24H}$	0.28	0.05	0.30	0.08		
RMSY (mm)†						
Pre	0.27	0.04	0.22	0.04	Group 0.368	0.024
$Post_{0Min}$‡	0.24	0.05	0.24	0.04		
$Post_{30Min}$	0.34	0.19	0.25	0.04	Time 0.082	0.228
$Post_{1H}$	0.26	0.03	0.26	0.06		
$Post_{6H}$‡	0.27	0.04	0.27	0.07	Group × time 0.529	0.094
$Post_{24H}$	0.26	0.07	0.25	0.06		

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta²
RMSX2 (mm)						
Pre	1.66	0.80	1.60	0.54	Group 0.589	0.080
$Post_{0Min}$	1.62	1.05	1.61	0.79		
$Post_{30Min}$	2.81	3.54	1.53	0.63	Time 0.558	0.114
$Post_{1H}$	1.39	0.83	1.89	1.07		
$Post_{6H}$	1.84	0.84	1.74	0.78	Group × time 0.151	0.221
$Post_{24H}$	1.36	0.70	1.73	0.87		
RMSY2 (mm)						
Pre	2.01	0.85	1.64	0.81	Group 0.260	0.036
$Post_{0Min}$§	1.79	0.85	1.95	1.11		
$Post_{30Min}$	2.59	1.23	1.80	1.12	Time 0.047	0.293
$Post_{1H}$	3.01	1.44	2.36	1.95		
$Post_{6H}$§	2.59	0.76	2.29	1.11	Group × time 0.126	0.233
$Post_{24H}$	2.23	1.14	2.41	1.57		

*RMSY and RMSY2 = Root mean squared amplitude of the CoP in antero-posterior direction; RMSX and RMSX2 = Root mean squared amplitude of the CoP in mediolateral direction; Eta² = Eta square, a measure of the magnitude of the treatment effect; Pre = measures before the training session; $Post_{0Min}$ = measures just after the training session; $Post_{30Min}$ = measures 30 minutes after the training session; $Post_{1H}$ = measures after 1 hour after the training session; $Post_{6H}$ = measures 6 hours after the training session; $Post_{24H}$ = measures 24 hours after the training session; CoP = center of pressure.

†Repeated-measured analysis of variance test adjusted for baseline measurement (pretreatment).

‡Differences between groups of the same mean $p < 0.05$.

§Differences between groups of the same mean $p < 0.001$.

TABLE 5. Mean values of mean mediolateral position and antero-posterior position and mean values of mediolateral rate covered by the center of pressure in mediolateral and antero-posterior plane.*

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta^2
Xmean (mm)						
Pre	2.77	2.75	4.84	3.70	Group 0.001	0.273
$Post_{0Min}$	4.06†	3.16	3.87	2.84		
$Post_{30Min}$‡	2.46	1.89	5.95§	3.10	Time 0.181	0.258
$Post_{1H}$||	4.13§	1.99	6.03§	2.20		
$Post_{6H}$	3.18	2.31	4.14	3.52	Group × time 0.016	0.350
$Post_{24H}$	3.78	2.09	4.97	3.54		
Ymean (mm)						
Pre	27.34	12.32	31.80	10.28	Group 0.509	0.013
$Post_{0Min}$	29.07	10.26	32.97	11.05		
$Post_{30Min}$	30.18	10.19	32.53	10.85	Time 0.010	0.374
$Post_{1H}$	25.96	3.67	29.73	11.67		
$Post_{6H}$	27.47	11.08	23.85	10.01	Group × time 0.156	0.218
$Post_{24H}$	28.41	8.65	28.34	12.41		

	Control ($n = 17$)		Experimental ($n = 20$)			
	Mean	*SD*	Mean	*SD*	*p*	Eta^2
DeltaX (mm)						
Pre	8.12	3.67	8.10	2.35	Group 0.438	0.017
$Post_{0Min}$	9.87	5.88	9.47	4.17		
$Post_{30Min}$	17.87	23.16	7.61	2.85	Time 0.089	0.255
$Post_{1H}$	7.29	4.07	10.70	8.20		
$Post_{6H}$	8.64	3.03	9.08	4.17	Group × time 0.085	0.258
$Post_{24H}$	7.47	4.14	9.13	3.17		
DeltaY (mm)						
Pre	9.61	3.66	8.60	4.50	Group 0.307	0.030
$Post_{0Min}$	8.26	3.85	9.07	4.33		
$Post_{30Min}$	14.97†	10.79	8.58	5.34	Time 0.006	0.293
$Post_{1H}$	12.37	6.19	10.66	6.76		
$Post_{6H}$	11.43	3.56	10.97	4.72	Group × time 0.039	0.303
$Post_{24H}$	9.32	3.81	10.79	5.24		

*Xmean = mean mediolateral position; Ymean = mean antero-posterior position; DeltaX = mediolateral rate covered by the center of pressure in mediolateral plane; DeltaY = mediolateral rate covered by the center of pressure in antero-posterior plane; Eta^2 = Eta square, a measure of the magnitude of the treatment effect; Pre = measures before the training session; $Post_{0Min}$ = measures just after the training session; $Post_{30Min}$ = measures 30 minutes after the training session; $Post_{1H}$ = measures after 1 hour after the training session; $Post_{6H}$ = measures 6 hours after the training session; $Post_{24H}$ = measures 24 hours after the training session.

†Differences respect to pretreatment measure in the same group $p < 0.05$.

‡Differences between groups of the same mean $p < 0.001$.

§Differences respect to pretreatment measure in the same group $p < 0.01$.

||Differences between groups of the same mean $p < 0.05$.

($p = 0.047$), the effect of interest to our investigation (group $\times$ time interaction) was not found in the variables related to the area covered by the CoP (RMSX, RMSX2, RMSY, and RMSY2, with $P = 0.151$ for the largest).

Finally, Table 5 shows the mean values of the CoP mean position in the mediolateral (Xmean) and the antero-posterior plane (Ymean), and the mean values of CoP rate in the mediolateral plane (DeltaX) and the antero-posterior plane (DeltaY). The repeated-measures ANOVA test (2 groups $\times$ 6 times) showed a main group effect and a group $\times$ time interaction in Xmean ($p = 0.001$ and 0.016, respectively). More specifically, the experimental group obtained significantly higher values than the control group in M_2 and M_3 ($p < 0.001$ and 0.010, respectively). The Xmean results were significantly higher in M_2 and M_3 ($p < 0.001$) compared with M_0 in the experimental group. Similar results were observed in the control group. The DeltaY variable showed a main time effect ($p = 0.006$) and a group $\times$ time interaction ($p = 0.039$). In the measurement taken 30 minutes after training (M_2), the experimental group remained at the mean value but the control group showed a significant increase ($p = 0.025$). No main effect and interaction were found in Ymean and DeltaX.

Discussion

The present study was designed to evaluate the effects of a 25-minute proprioceptive exercise session on the stabilometry of athletes. The results observed pointed out the presence of negative short-term effects on the stabilometry of athletes, which could be because of the potential acute fatigue caused by the demands of the proprioceptive exercise session. It must be taken into account that it lasted 25 minutes and that it implied a more demanding training session for the experimental group, and possibly with longer-lasting effects. Whereas some previous studies found, right after proprioceptive exercise session, an increase in the activity of agonist-antagonist muscles in EMG (1,2,17,18,19), which is prone to result in more stability as proved by Marshall and Murphy (18), in the present survey, the acute fatigue could have masked any positive stabilometric results.

According to our results, length and speed were significantly increased immediately after the proprioceptive program (M_1). This data could be translated as a less stable CoP. The immediate increase shown in length and speed was accentuated 6 hours later (M_4). Our data support Drinkwater et al. (9) who, apart from identifying the increase in the activity of antagonist muscles, reported short-term deterioration in sports conditioning parameters as a consequence of proprioceptive training.

Nevertheless, the lack of complete recovery might explain the negative results reported in the present study and in the sports parameters indicated by Drinkwater et al. (9). The fatigue induced by proprioceptive exercises could amount to an overload of proprioceptive inputs for the central nervous system of the athlete, thus preventing any positive benefit. Accordingly, in medium- and long-term conditions, where acute fatigue is not present, previous studies found an improvement in stabilometry and in sports parameters as a consequence of proprioceptive training (26,27). Stanton et al. (27) found that proprioceptive training improved core stability in sportsmen. Besides, Mattacola et al. (20), Stanton et al. (27), and Romero-Franco et al. (25) also found improvements on stabilometric parameters after 6 weeks of proprioceptive training.

The acute fatigue and the lack of recovery could also explain the deterioration in the mediolateral CoP position shown by our study. This parameter increased 30 minutes (M_2) and an hour (M_3) after the proprioceptive exercise session compared with the control group and with the baseline measurement. This increase could be interpreted as a more unstable medial-lateral position, which is deviated from the center in the medial-lateral plane. For this same variable, Romero-Franco et al. (25) and Bieć and Kuczyński (6) found a medium-term improvement after 6 weeks of proprioceptive training, with recovery having been completed at the moment of data collection.

Also, although any improvement of the CoP position might be because of the short-term design of the present study, the data suggest differences between the mediolateral and the antero-posterior plane, as seen in Romero-Franco et al. (25) and Bieć and Kuczyñski (6). They found medium-term improvements only in the mediolateral plane after 6 weeks of proprioceptive training, suggesting a priority in the improvement of this plane. These findings could be explained by the deterioration that the mediolateral plane suffers according to our results and a possible evolution of these parameters through time. Likewise, we did not observe any short-term effects in the antero-posterior plane as described by Romero-Franco et al. (25) and Bieć and Kuczyñski (6), who did not observe any improvement in this plane after 6 weeks of proprioceptive training. Contrary to our results, Hoffman and Payne (14) found improvements on postural sway in both the mediolateral and the anterior-posterior directions after 10 weeks of proprioceptive training. This could mean that an overall improvement takes longer to occur.

On the other hand, the control group exhibited a trend toward improvement in several stabilometric parameters at M_1. These data confirm the findings reported by Xu et al. (29), Bartlett and Warren (3), or Friemert et al. (10), who suggested that a warm-up before sports practice significantly improves proprioception and proprioceptive system performance in a general way. Besides, this improving trend was not found in later measures, supporting evidences from Miller (cited by Rabadán (23)) who no noted that the delay between warm-up and competition should be no longer than 5 minutes because of the considerable decrease of the warm-up effects in sports performance after this time.

In conclusion, contrary to our initial hypothesis, the findings of the present study suggest that a 25-minute proprioceptive exercise session can deteriorate static posturography in athletes. These findings were observed immediately after training and later became more acute in most of the affected variables. In fact, the mean position in the medial-lateral plane also suffered negative changes and resulted in a more deviated mediolateral position. These negative effects could be explained as a consequence of the acute fatigue induced by the potentially demanding proprioceptive exercise session. On the other hand, the control group showed a general trend to improve the static posturography as a consequence of the warm-up they performed.

Practical Applications

This study shows that a 25-minute proprioceptive exercise session has negative short-term effects on the bipedal postural stability of athletes. Our results also indicate the presence of a general improvement trend in the control group after a warm-up. According to our results, coaches, personal trainers, and physical therapists should take into account that, immediately after proprioceptive exercises, acute fatigue makes the athlete less stable, which is an important piece of information to plan subsequent training sessions. They should also give extra importance to the initial warm-up. Despite the negative short-term effects of a proprioceptive exercise session, this training is still recommended to be included in the training routine because of the positive medium- and long-term effects reported in previous studies conditions of no fatigue. Proprioceptive training may allow the athletes to gain better static and dynamic postural control. A better stabilometry can have important applications, not only to prevent injuries such as ankle sprains or knee injuries but also to improve sports conditioning parameters.

Acknowledgments

The results of the present study do not constitute an endorsement of any product by the authors or the NSCA. The authors would like to thank University of Jaén, the collaboration in the study. We would also like to thank all the people who gave their help and time without expecting anything in return and all the athletes who participated in the research.

References

1. Anderson, KG and Behm, DG. Maintenance of EMG activity and loss of force output with instability. *J Strength Cond Res* 18: 637–640, 2004.
2. Anderson, K and Behm, DG. Trunk muscle activity increases with unstable squat movements. *Can J Appl Physiol* 30: 33–45, 2005.
3. Bartlett, MJ and Warren, PJ. Effect of warming up on knee proprioception before sporting activity. *Br J Sports Med* 36: 132–134, 2002.
4. Behm, DG, Anderson, K, and Curnew, RS. Muscle force and activation under stable and unstable conditions. *J Strength Cond Res* 16: 416–422, 2002.
5. Behm, DG, Leonard, A, Young, W, Bonsey, A, and Mackinnon, S. Trunk muscle EMG activity with unstable and unilateral exercises. *J Strength Cond Res* 28: 30, 2003.
6. Bieć, E and Kuczyński, M. Postural control in 13-year-old soccer players. *Eur J Appl Physiol* 110: 703–708, 2010.
7. Colado, J, Chulví, I, and Heredia, JR. *Physical exercise in conditioning rooms. Scientific and medical basis for safe and healthy practice* Madrid, Spain: Médica Panamericana, 2008.
8. Cressey, EM, West, CA, Tiberio, DP, Kraemer, WJ, and Maresh, CM. The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. *J Strength Cond Res* 21: 561–567, 2007.
9. Drinkwater, EJ, Pritchett, EJ, and Behm, DG. Effect of instability and resistance on unintentional squat-lifting kinetics. *Int J Sports Physiol Perform* 2: 400–413, 2007.
10. Friemert, B, Bach, C, Schwarz, W, Gerngross, H, and Schmidt, R. Benefits of active motion for joint position sense. *Knee Surg Sports Traumatol Arthrosc* 14: 564–570, 2006.
11. Gioftsidou, A, Malliou, P, Pafis, G, Beneka, A, Godolias, G, and Maganaris, CN. The effects of soccer training and timing of balance training on balance ability. *Eur J Appl Physiol* 96: 659–664, 2006.
12. Granell, JC and Cervera, VR. *Theory and planning of sports training.* Barcelona, Spain: Paidotribo, 2003.
13. Gruber, M and Gollhofer, A. Impact of sensorimotor training on the rate of force development and neural activation. *Eur J Appl Physiol* 92: 98–105, 2004.
14. Hoffman, M and Payne, VG. The effects of proprioceptive ankle disk training on healthy subjects. *J Orthop Sports Phys Ther* 21: 90–93, 1995.
15. Lephart, SM and Fu, FH. *Proprioception and Neuromuscular Control in Joint Stability.* Champaign, IL: Human Kinetics, 2000.
16. Lephart, SM, Pincivero, DM, and Rozzi, SL. Proprioception of the ankle and knee. *Sports Med* 25: 149–153, 1998.
17. Marshall, P and Murphy, BA. Core Stability exercises on and off a Swiss Ball. *Arch Physi Med Rehab* 86: 242–249, 2005.
18. Marshall, P and Murphy, B. Changes in muscle activity and perceived exertion during exercises performed on a Swiss ball. *Appl Physiol Nutr Metab* 31: 376–383, 2006.
19. Marshall, P and Murphy, B. Increases deltoid and abdominal muscle activity during Swiss ball bench press. *J Strength Cond Res* 20: 4, 2006.
20. Mattacola, CG and Lloyd, JW. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: A single case design. *J Athl Train* 32: 127–135, 1997.
21. Michael, JW and Behm, DG. Not all instability training devices enhance muscle activation in highly resistance-trained individuals. *J Strength Cond Res* 22: 1360–1370, 2008.
22. Norwood, TJ, Anderson, SG, Gaetz, MB, and Twist, PW. Electromyographic activity of the trunk stabilizers during stable and unstable bench press. *J Strength Cond Res* 21: 343–347, 2007.
23. Rabadán, IC, Morente, AM, Benítez, JDS, and Guillén, MC. Theoretical and practical guidance for the application of warm-up competition in team sport. *Revista Digital–Buenos Aires* 106, 2007. Available at: http://www.efdeportes.com/efd106/calentamiento-de-competicion-en-deportes-de-equipo.htm.
24. Rodd, DW, Enzler, D, and Henning, N. Electromyografic analysis of the rectus abdominus. *Med Sci Sports Exerc* 34: 292, 2002.
25. Romero-Franco, N, Martínez-López, E, Lomas-Vega, R, Hita-Contreras, F, and Martínez-Amat, A. Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *J Strength Cond Res* 26: 2071–2077, 2012.
26. Schibek, JS, Guskiewicz, KM, Prentice, WE, Mays, S, and Davis, JM. The effect of core stabilization training on functional performance in swimming. Masteŕs Thesis, University of North Carolina, Chapel Hill, 2001.
27. Stanton, R, Reaburn, PR, and Humphries, B. The effect of short-term Swiss ball training on core stability and running economy. *J Strength Cond Res* 18: 522–528, 2004.
28. Vega-García, F, Grenier, S, and McGill, S. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther* 80: 564–569, 2000.
29. Xu, D, Hong, Y, Li, J, and Chan, K. Effect of tai chi exercise on proprioception of ankle and knee joints in old people. *Br J Sports Med* 38: 50–54, 2004.
30. Yaggie, JA and Campbell, BM. Effects of balance training on selection skills. *J Strength Cond Res* 20: 422–428, 2006.
31. Yasuda, T, Nakagawa, T, Inoue, H, Iwamoto, M, and Inokuchi, A. The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. *Eur Arch Otorhinolaryngol* 256: 27–32, 1999.

IV

SHORT-TERM EFFECTS OF A PROPRIOCEPTIVE TRAINING SESSION WITH UNSTABLE PLATFORMS ON THE MONOPODAL STABILOMETRY OF ATHLETES

N Romero-Franco, A Martínez-Amat, R Lomas-Vega, F Hita-Contreras, EJ Martínez-López

Journal of Physical Therapy Science
In press

J. Phys. Ther. Sci.
26: **–**, 2014

Short-term Effects of a Proprioceptive Training Session with Unstable Platforms on the Monopodal Stabilometry of Athletes

Natalia Romero-Franco[1)*], Antonio Martínez-Amat[1)], Fidel Hita-Contreras[1)], Emilio J Martínez-López[2)]

[1)] *Department of Health Sciences, University of Jaén: E-23071 Jaén, Spain*
[2)] *Department of Didactics of Musical, Plastic and Corporal, University of Jaén, Spain*

Abstract. [Purpose] To analyze the short-term effects of a proprioceptive session on the monopodal stabilometry of athletes. [Subjects] Thirty-seven athletes were divided into a control group (n=17) and an experimental group (n=20). [Methods] Both groups performed a conventional warm-up, after which a 25-minute proprioceptive session on ustable platforms was carried out only by the experimental group. Before the training session, all athletes carried out a single-leg stabilometry test which was repeated just after training, 30 minutes, 1 hour, 6 hours and 24 hours later. [Results] Analysis of covariance (α=0.05) revealed that the experimental group had lower values than the control group in length and velocity of center of pressure (CoP) of left-monopodal stance and in velocity of CoP of right-monopodal stance in post-training measurements. Also, the experimental group had values closer to zero for the CoP position in the mediolateral and anteroposterior directions of left-monopodal stance (Xmeanl and Ymeanl) and the anteroposterior direction in on right-monopodal stance (Ymeanr) in post-training measurements. Within-group analysis of Xmeanl and Ymeanl, length and velocity of CoP in right-monopodal stance showed continuous fluctuations of values between sequential measurements in the control group. [Conclusion] Proprioceptive training on unstable platfoms after a warm-up stabilizes the position of CoP in the anteroposterior and mediolateral directions and decreases CoP movements in short-term monopodal stability of athletes.
Key words: Proprioception, Athletes, Stabilometry

(This article was submitted Jun. 27, 2013, and was accepted Aug. 4, 2013)

INTRODUCTION

Monopodal postural stance and proprioception are very important parameters in the functionality of the lower limbs of athletes[1)]. In sports, fatigue and stress along with injuries, contribute to the deterioration of the proprioceptive sense. All these aspects put athletes at risk of possible relapses or new injuries[2–4)]. Training on unstable platforms has become a common tool in several sports to reduce injury risks of athletes, and to help them improve their proprioceptive sense[5)].

Proprioceptive training on unstable platforms has been shown to result in large and medium-to-long term improvement when practiced for several consecutive weeks. Its benefits appear mainly in stabilometric parameters[6–9)]. Several authors have stated that an improvement in postural stability provides athletes with a much more stable basic stance, from which they can perform movements in a stronger and more precise fashion[10)]. Romero-Franco et al. showed there were significant improvements in postural stability as well as in the control of the center of gravity after a six-week proprioceptive training program[9)]. Similarly, Stanton et al. and Mattacola and Lloyd observed an improvement in static balance and dynamic balance variables, respectively, after proprioceptive training[6, 7)]. Others surveys have tested the monopodal stability of athletes due to the fact that it is a more specific analysis, and therefore more fitting to the needs of their particular sport of choice. The research carried out by Paterno et al. is a good example of this. They observed that a six-week proprioceptive training program improved not only general monopodal postural stance but also the values of center of pressure position in the anteroposterior direction, which reduced the number of ACL (anterior cruciate ligament) injuries in the long term[1)].

Until now, proprioceptive training studies have mainly dealt with medium- and long-term effects, while short-term effects have received little attention. Some authors have analyzed muscle activation using EMG under conditions of instability, and have reported sizeable immediate increases in muscle activities[11–14)]. It is believed that this increase aims to stabilize and maintain the gravity center, thus avoiding a potential fall[4, 15)]. However, a consequence of this muscle activity increase compensating for the instability condition, is that athletes experience a great diminution of force output.

*Corresponding author. Natalia Romero-Franco (e-mail: narf52@gmail.com)

Table 1. Sociodemographic and anthropometric characteristics

		All	n=37	Control	n=17	Experi-mental	n=20
Age (y)		21.2	±4.6	21.1	±4.9	21.3	±4.5
Height (cm)		173.9	±6.9	172.4	±6.9	175.1	±6.9
Weight (kg)		63.7	±11.7	61.3	±12.9	65.7	±10.5
BMI (kg/m^2)		20.9	±2.7	20.5	±2.8	21.4	±2.7
Gender	Woman	12	32.40%	7	41.20%	5	25.00%
	Man	25	67.60%	10	58.80%	15	75.00%
Student	Yes	25	67.60%	14	82.40%	11	55.00%
	No	12	32.40%	3	17.60%	9	45.00%

Quantitative variables are shown as mean and SD. Categorical variables are shown as frequencies and percentages. BMI, Body Mass Index.

In spite of evidence about the improvement provided by proprioceptive training, studies to date have not investigated on the short-term stabilometric effects that come from proprioceptive training. The study of Romero-Franco et al. is the only study, to our knowledge, that has analyzed the short-term stabilometric effects of training on unstable platforms. In that study, measurements were taken inmediately after proprioceptive training, and the results which showed worse bipodal postural stability of the athletes. This decrease may have been a consequence of fatigue, according to the authors[16].

With so little scientific evidence it is difficult to know the immediate results of proprioceptive training. This would be of great importance for determining when, during the training process, such exercises should take place. The purpose of this study was to analyze the short-term effects of a proprioceptive training session on an unstable platform on the monopodal stabilometry of athletes. Based on previous reports of a great increase in muscle activity with a consequent loss of force under unstable conditions, and immediate adverse effects on bipodal stability, of proprioceptive training, we authors hypothesized that proprioceptive training would negatively affect athletes' monopodal stabilometry.

SUBJECTS AND METHODS

A 24-hour quasi-experimental study was carried out in March 2012 with 6 repeated measurements of the monopodal stance:

Pre (pre-training), Post$_{0Min}$ (right after training), Post$_{30Min}$ (30 minutes after training), Post$_{1H}$ (1 hour after training), Post$_{6H}$ (6 hours after training) y Post$_{24H}$ (24 hours after training).

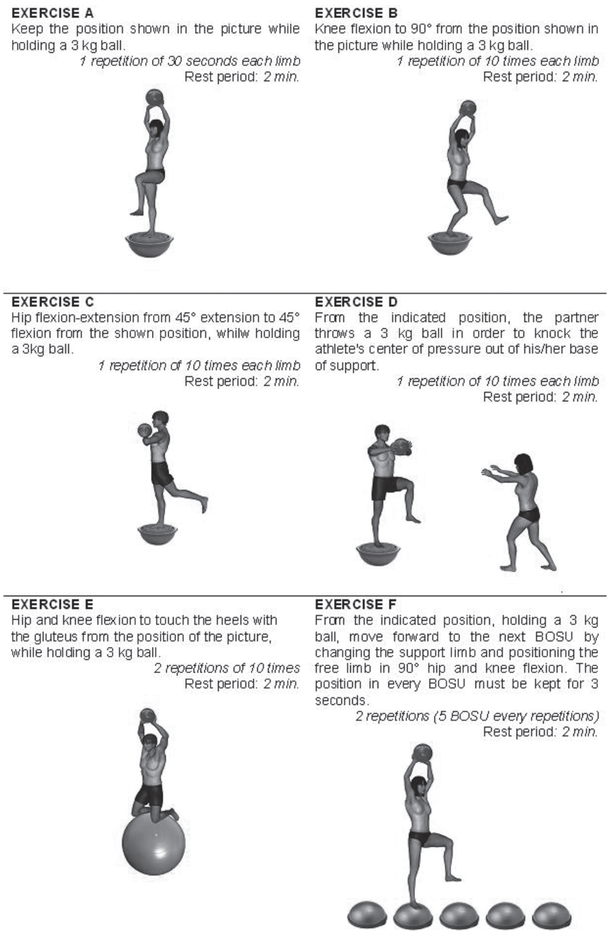


Fig. 1. Proprioceptive training session which the experimental group carried out (Designed and conducted by authors).

Subjects

We selected thirty-seven athletes who volunteered for this experiment (Table 1) and randomly divided them into two groups: the Control Group (CG) comprised 17 athletes who carried out a 25-minute conventional warm up, and the Experimental Group (EG), comprised 20 athletes who carried out the same warm up and then performed a 25-minute proprioceptive training session on unstable platforms (Fig 1). We excluded subjects who usually performed proprioceptive exercises, in addition to those who were injured at the time of the study. Before the start, we briefed all the athletes about the test and about the nature of proprioceptive training. In addition, we obtained written informed consent from each subject or their legal guardians in the case of underage athletes, according to the standards of the Declaration of Helsinki[17]. The ethical committee of the University of Jaén approved the study.

Methods

We used Five BOSU® Balance Trainers, five Swiss balls and five 3 kg medicine balls for the proprioceptive training session. We determined the correct diameter of the Swiss ball by measuring the height of each athlete: when athletes were sitting on the ball, their knees and hips had to be flexed at 90°[18]. A FreeMed© BASE model baropodometric platform was used for the stabilometric measurements (Rome, Italy). The platform's surface is 555 × 420 mm, with an active surface of 400 × 400 mm and 8 mm thickness, (Sensormédica® Sevilla, Spain). The reliability of this baropodometric platform has been shown in previous studies[16]. Calculations of center-of-pressure (CoP) movements were performed with the FreeStep© Standard 3.0 (Italy) software. We collected baseline features of the athletes with a 100 g–300 kg precision digital weight scale (Tefal) and a t201-t4 Asimed adult height scale to obtain weight and height respectively (Table 1).

To carry out the monopodal stabilometric measurement, we asked the athletes to stand for fifteen seconds on each lower limb, starting with the left one, in the middle of the platform. The athletes stood without shoes with both arms at the sides of the body and the non-support leg in 90° of knee flexion. Also, we asked athletes not to engage in any physical activity for the duration of the study.

The stabilometry test measured the following parameters of both the left- and right-leg stances: the center of pressure (CoP) position in the mediolateral (Xmean) and anteroposterior directions (Ymean), in addition to the length (Length) and the area (Area) covered by the CoP and the velocity (Velocity) of CoP movement. These variables are suffixed with "**l**" or "**r**" to indicate whether they belong to the left or right leg, respectively.

First, all athletes completed the pre-training stabilometry test. After those measurements, a 25-minute conventional warm-up was carried out by all athletes. The warm-up consisted of 10 minutes of slow running, 5 minutes of dynamic stretching and 10 minutes of specific running exercises. After the warm-up, the experimental group also performed the 25-minute proprioceptive training session (Fig. 1).

The 25-minute proprioceptive training session consisted of 6 Swiss ball and BOSU exercises and the correct performance of the exercises was carefully supervised by a fitness specialist and a sports physiotherapist, who worked with groups of 10 to 12 athletes. The effects of this type of training are based on disturbances caused under unstable conditions, which force the center of pressure out of the support base. To avoid a potential fall, stabilizing musculature is activated to make postural adjustments and maintain the center of pressure within the support base[19]. These postural adjustments and neural adaptations are the main responsible of benefits of proprioceptive training appearing in stabilometric parameters[6–9].

Just after the warm-up, in the case of the control group, and immediately after the proprioceptive session in the case of the experimental group, the $Post_{0Min}$ measurements were taken. $Post_{30Min}$ measurements were taken 30 minutes later and $Post_{1H}$ measurements were taken one hour after the proprioceptive session. $Post_{6H}$ was measured after 6 hours, and $Post_{24H}$, at 24 hours after the proprioceptive training session.

Descriptive statistics include averages and standard deviations for the continuous variables, and the frequencies and percentages of the categorical variables (Table 1). The Kolmogorov-Smirnov test was used to test the normal distribution of quantitative variables. Regarding the demographic and morphological variables, Student's t test was used for independent samples in the case of the continuous variables and the χ^2 test for the categorical variables. The general linear repeated measures model was employed for all variables, with time and intervention group as within- and between-subjects variables, respectively (repeated measures ANOVA). A covariance analysis was performed on variables showing differences from baseline, with the initial measurement as covariate (ANCOVA). The level of statistical significance used was $p < 0.05$. Data analysis was performed by means of the SPSS statistical data analysis package for Windows (v.19; Chicago).

RESULTS

Table 1 shows socio-demographic and morphological variables related to the sample as well as the differences between the experimental and control groups. No significant difference was noted ($p > 0.05$).

The mean CoP position in the mediolateral (Xmeanl and Xmeanr) and the anteroposterior (Ymeanl and Ymeanr) directions of both monopodal supports are shown in Table 2. Xmeanl showed a statistically significant group*time interaction (p=0.002). Within-group analysis showed that the control group experienced a significant decrease at $Post_{30Min}$ from 0.66±2.69 at baseline to −1.81±3.28 mm (p=0.024), another significant decrease at $Post_{1H}$ from 1.81±3.28 to −8.66±13.28 mm (p=0.042), an increase at $Post_{6H}$ from −8.66±13.28 to 1.68±2.93 mm (p=0.008) and a decrease at $Post_{24H}$ from 1.68±2.93 to −1.27±3.47 mm (p=0.013). Meanwhile, the experimental group showed similar values for all measurements with no significant differences (p>0.05). Also, between-group analysis showed significant differences at $Post_{1H}$, when the control group had values further from zero than the experimental group (−8.66±13.28 vs 0.40±2.67 mm, p=0.005).

Ymeanl showed a main time effect (p=0.042) and a statistically significant group*time interaction (p=0.043). In within-group analysis, the control group showed an increase at $Post_{30Min}$ from −11.83±7.07 at baseline to −4.97±7.61 mm (p=0.005), and another increase at $Post_{24H}$ from −11.26±8.91 to −7.11±5.41 mm (p=0.015), while the experimental group showed similar values for all measurements with no significant differences (p>0.05). Furthermore, between-group analysis showed significant differences at $Post_{0Min}$ and $Post_{6H}$, when the experimental group had values nearer to zero that the control group (−11.83±7.07 vs −0.73±10.84 mm, p=0.009 and −11.26±8.91 vs −3.22±5.10 mm, p=0.036, respectively).

Ymeanr showed a main time effect (p=0.003) and a non-

Table 2. Mean values of variables of center of pressure position in mediolateral (Xmean) and anteroposterior (Ymean) directions

	Control		Experimental			Control		Experimental	
	n=17		n=20			n=17		n=20	
Xmeanl (mm)	Mean	SD	Mean	SD	Xmeanr (mm)	Mean	SD	Mean	SD
Pre	−6.44	18.55	1.46	3.95	Pre	−1.35	3.48	−1.19	3.16
$Post_{0Min}$	0.66	2.69	−4.09	16.01	$Post_{0Min}$	0.67	20.48	−2.78	9.02
$Post_{30Min}$	+−1.81	3.28	−1.26	3	$Post_{30Min}$	−0.98	3.88	−0.73	5.47
$Post_{1H}$**	+−8.66	13.28	0.4	2.67	$Post_{1H}$	1.14	5.14	1.06	3.29
$Post_{6H}$	++1.68	2.93	1.29	3.45	$Post_{6H}$	−1.37	5.09	−2.04	3.47
$Post_{24H}$	+−1.27	3.47	−0.29	3.05	$Post_{24H}$	−0.84	3.12	−1.48	3.72
Ymeanl (mm)†	Mean	SD	Mean	SD	Ymeanr (mm)†	Mean	SD	Mean	SD
Pre	−6.44	18.55	1.61	3.89	Pre	−10.6	7.87	−1.57	9.97
$Post_{0Min}$**	−11.83	7.07	−0.73	10.84	$Post_{0Min}$	0.67	20.48	−2.78	9.02
$Post_{30Min}$	++−4.97	7.61	−0.31	9.82	$Post_{30Min}$	−8.01	9.46	−1.39	11.47
$Post_{1H}$	1.03	16.27	−1.72	8.48	$Post_{1H}$	4.24	20.82	1.07	18.66
$Post_{6H}$*	−11.26	8.91	−3.22	5.1	$Post_{6H}$*	−11.72	7.57	−3.91	10.73
$Post_{24H}$	+−7.11	5.41	−0.13	8.13	$Post_{24H}$*	−7.47	7.69	−1.15	9.27

Xmeanl= mediolateral mean position of center of pressure in left –side monopodal support. Ymeanl=anteroposterior mean position of center of pressure in left-side monopodal support. Xmeanr= mediolateral mean position of center of pressure in right-side monopodal support. Ymeanr=anteroposterior mean position of center of pressure in right-side monopodal support. Pre = measures before training session. $Post_{0Min}$ = measures just after the training session. $Post_{30Min}$ = measures 30 minutes after the training session. $Post_{1H}$ = measures after 1 hour after the training session. $Post_{6H}$ = measures 6 hours after the training session. $Post_{24H}$ = measures 24 hours after the training session·†=pre measurement as covariable; + (p<0.05), ++ (p<0.01)=denotes within-group differences with significant decrease or increase from the previous measurement; * (p<0.05), **p<0.01=denotes between-group differences in the same measurement.

significant group*time interaction, (p=0.052). Between-group analysis showed statistically significant diferences at $Post_{6H}$ (p=0.017) when the control group had values further from zero than the experimental group (−11.72±7.57 vs −3.91±10.73 mm). Similar results were observed at $Post_{24H}$, with values further from zero than the control group (−7.47±7.69 vs −1.15±9.27 mm, p=0.032). Also, results close to the level of significance (p=0.066) were found at $Post_{30Min}$ when the control group had values further from zero than the experimental group (−8.01±9.46 vs −1.39±11.47 mm). Within-group analysis did not find any significant result. The other variables did not show any significant group*time interactions (p>0.05).

Length and Area covered by CoP (Lengthl and Lengthr, Areal and Arear) and Velocity of CoP movement (Velocityl and Velocityr) are shown in Table 3.

Lengthr showed a main time effect (p<0.001) and a statistically significant group*time interaction (p=0.048). Within-group analysis showed that the control group experienced a decrease at $Post_{30Min}$ from 392.53±146.63 to 329.40±49.80 mm (p=0.014) and a new significant decrease at $Post_{24H}$ from 367.80±83.67 to 302.91±70.88 mm (p<0.001); however, the experimental group showed similar values for all measurements (p>0.05). In between-group analysis, significant differences were found at $Post_{0Min}$ when the experimental group showed lower values than the control group (392.53±146.63 mm vs 325.06±83.44 mm, p=0.030). Results close to the level of significance were observed at $Post_{6H}$ (p=0.068).

Velocityr showed a main time effect (p<0.001) and a statistically significant group*time interaction (p=0.032). In within-group analysis, the control group showed a decrease at $Post_{30Min}$ from 24.51±6.65 mm/sec at baseline to 19.53±3.70 mm/sec (p=0.001), a significant increase at $Post_{6H}$ from 19.27±2.63 to 23.33±5.84 mm/sec (p=0.024), and another decrease at $Post_{24H}$ from 23.33±5.84 to 19.09±4.62 mm/sec (p<0.001). In between-group analysis, significant differences were observed at $Post_{0Min}$, when the experimental group showed lower values than the control group (24.51±6.65 vs 19.96±4.74 mm, p=0.021). Significant results were also observed at $Post_{6H}$ (23.33±5.84 vs 20.04±3.77 mm/sec, p=0.046). The main time effects in Lengthr and Velocityr showed that both groups had significantly lower values with respect to Pre at all measurements except that of $Post_{0Min}$ one. The other variables did not show any significant group*time interactions (p>0.05).

DISCUSSION

The purpose of the present study was to analyze the short-term effects of a proprioceptive training session with unstable platforms on the monopodal stability of athletes. To this end, athletes were subjected to a monopodal stabilometry test before a 25-minute proprioceptive session and

Table 3. Mean values of variables of CoP movement (Length, Area, Velocity) in both left-side and right-side monopodal supports

	Control		Experimental			Control		Experimental	
	n=17		n=20			n=17		n=20	
Lengthl (mm)	Mean	SD	Mean	SD	Lengthr (mm)	Mean	SD	Mean	SD
Pre	357.3	138.86	348.29	106.47	Pre	401.99	140.27	359.53	89.83
Post$_{0Min}$	380.04	91.28	339.24	146.63	Post$_{0Min}$*	392.53	97.63	325.06	83.44
Post$_{30Min}$	322.61	63.12	320.47	84.34	Post$_{30Min}$	+329.4	49.8	325.48	76.38
Post$_{1H}$	295.08	36.46	305.86	89.96	Post$_{1H}$	322.33	46.77	318.5	43.01
Post$_{6H}$	315.3	105.74	353.68	209.02	Post$_{6H}$	367.8	83.67	322.17	63.75
Post$_{24H}$	289.64	72.61	309.41	72.17	Post$_{24H}$	+++302.91	70.88	319.82	82.48
Areal (mm)	Mean	SD	Mean	SD	Arear (mm)	Mean	SD	Mean	SD
Pre	421.16	357.22	447.08	342.23	Pre	664.84	778.65	467.94	352.93
Post$_{0Min}$	372.62	212.11	468.87	338.88	Post$_{0Min}$	501.49	311.79	401.14	260.49
Post$_{30Min}$	496.95	273.64	459.30	326.13	Post$_{30Min}$	391.60	144.14	518.99	330.55
Post$_{1H}$	569.22	333.67	417.35	305.88	Post$_{1H}$	348.67	129.88	394.13	134.59
Post$_{6H}$	425.98	289.62	631.77	1042.44	Post$_{6H}$	375.94	244.97	466.36	326.35
Post$_{24H}$	215.73	117.66	325.53	224.87	Post$_{24H}$	306.42	160.09	313.48	146.86
Velocityl (mm/sec)	Mean	SD	Mean	SD	Velocityr (mm/sec)	Mean	SD	Mean	SD
Pre	22.47	9.34	22.61	6.67	Pre	25.17	9.55	22.49	5.82
Post$_{0Min}$	23.22	6.19	21.68	9.20	Post$_{0Min}$*	24.51	6.65	19.96	4.74
Post$_{30Min}$	17.61	4.99	19.74	4.97	Post$_{30Min}$	++19.53	3.70	19.89	4.88
Post$_{1H}$	18.98	2.45	19.46	5.51	Post$_{1H}$	19.27	2.63	19.19	2.09
Post$_{6H}$	20.54	7.21	22.57	13.51	Post$_{6H}$*	+23.33	5.84	20.04	3.77
Post$_{24H}$	17.56	4.54	18.80	4.52	Post$_{24H}$	+++19.09	4.62	19.82	4.54

Lengthl= Length of Center of Pressure movement in left monopodal support. Areal=Area of Center of Pressure movement in left monopodal support. Velocityl=Velocity of Center of Pressure movement in left monopodal support. Lengthr= Length of Center of Pressure movement in right monopodal support. Arear=Area of Center of Pressure movement in righ monopodal support. Velocityr=Velocity of Center of Pressure movement in right monopodal support. Pre = measures before training session. Post$_{0Min}$ = measures just after the training session. Post$_{30Min}$ = measures 30 minutes after the training session. Post$_{1H}$ = measures after 1 hour after the training session. Post$_{6H}$ = measures 6 hours after the training session. Post$_{24H}$ = measures 24 hours after the training session; + ($p<0.05$), ++ ($p<0.01$), +++($p<0.001$) =within-group differences with significant decrease or increase from the previous measurement; *($p<0.05$)=between-group differences.

then 5 times more: right after the training, after 30 minutes, after 1 hour, after 6 hours and after 24 hours from the end of the proprioceptive training session.

Important findings were observed in variables refering to position of CoP in both the mediolateral and anteroposterior directions of the experimental group (Xmean and Ymean). The control group experienced several and important fluctuations in the mediplateral and anteroposterior directions during the 24 hours after the conventional warm-up session in left-side monopodal support. These fluctuations were not observed in the experimental group, which showed values over the whole time. These findings agree with the study of Romero-Franco et al., in which the control group showed worse stabilometric parameters with certain fluctuations in mediolateral stability after a 25-minute warm-up[16]. In contrast, Subasi et al., reported that a shorter warm-up had positive effects on the balance of healthy young individuals, without any difference between a 5-minute and a 10-minute warm up[20]. Regarding the uniformity of stabilometric parameters of the experimental group, the only study to date, to our knowledge, which has analyzed immediate effects of proprioceptive training on stability did not find similar results, only a certain deterioration in mediolateral stability[16].

All differences found between the experimental and control groups on both the left and right-side monopodal supports were always in favour of the experimental athletes, who showed values closer to zero than the control group, and consequently, a more central position of CoP in the anteroposterior and mediolateral directions of left-side monopodal support and in the anteroposterior direction of right-side monopodal support. In spite of these between-group differences, no clear stabilometric improvement was shown in the mediolateral and anteroposterior stability after the proprioceptive training session. Our findings partly agree with Romero-Franco et al., who showed that a proprioceptive training session had no effect on most stabilometric parameters of athletes[16]. They also reported a certain deterioration in the mediolateral stability in bipodal support after proprioceptive training, which would have been distinct from our results, where no changes were observed in the experimental group.

Regarding variables about the path covered by CoP, significant findings were observed in Length and Velocity of the right-side monopodal stabilometry. Both the experimental and control groups experienced a stabilometric improvement after the training session, and this improvement was higher in the experimental group after the proprioceptive training. Our findings differ from Romero-Franco et al. who reported deterioration in bipodal stability right after a proprioceptive training session[16]. The difference between our results and those of Romero-Franco et al. seems to mean that the effects of proprioceptive training are different for the cases of monopodal and bipodal support. This result could be explained by Ashton-Miller's suggestion about the specific improvement proprioceptive training often induces, which means that only similar exercises are improved[21]. This would explain the difference between the result of the present study and those of Romero-Franco et al., since proprioceptive training in both studies comprised mainly monopodal exercises. This explanation would also support the study of Paterno et al., in which athletes showed improvements in anteroposterior and general stability, but not in mediolateral stability in monopodal support after six weeks of proprioceptive training. Paterno et al. suggested that these results may have been due to the lack of mediolateral perturbation during their proprioceptive training program, which only consisted of anteroposterior perturbations[1].

In the present study significant fluctuations were found in the stabilometric values of the control group after the warm-up session, while the experimental group showed similar values for all measurements after the proprioceptive training session.

Despite the fact that no clear stabilometric improvement was found during the 24 hours after the proprioceptive training session, the uniformity observed in the stabilometric values of the experimental group may mean the proprioceptive training session had a stabilizing effect on stabilometry. Thus, taking into account the consensus about stabilometric deterioration as a risk factor of injuries[22–24], a more stable CoP without significant fluctuations would appear to be extremely important for injury prevention. However, further investigation is needed to verify this supposition.

Also, we suggest that differences found between right and left-side monopodal support may be explained by the sense of the curve of the track where all the athletes participing in this study trained, which is always to the left, according to the coaches of all athletes. However, no studies to date have analysed the effect of this on athletes.

This study had limitations that need to be considered. First, the size sample was small, which could have affect the limits of significance. Also, the athletes' inexperience with proprioceptive training may have been the main cause why clear improvements in monopodal stability did not appear. In futher investigations, we recommend the inclusion of a group of athletes experienced in proprioceptive training, in order to analyze its immediate effect and detail the best schedule for a training routine.

The inclusion of a 25-minute proprioceptive training session on unstable platfoms after a conventional warm-up by athletes stabilized the position of CoP in the anteroposterior and mediolateral planes in monopodal stability by decreasing CoP displacement. Contrary to our hypothesis, after 25-minutes of conventional warm-up, athletes showed stabilometric alterations. However, the inclusion of an additional 25-minute proprioceptive training on unstable platforms helped to regulate monopodal stabilometric parameters in the short-term mantaining the monopodal stability level of athletes.

In practical application, coaches and physiotherapists should taken into account the "stable stabilometry" gained immediately after the proprioceptive training which eliminates significant stabilometric fluctuations which could be a potential risk factor of injuries for athletes. Besides, the incorporation of proprioceptive exercises as part of the warm-up would not only result in better stability than a typical warm-up, but would also elicit medium and long-term improvements in stability that are essential for injury prevention.

REFERENCES

1) Paterno MV, Myer GD, Ford KR, et al.: Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther, 2004, 34: 305–316. [Medline] [CrossRef]
2) Arokoski JP, Valta T, Airaksinen O, et al.: Back and abdominal muscle function during stabilization exercises. Arch Phys Med Rehabil, 2001, 82: 1089–1098. [Medline] [CrossRef]
3) McGill SM, Grenier S, Kavcic N, et al.: Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol, 2003, 13: 353–359. [Medline] [CrossRef]
4) Chulvi I, Heredia JR. Acondicionamiento Deportivo: Análisis del trabajo con Fitball para el fortalecimiento de la zona Media. Alto rendimiento: ciencia deportiva, entrenamiento y fitness. 2006 31: 3.
5) Behm D, Colado JC: The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. Int J Sports Phys Ther, 2012, 7: 226–241. [Medline]
6) Mattacola CG, Lloyd JW: Effects of a 6-week strength and proprioception training program on measures of dynamic balance: a single-case design. J Athl Train, 1997, 32: 127–135. [Medline]
7) Stanton R, Reaburn PR, Humphries B: The effect of short-term Swiss ball training on core stability and running economy. J Strength Cond Res, 2004, 18: 522–528. [Medline]
8) Yaggie JA, Campbell BM: Effects of balance training on selected skills. J Strength Cond Res, 2006, 20: 422–428. [Medline]
9) Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, et al.: Effects of proprioceptive training program on core stability and center of gravity control in sprinters. J Strength Cond Res, 2012, 26: 2071–2077. [Medline] [CrossRef]
10) Yasuda T, Nakagawa T, Inoue H, et al.: The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. Eur Arch Otorhinolaryngol, 1999, 256: S27–S32. [Medline] [CrossRef]
11) Marshall P, Murphy B: Changes in muscle activity and perceived exertion during exercises performed on a swiss ball. Appl Physiol Nutr Metab, 2006, 31: 376–383. [Medline] [CrossRef]
12) Anderson KG, Behm DG: Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res, 2004, 18: 637–640. [Medline]
13) Anderson K, Behm DG: Trunk muscle activity increases with unstable squat movements. Can J Appl Physiol, 2005, 30: 33–45. [Medline] [CrossRef]
14) Drinkwater EJ, Pritchett EJ, Behm DG: Effect of instability and resistance on unintentional squat-lifting kinetics. Int J Sports Physiol Perform, 2007, 2: 400–413. [Medline]
15) McArdle W, Katch F, Katch V: Fundamentos de fisiología del ejercicio. 2nd Edición. Mardrid: McGrawHill-interamericana. 2004.

16) Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, et al.: Short-term effects of proprioceptive training with unstable platform on athletes' stabilometry. J Strength Cond Res, 2013, 27: 2189–2197. [Medline] [CrossRef]
17) Mundial AM. Declaración de Helsinki de la Asociación Médica Mundial. Principios éticos para las investigaciones médicas en seres humanos.[Internet]. 2008.
18) Spalding A, Kelly L, Santopietro J, et al.: Kids on the ball: using Swiss balls in a complete fitness program: Human Kinetics; 1999.
19) Behm DG, Anderson K, Curnew RS: Muscle force and activation under stable and unstable conditions. J Strength Cond Res, 2002, 16: 416–422. [Medline]
20) Subasi SS, Gelecek N, Aksakoglu G: Effects of different warm-up periods on knee proprioception and balance in healthy young individuals. J Sport Rehabil, 2008, 17: 186–205. [Medline]
21) Ashton-Miller JA, Wojtys EM, Huston LJ, et al.: Can proprioception really be improved by exercises? Knee Surg Sports Traumatol Arthrosc, 2001, 9: 128–136. [Medline] [CrossRef]
22) Tropp H, Ekstrand J, Gillquist J: Stabilometry in functional instability of the ankle and its value in predicting injury. Med Sci Sports Exerc, 1984, 16: 64–66. [Medline] [CrossRef]
23) Trojian TH, McKeag DB: Single leg balance test to identify risk of ankle sprains. Br J Sports Med, 2006, 40: 610–613. [Medline] [CrossRef]
24) Wang HK, Chen CH, Shiang TY, et al.: Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. Arch Phys Med Rehabil, 2006, 87: 821–825. [Medline] [CrossRef]

V

POSTURAL STABILITY AND SUBSEQUENT SPORTS INJURIES DURING INDOOR SEASON OF ATHLETES

N Romero-Franco, EJ Martínez-López, F Hita-Contreras, MC Osuna-Pérez, A Martínez-Amat

Journal of Physical Therapy Science
In press

POSTURAL STABILITY AND SUBSEQUENT SPORTS INJURIES DURING INDOOR SEASON OF ATHLETES

N Romero-Franco[1]; EJ Martínez-López[2]; F Hita-Contreras[1]; Osuna-Pérez MC[1]; A Martínez-Amat[1]

1. Department of Health Sciences, University of Jaén, E-23071 Jaén, Spain. Fax: +34953012141

2. Department of Didactics of Musical, Plastic and Corporal, University of Jaén, E-23071 Jaén, Spain. Fax: +34953212488

Corresponding Author:

Natalia Romero-Franco

Department of Health Sciences, University of Jaén, E-23071 Jaén, Spain

Tel +34-953-212917 Fax +34- 953-212239 Email: narf52@gmail.com

Ethical Approval: University of the city

Funding: Authors do not state any sources of funding.

Conflict of Interest: Authors are not aware of any conflicts of interest that may have affected the outcome of this study.

ACKNOWLEDGMENTS

Authors would like to thank the University of Jaen support. Besides, to be grateful for the great effort made and the time spent on the present study by all athletes, without whom the good performance of the investigation would not have been possible.

ABSTRACT

[Purpose] To analyze the stabilometry of athletes during their indoor season, in order to find out whether injured athletes show previous different stabilometric values than non-injured athletes in two different training periods (volume and pre-competition periods). [**Participants]** 51 athletes who trained regularly from Unicaja athletic club. [**Methods]** At the end of the pre-season and volume periods, athletes were subject to bipodal and monopodal stabilometries. In addition, all injuries happening in the periods following each of the stabilometries (volume and pre-competition periods) were tracked. [**Results]** Variance analysis of bipodal stabilometric measurements taken at the end of the pre-season period showed that athletes with higher values in the center-of-pressure spread variables suffered injuries during the volume period. Results right-leg monopodal stabilometric measurements taken at the end of the volume period showed that athletes with higher values in the center-of-pressure position variables suffered injuries during the pre-competition period. [**Conclusion]** Athletes showing the worst values in center-of-pressure spread variables are more prone to sports injuries in the subsequent training period. In monopodal measurements, athletes with poorer mediolateral stability were more prone to injuries in subsequent training period.

Key words: Sports injury, Athletes, Postural stability.

INTRODUCTION

Postural stability is deeply linked with sports injuries, and copious evidence exists that the first is greatly reduced by the latter. Back in 1965, Freeman first described stabilometric alterations in patients suffering from ankle sprain, and correlated lateral instability of the ankle with a lack of postural control[1)]. After Freeman, several authors have analyzed the effects of sports injuries on postural stability of athletes and concluded that its deterioration may cause re-injuries or even new injuries[2, 3)].

In addition to previous injuries, postural stability may be affected by changes in the level of activity, as well as by its type, intensity and volume [4-6)] which constitute a risk of injury for athletes[7)]. Some authors have carried out prospective assessments of athletes in order to determine how stabilometric changes can be a causing factor for injuries[8)]. McGuine et al. assessed the first two weeks of the season for basketball players, and correctly described balance as a predictor of injuries, showing that those with higher postural sway values at the start of the season were the ones most injured in the long term[9)]. Similar results were found by Wang et al., who established a correlation between poor mediolateral stability and suffering from ankle injuries later on[10)]. Likewise, Trojian and McKeag in 2006, showed the ability of maintaining single-leg balance of athletes at the beginnin of the preseason as predictor of ankle sprains for the autum season[11)]. Also, Soderman et al. correlated all lower extremity injuries with increases in postural sway in female soccer[12)].

From a physiological point of view, Murphy et al., in 2003 affirmed that the main cause of deteriorated postural stability as risk factor is an alteration in the control neuromuscular strategy which increases intersegmental joint forces and consequently, increases the development of forces about ligaments, tendons and muscles[13)].

In spite of findings reported by these authors, postural stability as predictor of sports injuries is not clear to date. There are also some similar studies which have not reported results in the same line. Hopper et al. analyzed single-leg stability by assesing time which female netball athletes could maintain unilateral posture, however they did not find correlation between postural stability and an increase of injuries[14)]. Similar results were reported by Beynnon et al. in socccer, field hockey and lacrosse athletes[15)].

Based on the controversy existing in postural stability as injury predictor and the evidence of effects of training on postural stability, and also considering that to date, no studies have taken into account the type of training as cause of postural stability deterioration in their prospective investigations, the aim of the present study is to analyze the stabilometry of athletes during their training stage in order to find out whether injured athletes scored differently in stabilometric tests than those who were injury-free in two different training periods.

SUBJECTS AND METHODS

Descriptive prospective five-month study (September – January) was divided into two parts according to the different training periods: first part was compounded by bipodal and monopodal stabilometry tests at the end of *Pre-season* (in September, mainly general exercises) and a record of injuries suffered by the athletes during the subsequent period of training which was *Volume Period* (in October and November, with training based on alternating general and specific high-volume, low-intensity exercises). The second part was compounded by bipodal and monopodal stabilometry tests at the end of volume period and a record of injuries suffered by the athletes during the subsequent period of training which was *pre-competition Period* (in December and January, with an majority of specific low-volume, high intensity exercises). In order to avoid interferences of previous injuries, all athletes injured during volume period were excluded in the second part. The record of injuries was performed by a physiotherapist specialized in sports injuries.

A total of 51 track and field athletes who were from 17 to 35 years old, from athletics club of the city with at least three years of experience took part in the first part of the present study, after excluding those who did not train regularly or who had been injured during the pre-season period. In the second part of the study, athletes who had been injured previously were excluded in order to avoid interferences in the results. Therefore, 39 athletes who were from 17 to 35 years old, participed in this part of investigation. Anthropometric and demographic data are shown in Table 1.

Location of table 1.

Before the start of the study, all athletes were briefed on how they would be tested, and written informed consent was obtained from each subject or from their legal tutors in the case of under-age athletes, according to the standards of the Declaration of Helsinki (2008 revision)[16]. The ethical committee of the University of Jaén approved the study.

Weight and height measurements were performed with a Tefal (France) digital precision scale (100g-300kg) and an Asimed t201-t4 (Spain) measuring rod, respectively. For stabilometric measurements, a modular electronic baropodometer was used, comprising a 120x160 cm Sensormédica® (Spain) platform with 19200 active sensors. The reliability of this piece of equipment has been proven in other studies[17].

Athletes were subject to a bipodal and a monopodal stabilometric measurement once at the end of each period. For the bipodal test, athletes were instructed to remain as still as possible on the baropodometric platform for 52 seconds, with a between-heels separation of 5 cm and their feet forming a 30º angle. For the monopodal test, athletes stood on each of their lower limbs for 15 seconds (left leg first) on the center of the platform (Figure 1). The following parameters were recorded for the bipodal test as well as for the left-leg and right-leg monopodal tests: length (Length) and area (Area) of the path described by the center of pressure, the speed for the center of pressure movement (Speed), and the position of the center of pressure in the mediolateral (Xmean) and anteroposterior (Ymean) planes. These variables are marked "l" or "r" to indicate whether they belong to the left or right leg, respectively. Tests were carried out before training started, in order to avoid any interference. Also, athletes were instructed not to engage in any sports activity in the day of testing.

Location of Figure 1.

In order to track injuries, athletes were previously instructed and then weekly interviewed by a sports physical therapist during the volume and pre-competition periods, in order to record any musculoeskeletal injury on lower limb they might have sustained during these periods. Injury was defined as “physical damage that resulted in missing or modifying one or more training sessions or competitions” (Kolt et al., 1999)[18].

A description of data was made which included means and standard deviations for the categorical variables (Table 1). Differences in social and demographic variables between the injured and non-injured in each period (volume and pre-competition) were analyzed by means of Student's *t* test for independent samples in the case of the continuous variables and a Chi-squared test for the categorical variables. For comparison between stabilometric variables between groups (injured and non-injured) Student's t test for independent samples was used. Normality of data was assessed through a Kolmogorov-Smirnov test. These variables are shown underlined in tables. A significance level of $p \leq 0.05$ was determined for all statistical procedures, and SPSS v. 19 software was used.

RESULTS

Table 1 shows the statistical social and demographic description of the injured and non-injured subjects during the volume and pre-competition periods. Results show a similar number of injured athletes in both periods. No differences were apparent in the social and demographic characteristics of injured and non-injured athletes (p>0.05).

Table 2 shows mean values for the center-of-pressure spread and position variables in both bipodal and monopodal support at the end of the pre-season period according to athletes injured and non-injured during volume period. Bipodal stabilometry tests show that those injured during the volume period had scored significantly higher in Length and Speed than those who were not injured (p=0.009 and p=0.003 respectively). Monopodal stabilometry tests did not show any statistically significant difference (p>0.05).

Location of Table 2.

Table 3 displays the mean values for the center-of pressure spread and position variables in both bipodal and monopodal support at the end of the volume period according to athletes injured and non-injured during pre-competition period. Right-leg monopodal stabilometry showed that injured subjects scored significantly higher in xmeanr variable (p=0.041). Left-leg monopodal and bipodal stabilometry did not show any statistically significant difference (p>0.05).

Location of Table 3.

DISCUSSION

The aim of the present study was to analyze stabilometric values of athletes through their training in order to determine their value as a predictor for injuries in each of the training periods. To this end, athletes were subject to a bipodal and monopodal stabilometry at the end of their pre-season period and a tracking of their injuries in the subsequent volume period (first part). In addition, a bipodal and monopodal stabilometry was carried out at the end of volume period and a tracking of their injuries in the the subsequent pre-competition period (second part).

Results obtained in the stabilometry made at the end of the pre-season period show that athletes with poorer values in center-of-pressure length and speed in bipodal support at the end of pre-season were the ones who were injured in the two subsequent months which compounded the volume period. At the same time that these findings agree with previous studies in which high variation of postural sway correlated or predicted posterior sports injuries[9, 10, 12)], our results did not show any significant difference in monopodal stability as ocurred in most of the previous studies. McGuine et al., in 2000, observed that basketball players with poorer pre-season unilateral balance values were seven times more prone to ankle sprains during the season[9)] and Soderman et al. reported similar findings for female soccer players, with the ones with lower scores in unilateral postural balance being more prone to leg-related injuries[12)]. Similar results were found in unilateral stability of athletes by Watson et al., who assessed the monopodal postural sway making soccer players maintain unilateral balance for 15 seconds and those who were not able to perform it without touching down were clasified as abnormal postural sway. This group was the most affected by posterior ankle sprains[19)]. Also, our findings contrast with the study by Trojian and

McKeag in 2006, in which they found a positive association between monopodal support stability and ankle sprains[11)].

In adittion, results of stabilometric tests carried out in the volume period show that athletes with worse center-of-pressure values in the mediolateral while on right-leg monopodal support were more commonly injured during the two subsequent months which compounded the pre-competition period. In spite of the fact that these results are found in monopodal stabilometry instead of bipodal support, these findings show the same trend that the previous values of center-of-pressure spread found during first part of the present study in which injured athletes had a stability deterioration. Besides, these results support the research by McGuine et al. and Soderman et al., who reported in basketball players and soccer players, respectively, poorer previous unilateral stabilometric center-of-pressure values for subjects who were injured later more frequently[9, 12)]. These results are also in accord with those of Trojian and McKeag who associated worse monopodal stabilometry with later ankle sprains in athletes[11)], in addition to agreeing with results by Wang et al. in 2006, who also established a correlation between poorer center-of-pressure mediolateral position and later ankle injuries[10)].

On the other hand, Beynnon et al., 2001 and Hopper et al., in 1995, did not find data to support the value of postural balance as a predictor of ankle sprains[14, 15)], which differ from the rest of the studies and the present investigation. The same procedure was used by Willems et al. in 2005 who, did not find significant differences in postural stability variables, however these authors discovered that subject with a weaker control over their center of gravity were more prone to later suffering ankle sprains[20)].

The results of both the stabilometric testing performed in the pre-season period plus the number of those injured in the volume period, and the testing performed in the volume period plus the number of those injured during the pre-competition period show a similar trend. Both sets of data point at athletes with higher values (and therefore poorer scores) in stabilometric variables being more prone to injuries in the subsequent periods. However, in the first part the stabilometric variables are shown in bipodal stability and in the second, findings are found in monopodal stance.

According to the difference between results of both parts of the present study, it is important to take into account that the injuries occurred during pre-competition period could have been influenced by other risk factor such as higher intensity of trainings or explosive actions, which supposed to be actions involving more damaging[21)] and charasteristic of this training period.

Also, it is important to indicate that the present investigation supports the only study to date in which all lower extremity injuries had been correlated with increases in postural sway. The rest of the investigation refered strictly to ankle-foot injuries.

In adittion, certains limits of our study may have played a part in determining the lack of more significant differences. The lower number of injuries recorded as consequence of a small size of the sample, it might conceivably have contributed to this discrepancy in results. Indeed, the difference in number of athletes participing in both study's parts could have affected the results due to the small size of the sample. For future research a bigger sample size is recommended, as well as including other age groups.

As a conclusion, athletes who show higher center-of-pressure spread on bipodal stabilometry at the end of pre-season are more prone to injuries during the subsequent training period. Also, while on right-leg monopodal support, athletes with a poorer stability on the mediolateral plane at the end of volume period are more prone to injuries in subsequent training period. As a practical application, specific proprioceptive training is recommended to include in the training routine of athletes, in order to improve stabilometric parameters and decrease and/or delete its role as risk factor.

REFERENCES

1) Freeman MA, Dean MR, Hanham IW: The etiology and prevention of functional instability of the foot. J Bone Joint Surg Br, 1965, 47: 678-85.

2) Paterno MV, Schmitt LC, Ford KR, et al.: Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. Am J Sports Med, 2010, 38: 1968-78.

3) Riemann BL, Lephart SM: The sensorimotor system, part II: the role of proprioception in motor control and functional joint stability. J Athl Train, 2002, 37: 80-4.

4) Lepers R, Bigard AX, Diard JP, et al.: Posture control after prolonged exercise. Eur J Appl Physiol Occup Physiol, 1997, 76: 55-61.

5) Gribble PA, Hertel J, Denegar CR, et al.: The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. J Athl Train, 2004, 39: 321-9.

6) Nagy E, Toth K, Janositz G, et al.: Postural control in athletes participating in an ironman triathlon. Eur J Appl Physiol, 2004, 92: 407-13.

7) Akbari M, Karimi H, Farahini H, et al.: Balance problems after unilateral lateral ankle sprains. J Rehabil Res Dev, 2006, 43: 819-24.

8) Leanderson J, Eriksson E, Nilsson C, et al.: Proprioception in classical ballet dancers. A prospective study of the influence of an ankle sprain on proprioception in the ankle joint. Am J Sports Med, 1996, 24: 370-4.

9) McGuine TA, Greene JJ, Best T, et al.: Balance as a predictor of ankle injuries in high school basketball players. Clin J Sport Med, 2000, 10: 239-44.

10) Wang HK, Chen CH, Shiang TY, et al.: Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. Arch Phys Med Rehabil, 2006, 87: 821-5.

11) Trojian TH, McKeag DB: Single leg balance test to identify risk of ankle sprains. Br J Sports Med, 2006, 40: 610-3.

12) Soderman K, Alfredson H, Pietila T, et al.: Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. Knee Surg Sports Traumatol Arthrosc, 2001, 9: 313-21.

13) Murphy DF, Connolly DA, Beynnon BD: Risk factors for lower extremity injury: a review of the literature. Br J Sports Med, 2003, 37: 13-29.

14) Hopper DM, Hopper JL, Elliott BC: Do selected kinanthropometric and performance variables predict injuries in female netball players? J Sports Sci, 1995, 13: 213-22.

15) Beynnon BD, Renstrom PA, Alosa DM, et al: Ankle ligament injury risk factors: a prospective study of college athletes. J Orthop Res, 2001, 19: 213-20.

16) Asociación Médica Mundial: La Declaración de Helsinki en debate. Revista Médica del Uruguay, 2008, 24: 67-8.

17) Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, et al.: Short-Term Effects of Proprioceptive Training with Unstable Platform on Athletes' Stabilometry. J Strength Cond Res, 2012, 26: 2071-7.

18) Kolt GS, Kirkby RJ: Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. Br J Sports Med, 1999, 33: 312-8.

19) Watson AW: Ankle sprains in players of the field-games Gaelic football and hurling. J Sports Med Phys Fitness, 1999, 39: 66-70.

20) Willems TM, Witvrouw E, Delbaere K, et al.: Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. Am J Sports Med, 2005, 33: 415-23.

21) Pastre CM, Carvalho Filho G, Monteiro HL, et al.: Lesões desportivas no atletismo: comparação entre informações obtidas em prontuários e inquéritos de morbidade referida. Revista Brasileira de Medicina do Esporte, 2004, 10: 01-8.

Table 1. Statistical Description of the Sample.

		First part of the study n=51				Second part of the study n=39			
		Injured in volume period n=12		Non-injured n=39		Injured in pre-competition period n=6		Non-injured n=33	
Age (years)		23.2	±8.0	22.3	±7.5	26.5	±9.0	21.6	±7.0
Height (m)		1.74	±0.07	1.74	±0.08	1.75	±0.05	1.74	±0.09
Weight (kg)		61.0	±11.0	62.9	±11.7	61.5	±7.9	63.2	±12.4
BMI (kg/m^2)		20.1	±2.4	20.7	±2.5	20.1	±1.5	20.8	±2.7
Gender	**Men**	8	66.7%	27	69.2%	5	83.3%	22	66.7%
	Women	4	33.3%	12	30.8%	1	16.7%	11	33.3%
Experience (years)		7.8	±4.7	7.2	±4.6	10.0	±4.8	6.7	±4.4

Quantitative variables are shown in mean and SD. Categorical variables are shown in frequencies and percentages. P values are from T-Student and Chi-cuadrado tests respectively. BMI. Body Mass Index.

Table 2. Mean Values of Stabilometric Variables in Bipodal and Monopodal Support Taken at the End of the Pre-season Period. Results are Split for Athletes Injured during the Volume Period.

	Total injured in Volume period n=12		Non-injured n=39	
Pre-season measures	**Mean**	**SD**	**Mean**	**SD**
Length (mm)*	366.5	183.9	340.2	104.0
Area (mm)	36.5	27.1	47.5	49.9
Speed(mm/sec)*	7.4	3.9	6.7	2.0
Xmean (mm)	3.9	4.7	4.4	3.2
Ymean (mm)	4.5	4.1	6.0	5.1
Lengthl (mm)	272.0	112.5	267.8	65.5
Areal (mm)	419.1	493.7	408.7	350.8
Speedl (mm/sec)	24.4	11.4	24.7	6.8
Xmeanl (mm)	4.9	3.6	6.0	13.5
Ymeanl (mm)	6.6	5.14	10.2	8.2
Lengthr (mm)	255.6	119.9	275.5	82.8
Arear (mm)	340.2	282.9	378.2	298.8
Speedr(mm/sec)	23.1	12.0	24.7	7.9
Xmeanr (mm)	3.4	2.9	3.0	2.8
Ymeanr (mm)	7.0	6.5	8.6	5.2

Length= Length of the path described by the center of pressure. Area=Area of the path described by the center of pressure. Speed=Speed of the center of pressure. Xmean=Mean position of the center of pressure in the medial-lateral plane. Ymean=Mean position of the center of pressure in the anteroposterior plane . First in bipodal support, then +l=of left foot, and +r =of right foot. Variables underlined were normalized. *=$p<0.05$.

Table 3. Mean Values of Stabilometric Variables in both Bipodal and Monopodal support at the End of the Volume Period. Results are Split for Athletes Injured during the Pre-competition Period.

	Total Injured in Pre-competition n=6		Non-injured n=33	
Volume measures	Mean	SD	Mean	SD
Length (mm)	310.1	±131.8	307.7	±143.6
Area (mm)	128.5	±103.1	98.8	±109.6
Speed (mm/sec)	6.2	±2.8	13.5	±42.0
Xmean (mm)	4.5	±1.8	5.7	±5.0
Ymean (mm)	8.7	±2.7	12.4	±9.4
Lengthl (mm)	335.3	±95.9	316.3	±127.4
Areal (mm)	615.0	±512.0	489.6	±506.8
Speedl (mm/sec)	31.1	±9.6	35.3	±40.2
Xmeanl (mm)	3.5	±2.5	5.8	±12.3
Ymeanl (mm)	10.8	±7.0	16.3	±11.6
Lengthr (mm)	349.0	±89.3	322.7	±132.8
Arear (mm)	631.1	±328.3	608.1	±624.0
Speedr (mm/sec)	31.9	±9.4	36.7	±40.2
Xmeanr (mm)*	15.2	±30.3	4.3	±3.6
Ymeanr (mm)	12.0	±6.8	15.3	±9.6

Length= Length of the path described by the center of pressure. Area=Area of the path described by the center of pressure. Speed=Speed of the center of pressure. Xmean=Mean position of the center of pressure in the medial-lateral plane. Ymean=Mean position of the center of pressure in the anteroposterior plane . First in bipodal support. then +l=of left foot, and +r=of right foot. Variables underlined were normalized. *=p<0.05

Figure 1. Bipodal, left monopodal and right monopodal stabilometry tests.

VI

INDOOR-SEASON CHANGES IN THE STABILOMETRY OF SPRINTERS AND MIDDLE-DISTANCE RUNNERS

N Romero-Franco, EJ Martínez-López, F Hita-Contreras, A Martínez-Amat

Submitted

INDOOR-SEASON CHANGES IN THE STABILOMETRY OF SPRINTERS AND MIDDLE-DISTANCE RUNNERS

Stabilométriques changements au cours de la saison d'athlétisme indoor dans sprinters et les coureurs de demi-fond

Romero-Franco N[1], Martínez-López EJ[2], Hita-Contreras F[1], Martínez-Amat A[1]

1. Department of Health Sciences, University of Jaén E-23071 Jaén, Spain. Fax: +34953012141

2. Department of Didactics of Musical, Plastic and Corporal, University of Jaén, E-23071 Jaén, Spain. Fax: +34953212488

Corresponding author:

Natalia Romero-Franco

Department of Health Sciences, University of Jaén, E-23071 Jaén, Spain

Tel +34-953-212917

Fax +34- 953-212239

Email: narf52@gmail.com

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgements

Authors would like to thank the University of Jaen for their support to the present study, and also to the athletes and coaches whose effort made our research possible. Any financial support must be cited in the present study. The present study complies with the current laws of the country in which they were performed.

ABSTRACT

Objectives. The purpose of the present study is to analyze the stabilometric differences in every training period of the indoor-season and evaluate the differences between sprinters and middle-distance runners.

Equipment and methods. Twenty-eight sprinters and twenty middle-distance runners took part in this study. All athletes were subject to four bipodal and monopodal stabilometries during the indoor-season: Pres=Pre-season, Volume=Volume period, Precomp=Pre-competitive period and Comp=Competitive period.

Results. Analysis of variance ($p<0.05$) showed main time effects in length and area of bipodal support, in length of left-side monopodal support and in length, area and speed of right-side monopodal support. Generally, athletes showed higher values in Volume than in Pres, in Volume than in Precomp and in Precomp than in Comp. Furthermore, main group effects were found in the antero-posterior stability of both monopodal supports, which displayed worse values for middle-distance runners.

Conclusion. Our results suggest that athletes have worse postural stability in training periods with a higher volume of workload, and then improve in periods with a low-volume, high intensity workload, without any influence from the athletic variety on these differences. However, sprinters display better monopodal stabilometry values regardless of the leg stance measured.

Key words: Athletes, Stability, Training.

INTRODUCTION

Postural stability is a key element in the successful execution of movements in sports and also in the prevention of injuries in athletics [1, 2]. It has been shown that stabilometric parameters can be modified due to changes in physical activity affecting the type of exercise undertaken and also the intensity and the volume of work [3-5]. These changes are observed in the different training periods in which sports training is organized to achieve the maximum performance of athletes[6]. The periodization of sports training produces continuous adaptations in the body which relate to the energy and neuromuscular system[7, 8] and which were associated with stabilometric changes because of the close relationship of the neuromuscular system and the proprioceptive system [8, 9].

Changes induced by the periodization of the training workload on the proprioceptive system as it affects postural stability have been reported before [3], although until now there has been little evidence. Paillard et al. (2006) described how national-level soccer players, who trained more frequently and intensely, had better stability than those in the regional level.

Stabilometric changes have been more thoroughly researched when they derive from the differences between sports and are thus related to modifications in the intensity and volume of work, as well as to the type of exercises carried out in each training period [10-13].

To the extent of our knowledge, studies to date correlate the sports workload with the postural stability of athletes according to levels of performance [3] or sports [10, 11] and none of them carried out a follow-up of every training period in the same athletes to test the possible stabilometric changes induced by a changing sports workload. The first goal of the present study was to analyze the stabilometric differences in every training period of the indoor-season of sprinters and middle-distance runners. The second one was to evaluate the differences between sprinters and middle-distance runners.

METHODS

A longitudinal quantitative non-experimental design was used for this study. The duration of study covered the entire indoor-season of athletes, which lasted six months (September-February). The indoor-season was divided into four training periods. Four measures of bipodal an monopodal stabilometry were taken at the end of every period: Pres=Pre-season (September): mainly general-type exercises; Volume=Volume period (October-November): high-volume training of general and specific exercises of low intensity; Precomp=Pre-competitive period (December): mainly specific low-volume and high-intensity exercises; Comp=Competitive period (January-February): specific, high-intensity, low-volume exercises.

Participants

Forty-eight athletes volunteers (21.46 ± 6.31 years, 62.17 ± 11.55 kg, 1.74 ± 0.08 m, 20.11 ± 3.79 kg/m^2) took part in this study. Of these, 28 were sprinters (21.07 ± 6.85 years, 63.5 ± 11.81 kg, 1.75 ± 0.08 m, 20.72 ± 2.70 kg/m^2) and 20 were middle-distance runners (22 ± 5.58 years, 60.30 ± 11.22 kg, 1.72 ± 0.08 m, 19.26 ± 4.91 kg/m^2). No significant differences were shown between both groups in age, weight, height and BMI (p=0.620, p=0.349, p=350 and p=0.191, respectively). Also, of these athletes 15 were women and 33were men: of sprinters, 10 women and 18 men and of middle-distance runners, 5 women and 15 men. Besides, all athletes had 7.02 ± 4.33 years of traininng experience, concretely sprinters had 7.29 ± 4.59 years of training experience and middle-distance runners had 6.65 ± 4.03 years of training experience. No significant differences were found in years of training experience of sprinters and middle-distance runners (p=0.622). All those who did not train regularly were excluded. Before the start of the study, all athletes were briefed on the nature of testing and written informed consent was obtained from each subject or from their legal tutors in the case of under-age athletes, according to the standards of the Declaration of Helsinki [14]. The present study has the ethical approval of University of the city.

Procedure and data collection

At the beginning, baseline features of the athletes were collected with a 100 g-300 kg precision digital weight scale (Tefal) and a t201-t4 Asimed adult height scale, which were used to obtain weight and height respectively.

All athletes were subject to a bipodal and a monopodal stabilometry for each training period. The reliability of these test has been proven in previous studies [15, 16]. To carry out bipodal stabilometric measurements, athletes were asked to stand on both feet over the baropodometric platform for 51.2 seconds. For the monopodal stabilometric measures, athletes were asked to stand for 10 seconds on each lower limb, starting with the left one, in the middle of the platform. Measures were always taken before training to avoid interferences.

The tests measured the following parameters in bipodal and monopodal left- and right-leg stance: the center of pressure (CoP) position in the medial-lateral (Xmean) and the antero-posterior plane (Ymean), in addition to the area covered by CoP (Area), the speed of movement of CoP (Speed) and the length (Length) covered by CoP. These variables are marked “l” or “r” in the name to indicate if they belong to the left or right leg, respectively. Variables reflecting bipodal measurements are not marked “l” or “r”.

Experimental device

A Freemed baropodometric platform and the FreeStep v.1.0.3 software were used for the stabilometric measurements (Rome, Italy). The platform's surface is 555x420 mm, with an active surface of 400x400 mm and 8 mm thickness [16].

Statistical analysis

To compare the anthropometric and demographic variables between sprinters and runners, a Student's *t* test was used for independent samples in the case of the continuous variables and a Chi-squared test for the categorical variables. Homoscedasticity and normality of the variables was tested by the Levenne and Kolmogorov-Smirnov tests, respectively. We used a two-factor (2Group x 4Time) analysis of variance (ANOVA) with repeated measures to assess the stability of athletes after every period of training. For each variable, the P-value for group (within-subject), time (between-subject) and group x time effects was calculated. The Bonferroni test was used to adjust the results of the multiple comparisons. Statistical significance was determined at $p \leq 0.05$. Data were analyzed using the SPSS package for Windows, version 19 (Chicago).

RESULTS

Table 1 shows mean values of length, area and speed in bipodal support. A mean time effect is observed in length (Length) and area (Area) covered by CoP (p_s<0.001), however, no main group effect and group x time interaction were found in any variable p>0.05). Eta-squared was 0.249 for Length and 0.128 for Area), and it can therefore be concluded that main time effect accounted for over 25% of the variation for Length and 13% for Area covered by CoP. More specifically, in Length, higher values were shown at the end of Pre-season period respect to Pre-competitive period (p=0.001), at the end of Competitive period respect to Pre-season period (p=0.007), at the end of Pre-competitive period respect to Volume period (p<0.001) and at the end of Competitive period respect to Volume period (p=0.005). In Area, higher values appeared at the end of Volume respect to Pre-season period (p<0.001), at the end of the Pre-competitive period respect to Pre-season period (p=0.003), at the end of Competitive period respect to Pre-season (p=0.006) and at the end of Volume period respect to Pre-competitive period (p=0.035).

Mean values of length, area and speed of left-side monopodal stability are shown in Table 2. Main time effect was only observed in the length covered by CoP (Lengthl, p=0.003). Eta-square was 0.096, the main time effect accounting for over 10% of the variation for the Lengthl. More concretely, higher values of Lengthl were found at the end of Volume period respect to Pre-season period (p=0.003), at the end of Pre-competitive period respect to Volume period (p=0.023) and at the end of Pre-competitive period respect to Pre-season period (p<0.001). No group effect and groupxtime interaction were shown in Lengthl, Areal and Speedl (p>0.05).

Stabilometric values of length, area and speed of right-side monopodal support are shown in Table 4. Main time effect are observed in length (Lengthr) and area (Arear) covered by CoP and speed (Speedr) of CoP. Eta-squared was 0.105 for Lengthr, 0.090 for Arear and 0.061 for Speedr, and it can be concluded that the main time effect accounted for over 10% of the variation of Lengthr, 9% of the variation of Arear and 6% of the variation of Speedr. More specifically, in Lengthr, higher values were shown at the end of Volume period respect to Pre-season period (p=0.001), at the end of Volume period respect to Competitive period (p=0.003) and at the end of Pre-competitive period respect to Competitive period (p=0.018). In Arear, higher values were observed at the end of Volume period respect to Pre-season period (p=0.004), at the end of Pre-competitive period respect to Pre-season period (p=0.002) and at the end of Pre-competitive period respect to Competitive period (p=0.043). In Speedr, higher values were found at the end of Volume period respect to Pre-season period (p=0.053), at the end of Pre-competitive period respect to Pre-season period (p=0.016) and at the end of Pre-competitive period respect to Competitive period (p=0.003).

Table 5 shows values for the mean position of CoP in the medial-lateral (Xmean) and the antero-posterior (Ymean) planes of bipodal and both monopodal supports. No main group effect, main time effect or group x time interaction were found in Xmean, Xmeanl and Xmeanr (p>0.05). In Ymean of left-side monopodal support (Ymeanl) a main group effect was observed, showing middle-distance runners significantly lower values than sprinters (p=0.005). Eta-squared was 0.159 and the main group effect accounting for over 16% of the variation of Ymeanl. In Ymeanr, also a main group effect was observable, middle-distance runners showed significantly lower values than sprinters (p=0.030). Eta-squared was 0.098, the main group effect accounting for over 10% of the variation of Ymeanr. No other main effect or interaction was found in Ymean, Ymeanl and Ymeanr ($p>0.05$).

DISCUSSION

The first aim of the present study was to analyze stabilometric differences in every training period of the indoor-season of sprinters and middle-distance runners. The second one was to evaluate the differences between sprinters and middle-distance runners.

All athletes showed significant stabilometric changes between the training periods in bipodal and both sides of monopodal supports, without an apparent effect of the athletic variety in almost any variable. Generally, differences were observed between the pre-season and the volume periods, indicating better postural stability in pre-season when general exercises composed the training. Consistent with this result, Perrin et al. [17] reported that more general training can help develop sensorimotor adaptations that are transferable to postural stability. Furthermore, stabilometric deterioration between the pre-season and the volume periods also matches an important increase in the volume of the workload. This influence of the amount of work undertaken agrees with the results reported in most of the stabilometric variables between the volume and the pre-competitive and competitive periods. Thus, postural stability shows an improvement from the volume to the pre-competitive periods and mainly from the pre-competitive to the competitive periods, both corresponding to a considerable decrease in the volume of the workload and an increase in its intensity. These findings are consistent with those of Paillard and Noe (2006)[11], whose results showed how national-level soccer players, who trained more frequently and intensively, had better stabilometric parameters than amateur soccer players. Similar results were reported by Paillard et al. (2002) [10] in judoka of different levels, such as better balance and postural stability. Both studies concluded that the intensity of training improves postural control.

The changes between training periods are in line with those reported by Thorpe and Ebersole[18], who concluded that stability could be sensitive to the current training phase and that body adaptations induced by the intensity and volume of the workload have an influence on postural stability. In agreement with that, Hyrsomallis[19] described the correlation between postural stability and the level of training by analyzing several performance parameters as well as postural stability. In addition, Ángyán et al. [4] reported a positive correlation between stabilometry and reaction time that appeared only in elite basketball players who carried out high-quality training, and not in basketball players with lower-quality training.

In contrast with our results, Chapman et al.[20] did not find any correlation between postural stability and level of training in surfers, just as Noe and Paillard [11] reported for skiers. These results could be explained by the fact that both sports have very important balance parameters, which could mask the effects of the intensity and volume of training.

As an additional finding, middle-distance runners showed worse antero-posterior stability in both monopodal supports due to the fact that middle-distance showed values significantly farther from value 0 than sprinters, which means significantly worse anteroposterior stability. Plane-related stabilometric differences were previously reported by Paterno et al., [21] whose research showed that athletes who had better stability in the antero-posterior plane did not show any differences in the medial-lateral plane. However, further research is required are needed to clarify this aspect. On the other hand, an improvement in stabilometric parameters was obtained in the anteroposterior plane by sprinters in both monopodal supports. This could be due to the fact that sprinters always trained on track, where the direction of the curve is always to the left. However, as middle-distance runners also train out of track, they did not experience this continuous left turning. Further research is needed in this regard to determine the origin of such differences.

CONCLUSION

As a conclusion, training has a clear effect on both bipodal and monopodal stabilometry. Athletes show worse postural stability in training periods with a higher volume of workload, and it improves in periods with a low-volume, high intensity workload. The athletic variety do not have any influence on these differences, but sprinters display better monopodal stabilometry regardless of the leg stance measured.

As clinical application, coaches and physiotherapist should take in account the effect of training on bipodal and monopodal stabilometry due to the established consensus by previous literature about stabilometric deficits as risk factor of injuries in sports. In order to improve the stability and reduce this risk factor of injuries, it would be interest the inclusion of proprioceptive training as main training that has shown stabilometric improvements.

REFERENCES

[1] Ashton-Miller JA, Wojtys EM, Huston LJ, Fry-Welch D. Can proprioception really be improved by exercises? Knee Surg Sports Traumatol Arthrosc. 2001;9:128-36.

[2] Yasuda T, Nakagawa T, Inoue H, Iwamoto M, Inokuchi A. The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. Eur Arch Otorhinolaryngol. 1999;256:27-32.

[3] Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. J Athl Train. 2006;41:172-6.

[4] Angyan L, Teczely T, Angyan Z. Factors affecting postural stability of healthy young adults. Acta Physiol Hung. 2007;94:289-99.

[5] Schmit JM, Regis DI, Riley MA. Dynamic patterns of postural sway in ballet dancers and track athletes. Exp Brain Res. 2005;163:370-8.

[6] Weineck J. ENTRENAMIENTO TOTAL: Paidotribo; 2005.

[7] Borghuis J, Hof AL, Lemmink KA. The importance of sensory-motor control in providing core stability: implications for measurement and training. Sports Med. 2008;38:893-916.

[8] Hoffman J. Physiological aspects of sport training and performance: HUMAN KINETICS PUB Incorporated; 2002.

[9] Sayenko DG, Masani K, Vette AH, Alekhina MI, Popovic MR, Nakazawa K. Effects of balance training with visual feedback during mechanically unperturbed standing on postural corrective responses. Gait Posture. 2012;35:339-44.

[10] Paillard T, Costes-Salon C, Lafont C, Dupui P. Are there differences in postural regulation according to the level of competition in judoists? Br J Sports Med. 2002;36:304-5.

[11] Paillard T, Noe F. Effect of expertise and visual contribution on postural control in soccer. Scand J Med Sci Sports. 2006;16:345-8.

[12] Era P, Konttinen N, Mehto P, Saarela P, Lyytinen H. Postural stability and skilled performance--a study on top-level and naive rifle shooters. J Biomech. 1996;29:301-6.

[13] Davlin CD. Dynamic balance in high level athletes. Percept Mot Skills. 2004;98:1171-6.

[14] Mundial AM. Declaración de Helsinki de la Asociación Médica Mundial. Principios éticos para las investigaciones médicas en seres humanos.[Internet]. 2008

[15] Bauer CM, Groger I, Rupprecht R, Tibesku CO, Gassmann KG. [Reliability of static posturography in elderly persons]. Z Gerontol Geriatr. 2010;43:245-8.

[16] Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, Hita-Contreras F, Osuna-Perez C, Martinez-Amat A. Short-Term Effects of Proprioceptive Training with Unstable Platform on Athletes' Stabilometry. J Strength Cond Res. 2012;26:2071-7.

[17] Perrin P, Deviterne D, Hugel F, Perrot C. Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. Gait Posture. 2002 Apr;15(2):187-94.

[18] Thorpe JL, Ebersole KT. Unilateral balance performance in female collegiate soccer athletes. J Strength Cond Res. 2008;22:1429-33.

[19] Hrysomallis C. Relationship between balance ability, training and sports injury risk. Sports Med. 2007;37:547-56.

[20] Chapman DW, Needham KJ, Allison GT, Lay B, Edwards DJ. Effects of experience in a dynamic environment on postural control. Br J Sports Med. 2008;42:16-21.

[21] Paterno MV, Myer GD, Ford KR, Hewett TE. Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther. 2004;34:305-16.

Table 1. Mean Values of Length and Area Covered by the Center of Pressure (Length and Area), Speed of Center of Pressure (Speed) in bipodal support.

	Middle-distance runners *n*=20	**Sprinters** *n*=28		
Length **(mm)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres††	347.25 ± 111.65	350.74 ± 136.30	group 0.542	,000
Volume##	300.09 ± 126.92	321.67 ± 140.84	time **0.000**	,249
Precomp§§§	441.75 ± 116.53	443.00 ± 138.09	group x time 0.898	,015
Comp++	437.01 ± 136.75	396.40 ± 135.44		
Area **(mm)**	**Mean±s**	**Mean±s**	p-value	**ETA Square**
Pres***	39.56 ± 30.92	51.95 ± 54.99	group 0.958	,000
Volume§	100.45 ± 91.75	97.66 ± 124.41	time **0.000**	,128
Precomp, †††	71.09 ± 35.63	74.28 ± 54.364	group x time 0.821	,007
Comp++	71.34 ± 63.71	61.70 ± 50.09		
Speed **(mm/sec)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres	6.84 ± 2.25	6.90 ± 2.77	group 0.440	,013
Volume	6.08 ± 2.76	15.01 ± 45.55	time 0.504	,008
Precomp	8.95 ± 2.39	9.05 ± 2.99	group x time 0.273	,017
Comp	8.96 ± 2.94	8.14 ± 2.94		

Length = Length covered by the center of pressure in bipodal support. Area = Area covered by the center of pressure in bipodal support. Speed = milimeters covered by the center of pressure every second. Pres = Pre-season period. Volume = Volume period. Precomp=Pre-competitive period. Comp = Competitive period. *** p<0.001 for Pres vs. Volume; †† p<0.01, ††† p<0.001 for Pres vs. Precom; ++ p<0.01 for Pres vs. Comp; § p<0.05, §§§ p<0.001 for Volume vs. Precomp.

Table 2. Mean Values of Length and Area Covered by the Center of Pressure (Length and Area), Speed of Center of Pressure (Speed) on left-side monopodal support

	Middle-distance runners *n*=20	**Sprinters *n*=28**		
***Lengthl* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres **	279.59 ± 76.20	267.87 ± 81.49	Group	
Volume §	342.23 ± 185.49	313.69 ± 80.77	0.137 Time	,047
Precomp †††	349.19 ± 96.36	329.27 ± 97.48	**0.003**	,096
Comp	323.30 ± 105.14	269.88± 78.99	group x time 0.720	0,10
***Areal* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres	431.86 ± 450.26	396.65 ± 346.45	Group	
Volume	627.56 ± 619.58	438.51 ± 358.80	0.386 Time	,016
Precomp	517.69 ± 302.40	497.29 ± 313.73	0.271 group x time	,028
Comp	399.19 ± 358.40	429.71 ± 279.66	0.514	,016
***Speedl* (mm/sec)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres	25.60 ± 7.41	24.56 ± 8.69	Group	
Volume	31.36 ± 17.79	35.99 ± 42.20	0.932 Time	,000
Precomp	31.027 ± 7.89	29.21 ± 9.65	0.073 group x time	,049
Comp	25.59 ± 6.13	24.73 ± 5.99	0. 826	,006

Lengthl = Length covered by the center of pressure in left-side monopodal support. Areal = Area covered by the center of pressure in left-side monopodal support. Speedl = milimeters covered by the center of pressure every second in left-side monopodal support. Pres = Pre-season period. Volume = Volume period. Precomp = Precompetitive period. Comp = Competitive period. ** $p<0.01$ for Pres vs. Volume; § $p<0.05$ for Volume vs. Precomp; ††† $p<0.001$ for Precom vs. Pres.

Table 3. Mean Values of Length and Area Covered by the Center of Pressure (Length and Area), Speed of Center of Pressure (Speed) on right-side monopodal support.

	Middle-distance runners *n*=20	**Sprinters *n*=28**		
***Lengthr* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres**	282.73 ± 107.69	266.95 ± 85.33	group	
Volume##	349.83 ± 118.39	345.82 ± 107.63	0.297 time	,024
Precomp	303.66 ± 87.59	304.69 ± 102.42	**0.002**	,105
Comp□	290.39 ± 77.51	256.45 ± 73.56	group x time 0.458	,019
***AREAr* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres**	379.24 ± 340.53	352.48 ± 262.01	group	
Volume	625.93 ± 410.10	569.06 ± 650.17	0.530 time	,009
Precomp††	531.63 ± 323.02	576.01 ± 335.49	**0.004**	,090
Comp□	517.97 ± 585.83	344.73 ± 209.70	group x time 0.488	,017
***Speedr* (mm/sec)**	**Mean±s**	**Mean±s**	**p-value**	**ETA Square**
Pres*	25.30 ± 10.23	23.95 ± 8.59	group	
Volume	32.48 ± 12.86	36.34 ± 43.41	0.943 time	,000
Precomp†	28.87 ± 8.68	28.06 ± 10.27	**0.033** group x time	,061
Comp□□	26.11 ± 7.17	23.54 ± 7.33	0. 837	,006

Lengthr = Length covered by the center of pressure in right-side monopodal support. Arear = Area covered by the center of pressure in right-side monopodal support. Speedr = milimeters covered by the center of pressure every second in right-side monopodal support. Pres = Pre-season period. Volume = Volume period. Precomp = Pre-competitive period. Comp = Competitive period.* $p<0.05$, ** $p<0.01$ for Pres vs. Volume; †† $p<0.01$ for Pres vs. Precom; ## $p<0.01$ for Volume vs. Comp; □ $p<0.05$, □□ $p<0.01$ for Precomp vs. Comp.

Table 4. Mean Values of Mean Medial-lateral Position (Xmean) and Anteroposterior Position (Ymean) on bipodal and both monopodal supports.

	Middle-distance runners *n*=20	Sprinters *n*=28				Middle-distance runners *n*=20	Sprinters *n*=28		
***Xmean* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**	***Ymean* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**
Pres	-3.29 ± 4.61	-1.69 ± 5.48	group		**Pres**	-4.79 ± 5.73	-2.84 ± 7.26	group	
Volume	-1.52 ± 6.37	7.04 ± 47.58	0.310 time	,022	**Volume**	-11.38 ± 7.73	-2.96 ± 49.78	0.234 time	,031
Precomp	.50 ± 7.39	-.99 ± 7.34	0.491	,017	**Precomp**	-10.82 ± 8.61	-9.45 ± 7.89	0.826	,022
Comp	-4.27 ± 9.71	-.83 ± 6.49	group x time 0.632	,012	**Comp**	-11.96 ± 9.26	-8.08 ± 9.96	group x time 0.377	,006
***Xmeanl* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**	***Ymeanl* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**
Pres	.12 ± 8.88	-.48 ± 16.22	group		**Pres**	-12.02 ± 9.01	-4.36 ± 9.61	group	
Volume	7.37 ± 49.13	7.37 ± 49.13	0.869 time	,001	**Volume**	-22.12 ± 14.13	2.09 ± 49.38	**0.005** ttime	,159
Precomp	.23 ± 4.98	-.44 ± 12.57	0.687	011	**Precomp**	-18.38 ± 13.85	-10.05 ± 11.85	0.500	,017
Comp	2.08 ± 4.52	-.56 ± 11.65	group x time 0.736	,009	**Comp**	-15.09 ± 11.57	-8.75 ± 12.19	group x time 0.102	,044
***Xmeanr* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**	***Ymeanr* (mm)**	**Mean±s**	**Mean±s**	**p-value**	**Eta Square**
Pres	-.29 ± 3.57	.84 ± 4.39	group		**Pres**	-11.23 ± 5.53	-3.53 ± 7.29	group	
Volume	-2.22 ± 4.09	8.42 ± 47.03	0.265 time	,027	**Volume**	-18.36 ± 11.81	-.05 ± 49.78	**0.030** time	,098
Precomp	-1.69 ± 5.59	-1.13 ± 4.49	0.621	,013	**Precomp**	-12.19 ± 13.19	-7.23 ± 13.48	0.791	,007
Comp	-1.31 ± 4.36	-.79 ± 4.89	group x time 0.459	,019	**Comp**	-13.13 ± 14.17	-10.14 ± 12.42	group x time 0.269	,028

Xmean = medial-lateral mean position of center of pressure in bipodal support. Ymean = anteroposterior mean posticion of center of pressure in bipodal support. Xmeanl = medial-lateral mean position of center of pressure in left –side monopodal support. Ymeanl = anteroposterior mean posticion of center of pressure in left-side monopodal support. Xmeanr = medial-lateral mean position of center of pressure in right-side monopodal support. Ymeanr = anteroposterior mean posticion of center of pressure in right-side monopodal support. Pres = Pre-season period. Volume = Volume period. Precomp = Pre-competitive period. Comp = Competitive period.

VII

EFFECTS OF AN ANAEROBIC LACTIC TRAINING SESSION ON THE POSTURAL STABILITY OF ATHLETES

N Romero-Franco, EJ Martínez-López, R Lomas-Vega, F Hita-Contreras, A Martínez-Amat

Submitted

EFFECTS OF AN ANAEROBIC LACTIC TRAINING SESSION ON THE POSTURAL STABILITY OF ATHLETES

Romero-Franco N[1], Martínez-López EJ[2], Hita-Contreras F[1], Lomas-Vega R[1], Martínez-Amat A[1]

1. Department of Health Sciences, University of Jaén, E-23071 Jaén, Spain. Fax: +34953012141

2. Department of Didactics of Musical, Plastic and Corporal, University of Jaén, E-23071 Jaén, Spain. Fax: +34953212488

The author responsible for correspondence is:

Natalia Romero-Franco

Department of Health Sciences — Tel +34-953-212917

Faculty of Physiotherapy — Fax+34- 953-212239

University of Jaén — Email: narf52@gmail.com

E-23071 Jaén, Spain

ACKNOWLEDGEMENTS

Authors would like to thank the University of Jaén for their support to the present study, and also to the athletes and coaches whose effort made our research possible. Authors are not aware of any funding or research contracts or conflicts of interest that may have affected the outcomes of our study.

ABSTRACT

Aim: To analyze the short-term effects of a lactate-accumulation training session on postural stability.

Methods: Fifteen athletes performed two trainings sessions (Warm-up and Lactic-Training session). Before training (Pre), immediately after ($Post_{0min}$), thirty minutes later ($Post_{30min}$) and after 24 hours ($Post_{24h}$), athletes were subject to a bipodal and a monopodal stabilometries and a lactate blood analysis to ensure a high stress level.

Results: Variance analysis (α=0.05) showed, in lactic training, athletes experienced an increase of Length and Velocity in $post_{0min}$, a decrease at $post_{30min}$ and a new decrease at $post_{24h}$, which was lower than basal values. In monopodal stability, left-leg support showed a decrease at $post_{0min}$ in antero-posterior plane of athletes after lactic training. Also, in both monopodal supports, athletes displayed higher values of Length and Velocity in $post_{0min}$ after lactic training, with a progressive decrease which was significant at $Post_{24h}$, when they reached baseline.

Conclusion: Right after anaerobic lactic training, center-of-pressure dispersion variables in bipodal stabilometry are worsened. Thirty minutes later, stabilometric variables are still deteriorated. At 24 hours, stabilometry is better than baseline. In monopodal support, dispersion values are worsened after lactic training and anteroposterior stability is impaired in left monopodal support, although the deterioration is less evident as time passes.

Keywords. Blood lactate. Training. Athletes. Postural Stability.

INTRODUCTION

A lactate accumulation after the practice of physical activity is considered the most important musculoskeletal stress level. The explanation is that in the face of an increase in the intensity of physical exercise, an accumulation of the lactate catabolite takes place, which at the same time increases the accumulation of hydrogen ions. These ions are responsible for muscle acidity and for subsequent contractile inefficacy [1, 2].

Effects of this contractile inefficacy have been studied at stabilometric levels due to the relationship between postural stability deterioration and sports injuries[3-8]. Surenkok et al., in 2006, analyzed postural stability after a lactate-accumulation-inducing protocol and reported a deterioration in monopodal stability, although they observed no correlation between stability and lactate level[9]. Other authors have studied effects of intense exercise in the postural stability of athletes [3, 4, 6, 10-14]. Mello et al. (2009) assessed the effects of a exercises protocol consisting of a maximal oxygen uptake test and prolonged cycle ergometer exercise[14]. Results showed a stabilometric deterioration. Similar results were observed by all other authors, who concluded that intense exercise protocol deteriorates the postural stability of athletes, although none of them took into account lactate accumulation as an indicator of muscle stress [3-9].

Despite being the main indicator of muscle stress induced by intense physical activity, lactate accumulation has not been measured in most of the studies that have analyzed the effects of this type of muscle stress on postural stability parameters. A close monitoring of lactate level as an indicator of high muscle stress and of its effects in postural stability would be of great importance in the prevention of injuries after practicing intense physical activity, and also to ensure the disappearance of effects 24 hours later, thus contributing to face the next training in the best conditions due to the fact that lactate-accumulation training sessions are normal training routine of sprinters.

Based on the mentioned reasons, the purpose of the present study was to analyze the short-term effects of lactate accumulation training session as normal training routine of sprinters on the postural stability of athletes until 24 hours after the end of lactic training session.

MATERIALS AND METHODS

A pre-experimental study was carried out with a group of 15 athletes, who carried out two different training sessions: Warm-up, which consisted of a 30-minute warm-up session (including ten minutes of low speed race, five minutes of dynamic stretching and fifteen minutes of technical running exercises), and Lactic Training session, consisting of the same 30-minute warm-up, followed by an anaerobic lactic training which included two groups of two series of 300m performed at 90-92%, with a five-minute rest between series and a ten-minute rest between groups[15]. A whole week passed between both training sessions. Four measures were carried out in each session: Pre= before training session, $Post_{0Min}$= immediately after training, $Post_{30Min}$= 30 minutes later and $Post_{24H}$= 24 hours after training. Every measure included three stabilometric values: one bipodal and two monopodal (left- and right-leg support), in addition to the lactate blood level ans heart rate as stress indicators. To determine the individual percentage of work in the 300 m run, the previous week all athletes performed a 300 m race at 100%.

Participants

Fifteen athletes with experience in performance of lactic trainings, and selected under randomized conditions from a total sample of thirty-three athletes, took part in the present study. The group comprised two female and thirteen male athletes, between 18 and 33 years old (26.2±7.42 years), a mean weight and height of 68.53±10.76 kg and 1.75±0.07m, respectively, and a BMI of 22.21±2.63 kg/m^2 (Table I). All athletes were specialists of the 200m and 400m races and had at least four years of experience in their respective modalities. The competition level of athletes was medium, so that their personal best results allowed them to compete in national championships. Before the start of the study, all athletes were briefed on the nature of testing and written informed consent was obtained from each subject, according to the standards of the Declaration of Helsinki. The study was approved by ethics commitee of University of the city.

Equipment

Baseline features of the athletes were collected with a 100g-300kg precision digital weight scale Tefal (France) and a t201-t4 Asimed adult height scale (Spain), which were used to obtain weight and height, respectively.

A FreeMed© BASE model baropodometric platform was used for the stabilometric measurements (Rome, Italy). The platform's surface is 555x420 mm, with an active surface of 400x400 mm and 8 mm thickness[16] by Sensormédica® (Sevilla, Spain). Calculations of center-of-pressure (CoP) movements were performed with the FreeStep© Standard 3.0 (Italy) software. The Lactate Pro blood lactate analyser™ (Japan) and the Lactate Pro Test Strip (Japan) were used to determine blood lactate accumulation. Heart rate was measured using the Polar RS300X (Finland) pulsometer. Also, a Nike WR0082-630 chronometer was used to register the time for the 300m runs and to control the resting time between repetitions and groups of repetitions.

Procedure

Bipodal stabilometry: athletes were instructed to remain as still as possible on the baropodometric platform for 52 seconds, with a between-heels separation of five cm and their feet forming a 30º angle (Figure 1).

Monopodal stabilometry: athletes stood on each of their lower limbs for 10 seconds (left leg first) on the center of the platform (Figure 1).

The following parameters were recorded for the bipodal test as well as for the left-leg and right-leg monopodal tests: length (Length) and area (Area) of the path described by the center of pressure, the speed for the center-of-pressure movement (Velocity), and the position of the center of pressure in the medial-lateral (Xmean) and anteroposterior (Ymean) planes. These variables are marked “l” or “r” to indicate whether they belong to the left or right leg, respectively. Tests were carried out before training started, in order to avoid any interference. Also, athleteswere instructed not to engage in any sports activity in the day of testing.

Blood lactate analysis: samples of blood were taken from the forefinger of either the left or the right hand of athletes. The fingertip was cleaned with alcohol (96º) and pricked with a lancet which was previously installed in the lancet device. The first drop of blood was cleaned with a piece of cotton to avoid blood contamination. Immediately after that, the fingertip was squeezed to obtain the second and definitive blood drop, as the lactate analyzer and the lactate strip were ready to catch this blood drop just coming out of the skin. One minute later, the blood lactate analyzer informed of the blood lactate level of the athlete.

300 m race test: it was performed in the week before the trainings sessions started, in order to determine the individual percentage of work in 300m repetitions. All athletes carried out only one 300m race at 100%. Time scored by athletes in the 300m race was recorded with a chronometer. This value later became the reference to calculate the 90-92% of work in the lactic training session.

Anaerobic lactic training session (Lactic Training): athletes carried out the same 30-minute warm-up performed in the warm-up training session, followed by an anaerobic lactic training which comprised two groups of two races of 300m with an intensity of

90-92% of the time recorded for the 300m reference test. Athletes rested for five minutes between races and for ten minutes between groups of races. Every race of 300m was measured with a chronometer.

Statistical analysis

The description of continuous variables was performed through the mean and the standard deviation, and for the categorical variables through frequencies and percentages. The normal distribution of continuous variables was verified with the Kolmogorov-Smirnov test ($p<0.05$). A separate 2X4 repeated measures ANOVA was performed to examine the effect of training (Warm-up or Lactic Training) and time (pre-treatment, post-treatment, 30 minutes post-treatment and 24 hours post-treatment) on stabilometric dependent variables (Length, Area, Velocity, X mean and Y mean), in three different tests (bipodal, left monopodal and right monopodal) and on parameters indicating stress level (Lactate Level and Heart Rate) to ensure the high stress level of Lactic Training session and the differences with Warm-up Training session. The hypothesis of interest was the time-by-training interaction at an alpha level of 0.05. For the determination of effect size of the time-by-training interaction, eta-squared was used. Additionally, if a significant interaction was identified, pairwise Bonferroni comparisons were performed to explore the differences between each training condition and within each time point. In order to analyze the relation between lactic acid concentration and stabilometric variables, Pearson's correlation was used. Management and data analysis were performed with the statistical package SPSS for Windows version 17.0 (SPSS Inc, Chicago, IL, USA) and MedCalc 12.5 (MedCalc, Mariakerke, Belgium). The level of statistical significance was set at $p<0.05$.

RESULTS

All the subjects performed the planned actions and completed the study. Table II shows the mean values of lactate level and heart rate on both Lactate Training session and Warm-up session ($p_s < 0.001$). Main time and training effects and the interaction time-by-training was statistically significant for Lactate Level and Heart Rate. Athletes showed an increase in lactate level and heart rate significantly higher after Lactic Training session than after Warm-up session ($p_s < 0.001$). Eta-squared was 0.935 for Lactate Level and 0.635 for Heart Rate (Table II), and it can be concluded that the interaction effect accounted for over 94% of the variation for Lactate Level and 64% for Heart Rate.

On bipodal tests, the interaction time-by-training was statistically significant for the Length Sway of center-of-pressure ($p < 0.001$), Velocity of the center-of-pressure ($p < 0.001$) and was on the limit of statistical significance for the Sway Area and X mean position (Table III). Eta-squared was 0.579 for Length and 0.582 for Velocity (Table III), and it can therefore be concluded that the interaction effect accounted for over 50% of the variation for Length and Velocity of Sway of center-of-pressure. On between-training analysis, pairwise Bonferroni comparisons showed worse stability values after lactic training, verified by an increment of Length ($p=0.004$) and Velocity ($p=0.002$) of center-of-pressure in the post-treatment evaluation. However, at 24 hours since training, better stability was observed after lactic training, expressed through significantly smaller Length (0.031) and Velocity ($p=0.030$) of Sway of center-of-pressure. On within-training analysis, lactic training showed a statistically significant increase of length in post 0 minutes ($p<0.001$), a decrease at 30 minutes ($p=0.013$) and a new decrease at 24 hours ($p<0.001$). Besides, these values at 24 hours were significantly lower than basal measures (p=0.046). No statistical change was observed on the warm-up training. The same effect was observed with the Velocity of Sway of center-of-pressure (p<0.001). No statistically significant changes were observed on Area, X mean or Y mean.

On the left-leg monopodal test (Table IV) the time-by-training interaction was statistically significant for the anteroposterior position (Y mean) of the center-of-pressure (p=0.010). Eta-squared was 0.233, the time-by-training interaction effect accounting for over 20% of the variation for the Y mean position of center-of-pressure (Table IV). Pairwise comparison showed a more posterior position of center-of-pressure at 30 minutes after lactic training (p=0.01). On within-training analysis, Length Sway of center-of-pressure exhibited a statistically significant increase at 0 Minutes post treatment (p=0.004) and a gradual decrease that became significant at 24 hours (p=0.003) after lactic training. No other significant changes were observed after the warm-up training. A similar effect was observed on Velocity of center-of-pressure with an initial increase at 0 minutes after lactic training (p=0.015) and a gradual decrease that became significant at 24 hours (p=0.016). No significant changes were observed on Sway Area, Y mean or X mean.

On the right-leg monopodal test no variable showed a statistically significant time-by-training interaction (Table V). However, on the Velocity of Sway of the center-of-pressure, a result was observed on the limit of significance (p=0.069). Furthermore, a temporary increase was observed at post treatment evaluation after lactic training. On within-training analysis, Length Sway showed an initial deterioration at 0 minutes after lactic training (p=0.038) and a gradual decrease that became significant at 24 hours (p=0.038) and reached baseline. A similar effect was observed on Velocity of Sway (p=0.015). No significant changes were observed for Area, X mean or Y mean.

Regarding the relation between lactate concentration and stabilometric variables, we found a positive correlation between Length, Area and Velocity on the right-leg test at 0 minutes of warm-up training, and between Area and Velocity on the right-leg test at 30 M after the warm-up training with lactate concentration at 24 hours after training. The highest correlations were found for Velocity on the right-leg test at 0 minutes (Adjusted R2=0.382, p=0.008) and for Area on the left-leg test at 30 minutes (adjusted R2=0.668, p<0.001). These data could be interpreted as the level of lactate at 24 hours of warm-up training depending in 38% on the Velocity values and in 66% on the Area values at 0 minutes or 30 minutes after training, respectively. No significant correlation was found between stabilometric variables and lactate concentration after lactic training.

DISCUSSION

The purpose of the present study was to analyze the short-term effects of a lactate-accumulation-induced training session on the postural stability of athletes until 24 hours after performing the lactic training session. To this end, fifteen athletes performed a training session consisting of a 30-minute warm-up session (Warm-up) and a whole week later, all athletes performed the same warm-up followed by an anaerobic lactic training session. Before training sessions, immediately after, 30 minutes later, and 24 hours later, athletes were subject to a bipodal and a monopodal stabilometry, in addition to a blood lactate analysis and the heart rate to confirm the high stress muscle presence, so that athletes showed an increase in lactate level and heart rate significantly higher after Lactic Training session than after Warm-up session.

Results from the bipodal stabilometry showed that after Lactic Training session, athletes had worse values of Length and Velocity in $Post_{0min}$. At $Post_{30min}$, despite a significant improvement, the stabilometric deterioration remained. The total recovery (and even an improvement of basal stability) was reached at $Post_{24h}$. Our results agree with those of Lepers et al., in 1997, who analyzed postural stability after 25km of running or 25km of cycling and reported deterioration on postural stability, although with differences depending on the type of the exercise. Lepers et al. (1997) also evaluated sensory afferents, and stated that during physical exercise adaptations could occur to this prolonged proprioceptive stimulation, which could be responsible of postural control deterioration[5]. Besides, the results of the present study support the research of Paillard et al. (2012), who assessed general and local stress level after intense exercise protocols and reported a subsequent deterioration of the postural stability of athletes, referring again to an alteration in sensory afferents and consequently, in motor control efferences[6]. At the same time, the results of the present study are in the same line of those found by Fox et al., (2008), where athletes performing an anaerobic training session showed a deterioration in posterior stabilometric values[4]. However, in contrast with our results, Fox et al. (2008) stated that athletes had recovered from this deterioration within 13 minutes[4]. Similar results were reported by Yaggie and Armstrong in 2004, with athletes who had worse stabilometric values after a general and intense exercise protocol recovering their the stabilometric baseline within 10 minutes[17]. Yet another example comes from Susco et al. (2004), who reported stabilometric deterioration and a subsequent improvement after 20 minutes[13]. In the present study, although bipodal stability values significantly improved 30 minutes after lactic training, it remained significantly worse than baseline. It was not until after 24 hours that baseline stabilometric levels were reached, and even improved. This improvement is consistent with results from Brown in 2002, who reported that after a prolonged proprioceptive stimulation, such as physical activity, athletes had better motor control[18]. This could lead us to the conclusion of Fanquin et al. (2005) about the better postural control from athletes vs non athletes due to the development of a more complex motor program brought about by sports practice[19].

On the other hand, despite the fact that our results show worse stabilometric parameters in CoP dispersion variables on the monopodal stabilometric test after Lactic Training session, this test did not return results as clear as those of the bipodal testing. The inequality between bipodal and monopodal results is consistent with previous studies [20, 21] where authors detected different results from both tests, with greater postural sway during monopodal, so that the difficulty added from monopodal stance could lead the difference between both tests.

Our investigation reported stabilometric deterioration right after lactic training in monopodal stability. Then, a progressive improvement appeared, which became statistically significant after 24 hours, although no significant deterioration appeared 30 minutes after the end of the lactic training session as was the case of bipodal stability tests. These findings agree with those of Surenkok et al. (2006) where athletes who performed a lactic training session later showed worse monopodal stability[9]. Similar results were found by Brito et al. (2012), who observed that after a competitive soccer match, soccer players exhibited a clear deterioration in the same CoP dispersion variables that do deteriorate in our study[3].

Regarding CoP position variables in the present study, Xmean and Ymean, significant results were found in anteroposterior stability while on left-leg monopodal support. More specifically, athletes showed a more posterior-leaning position 30 minutes after Lactic Training session. These findings are in line with those of Vuillerme and Hintzy in 2007, who reported that after fifteen minutes of cycling at 200W, athletes showed no stabilometric deterioration in the medial-lateral plane, although the deterioration was found in the anteroposterior plane[12]. On the other hand, the inequality between right- and left-leg monopodal support results, with worse stabilometric parameters for the left leg, could be explained by the fact that the type of athletes who took part in our study always train at tracks, where all turns are left-sided.

On the other hand, the Warm-up training session showed a positive correlation between Length, Area and Velocity at $Post_{0min}$ of right-leg monopodal stability tests and Area and Velocity at $Post_{30min}$ of left-leg monopodal stability tests with blood lactate levels at $Post_{24h}$. Thus, blood lactate level 24 hours after Warm-up depended in 38% on the value of the Velocity variable and in 66% on the value of the Area variable at 0 minutes or 30 minutes after training, respectively.

In the Lactic Training session, no correlation between stabilometric variables and blood lactate level was found. These results support those of Surenkok et al. (2006), who did not find any correlation between stability and blood lactate level after a lactic training[9].

Results from the present study show that motor control deterioration, as stated by authors like Lepers et al. (1997) and Paillard et al. (2012) in their respective studies, take place as a consequence of the alteration of proprioceptive afferents due to a continuous proprioceptive stimulation during prolonged physical exercise and to the subsequent stress level [5, 6]. However, the duration of these stabilometric changes depends on the intensity and length of the exercise[14]. This deterioration becomes apparent in motor control efferences and therefore in the efficacy of sports movements[22].

For future research, we suggest including an intense exercise protocol with more frequent stability measures in order to be able to determine in detail the time spent to recover stabilometric baseline values. Furthermore, we suggest analyzing several types of training sessions in order to assess the effects of different types of training sessions on the stabilometric values of athletes.

CONCLUSIONS

An anaerobic lactic training session, as normal training routine of sprinters, contributes to an important deterioration of the center-of-pressure dispersion values in the bipodal stability of athletes. Thirty minutes later, stabilometric parameters remain deteriorated. After 24 hours, stability is better than basal level. On monopodal support tests, athletes show worse stability right after a lactic training, although this deterioration fades out in time. Regarding center-of-pressure position, a lactic training session induces a deterioration in anteroposterior stability while on left-leg monopodal support.

As a practical application, personal trainers and sports physical therapists should take into account the important stabilometric deterioration happening right after a lactic training, as well as its persistence at least 30 minutes later. The risk of injury must be taken into account, as proprioceptive afferences are disturbed and therefore motor control efferences are altered. Potential injuries might become more likely at least thirty minutes after training, although the persistence of the increased risk might depend on the intensity and length of training.

REFERENCES

1. Alonso-Curiel D, Campo-Vecino JD, Balsalobre-Fernández C, Tejero-González CM and Ramírez-Parenteau C. Lactic Response of Elite Athletes to Specific Training for the 3,000 Metres. *Apunts Educación Física y Deportes* 2012; 107: 90-6.

2. Earle RW and Baechle TR. *Manual NSCA. Fundamentos del entrenamiento personal*. Paidotribo, 2008.

3. Brito J, Fontes I, Ribeiro F, Raposo A, Krustrup P and Rebelo A. Postural stability decreases in elite young soccer players after a competitive soccer match. *Physical Therapy in Sport* 2012; 13: 175-9.

4. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL and Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train* 2008; 43: 456-63.

5. Lepers R, Bigard AX, Diard JP, Gouteyron JF and Guezennec CY. Posture control after prolonged exercise. *Eur J Appl Physiol Occup Physiol* 1997; 76: 55-61.

6. Paillard T. Effects of general and local fatigue on postural control: a review. *Neurosci Biobehav Rev* 2012; 36: 162-76.

7. Derave W, De Clercq D, Bouckaert J and Pannier JL. The influence of exercise and dehydration on postural stability. *Ergonomics* 1998; 41: 782-9.

8. Gribble PA, Hertel J, Denegar CR and Buckley WE. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. *J Athl Train* 2004; 39: 321-9.

9. Surenkok O, Isler A, scedil, et al. Effect of knee muscle fatigue and lactic acid accumulation on balance in healthy subjects. *Isokinetics and Exercise Science* 2006; 14: 301-6.

10. Springer BK and Pincivero DM. The effects of localized muscle and whole-body fatigue on single-leg balance between healthy men and women. *Gait Posture* 2009; 30: 50-4.

11. McGregor SJ, Armstrong WJ, Yaggie JA, et al. Lower extremity fatigue increases complexity of postural control during a single-legged stance. *J Neuroeng Rehabil* 2011; 8: 43.

12. Vuillerme N and Hintzy F. Effects of a 200 W-15 min cycling exercise on postural control during quiet standing in healthy young adults. *Eur J Appl Physiol* 2007; 100: 169-75.

13. Susco TM, Valovich McLeod TC, Gansneder BM and Shultz SJ. Balance Recovers Within 20 Minutes After Exertion as Measured by the Balance Error Scoring System. *J Athl Train* 2004; 39: 241-6.

14. Mello RG, Oliveira LF and Nadal J. Effects of maximal oxygen uptake test and prolonged cycle ergometer exercise on sway density plot of postural control. *Conf Proc IEEE Eng Med Biol Soc* 2009; 2009: 1351-4.

15. Gorostiaga E. Ejercicio intermitente anaeróbico: bases fisiológicas y formas de controlarlo. *Jornadas Sobre Medicina y Deporte de Alto Nivel 11ª Conferencia*. Madrid2010.

16. Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, Hita-Contreras F, Osuna-Perez C and Martinez-Amat A. Short-Term Effects of Proprioceptive Training with Unstable Platform on Athletes' Stabilometry. *J Strength Cond Res* 2012; 26: 2071-7.

17. Yaggie J and Armstrong WJ. Effects of lower extremity fatigue on indices of balance. *Journal of Sport Rehabilitation* 2004; 13: 312-22.

18. Brown JP and Bowyer GW. Effects of fatigue on ankle stability and proprioception in university sportspeople. *Br J Sports Med* 2002; 36: 310.

19. Fanquin A, Melo SIL and Pires R. Comparação do equilíbrio entre atletas que treinam com calçado, descalços e não atletas. *CONGRESSO BRASILEIRO DE BIOMECÂNICA* Anais. Brasil 2005.

20. Muehlbauer T, Roth R, Bopp M and Granacher U. An exercise sequence for progression in balance training. *J Strength Cond Res* 2012; 26: 568-74.

21. Guskiewicz KM and Perrin DH. Research and clinical applications of assessing balance. *Journal of Sport Rehabilitation* 1996; 5: 45-63.

22. Roberts D, Ageberg E, Andersson G and Friden T. Effects of short-term cycling on knee joint proprioception in healthy young persons. *Am J Sports Med* 2003; 31: 990-4.

Table 1. Demographic characteristics

		All (n=15)
Age (y)		26.2 ± 7.42
High (m)		1.75 ± 0.07
Weight (kg)		68.53 ± 10.76
BMI (kg/m^2)		22.21 ± 2.63
Experience (y)		9.53 ± 4.61
Gender	Woman	2 / 13.3 %
	Man	13 / 86.7 %
Student	Yes	9 / 60 %
	No	6 / 40 %

BMI, Body Mass Index. Data are expressed as Mean ± Standard Deviation for continuous variables and as frequencies and percentages for categorical variables.

Table 2. Lactate level and heart rate.

	Pre	Post 0M	Post30M	Post24H	Effects	p-value	Eta2
LACTATE LEVEL (mmol/L)					Time	< 0.000***	0.996
Control	1.02 ± 0.16	3.26 ± 2.25	1.79 ± 1.13	1.11 ± 0.25	Training	< 0.000***	0.880
Experimental	1.05 ± 0.15	13.66 ± .86	11.90 ± 2.10	1.03 ± 0.13	**Time*Training**	**< 0.000*** **	**0.935**
HEART RATE (bpm)					Time	< 0.000***	0.949
Control	71.00 ± 11.46	104.67 ± 15.39	73.40 ± 13.23	69.00 ± 6.99	Training	< 0.000***	0.827
Experimental	70.13 ± 10.01	177.27 ± 9.89	94.47 ± 14.22	70.00 ± 8.96	**Time*Training**	**< 0.000*** **	**0.635**

Data are expressed as Mean ± Standard Deviation. Mmol/L= millimoles of lactate per litre. bpm=Beat per minute. ***p<0.001

Table 3. Bipodal analysis.

	Pre	Post 0M	Post30M	Post24H	Effects	p-value	Eta2
LENGTH (mm)					Time	< 0.001***	0.709
Control	396.75 ± 163.94	414.43 ± 191.10	433.45 ± 174.51	401.27 ± 177.93	Training	0.331	0.068
Experimental	409.41 ± 89.95	563.69 ± 103.27	470.15 ± 83.83	324.97 ± 143.03	**Time*Training**	**< 0.001*** **	**0.579**
AREA (mm)					Time	0.002**	0.302
Control	51.04 ± 39.09	104.47 ± 123.29	109.98 ± 143.82	93.65 ± 131.72	Training	0.455	0.041
Experimental	57.23 ± 42.26	192.66 ± 196.77	94.39 ± 59.10	74.31 ± 60.89	**Time*Training**	**0.075**	**0.150**
VELOCITY(mm/sec)					Time	< 0.001***	0.707
Control	7.80 ± 3.19	8.11 ± 3.73	8.49 ± 3.40	7.89 ± 3.48	Training	0.220	0.105
Experimental	8.27 ± 1.94	11.23 ± 2.07	9.42 ± 1.71	6.38 ± 2.81	**Time*Training**	**< 0.001*** **	**0.582**
X Mean (mm)					Time	0.690	0.034
Control	-1.84 ± 6.21	-2.47 ± 5.35	-0.63 ± 4.87	-4.75 ± 10.07	Training	0.744	0.008
Experimental	-4.05 ± 7.64	-4.18 ± 10.04	-2.92 ± 6.45	-0.07 ± 6.43	**Time*Training**	**0.053**	**0.165**
Y Mean (mm)					Time	0.480	0.057
Control	-8.18 ± 9.20	-7.03 ± 7.68	-7.17 ± 8.00	-6.47 ± 7.02	Training	0.913	0.001
Experimental	-7.35 ± 10.53	-4.79 ± 8.28	-9.06 ± 7.33	-8.12 ± 7.11	**Time*Training**	**0.211**	**0.101**

Data are expressed as Mean ± Standard Deviation. LENGTH= Length of Center of Pressure movement. AREA=Area of Center of Pressure movement. VELOCITY=Velocity of Center of Pressure movement. X Mean= Mean position of Center of Pressure in medial-lateral plane. Y Mean= Mean position of Center of Pressure in anteroposterior plane. *p< 0.05 **p< 0.01 ***p<0.001

Table 4. Left monopodal analysis

	Pre	Post 0M	Post30M	Post24H	Effects	p-value	Eta2
LENGTHl (mm)					Time	< 0.001***	0.517
Control	256.17 ± 82.82	345.49 ± 115.15	262.05 ± 59.41	234.33 ± 84.09	Training	0.002**	0.499
Experimental	276.10 ± 94.37	427.66 ± 170.03	366.92 ± 124.65	270.91 ± 69.10	**Time*Training**	**0.266**	0.089
AREAl (mm)					Time	0.035*	0.184
Control	391.39 ± 501.42	609.49 ± 857.40	388.31 ± 214.99	373.74 ± 324.49	Training	0.626	0.017
Experimental	303.27 ± 190.39	716.32 ± 477.58	488.24 ± 314.35	358.84 ± 170.22	**Time*Training**	**0.759**	0.027
VELOCITYl (mm/sec)					Time	< 0.001***	0.478
Control	22.31 ± 8.04	28.41 ± 11.80	22.49 ± 5.22	22.02 ± 6.35	Training	0.001**	0.532
Experimental	24.77 ± 7.63	38.46 ± 16.78	31.98 ± 11.47	23.53 ± 6.46	**Time*Training**	**0.109**	0.133
X Meanl (mm)					Time	0.487	0.056
Control	-0.78 ± 4.58	-2.08 ± 10.24	-0.72 ± 5.64	-1.22 ± 3.87	Training	0.726	0.009
Experimental	-0.91 ± 4.47	-4.75 ± 20.35	-0.60 ± 5.06	-0.88 ± 3.02	**Time*Training**	**0.926**	0.011
Y Meanl (mm)					Time	0.193	0.105
Control	-6.23 ± 6.88	-6.89 ± 10.61	-0.98 ± 10.58	-3.69 ± 9.26	Training	0.055	0.238
Experimental	-5.52 ± 13.81	-10.66 ± 9.92	-10.61 ± 10.99	-7.27 ± 8.97	**Time*Training**	**0.010***	0.233

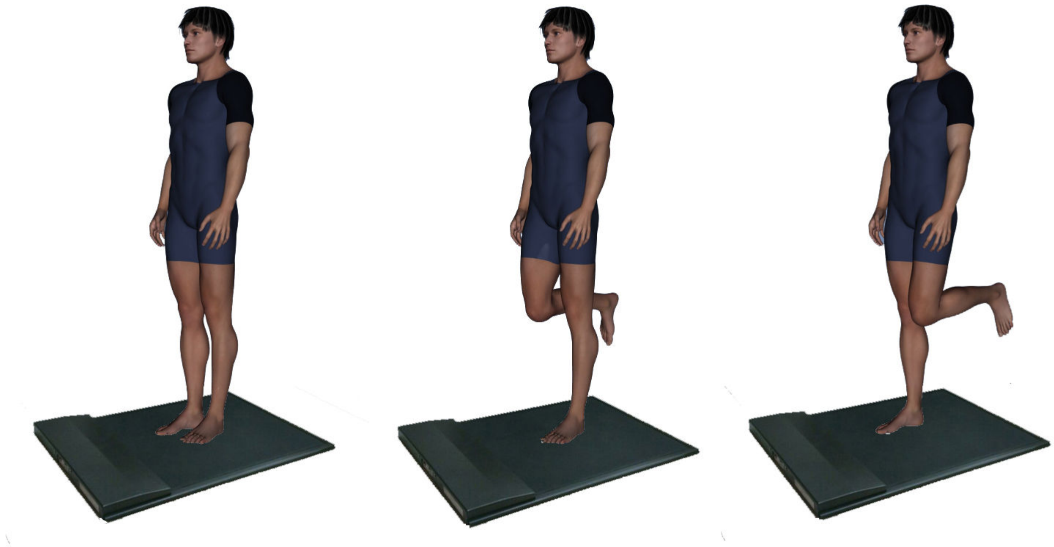
Data are expressed as Mean ± Standard Deviation. LENGTHl= Length of Center of Pressure movement in left monopodal support. AREAl=Area of Center of Pressure movement in left monopodal support. VELOCITYl=Velocity of Center of Pressure movement in left monopodal support. X Meanl= Mean position of Center of Pressure in medial-lateral plane in left monopodal support. Y Meanl= Mean position of Center of Pressure in anteroposterior plane in left monopodal support. $^*p< 0.05$ $^{**}p< 0.01$ $^{***}p<0.001$

Table 5. Right monopodal analysis.

	Pre	Post 0M	Post30M	Post24H	Effects	p-value	Eta2
LENGTHr (mm)					Time	0.006**	0.251
Control	229.95 ± 34.43	258.97 ± 54.10	270.94 ± 100.32	244.66 ± 58.36	Training	0.002**	0.495
Experimental	271.92 ± 53.02	355.94 ± 113.34	314.11 ± 132.05	256.23 ± 90.75	**Time*Training**	**0.130**	0.124
AREAr (mm)					Time	0.034*	0.185
Control	266.45 ± 135.56	372.26 ± 191.98	632.78 ± 916.12	311.44 ± 220.55	Training	0.160	0.136
Experimental	347.20 ± 221.86	812.44 ± 667.26	593.83 ± 592.78	408.44 ± 367.11	**Time*Training**	**0.190**	0.106
VELOCITYr (mm/sec)					Time	0.007**	0.249
Control	20.87 ± 3.84	22.72 ± 5.94	24.56 ± 9.13	21.95 ± 5.25	Training	0.003**	0.486
Experimental	24.00 ± 5.79	32.96 ± 10.39	28.11 ± 12.93	23.28 ± 9.32	**Time*Training**	**0.069**	0.154
X Meanr (mm)					Time	0.409	0.066
Control	0.57 ± 4.16	-1.10 ± 3.87	10.36 ± 26.39	5.22 ± 15.05	Training	0.169	0.131
Experimental	-1.07 ± 3.78	3.08 ± 16.18	-0.01 ± 3.45	-0.22 ± 3.90	**Time*Training**	**0.165**	0.113
Y Meanr (mm)					Time	0.889	0.015
Control	-3.04 ± 10.60	-3.43 ± 11.15	-2.01 ± 11.35	-6.17 ± 9.23	Training	0.018*	0.340
Experimental	-6.87 ± 11.04	-7.09 ± 10.70	-6.56 ± 8.91	-4.51 ± 13.40	**Time*Training**	**0.328**	0.078

Data are expressed as Mean ± Standard Deviation. LENGTHr= Length of Center of Pressure movement in right monopodal support. AREAr=Area of Center of Pressure movement in righ monopodal support. VELOCITYr=Velocity of Center of Pressure movement in right monopodal support. X Meanr= Mean position of Center of Pressure in medial-lateral plane in right monopodal support. Y Meanr= Mean position of Center of Pressure in anteroposterior plane in right monopodal support. *p< 0.05 **p< 0.01 ***p<0.001

Figure 1. Bipodal and left and right monopodal stability tests.



VIII

EFFECTS OF ANAEROBIC LACTIC TRAINING ON KNEE PROPRIOCEPTION OF TRACK AND FIELD ATHLETES

N Romero-Franco, EJ Martínez-López, R Lomas-Vega, F Hita-Contreras, A Martínez-Amat

Submitted

EFFECTS OF ANAEROBIC LACTIC TRAINING ON KNEE PROPRIOCEPTION OF TRACK AND FIELD ATHLETES

Lactic Training and Proprioception of Athletes

Romero-Franco N[1], Martínez-López EJ[2], Hita-Contreras F[1], Lomas-Vega R[1], Martínez-Amat A[1]

1. Department of Health Sciences, University of Jaén, E-23071 Jaén, Spain. Fax: +34953012141

2. Department of Didactics of Musical, Plastic and Corporal, University of Jaén, E-23071 Jaén, Spain. Fax: +34953212488

ACKNOWLEDGEMENTS

Authors would like to thank the University for their support to the present study, and also to the athletes and coaches whose effort made our research possible. The present study complies with the current laws of the country in which they were performed.

ABSTRACT

This study investigated short-term effects of an anaerobic lactic training session on the knee joint position sense of athletes and the duration of these effects until twenty-four hours later.

Fifteen athletes experienced in lactic training from one track and field team volunteered for the study. Subjects randomly performed two training sessions one week apart: Warm-up, consisting of a 30-minute warm-up, and Lactic Training, which included the same warm-up routine and an anaerobic lactic training session. All athletes carried out a joint position sense test of knee, as well as a blood lactate and heart rate analysis before (Pre), just after ($Post_{0Min}$), thirty minutes after ($Post_{30Min}$) and 24 hours ($Post_{24H}$) after each training session.

Within-training analysis showed an increase of absolute angular error at $Post_{0Min}$ after Lactic Training with stadistically higher values than after Warm-up Training (p=0.001), and a gradual decrease toward the measurement taken 24 hours later. On relative angular error, the initial increase at $Post_{0Min}$ after Lactic Training was not statistically significant (p=0.236) but the subsequent decrease at $Post_{24H}$ was statistically significant (p=0.021).

Anaerobic lactic training immediately depletes the accuracy of knee joint position sense, although it is recovered 30 minutes later. After 24 hours, knee joint position sense is better than it was at baseline.

Coaches, rehabilitation trainers and physical therapists should take into account the deleterious effects on joint position sense after intense phisical activity. Also, they could benefit from the improvement in proprioception twenty-four hours later, to perfect the more technical aspects of the athlete's training.

Key terms. Proprioception; knee; athletes; blood lactate; training.

INTRODUCTION

Proprioception leads the learning process of sports gestures and may maximize the performance and prevent injuries in athletics, informing about the body's position from muscles, tendons, joints, and skin (10, 11, 21, 40). However, intense exercise inducing muscle exhaustion might impair these proprioceptive afferents and increase the injury risk(1, 15, 19).

Many authors have reported that intense physical activity protocols depletes proprioceptive skills that play a role in sport injury such as joint position sense(23, 24, 27, 28, 40). These included protocols involving the whole body (i.e., cycling on an ergometer bicycle, running intervalic training, or performing ramp and interval test); as well as protocols involving part of the body (i.e., specific sports gesture, eccentric contractions of upper or lower limb, or flexion-extension of knee). Both general and local exercise protocols blunted the accuracy of joint position sense(8, 20, 26-28, 32, 33, 35, 38).

Despite the evidence about proprioceptive impairment after intense exercises, the duration of this depletion is unclear – studies to date lacks follow-up of joint position sense test after the intense physical activity(31). Indeed, very few authors have analyzed the effects of alternative intense exercises that may also impair proprioceptive skills such as anaerobic lactic training(29).

To address these questions, the purpose of the present study was to analyse the short-term effects of an anaerobic lactic training session on the joint position sense (JPS) of the knee of athletes – the most frequently affected joint. To analyse the gradual decrease in these effects, we measured joint position sense of athletes thirty minutes and twenty-four hours after training. Additionally, we assessed heart rate and blood lactate level to ensure the stressing level of the exercise(4). We included track and field athletes due to the high frequency of intense lactic exercise in their training routines. Authors hypothesize that lactic training will impair the JPS of athletes in immediately post-training measurements and it decreased gradually at the following measurements (thirty minutes and twenty-four hours later).

METHODS

Experimental Approach to the Problem

Authors used a repeated-measures crossover design with a single group in this research. The group comprised 15 athletes who carried out two different training sessions: Warm-up and Lactic Training. Pre= before training session, $Post_{0Min}$= immediately after training, $Post_{30Min}$= 30 minutes later and $Post_{24H}$= 24 hours after training. Every measurement included joint position sense test, as well as lactate blood level and heart rate assessments as control training indicators.

Subjects

Authors used a repeated-measures crossover design with a single group in this research. Fifteen athletes – 26.2 ± 7.4 years; 1.75 ± 0.07 m; 68.5 ± 10.8 kg; 2 women (13.3%) and 13 men (86.7%) – from one track and field team and with experience in lactic training were selected under randomized conditions from a total sample of twenty-three athletes. Baseline levels of the athletes were collected with a 100 kg – 300 kg precision digital weight scale Tefal (France) and a t201-t4 Asimed adult height scale (Spain), for weight and height, respectively. All subjects were specialists of the 200 m or 400 m races and had at least four years of experience in their respective modalities. The competition level of athletes was national - their personal best results allowed them to compete in national championships. Before the start of the study, all athletes were briefed on the nature of testing and written informed consent was obtained from each subject, according to the standards of the Declaration of Helsinki - 2008 revision(16). Also, Ethical Committee of the University of the city approved the present study.

Procedures

All athletes carried out two different training sessions: Warm-up - a 30 minutes warm-up including ten minutes of low-speed race, 5 minutes of dynamic stretching and 15 minutes of technical running exercises- and Lactic Training - the same 30-minute warm-up, followed by an anaerobic lactic training which included two groups of two series of 300 m performed at 90-92% - all athletes performed a 300 m race at maximum intensity (100%) to determine the individual percentage of work - with a rest of 5 minutes between series and 10 minutes between groups(9). A whole week passed between training sessions and the order of training sessions performance was randomly assigned.

Four measurements were taken in each session: Pre= before training session, $Post_{0Min}$= immediately after training, $Post_{30Min}$= 30 minutes later and $Post_{24H}$= 24 hours after training. Every measurement included joint position sense test, as well as lactate blood level and heart rate assessments as control training indicators.

Knee joint position sense. It was measured in the dominant limb of athletes, for open-kinetic-chain and active-leg movements. Muscle receptors being the primary contributors to proprioceptive information, through active testing the input from these receptors is maximized(2). Besides, active testing is more functional and accurate than passive testing(2). A system of digital photography Canon 8MP, MV750i (United Kingdom), non-reflective markers and the AutoDESK® AutoCAD© 2008 software were used.We attached four colour markers of 4x4cm to the dominant limb in the following locations: 1) tip of greater trochanter; 2) over the iliotibial track – at the level of posterior skin crease when knee is flexed to 80º; 3) neck of the fibula; and 4) over the proximal of lateral malleolus (Figure 1). The location of four markers is based on previous studies(12, 24, 36).

All athletes sat on the treatment couch with their leg not touching the floor and eyes covered with an eye shield to block the visual inputs in the joint positioning. The researcher held the heel of the athlete and passively – with a speed of 2º per second - moved the leg from the resting position of 90º to a target angle - randomly selected between 40º and 60º (intermediate ranges of knee flexion), where the mediation of muscle sensory in the sense of knee-position predominate. Subjects were asked to actively hold their knee in that position for five seconds and to concentrate on the angle. During this time, a photography was taken of the target position. Then, the researcher passively returned the leg to the resting position. Some seconds later, the athlete was instructed to replicate the previous position actively and to maintain it for three seconds, while a photography of the replicated position was taken. Each replication was repeated three times. The digital camera was supported on a tripod, located 185 cm away from the athlete, and perpendicular to the knee joint axis of movement. All athletes were familiarized with the procedure through one explanation, one demonstration, and one practice repetition(18).

Figure 1 about here

To evaluate proprioception of the knee, the following parameters were obtained from the JPS test: absolute angular error (AAE) – absolute difference between the target and the estimated position ignoring the direction of error (determined as the mean value of the absolute error between the passively-positioned knee angle and the actively-produced knee angle in three consecutive trials); relative angular error (RAE) – the arithmetic difference between the test and the response position; and variable angular error (VAE) – standard deviation of the three repetitions (determined as the standard deviation from the mean of the relative errors). Test-retest reliability has been shown in previous studies(17, 18, 24, 25). In the present study, participants carried out two measures of joint position sense with a 72 hours interval and the measure showed an high intra-class correlation coefficien (r = 0.861, 95% CI=0.812- 0.947).

Lactate blood level. Lactate Pro blood lactate analyser™ (Japan) and the Lactate Pro Test Strip (Japan) were used to determine blood lactate accumulation. Accuracy and reliability of this blood lactate analyzer has been shown previously(22).

Heart rate. It was measured with a Polar RS300X pulsometer (Finland). Also, a Nike WR0082-630 chronometer was used to register the time for the 300m runs and to control the resting time between repetitions and groups of repetitions.

Statistical Analyses

Data management and analysis were carried out with the statistical package SPSS for Windows version 17.0 (SPSS Inc, Chicago, IL, USA) and MedCalc 12.5 (MedCalc, Mariakerke, Belgium). The description of continuous variables was performed through the mean and the standard deviation, and for the categorical variables through frequencies and percentages. The normal distribution of continuous variables was verified with the Kolmogorov-Smirnov test ($p<0.05$). A separate 2X4 repeated measures ANOVA was performed to examine the effect of training (Warm-up or Lactic Training) and time (pre-treatment, post-treatment, 30 minutes post-treatment, and 24 hours post-treatment) on dependent variables (AAE, RAE, and VAE). The hypothesis of interest was the time-by-training interaction at an alpha level of 0.05. In order to determine the effect size of the time-by-training interaction eta-squared was used. Pairwise Bonferroni comparisons were performed to explore the differences between each training condition and within each time point. In order to analyze the relation between lactic acid concentration and proprioception, Pearson's correlation was used. The level of statistical significance was set at $p<0.05$.

RESULTS

Results from lactate blood level and heart rate showed a statistically significant increase at $Post_{0Min}$ after both training sessions, that was significant higher in Lactic Training than Warm-up Training (p_s<0.001). Despite decreasing significantly at $Post_{30Min}$ in both training sessions, lactate blood level and heart rate were still significant higher in Lactic Training than Warm-up Training (p_s<0.001). Differences were equalized at $Post_{24H}$ (Figure 2).

Figure 2 about here

The 2x4 repeated measures ANOVA showed a significant interaction time-by-training in the AAE variable (p=0.013) (Table 1). RAE and VAE analysis showed no significant interaction. The effect size measured with eta-squared showed that over 50% of the variation in VAE could be explained by the time-by-training interaction. In RAE, the effect size was near 50% (Table 1). Regarding the pairwise comparison of between-training analysis, a statistically significant difference was found immediately post-intervention (p=0.001) on AAE. On the within-training analysis, AAE initially increased at $Post_{0Min}$ (p=0.147), and gradually decreased toward the 24-hours measurement values, although it was not statistically significant (p=0.062). On RAE, the initial increase at 0 minutes after lactic training was not statistically significant (p=0.236) but the later decrease toward the 24-hours measurement was statistically significant (p=0.021). No significant changes were observed after warm-up in AAE or RAE, or in VAE.

Table 1 about here

DISCUSSION

The purpose of the present study was to analyze the short-term effects of an anaerobic lactic training session on the joint position sense (JPS) of the knee of athletes. We analyzed blood lactate level and heart rate to ensure a more stressing level of the physical activity in the Lactic Training session.

The main findings of the present study indicate that subjects exhibited impaired knee proprioception after an anaerobic lactic training, as revealed by higher values of AAE in JPS. This results match those in previous literature and support the theory of Voight et al. (1996), who proposed the desensitization and inefficiency of the muscle spindles after intense training sessions, which would affect proprioceptive afferents and the information arriving to the nervous system(6, 27, 33, 34, 37). Consequently, the ability to recognize and replicate movements would be deteriorated as well. These findings are also in agreement with those of Paillard (2012) and Lepers et al. (1997), who evaluated sensory input after prolonged proprioceptive stimulation by practicing physical activity and detected adaptations to this stimulation, reflected in immediate damage to the efferent motor control(15, 19).

On the other hand, the significance of our results lies in the progressive recovery of proprioceptive impairment in the value of RAE and AAE measured in JPS. Thus, thirty minutes after the lactic training, proprioceptive parameters had returned baseline. In contrast to our results, the only study to our knowledge that analyzed the recover of joint position sense after a intense exercise protocol was designed by Torres et al., and consisted of eccentric training until exhaustion(31). In its findings, the reported proprioceptive knee deficit was significantly decreased up to 48 hours later, suggesting that there might be an impairment in the intrafusal fibres of spindle muscles and in the tendon organs. Despite having the same physiological explanation for the reduction of JPS, the difference in recovery time could be due to the muscle damage after eccentric work being more serious and lasting than after lactic training(31). All other studies analyzed postural stability as a proprioceptive deficit after intense exercise protocols, and all reported total proprioceptive recovery from 10 to 20 minutes after the training session, depending on its intensity and duration(7, 30, 39). These findings match ours, in which proprioceptive parameters had reached baseline within 30 minutes.

Indeed, twety-four hours after Lactic Training, RAE and AAE improved with respect to baseline. These findings agree with Brown et al. (2002), who stated that prolonged proprioceptive stimulation by practicing physical activity implies medium- and long-term adaptations which improve the motor control of athletes(3). Fanquin et al (2005) corroborated this affirmations concluding that sports practice confers a complex postural control significantly better than that of any sedentary person(5).

Any findings appeared after Warm-up, in disagreement with the study by Konradsen et al. (2000), who reported improvements in JPS of ankle after a 20-minute warm-up(11). The different duration of warm-up could have affected the results.

On the other hand, VAE values exhibited no significant difference after any training session, similarly to previous literature using JPS as proprioceptive evaluation method(24).

An important limitation of this study was the sample size and the lack of a comparator control group instead of a single group of same people. Despite achieving comparable groups in terms of subjects' characteristics, this could have affected the results in terms of learning effects. Indeed, we dare recommend the inclusion of intermediate proprioceptive analysis from 0 to 30 minutes after the intense exercise protocol to determine in detail the time required to completely recover JPS. In addition, it would be advisable to evaluate training sessions containing different sorts of exercises, to control for the effects of each on the proprioception of athletes.

In summary, intense exercise immediately reduces proprioceptive sense. The consensus is that this deterioration could considerably increase the risk of injury in sports(13, 14, 28, 40).

CONCLUSIONS

The accuracy of the knee joint position sense of athletes is deteriorated after anaerobic lactic training, when athletes are not able to fully recognize and reproduce knee movements. This loss is recovered after 30 minutes, when athletes are again able to reproduce the joint angle as they did prior to strenuous exercise. Twenty-four hours after lactic training athletes are able to reproduce with more accuracy the joint movement of knee than before training.

Practical applications

Coaches, rehabilitation trainers and physical therapists should take into account the deleterious effects on joint position sense after intense phisical activity. The condition of proprioceptive deterioration is a potential injury risk for athletes, who are unable to recognize and replicate sports gestures effectively; most of sports movements are performed in extreme joint ranges, where proprioceptive alteration implies significant risks. Additionally, health and sports professionals could benefit from the improvement in proprioception twenty-four hours after an intense training session, to perfect the more technical aspects of the athlete's training.

REFERENCES

1. Alonso-Curiel D, Campo-Vecino JD, Balsalobre-Fernández C, Tejero-González CM, and Ramírez-Parenteau C. Lactic Response of Elite Athletes to Specific Training for the 3,000 Metres. *Apunts Educación Física y Deportes* 107: 90-96, 2012.
2. Bennell K, Wee E, Crossley K, Stillman B, and Hodges P. Effects of experimentally-induced anterior knee pain on knee joint position sense in healthy individuals. *J Orthop Res* 23: 46-53, 2005.
3. Brown JP and Bowyer GW. Effects of fatigue on ankle stability and proprioception in university sportspeople. *Br J Sports Med* 36: 310, 2002.
4. Earle RW and Baechle TR. *Manual NSCA. Fundamentos del entrenamiento personal.*: Paidotribo, 2008.
5. Fanquin A, Melo SIL, and Pires R. Comparação do equilíbrio entre atletas que treinam com calçado, descalços e não atletas, in: *CONGRESSO BRASILEIRO DE BIOMECÂNICA*. Anais. Brasil, 2005.
6. Forestier N, Teasdale N, and Nougier V. Alteration of the position sense at the ankle induced by muscular fatigue in humans. *Med Sci Sports Exerc* 34: 117-122, 2002.
7. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, and Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train* 43: 456-463, 2008.
8. Givoni NJ, Pham T, Allen TJ, and Proske U. The effect of quadriceps muscle fatigue on position matching at the knee. *J Physiol* 584: 111-119, 2007.
9. Gorostiaga E. Ejercicio intermitente anaeróbico: bases fisiológicas y formas de

controlarlo, in: *Jornadas Sobre Medicina y Deporte de Alto Nivel 11ª Conferencia*. Madrid, 2010.

10. Jones L. Proprioception and Its Contribution to Manual Dexterity, in: *Hand and Brain*. MW Alan, H Patrick, PH J. Randall FlanaganA2 - Alan M. Wing, JR Flanagan, eds. San Diego: Academic Press, 1996, pp 349-362.

11. Konradsen L. Factors Contributing to Chronic Ankle Instability: Kinesthesia and Joint Position Sense. *J Athl Train* 37: 381-385, 2002.

12. Lafortune MA, Lambert C, and Lake M. Skin marker displacement at the knee joint, in: *Proceedings of NACOB II The second North American congress on biomechanics*. Chicago, 1992, pp 101-102.

13. Lattanzio PJ and Petrella RJ. Knee proprioception: a review of mechanisms, measurements, and implications of muscular fatigue. *Orthopedics* 21: 463-470; discussion 470-461; passim, 1998.

14. Lattanzio PJ, Petrella RJ, Sproule JR, and Fowler PJ. Effects of fatigue on knee proprioception. *Clin J Sport Med* 7: 22-27, 1997.

15. Lepers R, Bigard AX, Diard JP, Gouteyron JF, and Guezennec CY. Posture control after prolonged exercise. *Eur J Appl Physiol Occup Physiol* 76: 55-61, 1997.

16. Mundial AM. La Declaración de Helsinki en debate. *Revista Médica del Uruguay* 24: 67-68, 2008.

17. Nasseri N, Hadian MR, Bagheri H, Talebian S, and Olyaei G. Reliability and accuracy of joint position sense measurement in the laboratory and clinic: Utilising a new system. *Acta Medica Iranica* 45: 395-404, 2007.

18. Olsson L, Lund H, Henriksen M, Rogind H, Bliddal H, and Danneskiold-

Samsøe B. Test–retest reliability of a knee joint position sense measurement method in sitting and prone position. *Advances in Physiotherapy* 6: 37-47, 2004.

19. Paillard T. Effects of general and local fatigue on postural control: a review. *Neurosci Biobehav Rev* 36: 162-176, 2012.

20. Paschalis V, Nikolaidis MG, Giakas G, Jamurtas AZ, Pappas A, and Koutedakis Y. The effect of eccentric exercise on position sense and joint reaction angle of the lower limbs. *Muscle Nerve* 35: 496-503, 2007.

21. Proske U and Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiol Rev* 92: 1651-1697, 2012.

22. Pyne DB, Boston T, Martin DT, and Logan A. Evaluation of the Lactate Pro blood lactate analyser. *Eur J Appl Physiol* 82: 112-116, 2000.

23. Ribeiro F, Gonçalves G, Venâncio J, and Oliveira J. A fadiga muscular diminui a sensação de posição do ombro em andebolistas. *Revista Portuguesa de Ciências do Desporto* 8: 271-276, 2008.

24. Ribeiro F, Mota J, and Oliveira J. Effect of exercise-induced fatigue on position sense of the knee in the elderly. *Eur J Appl Physiol* 99: 379-385, 2007.

25. Ribeiro F and Oliveira J. Effect of physical exercise and age on knee joint position sense. *Arch Gerontol Geriatr* 51: 64-67, 2010.

26. Ribeiro F, Venancio J, Quintas P, and Oliveira J. The effect of fatigue on knee position sense is not dependent upon the muscle group fatigued. *Muscle Nerve* 44: 217-220, 2011.

27. Roberts D, Ageberg E, Andersson G, and Friden T. Effects of short-term cycling on knee joint proprioception in healthy young persons. *Am J Sports Med* 31:

990-994, 2003.

28. Skinner HB, Wyatt MP, Hodgdon JA, Conard DW, and Barrack RL. Effect of fatigue on joint position sense of the knee. *J Orthop Res* 4: 112-118, 1986.

29. Surenkok O, Isler A, scedil, e K, Aytar A, Gultekin Z, and Akman MN. Effect of knee muscle fatigue and lactic acid accumulation on balance in healthy subjects. *Isokinetics and Exercise Science* 14: 301-306, 2006.

30. Susco TM, Valovich McLeod TC, Gansneder BM, and Shultz SJ. Balance Recovers Within 20 Minutes After Exertion as Measured by the Balance Error Scoring System. *J Athl Train* 39: 241-246, 2004.

31. Torres R, Vasques J, Duarte JA, and Cabri JM. Knee proprioception after exercise-induced muscle damage. *Int J Sports Med* 31: 410-415, 2010.

32. Tripp BL, Boswell L, Gansneder BM, and Shultz SJ. Functional Fatigue Decreases 3-Dimensional Multijoint Position Reproduction Acuity in the Overhead-Throwing Athlete. *J Athl Train* 39: 316-320, 2004.

33. Tripp BL, Yochem EM, and Uhl TL. Functional fatigue and upper extremity sensorimotor system acuity in baseball athletes. *J Athl Train* 42: 90-98, 2007.

34. Tripp BL, Yochem EM, and Uhl TL. Recovery of upper extremity sensorimotor system acuity in baseball athletes after a throwing-fatigue protocol. *J Athl Train* 42: 452-457, 2007.

35. Tsay A, Allen TJ, Leung M, and Proske U. The fall in force after exercise disturbs position sense at the human forearm. *Exp Brain Res* 222: 415-425, 2012.

36. Tully EA and Stillman BC. A Revised Model for 2D Kinematic Analysis of Spine Hip and Knee Motion in the Sagittal Plane, in: *Proceedings of the Twelth*

World Congress of Physical Therapy. Washington (DC), 1995, p 732.

37. Voight ML, Hardin JA, Blackburn TA, Tippett S, and Canner GC. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *J Orthop Sports Phys Ther* 23: 348-352, 1996.

38. Walsh LD, Hesse CW, Morgan DL, and Proske U. Human forearm position sense after fatigue of elbow flexor muscles. *J Physiol* 558: 705-715, 2004.

39. Yaggie J and Armstrong WJ. Effects of lower extremity fatigue on indices of balance. *Journal of Sport Rehabilitation* 13: 312-322, 2004.

40. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, and Cholewicki J. The effects of core proprioception on knee injury: a prospective biomechanical-epidemiological study. *Am J Sports Med* 35: 368-373, 2007.

Figure 1. Joint position sense of the knee test.

Figure 2. Lactate blood level and heart rate of athletes.

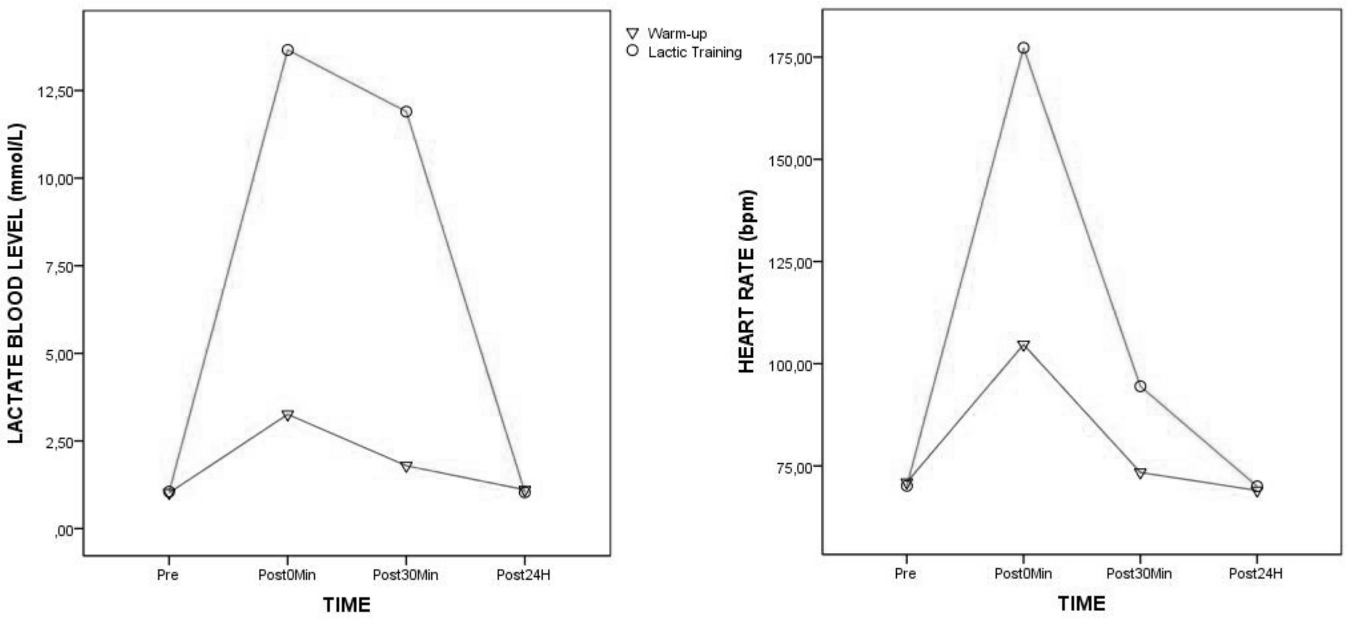


Table 1. Data and effects of time, training and time-by-training interaction.

	PRE-intervenction	POST 0 Minutes	POST 30 Minutes	POST 24 Hours	Effects	p-value	Eta2
AAE (degrees)					Time	0.069	0.434
Warm-up	2.43 ± 1.53	2.45 ± 1.64	3.78 ± 1.67	2.67 ± 1.88	Training	0.006**	0.433
Lactic Training	3.50 ± 2.09	4.71 ± 2.14	3.86 ± 2.53	2.83 ± 1.17	**Time*Training**	**0.013***	**0.579**
RAE (degrees)					Time	0.027*	0.521
Warm-up	1.80 ± 2.14	2.12 ± 1.85	3.07 ± 2.72	1.44 ± 2.87	Training	0.003**	0.469
Lactic Training	2.64 ± 3.03	4.52 ± 2.49	3.48 ± 3.02	1.79 ± 2.47	**Time*Training**	**0.089**	**0.407**
VAE (degrees)					Time	0.054	0.459
Warm-up	1.11 ± 0.66	1.05 ± 0.70	1.16 ± 0.66	0.86 ± 0.35	Training	0.343	0.064
Lactic Training	1.22 ± 0.90	1.33 ± 0.59	1.24 ± 0.56	0.88 ± 0.61	**Time*Training**	**0.803**	**0.077**

AAE, Absolute Angular Error. RAE, Relative Angular Error. VAE, Variable Angular Error. PRE-intervenction, measurements before training session. POST 0 Minutes, measurements just after training session. POST 30 Minutes, measurements thirty minutes after traininf session. POST 24 Hours, measurements 24 hours after training session. Eta2, Eta Squared.*$p<0.05$. **$p<0$.