TESIS DOCTORAL

UCAM
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ESCUELA INTERNACIONAL DE DOCTORADO

Programa de Doctorado Ciencias del Deporte

Biomechanical Perspectives in Flamenco Dance: Use of Triaxial Accelerometers

Autor

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The present thesis Biomechanical Perspectives in Flamenco Dance: Use of Triaxial Accelerometers, is a compendium of previously published or accepted for publication works. Below, the complete references of the articles that constitute the body of this Thesis are presented in chronological order:

Zhang, N., Lozano, S. G., & Vargas-Macías A. (2022). Hotspots and trends of flamenco dance research: A CiteSpace analysis. Cultura, ciencia y deporte, 17(53), 99-108. (Anexo 2)

Zhang, N., Gómez-Lozano, S., Armstrong, R., Liu, H., & Vargas-Macías, A. (2022). External load of flamenco Zap-3 footwork test: use of PlayerLoad concept with triaxial accelerometry. Sensors, 22(13), 4847. (Anexo 3)

Zhang, N., Gómez-Lozano, S., Armstrong, R., Liu, H., & Vargas-Macías, A. (2023). Ankle Active Range of Motion as an Essential Factor of Footwork Technique in the Prevention of Overuse Injuries in Flamenco Dancers. Archivos de Medicina del Deporte, 40(2), 77-84. (Anexo 4)

Zhang, N., Gómez-Lozano, S., Armstrong, R., Liu, H., & Vargas-Macías, A. (In press). The effect of lower limb balance ability and bilateral asymmetry on Flamenco footwork. Cultura, ciencia y deporte. (Anexo 5)

Zhang, N., Gómez-Lozano, S., Armstrong, R., Liu, H., Abadía, O., & Vargas-Macías, A. (2023). Monitoring flamenco dance movement with Accelerometer: Methodological and practical commendations. Revista del Centro de Investigación Flamenco Telethusa, 17(19), 8-12. (Anexo 6)

AUTORIZACIÓN DEL DIRECTOR DE LA TESIS

PARA SU PRESENTACIÓN

El Dr. D. Sebastián Ramón Gómez Lozano y el Dr. Alfonso Vargas Macías como Directores(1) de la Tesis Doctoral titulada "Biomechanical Perspectives in Flamenco Dance: Use of Ttriaxial Accelerometers" realizada por Da. Ningyi Zhang (E77496612) en el Programa de Doctoradoen Ciencias del Deporte en la línea de investigación del Análisis del hecho coreográfico y performativo en el contexto del Grupo de Investigación en Artes Escénicas, autoriza su presentación a trámite dado que reúne las condiciones necesarias para su defensa.

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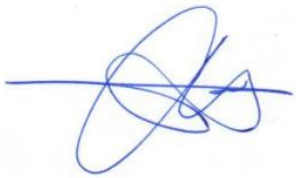

D. Sebastián R Gómez Lozano

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(1) Si la Tesis está dirigida por más de un Director tienen que constar y firmar ambos.

RESUMEN

El análisis biomecánico nos permite comprender la mecánica del movimiento de los bailaores/as de flamenco y con ello mejorar la técnica de baile, prevenir lesiones o dolores, evaluar los niveles de condición física, supervisar la carga de trabajo y elaborar planes científicos de práctica y entrenamiento. Se trata de un tipo de baile que requiere altas cargas de demandas físicas. Las técnicas de zapateado flamenco requieren el uso de diferentes partes del pie, incluyendo el talón y la punta de los dedos, para golpear el suelo y crear una serie de ritmos y sonidos fuertes que producen vibraciones de gran intensidad. Un ejemplo de esto son las técnicas usadas en el test de zapateado Zap-3, que consta de una secuencia de seis pasos que requieren golpear el suelo y alternar rápidamente entre el talón y la punta de los dedos. Al mismo tiempo, se exige a los bailaores y bailaoras mantener la estabilidad de las extremidades superiores y el tronco durante todo el movimiento. Por lo tanto, la capacidad de equilibrio de las extremidades inferiores, la asimetría y el rango de movimiento activo del tobillo pueden afectar la estabilidad corporal, aumentar las cargas externas y el riesgo de lesiones. Además, se han registrado dolores y lesiones en diferentes partes del cuerpo de los bailaores, lo que podría implicar graves consecuencias para sus carreras profesionales y también en sus vidas cotidianas. La difusión del flamenco a nivel global ha proliferado significativamente atrayendo a numerosos participantes, pero a pesar de ello, existe sólo un reducido número de fundamentos teóricos integrales que ayuden a optimizar las técnicas de baile y prevenir lesiones. Por lo tanto, los objetivos de esta tesis fueron, en primer lugar, investigar el marco del campo de investigación del baile flamenco para demostrar los puntos destacados de investigaciones y las tendencias actuales; en segundo lugar, estudiar la aplicación de acelerómetros en la investigación del baile flamenco, con aspectos que describen las cargas externas de las bailaoras de flamenco, tanto amateur como profesionales, durante el zapateado, explorando el efecto del rango de movimiento activo del tobillo, la capacidad de equilibrio de las extremidades inferiores y la asimetría en la carga externa, teniendo en cuenta la posición de los sensores y el nivel de habilidad de las bailaoras; en tercer lugar, determinar una propuesta concreta para monitorizar el movimiento del baile flamenco con acelerómetros, incluyendo la

selección y validación de los acelerómetros, los protocolos de uso y el procesamiento y análisis de datos.

Para el análisis del marco del campo de investigación del baile flamenco, se utilizó el software CiteSpaceV para explorar los puntos destacados de investigación y tendencias del baile flamenco desde la perspectiva del horizonte temporal, la red de colaboración que incluye autores, instituciones, regiones y palabras clave, basado en 130 artículos publicados desde 1982 hasta 2021 (base de datos actualizada el 4 de diciembre de 2021) sobre el baile flamenco en Scopus y Web of Science Core Collection. El número de publicaciones muestra una tendencia al alza con fluctuaciones desde 2008. Se formaron nueve grupos principales de investigación. La Universidad de Sevilla es la institución más prolífica y la Universidad Católica San Antonio de Murcia ocupa el lugar más destacado en la centralidad. España es la región con mayor producción. Los puntos destacados incluyen aspectos culturales, que abarcan la identidad y el arte en Andalucía, así como aspectos biomecánicos y físicos, que incluyen el cuerpo, la antropometría y la actividad física centrada en los bailaores/as. En conclusión, las investigaciones recientes sobre el flamenco han enfocado más su atención a estudios físicos sobre bailaores y bailaoras que a los iniciales estudios de carácter cultural o histórico.

En cuanto a las cargas externas del baile flamenco durante la técnica de zapateado y sus factores influyentes, se utilizó la acelerometría triaxial para cuantificar las cargas externas, a través de la variable PlayerLoad, en el test de zapateado flamenco Zap-3. Los acelerómetros se colocaron en diferentes partes del cuerpo: la quinta vértebra lumbar, la séptima vértebra cervical y el tobillo tanto dominante como el no dominante. Se midió, por un lado, el rango de movimiento activo del tobillo para la dorsiflexión y la flexión plantar utilizando un goniómetro. Por otro lado, también se estudió la capacidad de equilibrio y la asimetría, evaluadas mediante el test Y-balance. Se compararon y describieron las cargas externas en las diferentes posiciones, explorando el efecto del rango de movimiento activo del tobillo, la capacidad de equilibrio de las extremidades inferiores y la asimetría en las cargas externas, teniendo en cuenta la velocidad, la posición, el eje y el nivel de habilidad de las bailaoras de flamenco (amateurs y profesionales). Respecto al PlayerLoad, este estudio identificó efectos significativos entre la velocidad y la posición. Los resultados sobre la interacción entre estas dos variables muestran valores significativamente más altos en el tobillo dominante que en la

séptima vértebra cervical y la quinta lumbar. También se identificaron efectos significativos de un solo eje y efectos de grupo, así como efectos de las interacciones entre la posición, un solo eje, el grupo (profesional o amateur) y la velocidad. El efecto que la dorsiflexión tenía en las cargas externas del tobillo dominante de las bailaoras profesionales y aficionados existía solo en el eje anteroposterior, mientras que la dorsiflexión mostró conexión sólo con las cargas externas a nivel de la séptima vértebra cervical y únicamente en el grupo de bailaoras amateurs. La flexión plantar solo afectó a la contribución uniaxial del eje vertical en las bailaoras profesionales. Las bailaoras amateurs son más susceptibles al efecto de la capacidad de equilibrio, por lo que una mejor capacidad de equilibrio puede producir menores cargas externas. Tener una buena simetría de equilibrio bilateral entre ambas extremidades tiene un efecto positivo en las bailaoras de flamenco: reduce las sobrecargas a nivel cervical, los riesgos de lesiones, y puede optimizar su técnica percusiva de zapateado.

Por todo ello, se recomienda el uso de acelerómetros triaxiales para monitorizar las pruebas de técnica de baile flamenco, independientemente de la marca que se utilice, en lugar del uso de acelerometría uniaxial. El uso de acelerómetros en el rendimiento de baile se utiliza a menudo para monitorizar la condición física durante un período de tiempo, que puede ser de segundos o días, según el objeto de estudio. Los acelerómetros se pueden utilizar en diferentes entornos, como el aula, una sala de ensayo o un escenario, y también se pueden colocar en diferentes partes del cuerpo para obtener datos. Los estudios existentes sobre el baile flamenco incluyen el análisis de un movimiento de técnica de baile mediante la colocación de acelerómetros en diferentes partes del cuerpo para calcular las cargas externasen esas zonas corporales o para describir las vibraciones en sí. Existen también estudios que analizan la actividad física a lo largo del tiempo, como la intensidad y la duración del ejercicio durante una clase. En la actualidad, muchas problemáticas pueden ser estudiadas mediante el uso de acelerómetros en el baile flamenco, como la intensidad de la actividad física en diferentes partes de coreografía, el análisis de datos de aceleración y factores relacionados con otras variables para interpretar de manera más completa las características fisiológicas del baile flamenco. Estos estudios serán muy útiles para comprender en profundidad el movimiento del flamenco, brindar consejos para mejorar las

técnicas, prevenir lesiones y planificar el entrenamiento de manera eficiente, entre otros.

El test de zapateado Zap-3 registró unas cargas externas significativas en diferentes posiciones, que dependieron de la velocidad, el eje y el nivel técnico de las bailaoras de flamenco. Aunque el tobillo soporta las cargas externas más altas al bailar flamenco, algunas cargas externas también son intensas en las vértebras lumbares y cervicales, causadas por unas vibraciones muy significativas El rango de movimiento activo del tobillo, la capacidad de equilibrio y la asimetría mostraron una correlación con las cargas externas durante el zapateado flamenco, registrándose diferencias en función del nivel técnico de las bailaoras. Los acelerómetros podrían ser utilizados en el campo de estudio del baile flamenco también para monitorizar el movimiento y reducir los riesgos de lesiones y dolencias, así como para brindar recomendaciones para elaborar un plan de entrenamiento razonable y científico para los/as bailaores/as y que los bailaores y bailaoras mejoren su técnica. Además, los entrenadores, los/as bailaores/as y los practicantes podrían comprender mejor las características biomecánicas del zapateado flamenco lo cual podría ofrecer asesoramiento teórico para desarrollar programas de entrenamiento técnico. Este estudio proporciona una información adicional respecto al efecto que las cargas externas, la capacidad de equilibrio y el rango de movimiento activo del tobillo del zapateado, de modo que los planes de entrenamiento y la vigilancia de lesiones puedan optimizarse de acuerdo con la destreza técnica de los bailaores/as , con el fin de reducir el riesgo de lesiones. Estos programas se aplicarían para desarrollar un sistema de retroalimentación de técnica para el bailaor/a de flamenco, de modo que puedan seguir su propio modelo en relación con un patrón ideal. Esto permitiría intervenir en la prevención de lesiones por sobrecarga en los artistas del baile flamenco. Además, este estudio proporciona un marco del campo de investigación del baile flamenco con análisis de visualización y un método factible para evaluar las técnicas de zapateado flamenco con acelerómetros triaxiales en futuros estudios.

ABSTRACT

The biomechanical analysis allows us to deeply understand the body and movement of dancers in the aspect of mechanical motion and to improve dance technique, prevent injuries or pains, assess fitness levels monitor workload, and make scientific plans of practice and training. It is a type of dance that requires a high physical demand. Flamenco footwork techniques are required to utilize of different parts of the foot to strike the floor including the heel and tip of the toes and make a series of rhythms and loud sounds with these movements producing huge vibrations, an example is Zap-3 footwork techniques in flamenco dance, it is composed of a sequence of six steps requires striking the floor and quickly alternating the heel and tip of the toes, meanwhile, dancers are required to maintain the stability of the upper limbs and trunk during the whole movement, therefore lower limb balance ability, asymmetry and ankle active range of motion may affect the body stability, increase the external load, and injury risk. Additionally, pains and injuries have been reported in different body locations of dancers, which could have serious consequences for their careers and daily lives, The dissemination of flamenco on a global scale has proliferated significantly, attracting numerous participants, but there remains a paucity of comprehensive theoretical underpinnings for improving dance techniques and preventing injuries. Therefore, the purposes of this thesis were to firstly investigate the framework of the flamenco dance research field to demonstrate the hotspots and trends; secondly, to study the accelerometer application in flamenco dance research, with aspects of describing the external load of flamenco dancers during footwork, exploring the effect of ankle range of motion, lower limb balance ability and asymmetry on the external load of dancers, with consideration of the sensors position and proficiency level of dancers, and thirdly, to establish a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection of accelerometers, usage protocols, and data processing and analysis.

For demonstrating the framework of the flamenco dance research field, the CiteSpaceV software was utilized to explore the research hotspots and trends of the flamenco dance from the time horizon, collaborate network incorporates authors, institutions, regions, and keywords, based on 130 articles published from 1982 to 2021 (database updated on 4 December 2021) about flamenco dance in Scopus and

Web of Science Core Collection. The number of publications shows an upward trend with fluctuations Since 2008. Nine main research groups are formed. The University of Seville is the most prolific institution, and the Saint Anthony Catholic University of Murcia ranks the highest centrality. Spain is the highest yield region. The hotspots included cultural aspects, which include identity and art in Andalusia, as well as biomechanical and physical aspects, including body, anthropometry, and physical activity focusing on dancers. The trend of this field will be physical and psychological aspects. Researchers have shifted more attention from cultural and historical studies to more physical studies of dancers.

Regarding the external load of flamenco dance during footwork technique and its related influencing factors, triaxial accelerometry was used to quantify the external load of the flamenco Zap-3 footwork in the form of PlayerLoad concept in the position of the fifth lumbar vertebra, the seventh cervical vertebra and the dominant ankle, the non-dominant ankle, the ankle active range of motion was measured for dorsiflexion and plantarflexion using a goniometer, balance ability and asymmetry was tested by Y-balance test. Comparing and describing the external loads in the different position, exploring the effect of ankle active range of motion, lower limb balance ability and asymmetry on external load with consideration of speed, position, axis and proficiency level of the flamenco dancers (amateurs and professional dancers). For both PlayerLoad, this study identified significant effects of speed and position, as well as the interaction between speed and position, and at the DA, values were significantly higher than those at C7 and L5. Significant single-axis and group effects were found and effects of the interactions between the position and a single axis, and between the group and speed were also identified for uniaxial PlayerLoad. The effect of dorsiflexion on the external load of the dominant ankle of both professional and amateur dancers existed only in the anteroposterior axis while dorsiflexion was related to the external load at the 7th cervical vertebrae and only amateurs were affected. Plantarflexion only affected the uniaxial contribution of the vertical axis of professional dancers. Amateur dancers are more susceptible to the effect of balance ability and better balance ability may produce less external load. Having good bilateral balance symmetry between both limbs has a positive effect among flamenco dancers: it reduces overloads at the cervical level and injury risks and could optimize their percussive tapping technique.

Triaxial accelerometers were recommended to be used to monitor flamenco technique tests no matter what brand it is, which may be better than uniaxial accelerometry for dance movement. The use of accelerometers in dance performance is often used to monitor physical conditions over a period of time, which can be days or seconds, depending on the problem to be studied. Accelerometers can be used in different settings, such as a classroom, rehearsal hall, or stage, and can also be placed in different locations on the body to obtain data. Existing studies of flamenco dance include the analysis of a dance technique movement by placing accelerometers at different locations to calculate external loads at different locations, or to describe vibrations. Another type of study looks at physical activity over time, such as the intensity and duration of exercise during a class. At present, there are many problems that can be studied by using accelerometers in flamenco dance, such as the intensity of physical activity in different chapters of a choreographer, or the analysis of acceleration data and related factors of other variables to interpret the physiological characteristics of flamenco dance more fully. Those studies will be significantly meaningful to deeply know the flamenco movement, giving advice to improve the techniques, prevent injuries, plan the training efficiently etc.

In conclusion, recent researchers have shifted more attention from cultural and historical studies to more physical studies of dancers in the flamenco dance research field. The Zap-3 footwork produced a significant external load at different positions, which was affected by speed, axis and the proficiency level of the flamenco dancer. Although the ankle bears the highest external load when dancing the flamenco, some external load is also experienced by the lumbar and cervical vertebrae, caused by significant vibrations. Ankle active range of motion, balance ability and asymmetry have a correlation with the external load during flamenco footwork techniques and the effect showed differences according to dancers' proficiency. Accelerometers could be utilized in the flamenco dance study field for monitoring the movement to reduce the risks of injuries or pain, as well as to give recommendations for making a reasonable and scientific training plan for dancers to improve their technique. This study provides further stimulus regarding the description of external load and how balance ability and ankle active range of motion affect footwork so that training plans and injury surveillance could be optimized according to participants' dance proficiency to reduce injury risk. These

programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists. Furthermore, this study provides a frame of the flamenco dance research field with visualization analysis and a feasible method for assessing flamenco footwork techniques with triaxial accelerometers in future studies.

PALABRAS CLAVE

Biomecánica, Baile flamenco, Carga externa, Acelerómetro, Capacidad de equilibrio, Asimetría, Rango de movimiento activo del tobillo, Lesión.

KEYWORDS

Biomechanics, Flamenco dance, External load, Accelerometer, Balance ability, Asymmetry, Ankle active range of motion, Injury.

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"La originalidad consiste en el retorno al origen; así pues, original es aquello que vuelve a la simplicidad de las primeras soluciones". Antoni Gaudi (1852-1926).

ÍNDICE GENERAL

SIGLAS Y ABREVIATURAS

AAROM	Ankle active ROM
AI	Asymmetry index
BMI	Body mass index
bpm	Beats per minute
C7	The seventh cervical vertebra
DA	The ankle of dominant foot
F	At the fastest level
Group A	Amateur group
Group AM	Amateur group
Group P	Professional group
Group PRO	Professional group
kg	Kilograms
L5	The fifth lumbar vertebra
m	Meters
m2	Square meters
MVPA	Moderate to vigorous intensity physical activity
NDA	non-dominant foot
P	Zapateado de planta
PLAP/ PLap	The uniaxial PlayerLoad in the anterior–posterior plane
PLAP%/PLap%	The uniaxial contributions in the anterior–posterior plane
PL	PlayerLoad
PL%	Uniaxial contributions
PLML/PLml	The uniaxial PlayerLoad in the medial–lateral plane
PLML%/PLml%	The uniaxial contributions in the medial–lateral plane
PLTOTAL/PLtotal/PLt	Total PlayerLoad
PLUNI/PLuni	Uniaxial PlayerLoad
PLV/ PLv	The uniaxial PlayerLoad in the vertical plane
PLV%/PLv%	The uniaxial contributions in the medial–lateral vertical plane
PNT	Zapateado de Punta
ROM,	Range of motion
SEBT	Star Excursion Balance Test
T	Zapateado de Tacón
TP	Tacón-planta
YBant	Y-balance test anterior scores
YBcom	Y-balance test composite scores
YBpl	Y-balance test posterolateral scores
YBpm	Y-balance test posteromedial scores
YBT	Y-Balance test
Zap-3	Zapateado-3

ÍNDICE DE FIGURAS, DE TABLAS Y DE ANEXOS

ÍNDICE DE FIGURAS

ÍNDICE DE TABLAS

ÍNDICE DE ANEXOS

I – INTRODUCCIÓN

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1.1. A GENERAL INTRODUCTION

Biomechanics is the scientific discipline that studies the mechanical principles of human movement and provides information on muscular function and its characteristics (Koutedakis, 2008). The forces exerted upon the human body and their resultant impacts could be investigated by applying mechanics and engineering by employing methodologies such as motion capture, electromyography, anthropometrics, and dynamometry, which contribute to the biomechanics progression of knowledge across diverse domains, including the development of sports biomechanics, which includes dance since it is a kind of physical exercise (Koutedakis et al., 2008). The biomechanical analysis serves to quantify the limitations and extents of motion for each joint segment, examines forces generated in the body, and assesses external forces that influence dancers during their interactions with their surroundings, which allows us to deeply understand the body and movement of dancers in the aspect of mechanical motion (Wilson & Kwon, 2008). The quantification of performance contributes to improving dance technique, preventing injuries or pains, assessing fitness levels monitoring workload, and making scientific plans of practice and training (Koutedakis, 2008).

The study of dance involving biomechanical principles and techniques dates back to the early 1960s, measurement tools and research methods were first introduced in the 1970s (Krasnow et al., 2011). However, flamenco dance inquiry involving biomechanics first appeared in 1988, published in the USA, the electrodynogram system and light-weight unidirect accelerometers were used on 10 female flamenco dancers during walking and dancing for recording foot pressures and vibrations of hip and knee (Bejjani et al., 1988). Nearly more studies considered the biomechanical aspect of flamenco dance by using types of equipment for measuring biomechanical parameters like goniometer (Gómez-Lozano et al., 2012), uniaxial accelerometer (Bejjani et al., 1988; Voloshin et al., 1989), inclinometer (Gómez-Lozano et al., 2014), force platform (Echegoyen et al., 2013)

etc. However, the triaxial accelerometers were first utilized in our studies for investigating flamenco movement in biomechanical and health perspectives.

Meanwhile, flamenco dance has attracted some attention from academic research. At present, there are some articles related to its biomechanics, ethnography, psychology, cultural aspect, and so on (Forczek et al., 2017; Matteucci, 2014; Schindler, 2018). However, there is few studies have looked at review of flamenco's academic research field which could enable us to better understand the development and phenomenon of flamenco dance. For this reason, the first study of this thesis investigated the hotspots and trends of flamenco dance research and pointed out that biomechanics is one of the hotspots and trends of future research. Therefore, it's important and valuable to explore a thorough biomechanical analysis of flamenco dance.

1.2. THE GROUNDS FOR THE COMPENDIUM OF PUBLICATIONS: JUSTIFICATION OF THE THEMATIC UNIT.

Study 1 is a previous review study of this thesis, investigated the hotspots and trends in flamenco research, and indicated biomechanical aspect was one of the hotspots and trends in future studies. Through this review it could be found that the dissemination of flamenco on a global scale has proliferated significantly, attracting numerous participants, but there remains a paucity of comprehensive theoretical underpinnings for improving dance techniques and preventing injuries. On the other hand, there was no triaxial accelerometer studies were found previously in flamenco dance research, even though it has been widely used in physical activity research. Therefore, it was decided to conduct studies with accelerometers in flamenco dancing in this thesis, using protocols that had been applied in other physical activities as a reference. Study 2 analysed the external load by using triaxial accelerometers, and considering of speed, position, axis and proficiency level of the flamenco dancers. Study 3 and Study 4 investigated the effect of the ankle active range of motion, lower limb balance ability and asymmetry on the external comparing professional and amateur flamenco dancers. Study 5 as the final article of the thesis, concluded and established a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection of accelerometers, usage protocols, and data processing and analysis.

1.2.1. The necessity of studying the biomechanics of flamenco dance

1.2.1.1. Injuries and pains have been reported.

Dance performance is a combination of physical movement and aesthetics, it demands a high level of physical conditioning, excellent artistic, and proficient techniques and dancers are also required to reach a similar demand for training and rehearsal, which could contribute to potential injury risk (Angioi et al., 2009; Bronner et al., 2003; Motta-Valencia, 2006). Injuries have been reported in various styles of dance (Allen et al.,2013; Cardoso et al., 2020; Dang et al., 2020). Lower limb injuries and pain are reported in ballet (Biernacki et al., 2021; Swain et al., 2019), contemporary dance (van Winden et al., 2021), Irish dance (Cahalan et al., 2018), including flamenco dance and a high incidence of injuries is prevalent in the lower limbs, lumbar and cervical vertebrae (Baena-Chicón et al., 2020; Forczek, et al., 2016; Pedersen & Wilmerding, 1998). Flamenco dance is performed with strong emotional expression, and its footwork techniques, which include striking the floor with a loud and rhythmic sound, make it different from other dance genres (Baena-Chicón, 2016; Pedersen & Wilmerding, 1998). The physical effort demanded in performing flamenco is similar to that of elite sports (Vargas-Macías, 2006; Vargas-Macías et al., 2008; Pedersen et al., 2001). Therefore, practicing the required footwork in flamenco may cause chronic repetitive pain and injuries of the feet, knees and spine, mainly at the lumbar and cervical levels (Baena-Chicón et al., 2020; Bejjani et al., 1988; Castillo-López et al., 2014; Vargas-Macías, 2006; Vargas-Macías et al., 2012; Mayers et al.,2003). Professional dancers or athletes is greater than students or amateurs (Campoy et al., 2011; Pedersen & Wilmerding, 1998; Vassallo et al., 2018; Vetter & Symonds, 2010; Young & Paul, 2002).Injuries can have serious consequences for a dancer's career and can impact on their daily life (Vassallo et al., 2018; Wainwright et al., 2005), and result in psychological suffering (Baena-Chicón, et al., 2021; Steinberg et al.,2016). Injuries can be caused by various factors including demographic characteristics, such as the body mass index, gender, age, and evidence suggests different factors may cause injury according to the dancers' professional level (Biernacki et al., 2021). Previous studies have demonstrated that the injury frequency suffered by professional career development for dancers and can lead to injured dancers being replaced by healthy dancers (Vassallo et al., 2018) which can influence daily life and mental state (Baena-Chicón et al., 2021).

*1.2.1.2. **High physical demanding, but a lack of available theoretical basis to train***

"Flamenco baile is a dance of passion, courtship, expressing a wide range of situations ranging from sadness to joy." (UNESCO, 2010). It has a history of more than 200 years, and it is commonly considered that it is the result of the integration of multiple cultures which have developed in Andalusia (Machin-Autenrieth, 2015) (Moon, 2015; Palma et al.,2017). It was listed as Intangible Heritage of Humanity in 2010 and has become the culture feature of Spain, which has been widely spread and recognized on the world stage and has attracted an increasing number of enthusiasts all over the world like United States, the United Kingdom, France (Cuellar-Moreno, 2016; De Santiago Ortega, 2018). The impact of flamenco dance has been increasing by the international market demand (Aoyama, 2007), it has been proofed by universities' program between different countries, and activities or festivals and cultural tourism over continents (García et al.,2019; Palma et al., 2017). It also popular in Asia, like South Korea, the Philippines, Singapore, more and more practitioners are from China, and Japan has the largest number of amateurs and dancers of flamenco (Aoyama, 2007; Diamond, 2018). In Spain, some municipal schools and some professional and higher conservatories of dance have included flamenco as a part of courses. Flamenco dance is performed with strong emotional expression and its footwork techniques, which include striking the floor with a loud and rhythmic sound, makes it different from other dance genres (Baena-Chicón, 2016; Pedersen & Wilmerding, 1998). The physical effort demanded in performing flamenco is similar to that of elite sports (Vargas-Macías, 2006; Vargas-Macías et al., 2008; Pedersen et al., 2001). It has been proven that athletes achieve better performance if they follow a systematic and well-planned training program from childhood and/or adolescence (Armstrong & Davies, 1984). However, as far as our knowledge goes, there is currently a lack of theoretical basis to recommend how scientific training should be conducted for different populations, or specific manuals where adequate and systematized physical preparation is developed to improve performance and prevent injuries in flamenco dance. Additionally, there is even few studies have looked at review of flamenco's academic research field which could enable us to better understand the development and phenomenon of flamenco dance.

1.2.2. What is external load in the form of PlayerLoad?

The correlation between external load and injury risk has been proven in different sports and highlighted the importance of monitoring external workload metrics routinely for reducing injury risks. In a systematic review, the study revealed that there was a significant relationship between training load and injury incidence (Drew & Finch, 2016; Eckard et al.,2018) Furthermore, external load as measured by PlayerLoad has been proven reliable and sensitive to monitoring and injury screening outcomes (Armstrong, 2020; Armstrong et al., 2019; Brogden et al., 2018; Moulder, et al., 2021; Nagy et al.,2022).

The concept of PlayerLoad enables the measurement of a vector modified algorithm proposed by the technological company Catapult Sports, utilizing a micro-electrical mechanical system. It is expressed as the square root of the sum of the squared instantaneous rates of change in acceleration for each of the three vectors (medial–lateral, anterior–posterior and vertical) divided by 100. This technology requires highly responsive motion sensors to record movement along these vectors. The micro-electrical mechanical system device contains a triaxial piezoelectric linear accelerometer that samples at a frequency of 150Hz, therefore providing the opportunity to quantify movement performance. Due to its low user dependence, PL has been used in various physical activity tests to describe the external load (Bowen, et al., 2019; Bredt, et al., 2020; Bullock et al., 2021; Scanlan et al., 2021) and is associated with sports training and competition for a broad range of athletes. Within dance research, PL has also been used extensively to quantify the external load or mechanical load and the relationship with dance injuries (Armstrong et al., 2019; Armstrong et al., 2020; Moulder et al., 2021). Nagy investigated within-day and between-day loading responses to ballet choreography and reported that PL is sufficiently sensitive for use with a progressive routine and that accelerometers are effective for athlete monitoring and injury screening protocols (Nagy et al., 2022).

1.2.3. Flamenco footwork Characteristics and Factors Potentially Impacting

Dance is a kind of intermittent physical activity characterized by short sets of explosive movements that demand a combination of balance, athleticism, and artistic expression (Armstrong & Relph, 2018). Balance ability is one of the key

functions of a dance performance (Clarke et al., 2019) and is an important factor in dance training (Batson, 2010), dance performance (Strešková & Chren, 2009), and dance injury (Clark & Redding, 2012). The relationship between balance ability and sports injury risk has been established (Hrysomallis, 2011). For instance, poorer balance ability was related to the possibility of development of chronic injury on the right side in dancers (Wanke et al., 2018), and in female team field and court sports, the greater anterior reach distance of the Star Excursion Balance Test (SEBT) for the right leg was identified as a factor for lower limb injury risk (Collings et al., 2021). Less anterior reach on the SEBT was identified as a significant factor for ankle injury risk (Attenborough et al., 2017; Collings et al., 2021; Hartley et al., 2018). Bilateral asymmetry of the lower limbs may affect performance and injury. Most dancers have a leg they prefer to perform movement with, which is termed as "lateral bias" or "preference" distinguishing it from the developed intuitive skill of lateral awareness (Kimmerle, 2001). The lateral profiles for pre-professional ballet dancers have been described and the dominant leg has the higher injury risk (McMahon et al., 2021). The asymmetry assessment normally measures the asymmetry index (Biernacki et al.) left-to-right or through statistical procedures. Bilateral AI is associated with sport performance such as jumping, kicking and cycling (Bishop et al., 2018), and fundamental movement pattern asymmetry (as measured by the Functional Movement Screen, when the right and left sides are scored differently, the lowest of the right and left scores is used in the composite and the movement is categorized as asymmetrical) is related to the time-loss injury in professional football players (Kiesel et al., 2014).

On the other hand, previous studies indicated that range of motion (Mathias et al., 2016) is an important contributor to dance performance (Deighan, 2005). Efficient ankle function is fundamental to success in dance (Koutedakis, 2008) and is an important factor in establishing low extremity stability between the leg and the foot (Russell et al., 2008) and can improve dance performance (Kadel et al., 2005). Ankle ROM is related to the injury development (Armstrong et al., 2018), and research has suggested that reduced right ankle plantarflexion is a risk factor for injury between injured and non-injured pre-professional dancers (Gamboa et al., 2008) and hyper ankle plantarflexion is related to increased injury rate (Briggs, et al., 2009; Steinberg et al., 2011; Steinberg et al., 2016). Dancers with decreased hip and ankle/foot joint ROM are less prone to developing patellofemoral pain

syndrome (Steinberg et al., 2012). Research investigating injury risk factors in contemporary dance students demonstrated that limited ankle dorsiflexion during a single-leg squat was significantly associated with the occurrence of substantial lower extremity injury (van Seters et al., 2020). These injuries may occur due to the aesthetic requirement of dance which require dancers to increase the ROM to sometimes excessive levels and can relate to injury (Bennell et al., 2001; Steinberg et al., 2011). Ankle ROM could also affect joint stability and static balance performance (Kim & Kim, 2018), which could also be a potential injury risk. Currently the majority of research investigating the effect of ROM on dance performance and injury involves ballet or contemporary dancers with some research failing to specify dance genre.

Regarding flamenco dance footwork techniques, there is a high physical demand for dancers (Forczek et al., 2016). Flamenco dancers are required to utilize different parts of their foot to strike the floor including the heel and tip of the toes and make a series of rhythms and loud sounds (Forczek-Karkosz et al., 2021) with these movements producing huge vibrations (Pedersen & Wilmerding, 1998), and the impact of the shoe is transmitted by vibrational waves from the joints of the lower limbs to the spine, which can trigger pain and overuse injuries (Baena-Chicón et al., 2020). Zap-3 is a representative footwork technique in flamenco dance and is composed of a sequence of six steps with the right and the left foot and requires striking the floor and quickly alternating the heel and tip of the toes. When one sequence is completed, the next sequence is repeated with the other foot and repeated alternately. During the whole movement, dancers are required to maintain stability of the upper limbs and trunk (Forczek-Karkosz et al., 2021; Vargas-Macías, 2006), therefore proficient balance ability is required to complete the movement and asymmetry may affect the body stability and increase injury risk. In addition, it requires striking the floor and quickly alternating the heel and tip of the toes. The heel striking occurs with the foot in dorsiflexion in front of the base of support and toes striking with the foot in plantarflexion by tapping the floor behind the supporting base (Forczek-Karkosz et al., 2021). Furthermore, the frequency of this step can reach 11.8 steps for each second (Vargas-Macías et al., 2021). Existed studies have proved that Screening tools play an important role in injury prevention, as they have the capability to identify athletes who are at risk of injury development. Joint measurements such as range of motion and the Star

Excursion Balance Test have included scales that grade movements (Armstrong & Relph, 2018). Therefor this requirement of ankle active ROM (AAROM) and frequency for floor tapping may increase external load and reduce body stability. Therefore, we hypothesized that the balance ability and asymmetry of the lower limbs, as well as the range of motion of the ankle joints, would affect the footwork technique and may be potential risks of injury.

Therefore, the purposes of this thesis were to firstly investigate the framework of the flamenco dance research field to demonstrate the hotspots and trends; secondly, to study the accelerometer application in flamenco dance research, with aspects of describing the external load of flamenco dancers during footwork, exploring the effect of ankle range of motion, lower limb balance ability and asymmetry on the external load of dancers, with consideration of the sensors position and proficiency level of dancers, introducing how to monitor flamenco dance movement with accelerometers with accelerometer selection, monitor use protocols, data process and analysis.

II – OBJECTIVES

II - OBJECTIVES

We provide a comprehensive exposition of the objectives for each of the studies integrated into this thesis.

Study 1:

-Objective 1: To explore the research hotspots and trends of the flamenco dance from the time horizon, collaborate network incorporates authors, institutions, regions, and keywords.

Study 2:

-Objective 1: To compare the difference in external loads at the fifth lumbar vertebra, the seventh cervical vertebra and the ankle of the dominant foot, with quantifying the external load of the flamenco Zapateado-3 (Zap-3) footwork via triaxial accelerometry in the form of PlayerLoad

-Objective 2: To explore whether the speed, position, axis and proficiency level of the flamenco dancer affected the external load.

Study 3:

-Objective 1: To investigate the effect of ankle active range of motion on external load.

-Objective 2: To study on the efficacy of ankle active range of motion as a predictor during a flamenco footwork technique, with consideration of accelerometer positions and dance proficiency.

Study 4:

-Objective 1: To investigate the effect of lower limb balance ability on the relationship with external load during flamenco footwork with consideration of accelerometry position and dance proficiency.

-Objective 2: To investigate the effect of lower limb balance asymmetry on the relationship with external load during flamenco footwork with consideration of accelerometry position and dance proficiency.

-Objective 3: To compare the difference between professional and non-professional dancers

Study 5:

-Objective 1: To establish a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection of accelerometers, usage protocols, and data processing and analysis

III – STUDY 1

III - STUDY 1: HOTSPOTS AND TRENDS OF FLAMENCO DANCE RESEARCH: A CITESPACE ANALYSIS

3.1. INTRODUCTION

"Flamenco baile is a dance of passion, courtship, expressing a wide range of situations ranging from sadness to joy." (UNESCO, 2010). It has a history of more than 200 years and it is commonly considered that it is the result of the integration of multiple cultures which have developed in Andalusia (Machin-Autenrieth, 2015; Moon, 2015; Palma et al., 2017). It was listed as Intangible Heritage of Humanity in 2010 and has become the culture feature of Spain, which has been widely spread and recognized on the world stage and has attracted an increasing number of enthusiasts all over the world like United States, the United Kingdom, France (Cuellar-Moreno, 2016; De Santiago Ortega, 2018; Diamond, 2018). The impact of flamenco dance has been increasing by the international market demand (Aoyama, 2007), it has been proofed by universities' program between different countries, and activities or festivals and cultural tourism over continents (García et al., 2019; Palma et al., 2017). It also popular in Asia, like South Korea, the Philippines, Singapore, more and more practitioners are from China, and Japan has the largest number of amateurs and dancers of flamenco (Aoyama, 2007; Diamond, 2018).

Previous research studied the biomechanical aspect of flamenco dance generally related to footwork technique analysis with professional dancers as subjects described the average values of the vertical component of ground reaction force, analyzed the range of motion in lower limbs joints and pelvis (Forczek-Karkosz et al., 2021), demonstrated the smooth oscillations of the centre of mass in all three trajectory planes, which provide theoretical information to flamenco dancers and teachers (Forczek et al., 2016). In terms of injury research, pains and injuries have been reported in professional flamenco dancers and students, and indicated knees, lumbar and cervical spine shows high incidence (Baena-Chicón et al., 2020). Already early studies such as those by Bejjani et al., 1988 suggested it may be caused by the huge vibrations accompanying the flamenco dance form. Considering physiological aspects, previous studies described the energy requirements of flamenco dancers by testing aerobic and anaerobic capacities,

indicating flamenco dancers have those two both and have a substantial anaerobic power output, which is meaningful for developing training strategy (Pedersen et al., 2001). Meanwhile, the data on the average heart rate and maximal oxygen consumption of professional flamenco dancers have been described. It proved great physical workloads requirement in flamenco dance (González Montesinos et al., 2011). However, there are still many limitations to applying flamenco in biomechanics or physiology, and fewer studies covered the holistic perspective of flamenco movement (Forczek et al., 2017). Some articles involved psychological analysis of flamenco participants. There is evidence that shows both students and professionals displayed higher levels of helplessness than those who were only students, and anxiety states which can be triggered by the artistic professional development on stage before spectators may relate to the levels of catastrophism (Baena-Chicón et al., 2021). Meanwhile, there is research that studied Brazilian female flamenco dancers and indicated 64.7% of participants were not satisfied with their bodies though they had high self-esteem (Nakamura et al., 2012). Relating to the perspective of flamenco culture, tourists use the dance expression as a positive factor for self-esteem self-expression, and self-exploration, also, as a way to differentiate themselves from other groups (Matteucci, 2014). One empirical study focused on ethnography recorded from a martial arts club and a flamenco class, observing, recording filming and participating in the classes they found trans-situational practice, matching and combining situations and communications, can explain ethnography to some extent, for better understanding other social practices for sociological reasons, and being able to reconstruct it (Schindler, 2018). However, there is few studies have looked at review of flamenco's academic research field which could enable us to better understand the development and phenomenon of flamenco dance.

Through Citespace software, we can make a comprehensive review of the academic research status and hotspot of flamenco field and infer future research trends and what we can see more clearly than other types of review are that this software shows the hotspots and trend in visualized analysis. CiteSpace, commonly advanced by Dr Chen Chaomei, is an intellectual visualization software for analysing and visualizing co-citation networks (Chen, 2006). It was designed to behaviour the visualization electric network. The collaborate networks incorporate authors, institutions, and regions; the co-occurrence network includes terminology,

keywords, and categories. The collaborate network is to manifest the community connection with author, organization, and district in a study field; the co-occurrence network is to uncover the development of study hotspots and trends (Chen, 2005; Chen, Chen et al., 2014).

Therefore, the objective of this study, with using of the CiteSpaceV software is to analyse and review the flamenco researches, which enables the development of flamenco dance research since 1982 to 2021 to be reported precisely and visually and provides reference information for the further research of flamenco dance in the future.

3.2. MATERIALS AND METHODS

The information was gathered from the Scopus and Web of Science Core Collection. This study strategy is used for the research without publishing time limitation: TOPIC: (flamenco) AND TOPIC: (danc* OR baile) AND LANGUAGE: (English OR Spanish) AND DOCUMENT TYPES: (Article OR Review). After the initial screening, 114 related documents were retrieved in WOS, 107 in the Scopus. After removing duplicates and screening records, there are 130 publications in total, database updated on 4 December 2021.

CiteSpaceV were used to parse the literature in this research. It is an intellectual visualization software commonly advanced by Dr Chen Chaomei. It was made use for behaviour visualization electric network. The collaborate network incorporates authors, institutions, and regions; the co-occurrence network includes terminology, keywords, and categories. The collaborate network is to manifest the community connection with author, organization, district in a study field; the co-occurrence network is to uncover the development of study hotspots and trends (Chen et al., 2014). Co-citation is defined as the third article citing two references, it can be one case of co-occurrence, which can include co-occurrence words, as well as co-author, co-region. A reference may be cited for many purposes or for different reasons (Chen, 2003; White & McCain, 1998). However, the cited literature may be cited in a manner similar to the function of citing underlying concepts. Therefore, the visualized map from CiteSpace can identify the structure of patterns and trends and the dynamics of the underlying scientific literature (Braam et al., 1991). The citation tree rings show the citation history of an article.

The ring's colour indicates the corresponding citation time. The thickness of the ring is proportional to the number of references in a given period (Chen, 2003; Lin, et al., 2013).

The 130 documentations downloaded were inputted into the CiteSpace 5.5.R2 software for bibliographic analysis with the time spacing set from 1982 to 2021 (130 records), and content analysis with the time span set 2000 to 2021 (114 records), both with the time part of a place as one piece each year. The nodes of the author, organization, region, and keyword were selected. Selection criteria were g-index, k=15.

3.3. RESULTS

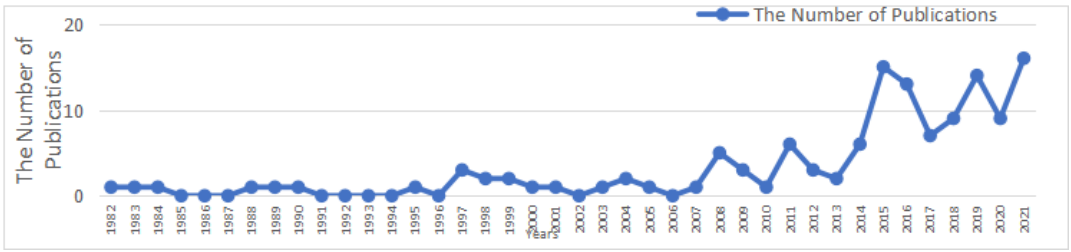
3.3.1. Bibliographic analysis

3.3.1.1. Time distribution of published papers

The relationship between the number and time of published papers can reveal the research history and development speed in this field and predict its development trend. The time distribution of published papers in the field of flamenco dance research is shown in Figure 1.

It can be seen that the research papers on flamenco dance were first published in 1982. However, before 2008, researchers did not pay enough attention in this field, there are at most 3 articles published a year. Since 2008, it shows an upward trend with fluctuations even though the most was only 16 articles in 2021. While it also saw a surge in 2015 with 15 records and in 2019 with 14 records.

Figure 1 The number of publications on flamenco dance per year from 1982 to 2021



3.3.1.2. The co-occurrence network of scientific research authors

CiteSpace is only being equipped with use of counting the quantity of the first writers, so the writer is referred to underneath all first writers. Table 1 lists the authors with further than 2 articles. Alfonso Vargas-Macías, with 5 articles. Luis Gadea-Mateos, Alba Paris-Alemany and F.J. Bejjani with 3 articles, respectively.

Table 1. High-yield authors in the flamenco dance research

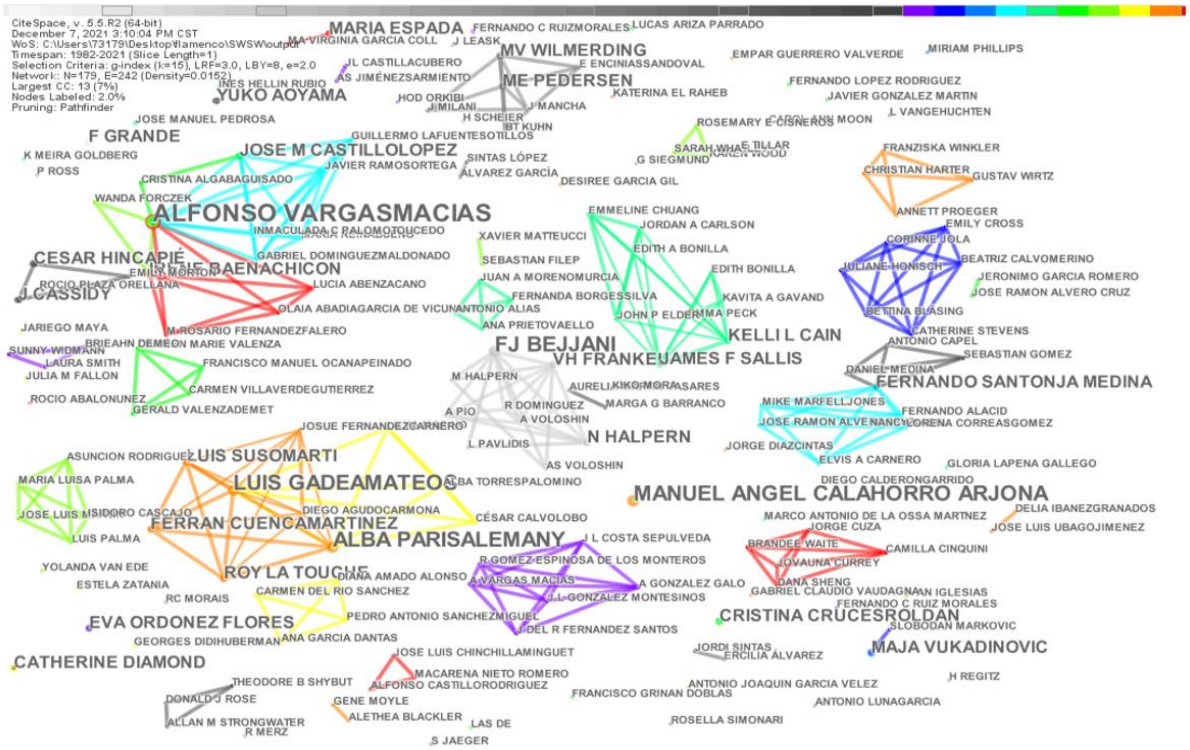
Author	Frequency
Alfonso Vargas-Macias	5
Luis Gadea-Mateos	3
Albea Paris-Alemany	3
F.J. Bejjani	3

As shown in Figure 2, 179 researchers (N = 179) participate in the related researches of flamenco dance, and they have 242 (N = 242) research cooperation of varying degrees, showing that 24 groups with at least 3 members are formed in the field, 9 of them have more than 2 publications and show relatively stable.

It also can be seen from Figure 2, Alfonso Vargas-Macías, as a professor at the Telethusa Centre for Flamenco Research, has involved three teams and formed the largest research cooperation network in the field of flamenco dance. They focused on the aspects of biomechanics, podiatry, and injury of flamenco dance. One of the most cited articles is Metatarsal Pain and Plantar Hyperkeratosis in the Forefeet of Female Professional Flamenco Dancers (Castillo-López et al., 2014). The group of Fernando Santonja Medina did researches in the same area as well, such as Magnetic Resonance Study of Lumbar Disks in Female Dancers (Capel et al., 2009) and Comparison of two field methods for estimating body fat in different Spanish Dance disciplines (Alvero-Cruz et al., 2014). F.J. Bejjani with other members as a team also focused on the biomechanics aspects, publishing articles such as Musculoskeletal demands on flamenco dancers: a clinical and biomechanical study (Bejjani et al., 1988). Cain, K.L group studied on the physiological aspects, such as Physical activity in youth dance classes (Cain et al., 2015), as well as ME Pedersen group, which did research about energy requirement, plantar flexion and dorsiflexion strength in flamenco, such as Energy requirements of the American professional flamenco dancer (Pedersen et al., 2001) and Measures of plantar

flexion and dorsiflexion strength in flamenco dancers (Pedersen et al., 1999). Alba Paris-Alemany with other researchers as a group focused on the motor image published, such as Visual-motor imagery predominance in professional Spanish dancers (Paris-Alemany et al., 2019). It can be seen that most of these groups focus on biomechanical and physical research.

Figure 2. The co-occurrence network of authors in the flamenco dance research



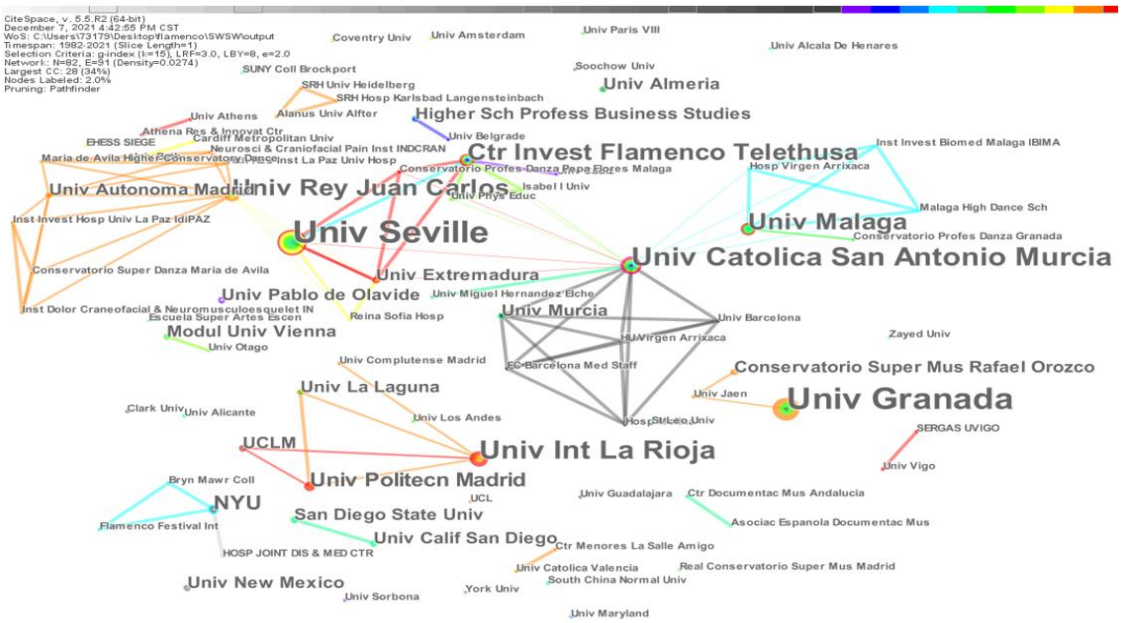
3.3.1.3. *The co-occurrence network of scientific research institutions*

The authors' institutions which have more than 3 articles are listed in Table 2. The University of Seville with 8 articles are the most prolific institution, followed by the University of Granada with 7, Saint Anthony Catholic University has 6 publications as well as International University of La Rioja. And Telethusa Centre for Flamenco Research has 5, University of Malaga and Rey Juan Carlos University published 4 articles respectively. It shows the main research institutions are universities in different regions.

Table 2. High-yield institutions in the flamenco dance research

Institution	Frequency	Centrality
Univ Seville	8	0.05
Univ Granada	7	0
Univ Int La Rioja	6	0
Univ Catolica San Antonio Murcia	6	0.14
Ctr Invest Flamenco Telethusa	5	0.02
Univ Malaga	4	0.02
Univ Rey Juan Carlos	4	0.09

Figure 3. The co-occurrence network of institutions in the flamenco dance research



According to Figure 3, there are 82 (N=82) institutions involved in flamenco dance research, and these research institutions have 91 cooperations (E = 91). In the network, the density is 0.0274, which shows the cooperation network of scientific research institutions is relatively stable. However, as table 2 shows, in the largest groups, the centrality value of Saint Anthony Catholic University is 0.14, Rey Juan Carlos University with 0.09, The University of Seville with 0.05, University of Malaga and Telethusa Centre for Flamenco Research with 0.02, the rest all as 0.00.

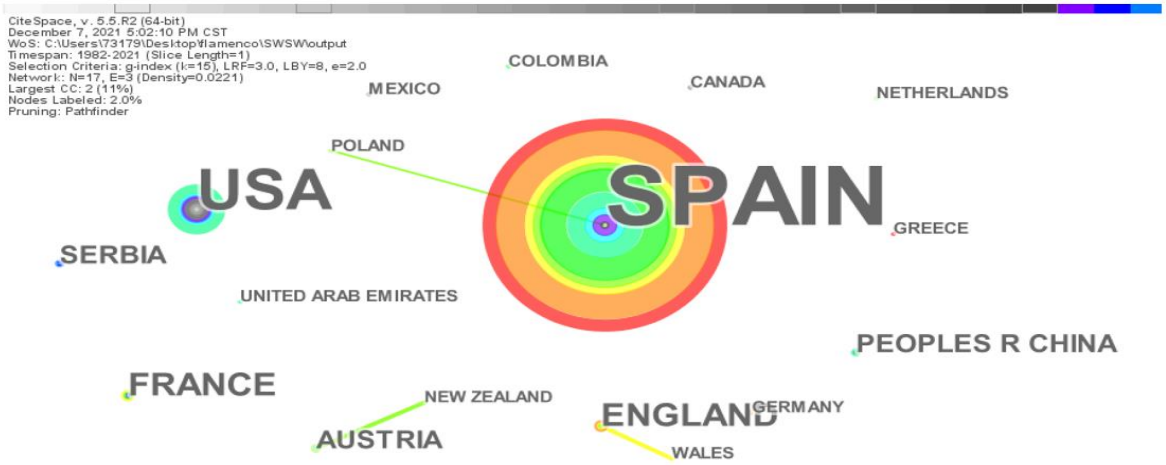
3.3.1.4. The co-occurrence network of scientific research region

As Table 3, Spain, as a place where flamenco developed, ranks the top with 60 publications. The second is the USA with 15. France and England with 3, respectively. Other regions which did not list on the table made little contribution. As Figure 4 shows, there is less cooperation research between regions.

Table 3. High-yield regions in the flamenco dance research

Region	Frequency
Spain	60
USA	15
France	3
England	3

Figure 4. The co-occurrence network of regions in the flamenco dance research



3.3.2. Content analysis

3.3.2.1. 1 Keywords co -occurrence analysis: thematic hotspots

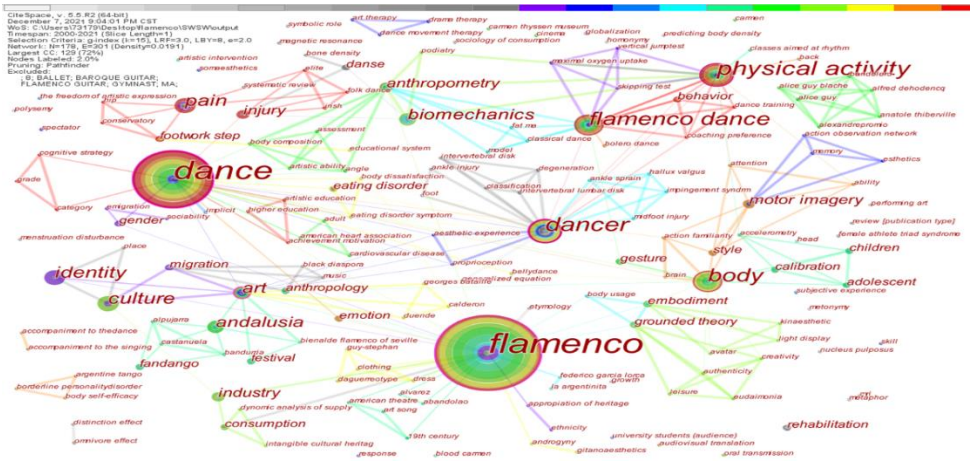
As shown in Table 4 and Figure 5, “flamenco” has the largest nodes with 25 frequencies in the co-occurrence network, which is closely related to the keyword “dance”, “flamenco dance”. “Physical activity” is the 3rd on the list with 8 frequencies as well as “dancer”. Followed with “body” with 7 frequencies. Other

keywords whose frequency is more than 3 and less than 6 in the field are “culture” “identity” “pain” “Andalusia” “biomechanics” and “art”.

Table 4. High frequency and centrality keywords in the flamenco dance research

Frequency	Centrality	Keyword
25	0.43	flamenco
19	0.42	dance
8	0.12	physical activity
8	0.24	dancer
7	0.06	flamenco dance
7	0.15	body
5	0.01	culture
5	0.01	identity
5	0.01	pain
4	0.06	Andalusia
4	0.02	biomechanics
4	0.22	art

Figure 5. The co-occurrence network of keywords in the flamenco dance research



The High-centrality keywords in the flamenco dance research. “Flamenco” (0.43) “dance” (0.42) and “dancer” (0.24) ranked the top 3 of the high-centrality keywords, while “art” (0.22) “body” (0.15) “anthropometry” (0.15) “physical activity” (0.12) are also the keywords whose centrality is more than 0.10. “injury” (0.09) “flamenco dance” (0.06) “Andalusia” (0.06) and “motor imagery” (0.05) are also high-centrality keywords but less than 0.10 and more than 0.04. Combining with Tables 4 and Figure 5, it can be seen that there are two main hotspots in the last 21 years.

1) Biomechanical and physical aspects, as related keywords are "body", "anthropometry" "physical activity" "injury" "pain" and "biomechanics", focusing on "dancer", such as articles Physical Activity in Youth Dance Classes (Cain et al., 2015), Comparison of two field methods for estimating body fat in different Spanish Dance disciplines (Alvero-Cruz et al., 2014), Analysis of selection criteria in the access tests to official Dance Studies (Mathias et al., 2016; Parent et al., 2016), Algias as a predisposing factor of injury in flamenco dance students (Baena-Chicón et al., 2020), Receptiveness of Spanish and Flamenco Professional Dancers in Their Training and Development (de las Heras-Fernández et al., 2020).

2) Cultural aspects, including related keywords "culture", "identity" "art" and related about "flamenco dance", especially in "Andalusia". Such as Domains of public activity in touristic flamenco shows (Wieczorek, 2017), Identity, Migration, and the Arts: Three Case Studies of Translocal Communities (Smith et al., 2011), Artists, Tourists, and the State: Cultural Tourism and the Flamenco Industry in Andalusia, Spain (Aoyama, 2009).

3.3.2.2. ***Strongest citation burst analysis: thematic trends***

As Table 5 shows the strongest citation bursts of keywords in the field of flamenco dance, it can be seen that "body" shows the strongest burst from 2015 to 2021. "Physical activity", "motor imagery", "emotion" and "style", show a burst in the last three years. It indicated that the attentions of future studies on flamenco dance may pay to physical and psychological research.

Table 5. The keywords with the strongest citation bursts in the flamenco dance research

Keywords	Year	Strength	Begin	End	2000 - 2021
rehabilitation	2000	1.1761	2008	2010	
pain	2000	1.1672	2008	2011	
danse	2000	1.1761	2008	2010	
migration	2000	1.088	2009	2011	
identity	2000	2.76	2009	2011	
gender	2000	1.2439	2011	2011	
biomechanics	2000	1.1397	2014	2014	
Andalusia	2000	1.8822	2015	2016	
fandango	2000	1.1558	2015	2015	
body	2000	1.3214	2015	2021	

Keywords	Year	Strength	Begin	End	2000 - 2021
flamenco	2000	1.2649	2015	2016	
festival	2000	1.1558	2015	2015	
calibration	2000	1.1558	2015	2015	
adolescent	2000	1.1558	2015	2015	
children	2000	1.1558	2015	2015	
dance	2000	2.133	2016	2021	
gesture	2000	1.1761	2016	2016	
industry	2000	1.1001	2017	2017	
culture	2000	1.6147	2017	2017	
physical activity	2000	1.3459	2019	2021	
motor imagery	2000	1.1205	2019	2021	
emotion	2000	1.21	2019	2021	
style	2000	1.21	2019	2021	

3.4. DISCUSSION

This study revealed that the hotspots and trends of flamenco dance research with a visualization analysis based on 130 articles published from 1982 to 2021 in Scopus and Web of Science Core Collection with CiteSpaceV software, which included time distribution of published papers, Co-occurrence network of scientific research authors, institutions, regions, and keywords co-occurrence and strongest citation bursts analysis as well.

3.4.1. "Cultural", "physical" and "biomechanical" researches as hotspots and trend over the world in the flamenco field

It is not difficult to predict that "cultural" study is one of the hotspots. First of all, it is a multi-cultural background art product integrated and developed in the Andalucia region in Spain with various elements (Palma et al., 2017) and it was listed as Intangible Heritage of Humanity in 2010 and has become the culture feature of Spain. Secondly, even though flamenco was considered a marginal art for Spanish society and it is not until the 1980s that the form was professionalized (Millán Vázquez de la Torre et al., 2019), a number of scholars tried to improve the recognition of flamenco as heritage at a political level since 1990s, and it was chosen as a symbol of regional cultural development and a prominent symbol of Andalusian identity (Machin-Autenrieth, 2015). Therefore, the cultural aspects,

including identity and art research related to flamenco dance, especially in Andalusia, is one of the hotspots in the last 21 years. Furthermore, Flamenco promotes tourism in Spain, as an important part of cultural tourism, it has attracted many people and creates a huge global market demand (Millán Vázquez de la Torre et al., 2019). So, to find the way to improve the experience to the tourists, bringing the emotion and also living it (García et al., 2019), some researches about "cultural" aspect was studied.

We can also notice that these researches are not only in Spain, there are also some from different regions. It is widely popular in the United States, the United Kingdom, France, and other Europe countries (Machin-Autenrieth, 2015; Palma et al., 2017). as well included regions like Mexico, Poland, Canada according to results of this research. Except for tourism, emigration could also be a reason of this popularization. Some of emigrants from Spain developed flamenco where they stayed. They devised training program, run restaurants, bars and related activities which is a medium to bonds between them (Ruiz-Morales, 2011). Activities are formed through individual groups, universities and communities related to flamenco dance, which not only expands social identity and strengthens regional identity, but also developed the flamenco culture world widely (Crespi-Vallbona & Richards, 2007; García et al., 2019). Eva Encinias Sandoval, who built the flamenco program at the the University of New Mexico, could be a great example. She wove flamenco into the cultural fabric of New Mexico and started Festival called "Flamenco de Alburquerque" which draws audiences and dancers. Additionally, in both the United States and Canada in the first half of the century also the intangible cultural heritage such as the art of flamenco has been moved (Briseno, 2021). Flamenco dance is popular in Asia as well, South Korea, the Philippines, Singapore, more and more practitioners are from China, and Japan has the largest number of amateurs and dancers of flamenco (Aoyama, 2007). This phenomenon may be caused by globalization. There were universities' program between different countries, and activities or festivals and cultural tourism over continents. On the contrary, unlike emigration or social identity, the main reason why it became popular in Japan is that it has a completely different culture from flamenco. The culture of Japan is opaque with its highly codified gestures in the observance of which propriety represses emotion to preserve a calm exterior of social harmony (Diamond, 2018). In the 21st century in Japan, although many

women have achieved economic independence, they still suffer from gender discrimination. Therefore, flamenco can express strong emotions and it does not necessary a partner, which is also a reason for its popularity in Japan (Diamond, 2018).

About "physical" and "biomechanical" aspect as hotspots, there are some main reasons. Flamenco dance has its unique characteristics with strong emotion and the footwork technique (Baena-Chicón et al., 2021), which requires dancers strike the floor to make a loud and rhythm voice (Vargas-Macías et al., 2021). Therefore, dancers were usually required to have a high level of physical conditions (Forczek et al., 2017), there is research indicate that the require is similar to those of elite sports (Pedersen et al., 2001). Meanwhile, some research investigated as well as the injury frequency of flamenco dancers and deduced that the pain and injuries on lower limbs and back may be caused by the model of footwork movement (Castillo-López et al., 2014; Pedersen & Wilmerding, 1998). Therefore, the biochemical and physical descriptions and relevant studies have been demanded to be researched, in order to prevent the injury or pain and improving dance performance. On the other hand, thanks for the advancement of research in the entire dance field, people are pursuing technical and aesthetic improvement in a more scientific way, and they have increased their awareness of physical health and injury protection. Also, compared with the previous family-style or mentor-apprentice-style methods (Millán Vázquez de la Torre et al., 2019; Palma et al., 2017), the official organizations and institute of development are more capable of academic research. The professional researchers who have been trained by institutionalization are more aware of scientific training methods. Meanwhile, flamenco has reached schools and universities, that could be also the reason that "psychological" aspect may be one of the trends for future studies. Therefore, biomechanical and physical aspects have become the hotspots in the field, including body, anthropometry, and physical activity research focusing on dancers, and it is going to act as an increasingly significant character in the future.

3.4.2. Comparing with related researches with Citespace software

There is limited research currently existing on research hotspots and trends in flamenco dance, but some articles have been reported to explore hotspots and

trends related to other style dance fields. For instance, the article Quantitative Analysis on Research Trends of Dance Sport at Home and Abroad (Ma & Huang, 2019) studied on the hotspots and trends of DanceSport (Latin dance and Ballroom dance) research, including 61 records (1990-2018) with CiteSpaceV as well, which has been found that the number of articles related to DanceSport published in Web of Science database, shows a skipping trend of rising since 2007, which is similar with flamenco dance time range in this article. Furthermore, another similar result is that in co-occurrence network of scientific research authors and institutions aspects, both of DanceSport and flamenco dance research show that although the number of research groups is less, there are some groups relatively stable, and the main research institutions are universities in different regions.

By contrast, the difference between DanceSport and flamenco dance researches is that the main research regions, Spain and the USA ranked the top of flamenco research, while the UK and the USA were the main regions in DanceSport research area. It may be due to the origin and level of development of those two styles of dance. Additionally, in terms of hotspots and trends, DanceSport researchers focused on the exercise, health, and disease interventions of adolescence and the elderly, while flamenco researchers draw more attention to the biomechanical and physical aspects as well as the psychological aspects of dancers.

3.4.3. Comparing with related researches with other statistical methods

Some bibliometric analysis about the dance field has been documented with other statistical methods: information was downloaded into spreadsheet software (Microsoft Office Excel), and additional coding was manually performed for all analysis. For example, Publications in dance field in Arts & Humanities Citation Index: a bibliometric analysis (Ho & Ho, 2015) and A bibliometric analysis of dance performance reviews in the dance category of the Web of Science (Wang & Ho, 2019), these two with this method analysis about dance research and dance reviews respectively, based on Arts & Humanities Citation Index database of the Clarivate Analytics' Web of Science Core Collection.

According to the results in the face of the authors, they all indicated that most of the authors are single-authors. Interestedly, comparing with this study of

flamenco dance research that the number of relatively stable groups was few to 9. That might mean researchers in the dance area should strengthen cooperation in the future. Furthermore, Huei-Chen Ho has also found that "body" and "education" were new popular words in article titles. Similarly, "body" is also one of the high-frequency keywords with high-centrality in flamenco dance research. Simultaneously, a common result of those two above articles about dance research and review is that "Ballets" is the main area for current dance researches and reviews, which may partially indicate that other dance style research needs to be studied in the future. Even though those above two pieces of research included more records of the data, they had limited to the bibliometric analysis including aspects of publication language, output, authors, journals, and distribution of words in the article title. Rather, this article, researching flamenco dance with CiteSpaceV, can more clearly show the bibliographic and visual analysis evolution, hotspots, trends in Co-occurrence network and keywords with the strongest citation bursts.

3.5. CONCLUSION

CiteSpace software applies to fix quantify analyse added apparently, intuitionistic, and objective. Precise algorithms can analyse the hotspots, trends, knowledge base, and high-quality literature. Although the data recorded in this study are only 130 publications, hotspots and trends in the field of flamenco dance could be detected, this research could manifest the start, bursts, high-centrality and frequency reveal the evolutionary trends of hotspots. Based on the above analyse, the following conclusions can be drawn:

From the bibliographic analysis, the number of announced works in this field shows a growing trend in 2008 and reaches its peak by 2021. From the scientific research authors, Alfonso Vargas-Macías is the highest yield author in flamenco dance research, followed by Luis Gadea-Mateos, Alba Paris-Alemany and F.J. Bejjani. 9 research cooperative groups which have more than 2 publications and at least 3 authors are formed in the field of flamenco dance research, and most of these groups focus on biomechanical and physical research. In terms of scientific research institutions, The University of Seville with 8 articles is the most prolific institution and Saint Anthony Catholic University ranks the highest centrality value. Main

research institutions are universities in different regions. The cooperation network of scientific research institutions is relatively stable. Spain and the United States are high yield regions.

From the content analysis, the cultural aspects, including identity and art research related to flamenco dance, especially in Andalusia, which is one of the hotspots in the last 21 years. Furthermore, biomechanical and physical aspects have become the hotspots in the field of flamenco dance, including body, anthropometry, and physical activity research in the last years focusing on the dancer, and it is going to act as an increasingly significant character in the future. Besides, as physical activity, motor imagery, emotion, and style as keywords showed a burst in the last three years, the attention of future studies on flamenco dance might change to psychological aspects as well.

IV – STUDY 2

IV -STUDY 2: EXTERNAL LOAD OF FLAMENCO ZAP-3 FOOTWORK TEST: USE OF PLAYERLOAD CONCEPT WITH TRIXIAL ACCELEROMETRY

4.1. INTRODUCTION

Flamenco dance is performed with strong emotional expression, and its footwork techniques, which include striking the floor with a loud and rhythmic sound, make it different from other dance genres (Baena-Chicón, 2016; Pedersen & Wilmerding, 1998). The physical effort demanded in performing flamenco is similar to that of elite sports (Koutedakis & Jamurtas, 2004; Macías, 2006; Macías et al., 2008; Pedersen et al., 2001). Therefore, practicing the required footwork in flamenco may cause chronic repetitive pain and injuries of the feet, knees and spine, mainly at the lumbar and cervical levels (Baena-Chicón et al., 2020; Bejjani et al., 1988; Castillo-López et al., 2014; Macías, 2006; Macías et al., 2012; Mayers et al., 2003; Nogareda, 2008). Previous studies regarding flamenco's technical movements have focused on analyzing them from the perspective of electromyography, kinematics and epidemiology (Bejjani et al., 1988; Forczek-Karkosz et al., 2021; Forczek et al., 2017; Vargas-Macías et al., 2021). However, questionnaires and labor-intensive methods were often used in these studies. Normally, labor-intensive methods test one subject and cannot provide real-time live feedback (Edgecomb & Norton, 2006). These shortcomings, along with the vast amounts of data downloaded and analyzed in a single study (Brogden et al., 2018), have raised questions about the ability of these technologies to influence everyday dance practices.

Triaxial accelerometers are motion sensors used to detect movement in three planes of movement (medial–lateral, anterior–posterior and vertical) and therefore to provide data regarding the magnitudes and frequency of movement. The concept of PlayerLoad (Kiesel et al.) enables the measurement of a vector modified algorithm proposed by the technological company Catapult Sports, utilizing a micro-electrical mechanical system. It is expressed as the square root of the sum of the squared instantaneous rates of change in acceleration for each of the three vectors (medial–lateral, anterior–posterior and vertical) divided by 100. This technology requires highly responsive motion sensors to record movement along

these vectors. The micro-electrical mechanical system device contains a triaxial piezoelectric linear accelerometer that samples at a frequency of 150Hz, therefore providing the opportunity to quantify movement performance. Due to its low user dependence, PL has been used in various physical activity tests to describe the external load (C. Bowen et al., 2019; Bredt et al., 2020; Bullock et al., 2021; Scanlan et al., 2021) and is associated with sports training and competition for a broad range of athletes. Within dance research, PL has also been used extensively to quantify the external load or mechanical load and the relationship with dance injuries (Armstrong et al., 2019, 2020; Moulder et al., 2021). Nagy (Nagy et al., 2022) investigated within-day and between-day loading responses to ballet choreography and reported that PL is sufficiently sensitive for use with a progressive routine and that accelerometers are effective for athlete monitoring and injury screening protocols, supporting previous work indicating that triaxial PL was sensitive enough to detect the increased loading associated with increases in exercise intensity when quantifying PL, PLUNI and PL% (Brogden et al., 2018).

In summary, future research regarding the external load during the footwork routines of flamenco dance is required to provide medical practitioners, coaches and dancers with a theoretical basis for the effective management of training programs, to reduce injury risk in accordance with the proficiency levels of dancers and to provide a feasible method for assessing flamenco footwork techniques. Furthermore, Zapateado-3 (Zap-3) is a topical issue surrounding flamenco footwork. It is widely used to analyze flamenco technique and associated movements (Forczek-Karkosz et al., 2021; Macías, 2006; Scanlan et al., 2021). Therefore, this study aimed to quantify the external load during performance of the Zap-3 footwork technique via triaxial accelerometry in the form of PL values, comparing the difference in external load at a lumbar vertebra, a cervical vertebra and the dominant ankle, and to explore whether speed, position, axis and the proficiency level of the flamenco dancer affected the external load.

4.2. MATERIALS AND METHODS

4.2.1. Participants

Twelve flamenco dancers volunteered for this study. They were recruited by via posters promoting the study in three dance institutions that included flamenco dance training and performance. The participants' demographics are reported in Table 6. The procedures, risks and benefits of the test were explained to the participants in advance. Participants provided informed consent prior to testing. Ethical approval was granted by the Sports Science Experiment Ethics Committee of Beijing Sport University (2022037H), and the study was completed in accordance with the Declaration of Helsinki.

The participants consisted of a professional group (group P, 6 participants) and an amateur group (group A, 6 participants). The inclusion criteria for group P were that participants had to be professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves to be professional flamenco dancers with a minimum of 3 years' experience. For group A, participants had to be amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training for at least 3 h per week. All participants were over 18 years of age and had had no musculoskeletal injuries in the 6 months preceding the test.

Table 6. Descriptive characteristics of participants (n = 12)

Characteristics	Group P n = 6	Group A n = 6	p
Age (years)	38.83 ± 7.96	34.50 ± 10.67	0.148
Height (m)	1.67 ± 0.10	1.62 ± 0.03	0.681
Mass (kg)	63.33 ± 6.38	56.17 ± 15.99	0.055
BMI (kg/m2)	22.79 ± 1.95	21.36 ± 6.00	0.078
Flamenco dance experience (years)	7.67 ± 4.89	1.83 ± 1.17	* 0.009

** Denotes a significant difference between groups at the p < 0.05 level. kg: kilograms; m: meters; m^2: square meters.*

4.2.2. Procedures

All participants were informed about the experimental methods and procedures, and the flamenco techniques were demonstrated by a teacher with 12 years' experience as a qualified flamenco dance teacher. Accelerometer application was performed by a laboratory technician with 5 years' experience and training in the use of accelerometers. The process order was fixed for each participant. Each participant was required to perform the Zap-3 footwork at 160 bpm (beats per minute), 180 bpm and the fastest (as fast as they could) speed level, in sequence, on the same flamenco dance folding portable floor (measuring 0.92 X 1 m2, made of wood) in a dance studio. Each speed level was presented 3 times for a duration of 15 s. At 160 bpm and 180 bpm, participants had to strike the floor twice on each beat, utilizing earphones that played a metronome. At the fastest level (F), the sound had to be rhythmic, and the frequency at each speed level is reported in Table 7. Group P demonstrated a significantly higher speed than Group A ($p < 0.05$). Participants were allowed to practice 3 times before the data were recorded, to facilitate adaptation to the next speed level, and they were allowed a 3-min rest between recordings to reduce fatigue. Participants were asked to perform wearing flamenco shoes that were similar to those they wore during performances, rehearsals or daily training. During the entire footwork movement, participants were required to maintain an akimbo posture with their hands (Figure 6), to keep their upper limbs and trunk stable and to perform smooth and coherent movements. Figure 7 provides a flowchart of the procedure for the Zap-3 footwork test.

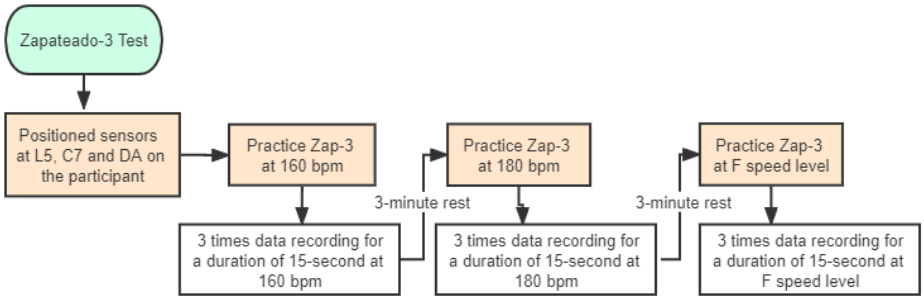
Table 7. Descriptive speed levels for professional and amateur groups (n = 12)

Speed	160 BPM		180 BPM		*F	
Group	Group P	Group A	Group P	Group A	Group P	Group A
Frequency (Hz)	5.33	5.33	6.00	6.00	8.99 ± 0.78	7.08 ± 0.50

** Denotes a significant difference between groups at p < 0.05. F: the fastest speed level; Hz: Hertz; BPM: beats per minute.*

Figure 6 Akimbo posture required for completing the footwork test.

Figure 7. The procedure for the footwork test. L5: the 5th lumbar vertebra; C7: the 7th cervical vertebra; D: the dominant ankle; bpm: beats per minute; F: the fastest speed level



4.2.3. Flamenco Zap-3 Footwork

Participants completed the sequence of flamenco Zap-3 footwork, which is a sequence of 6 steps completed bilaterally. When one sequence is completed, it is repeated with the other foot, and this repetition continues with alternating feet (Forczek-Karkosz et al., 2021; Vargas-Macías, 2006). The 6 steps are:

(1) Zapateado de planta (P);

(2) Zapateado de Tacón-planta (TP);

(3) Zapateado de Tacón (T);

(4) Zapateado de Tacón-planta (TP);

(5) Zapateado de Punta (PNT);

(6) Zapateado de Tacón-planta (TP).

4.2.4. Data Processing

Trigno Avanti™ sensors (Trigno Wireless EMG System, Delsys, Natick, MA, USA), which have a built-in nine-degrees-of-freedom inertial measurement unit and can relay acceleration, rotation and earth magnetic field information, were utilized to record the flamenco Zap-3 footwork's external load responses, with data sampling at 150 Hz. The sensors were positioned at the 5th lumbar vertebra (L5), the 7th cervical vertebra (C7) and the dominant ankle (DA) (Alberts et al., 2015; Baena-Chicón et al., 2020; Brogden et al., 2018; Heebner et al., 2015; Nagy et al., 2022; Shahabpoor & Pavic, 2018; Whitney et al., 2011). The dominant foot was defined as the foot which participants would most often use to kick a ball (Alberts et al., 2015; Lin et al., 2013). The sensors were attached directly to the skin using medical tape and secured using elastic bandage. The locations were determined by palpation, and the ankle location was 1cm proximal to the lateral malleolus.

The uniaxial PlayerLoad (PLUNI) was calculated as the square root of the instantaneous rate of change in acceleration in each of the medial–lateral (PLML), anterior–posterior (PLAP) and vertical (PLV) planes divided by 100. The accumulated total PlayerLoad (PLTOTAL) was defined as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes divided by 100 and was calculated at L5, C7 and the DA. The uniaxial contributions (PL%), defined as the percentage contributions of the PLUNI in the medial–lateral (PLML%), anterior–posterior (PLAP%) and vertical (PLV%) planes, was also quantified by dividing the individual PLUNI value by PLTOTAL and by multiplying that value by 100.

4.2.5. Statistical Analysis

Data were analyzed using SPSS (SPSS IBM Statistics V21.0, IBM, Armonk, New York, NY, USA). Descriptive statistics are reported as means ± standard deviations. The descriptive characteristics of age, height, mass, body mass index (BMI) and years of experience dancing flamenco, together with the frequency of

the F speed level, were analyzed between group P and group A using a Mann–Whitney U test, as the dependent variable was not normally distributed. The assumptions of normality were verified using the Shapiro–Wilk test. Differences in each dependent variable during the Zap-3 footwork were quantified using a general linear model (GLM). Bonferroni correction factors were used for a post hoc comparison, to determine where any significant differences occurred. The 95% confidence intervals (Migueles et al.) and Cohen's d effect sizes were as follows: small, 0.20–0.49; moderate, 0.50–0.79; large > 0.80 [31,32]. Statistical significance was set at the $p < 0.05$ level.

4.3. RESULTS

4.3.1. Zap-3 Footwork Load Responses—Total PlayerLoad

Figures 8 and 9 report the results for different speed levels for PLTOTAL for the Zap-3 footwork in the professional and amateur groups. A significant main effect was identified for speed ($p < 0.001$), and the value of PLTOTAL increased with speed level. There was no significant main effect for the groups ($p > 0.05$). There was also no significant group x speed interaction ($p > 0.05$).

*Figure 8. The professional group total PlayerLoad responses to the Zapateado-3 footwork at 160 bpm, 180 bpm and the fastest speed level (F) for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7). * Denotes a significant main effect for the unit position*

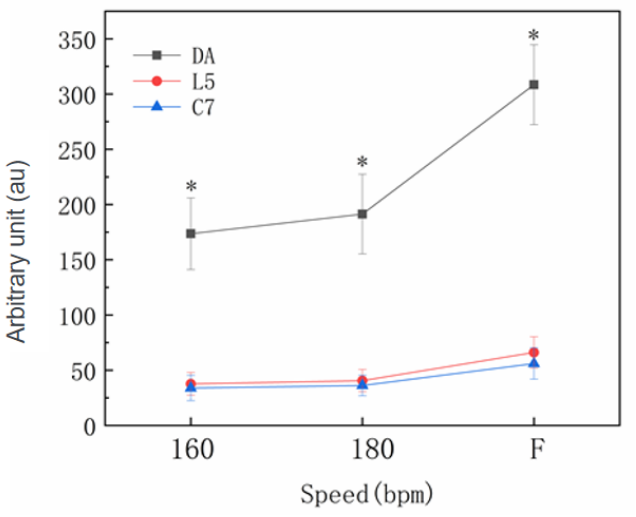
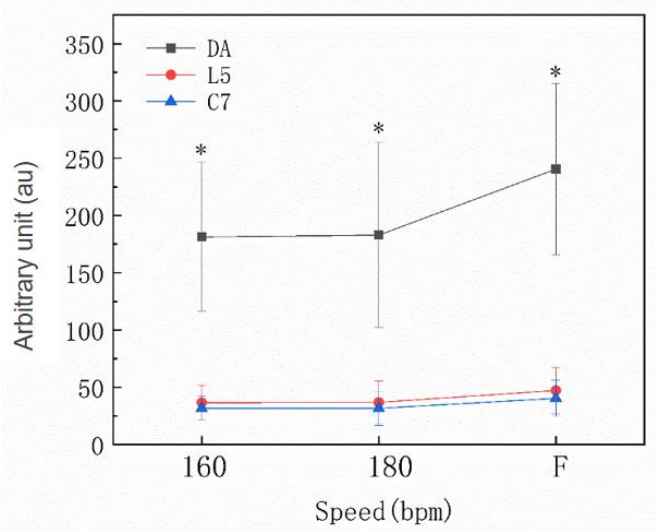


*Figure 9. The amateur group total PlayerLoad responses to the Zapateado-3 footwork at 160 bpm, 180 bpm and the fastest speed level (F) for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7). * Denotes a significant main effect for the unit position*

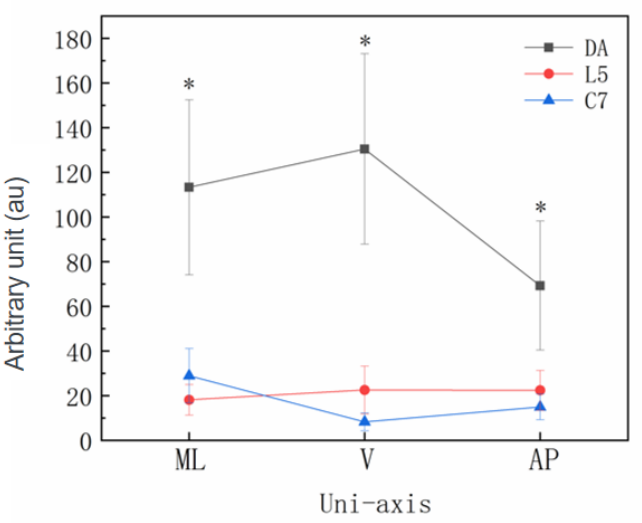


Significant main effects for unit position ($p < 0.001$) as well as for the speed x position interaction ($p \leq 0.001$) were identified. PLTOTAL values were higher for the DA (212.98 ± 72.27 au; CI = 201.30–224.66 au) compared with C7 (38.27 ± 14.70 au; CI = 26.59–49.95 au; $p < 0.001$; $d = 3.35$) and L5 (44.15 ± 17.68 au; CI = 32.47–55.83 au; $p < 0.00\ 1$; $d = 3.21$), with the differences becoming more pronounced as the speed increased. There was no significant difference between L5 and C7 ($p > 0.05$). There was a significant difference for the DA at different speed levels ($p < 0.001$), but this difference was not identified in the L5 and C7 positions ($p > 0.05$). There was no significant interaction between group and position ($p > 0.05$) or between group, speed and position ($p > 0.05$).

4.3.2. Zap-3 Footwork Load Responses—Uniaxial PlayerLoad

Significant main effects for unit position ($p < 0.001$) and a single axis ($p < 0.001$) were identified (Figure 10), and there was also a position x single axis interaction effect ($p < 0.001$). The PLML values were higher at the DA (113.33 ± 39.20 au; CI = 107.28–119.38 au) compared with C7 (28.94 ± 12.14 au; CI = 22.89–34.99 au; $p < 0.001$; $d = 2.91$) and L5 (18.17 ± 6.80 au; CI = 12.12–24.22 au; $p < 0.001$; $d = 3.38$). A significant difference existed between L5 and C7 ($p < 0.05$; $d = 1.09$).

*Figure 10. The differences in PlayerLoad responses between the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7) for the Zapateado-3 footwork in three planes: medial–lateral (ML), vertical (V) and anterior–posterior (AP). * Denotes a significant main effect for the unit position*



The PLV values were higher at the DA (130.49 ± 42.62 au; CI = 124.44–136.54 au) compared with C7 (8.31 ± 3.95 au; CI = 2.26–14.36 au; $p < 0.001$; $d = 4.04$) and L5 (22.57 ± 10.71 au; CI = 16.52–28.62 au; $p < 0.001$; $d = 3.47$). There was a significant difference between L5 and C7 ($p < 0.01$; $d = 1.77$).

The PLAP values were higher at the DA (69.31 ± 28.85 au; CI = 63.26–75.36 au) compared with C7 (15.02 ± 5.72 au; CI = 8.97–21.07 au; $p < 0.001$; $d = 2.61$) and L5 (22.14 ± 8.93 au; CI = 16.36–28.46 au; $p < 0.001$; $d = 2.21$). There was no significant difference between L5 and C7 ($p > 0.05$).

There was a significant different in the DA position for different axes ($p < 0.001$), but this difference was not identified in L5 ($p > 0.05$). At C7, there was a significant difference between PLML and PLV ($p < 0.001$) and between PLML and PLAP ($p < 0.01$) but no difference between PLV and PLAP ($p > 0.05$).

4.3.3. Zap-3 Footwork Load Responses—Uniaxial Contributions

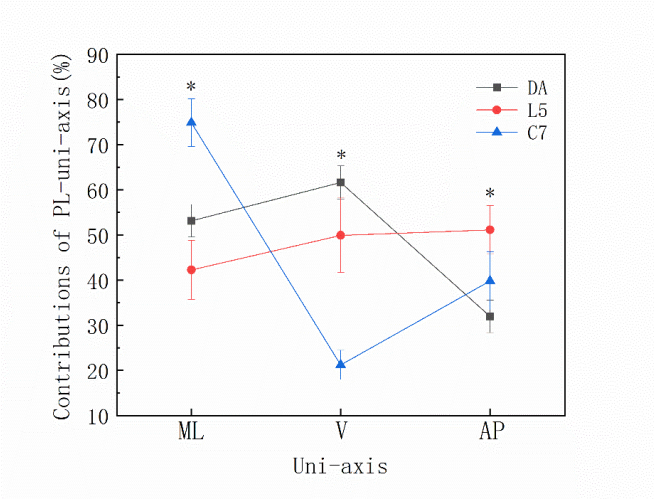
There was no significant main effect for group ($p = 0.841$) or speed ($p = 0.739$) for any axis. Although the statistical significance value indicated a significant

difference ($p < 0.001$), the Cohen's d effect sizes between positions were smaller than 0.2, showing no significant main effect differences for the position.

There was a significant main effect identified for PL% ($p < 0.001$), with PLML% (56.75 ± 14.59%; CI = 55.70–57.80) representing a significantly larger contribution compared with PLV% (44.25 ± 17.92%; CI = 43.20–45.30; $p < 0.001$; $d = 0.76$) and PLAP% (41.97 ± 9.47; CI = 39.90–42.00; $p < 0.001$; $d = 1.20$). The PLAP% values were lower than the PLV values ($p < 0.001$; $d = 0.16$). Although the difference between PLAP% and PLV% was statistically significant ($p < 0.001$), the Cohen's d effect sizes ($d = 0.16$) were smaller than 0.2, which demonstrates that there was no significant difference.

Post hoc analysis of a significant unit position x uniaxial interaction contribution ($p < 0.001$) demonstrated that the PLML% at C7 (74.87 ± 5.28%; CI = 73.00–76.70) was significantly greater than that at both L5 (42.26 ± 6.51%; CI = 40.40–44.10; $p < 0.001$; $d = 5.50$) and DA (53.13 ± 3.59%; CI = 51.30–55.00; $p < 0.001$; $d = 4.82$). Moreover, there was a significant difference between DA and L5 ($p < 0\ 001$; $d = 2.07$) (Figure 11).

*Figure 11. The different uniaxial contributions to the total PlayerLoad responses for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7) for the Zapateado-3 footwork in three planes: medial–lateral (ML), vertical (V) and anterior–posterior (AP). * Denotes a significant main effect for the position*



The PLV% values at the DA (61.63 ± 3.66%; CI = 59.80–63.50) were significantly higher than at both C7 (21.22 ± 3.26%; CI = 19.40–23.10; $p < 0.001$; $d =$

11.66) and L5 (49.92 ± 8.27%; CI = 48.10–51.80, p < 0.001; d = 1.83), and those at L5 were significantly higher than those at C7 (p < 0 001; d = 4.57). The PLAP% values at L5 (51.13 ± 5.40%; CI = 49.30–53.00) were significantly higher than at both DA (31.96 ± 3.60%; CI = 30.10–33.80; p < 0 001; d = 4.18) and C7 (39.82 ± 6.42; CI = 38.00–41.70; p < 0.001; d = 1.91), and there was a difference between DA and C7 (p < 0.001; d = 1.51) (Figure 6). There was no interaction among other effects in uniaxial contributions.

4.4. DISCUSSION

This study aimed to quantify the external load in flamenco Zap-3 footwork via triaxial accelerometry in the form of PlayerLoad (Kiesel et al.), comparing the differences in external load at a lumbar vertebra, a cervical vertebra and the dominant ankle, with consideration of speed, position, axis and the proficiency level of the flamenco dancer. The triaxial PlayerLoad is sensitive enough to detect a load change associated with the intensity of the dance movement (Armstrong et al., 2019; Armstrong et al., 2018a; Domene & Easton, 2014) and it is hypothesized that an increase in cumulative accelerometer load may cause injury (Bowen et al., 2017; Brogden et al., 2018). Consequently, the results of this study could have implications for potential injury risk, from the perspective of variables such as position, speed and the proficiency level of flamenco dancers.

An important finding of this study is that PLTOTAL, PLUNI and PL% were all higher at the DA compared with C7 and L5, suggesting that in flamenco, when practicing footwork techniques, the ankle is subject to higher loading, which consequently might have implications for injury risk. Furthermore, the PLML was higher at the DA, which is potentially due to the normal foot imbalance when practicing the Zap-3 footwork. The PLV was higher at the DA, which may be due to the body positions required while practicing the Zap-3 footwork, which requires more movement in the vertical plane. The PLAP was higher at the DA, which may be due to the flamenco Zapateado technique being performed with knee flexion extensions. Additionally, our study found a significant difference for the DA for different axes, potentially because, during the Zapateado, the foot performs movements on all three axes (Macías et al., 2012). Previous studies that used triaxial accelerometry in other dance genres have reported that lower limbs bear higher

loads on the three axes than C7, specifically in both dance aerobic fitness tests and ballet choreography (Brogden et al., 2018; Nagy et al., 2022). Flamenco dance injury studies have reported that the frequency of injury or pain in the foot is higher than in the spine or in other body locations and have highlighted the fact that that the amount of time spent practicing footwork may affect the rate of injury incidence (Baena-Chicón et al., 2020; Pedersen & Wilmerding, 1998). Foot disorders such as metatarsal pain and hyperkeratosis in the forefoot are not an uncommon phenomenon for female flamenco dancers and may be caused by chronic repetitive trauma suffered during footwork practice (Castillo-López et al., 2014). Therefore, the higher loads observed at the DA in this study may potentially increase injury risk.

Although the PLTOTAL and PL% values for C7 were lower than for the DA in flamenco Zap-3, they were comparatively higher than in other dance tests. In ballet, a specific choreographed routine test with five stages was performed by 10 participants (Nagy et al., 2022), and the routine's fifth stage had the highest PL. The highest uniaxial PL and PL% values were lower than our results for the Zap-3 test, and we found that the PLTOTAL and PL% values at C7 were lower than at the DA and L5 for the flamenco Zap-3 footwork test with the fastest speed level in both the professional and amateur groups. Although the speed (beats per minute) in these two tests was slower, they were performed for 4 min; in contrast, the Zap-3 lasted for just 15 s. Therefore, we can deduce that potentially the cervical vertebrae can be loaded to a greater extent during flamenco and could therefore potentially be injured by practicing flamenco footwork. Other flamenco studies have reported a high frequency of injury or pain in the cervical spine (Baena-Chicón et al., 2020; Pedersen & Wilmerding, 1998).

For the external load in the lumbar vertebrae, this study found that the PLTOTAL, PLV, PLV% and PLAP values were lower than at the DA but greater than at C7. The PLML and PLML% contribution for L5 was lower than for both C7 and DA, which indicates that increased loading and the potential for injury risk on the ML axis may potentially be less, if load is directly related to injury occurrence. However, consideration of the different mechanisms of injury that can occur at the spine is required, as loading directions might potentially influence injury development. For example, the L4/5 level is the most common location for lumbar spine injury; however, the influence of the direction of force, e.g., anterior–posterior,

vertical or medial–lateral is not known, and therefore this could be an important consideration for future research. Previous injury studies of flamenco dancers stated that the lumbar spine is associated with a high risk of injury (Baena-Chicón et al., 2020) and that the highest prevalence of spinal injury in flamenco dancers occurs in the lumbar spine (Pedersen & Wilmerding, 1998). To the best of our knowledge, limited research exists using accelerometer placement at L5 to determine injury risk in dance. However, L5 has been proven to have sufficient sensitivity to detect the external load in this region (Alberts et al., 2015; Heebner et al., 2015; Whitney et al., 2011).

Zap-3 is a symbolic flamenco dance training footwork technique that does not require much movement of the upper limbs or trunk. The displacements of the center of gravity are minuscule: 0.136 m in anteroposterior movement, 0.105 m in lateral and 0.018 m in vertical displacement (Forczek et al., 2016). In our study, participants were asked to keep their hands in an akimbo posture and to keep their upper limbs and trunk stable; however, we found that significant external loads were recorded at the cervical and lumbar positions. It should be noted that this Zap-3 movement model, which does not engage the upper body, could be the fundamental reason why the spinal structures are forced to absorb vibrations that have not been dissipated during tilts (Baena-Chicón et al., 2020). The biomechanical stomping mechanisms have a similar impact on the musculo-articular kinetic chain. Vibrational waves transmit the impact of the shoe from the joints of the lower body to the spine, which can trigger vertebral pain (Gómez-Lozano et al., 2010) and overload the spinal muscles (Echegoyen et al., 2010). A survey of the injury frequency of 75 flamenco dancers demonstrated that 16% and 22.7% suffered from lumbar and cervical spine injury, respectively. In other forms of percussive dance, back injury was not as prevalent, e.g., in Irish dancers (5% of 159 dancers) (McGuinness & Doody, 2006) and tap dancers (15% of 104 dancers) (Mayers et al., 2003). Furthermore, cervical injury was not as prevalent in Irish dancers (1% of 159 dancers). Such differences could be due to different performance characteristics and could be explained by jumping during percussions with the foot, which more effectively dissipates the large vibrations.

Regarding differences between professional and amateur flamenco dancers, our study demonstrated that a difference in external load occurs only at the fastest speed level and that the professional group had more external load than the

amateurs for uniaxial PL. This difference may be because the professional group had a higher fastest speed and their movement quality was higher. Professional dancers tended to strike the floor firmly to make a louder sound while performing the footwork, producing more ground reaction force (Forczek-Karkosz et al., 2021). Therefore, professional dancers may have higher injury risk when practicing their footwork. Considering the dancers' experience, M. Elizabeth Pedersen reported that the number of injuries sustained by professional flamenco dancers was greater than the number sustained by student flamenco dancers (Pedersen & Wilmerding, 1998). Similar findings have been reported for other dance styles and sports (Campoy et al., 2011; Vetter & Symonds, 2010; Young & Paul, 2002). Eileen M. Wanke's group reported a greater asymmetric load in the highest national league group of Latin dancers than in the regional or lower groups, and they were injured more often in their right hands and shoulders (Wanke et al., 2018).

Regarding the difference between the speed levels, our study identified a main effect of speed ($p < 0.001$) in the case of PLTOTAL or uniaxial PL, and PLTOTAL increased with speed level. Additionally, a speed x position interaction ($p \leq 0.001$) between PLTOTAL and PL was also found. Post hoc analyses revealed that the differences became more pronounced as the speed increased. Furthermore, a group x speed interaction for uniaxial PL was also proven, indicating a significant difference at the fastest level between professional and amateur dancers ($p < 0.05$). This evidence, combined with the differences existing in group, position and axis effect suggests that the accelerometry technique demonstrated sufficient sensitivity during the Zap-3 flamenco dance footwork test.

Accelerometry has been used infrequently in flamenco footwork tests. Literature searches identify only one article, which explored musculoskeletal demands on flamenco dancers more than thirty years ago (Bejjani et al., 1988). In this study, ten dancers performed dance steps with accelerometry sensors located at their tibial tuberosity and the anterior superior iliac spine. Data from these accelerometry sensors were recorded as peak frequencies and amplitudes. The current study involved the concept of PlayerLoad, which is a more modern concept allowing for greater reliability and standardization. Additionally, the use of triaxial accelerometry allowed us to analyze the details of each plane. Furthermore, the triaxial accelerometry sensor used in this study provided a non-invasive way to measure the external loads encountered by a dancer's body, which helps dancers,

teachers and medical staff improve performance quality, adapt training loads and programs and inform on rehabilitation strategies. These are practices that are currently observed in sports with high injury incidence. One of the main contributions of this biomechanical study was the involvement of six professional flamenco dancers, while a previous study analyzed the case of professional flamenco dancers with only one participant, as a case study (Forczek-Karkosz et al., 2021; Forczek et al., 2016; Vargas-Macías et al., 2021). The second contribution was the comparison between the professional and amateur groups, which allowed the assessment of the association between technical progression and biomechanical variables. The last relevant contribution of this research compared to previous studies was that triaxial accelerometers were used for the first time to determine the external load in the form of PlayerLoad in flamenco dance. Study limitations included the relatively small sample size and the fact that only one type of footwork was investigated. Future studies could consider a larger sample and explore the external load at other positions such as the knees and upper limbs and could analyze a complete flamenco dance choreography.

4.5. CONCLUSIONS

This study quantified the mechanical demands of the footwork required of flamenco dancers and explored whether speed, position, axis and the proficiency level of the flamenco dancer affected the external load. In conclusion, the Zap-3 footwork produced a significant external load at different positions, which was affected by speed, axis and the proficiency level of the flamenco dancer. Although the ankle bears the highest external load when dancing the flamenco, some external load is also experienced by the lumbar and cervical vertebrae, caused by significant vibrations. This study provides medical practitioners, coaches and dancers with a theoretical basis for the development of an appropriate training program to reduce injury risk and to provide a feasible method for assessing flamenco footwork techniques in future studies.

V – STUDY 3

V - STUDY 3: ANKLE ACTIVE RANGE OF MOTION AS AN ESSENTIAL FACTOR OF FOOTWORK TECHNIQUE IN THE PREVENTION OF OVERUSE INJURIES ON FLAMENCO DANCERS

5.1. INTRODUCTION

Dance performance is a combination of physical movement and aesthetics, it demands a high level of physical conditioning, excellent artistic, and proficient techniques and dancers are also required to reach a similar demand for training and rehearsal, which could contribute to potential injury risk (Angioi et al., 2009; Bronner et al., 2003; Motta-Valencia, 2006). Injuries have been reported in various styles of dance (Allen et al., 2013; Cardoso et al., 2020; Dang et al., 2020; Domene et al., 2018; Uršej & Zaletel, 2020), including flamenco dance and a high incidence of injuries is prevalent in the lower limbs, lumbar and cervical vertebrae (Baena-Chicón et al., 2020; Forczek et al., 2016; Pedersen & Wilmerding, 1998). Injuries can have serious consequences for a dancer's career and can impact on their daily life (Vassallo et al., 2018; Wainwright et al., 2005), and result in psychological suffering (Baena-Chicón et al., 2021; Steinberg et al., 2016). Injury can be caused by various factors including demographic characteristics, such as the body mass index, gender, age, and the level of proficiency of dancers (Domene et al., 2018). Previous studies have demonstrated that the injury frequency suffered by professional dancers or athletes is greater than student or amateurs (Campoy et al., 2011; Pedersen & Wilmerding, 1998; Vassallo et al., 2018; Young & Paul, 2002). Furthermore, the correlation between external load and injury risk has been proven in different sports and highlighted the importance of monitoring external workload metrics routinely for reducing injury risks (Cummins et al., 2019; Drew & Finch, 2016; Jaspers et al., 2018).

Previous studies indicated that range of motion (Mathias et al.) is an important contributor to dance performance (Deighan, 2005). Efficient ankle function is fundamental to success in dance and is an important factor in establishing low extremity stability between the leg and the foot (Russell et al., 2008) and can improve dance performance (Kadel et al., 2005). Ankle ROM is related to

the injury development (Armstrong & Relph, 2018; Steinberg et al., 2011; Storm et al., 2018), and research has suggested that reduced right ankle plantarflexion is a risk factor for injury between injured and non-injured pre-professional dancers (Gamboa et al., 2008) and hyper ankle plantarflexion is related to increased injury rate (Briggs et al., 2009; Steinberg et al., 2011; Steinberg et al., 2016). Dancers with decreased hip and ankle/foot joint ROM are less prone to developing patellofemoral pain syndrome (Steinberg et al., 2012).

Research investigating injury risk factors in contemporary dance students demonstrated that limited ankle dorsiflexion during a single-leg squat was significantly associated with the occurrence of substantial lower extremity injury (van Seters et al., 2020). These injuries may occur due to the aesthetic requirement of dance which require dancers to increase the ROM to sometimes excessive levels and can relate to injury (Bennell et al., 2001; Steinberg et al., 2011). Ankle ROM could also affect joint stability and static balance performance (Kim & Kim, 2018), which could also be a potential injury risk. Currently the majority of research investigating the effect of ROM on dance performance and injury involves ballet or contemporary dancers with some research failing to specify dance genre.

There is a high loading demand of flamenco dancers on the foot and ankle joints (Forczek et al., 2016). The footwork technique requires dancers to use different foot locations to strike the floor and produce a rhythmic and loud sound (Vargas-Macías et al., 2021), and the huge vibration produced during this time (Pedersen & Wilmerding, 1998), the impact of the shoe is transmitted by vibrational waves from the joints of the lower body to the spine, which can trigger pains and overuse injuries (Baena-Chicón et al., 2020). For instance, the Zapateado-3 (Zap-3) flamenco footwork technique, utilized in this study requires striking the floor and quickly alternating the heel and tip of the toes. The heel striking occurs with the foot in dorsiflexion in front of the base of support and toes striking with the foot in plantarflexion by tapping the floor behind the supporting base (Forczek-Karkosz et al., 2021). Furthermore, the frequency of this step can reach 11.8 steps for each second (Vargas-Macías et al., 2021). This requirement of ankle active ROM (AAROM) and frequency for floor tapping may increase external load and reduce body stability.

Consideration of potential factors that may contribute to overusing injury risk in dance and specifically the relationship between ankle active ROM and

external load is required. The aims of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during the flamenco footwork technique with consideration of accelerometer positions and dance proficiency. We hypothesis that the ankle active range of motion significantly affects the external load and its efficacy as a predictor could be proved during a flamenco footwork technique, the effects may show difference between different dance proficiency and body positions.

5.2. MATERIALS AND METHODS

5.2.1. Participants

Twelve flamenco dancers were recruited by asking for volunteers via posters in three flamenco dancing training institutions or performance company. Participants were composed of a professional group (PRO group, 6 participants, age: 38.83 ± 7.96 years; height: 1.67 ± 0.10 m; mass: 63.33 ± 6.38 kg; BMI: 22.79 ± 1.95 kg/m2; flamenco dance experience: 7.67 ± 4.89 years) and an amateur group (AM group, 6 participants, age: 34.50 ± 10.67 years; height: 1.62 ± 0.03 m; mass: 56.17 ± 15.99 kg; BMI: 21.36 ± 6.00 kg/m2; flamenco dance experience: 1.83 ± 1.17 years). Only flamenco dance experience years shows significant difference between groups ($p = 0.09$). The inclusion criteria for the PRO group were that participants were professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves as a professional flamenco dancer. For the AM group, participants were amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training at least 3 hours per week. Participants completed a self-reported questionnaire before the study, and those who under 18 years of age and had a minimum of 1-year flamenco dance experience and/or reported heart disease and/or were pregnant and/or had musculoskeletal injuries in the 6 months preceding the study were excluded. No participants reported they had been diagnosed with either Ehlers-Danlos syndrome, Marfan syndrome, or osteogenesis imperfecta. The dancers provided informed consent in writing before commencing the study. Ethical approval was

granted by the Faculty Ethics Committee at Beijing Sport University (2022037H), and the study was conducted in accordance with the Declaration of Helsinki.

5.2.2. General Procedures

Participants were informed regarding the experimental methods and procedures. Firstly, AAROM was measured, and then accelerometer data was recorded during performing the Zap-3 footwork. The order of progress was fixed for each participant. One professional dance teacher who experienced at 12-years flamenco dance teaching demonstrated the Zap-3 footwork technique. Laboratory technicians who have at least 5-year of lab experience and are trained were responsible for data collection.

5.2.3. Ankle active ROM measurement

AAROM were measured prior to the Zap-3 footwork test to prevent any potential warm-up effects. Participants adopted a sitting position with their feet off the ground and legs relaxed with their knee joints flexed at 90°. AAROM was measured for dorsiflexion and plantarflexion using a goniometer (Mitutoyo, Jiangsu, China) by a physiotherapist with 5 years' experience. The angle was measured at the maximum extent (Russell et al., 2010; Steinberg et al., 2006; Steinberg et al., 2016; Steinberg et al., 2012) with the measurement axis set to the lateral malleolus. While measuring, the fixed arm was parallel to the lateral aspect of the gastrocnemius and the moving arm was parallel to the lateral aspect of the 5th metatarsal bone (Kim & Kim, 2018).

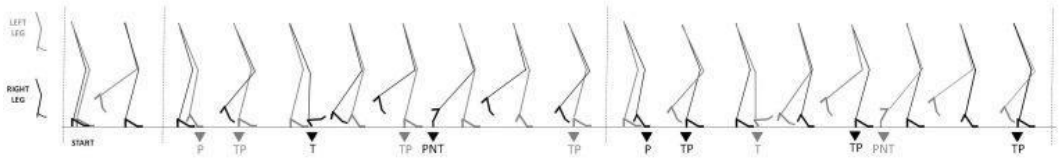
5.2.4. Flamenco Zapateado-3 footwork Technique

Participants were asked to perform the Zap-3 composed of a sequence of 6 footwork steps with the right and the left foot (figure 12). When one sequence was completed, participants repeated the next sequence with the other foot and then repeated alternately with each foot (Forczek-Karkosz et al., 2021; Vargas-Macías, 2006). Participants were required to start with the dominant foot which was defined as that the foot they would kick a ball with (Coren, 1993; Lin et al., 2013; Wilson et al., 2018). During the entire footwork movement, participants were required to

keep their upper limbs and trunk stable, with maintaining in akimbo, and to perform smooth and coherent movements. The six Zap-3 steps were included and followed in this order: Zapateado de planta (P); Zapateado de Tacón-planta (TP); Zapateado de Tacón (T); Zapateado de Tacón-planta (TP); Zapateado de Punta (PNT); snd Zapateado de Tacón-planta (TP).

Subsequently, for the flamenco footwork test, each participant was asked to complete Zap-3 footwork at 3 different speed levels on the same portable flamenco dancing wood floor (92 × 100 cm), respectively at 160 bpm (beats per minute), 180 bpm, and at their own the fastest speed possible (F speed level) in sequence. The sequence was performed in a dance studio and each speed was completed 3 times for a duration of 15 seconds. At 160 bpm and 180 bpm participants were required to dance while listening to an earphone which was linked to a metronome and had to strike the floor twice on each beat. At the fastest speed level (F), participants were required to perform every footwork step of Zap-3 as quickly as possible and maintain a rhythmic sound (Forczek-Karkosz et al., 2021; Vargas-Macías et al., 2021). During the test, PRO and AM groups performed the 160 bpm and 180 bpm at the same frequency, 5.33 and 6.00 respectively. At F speed level, dancers tapped at 8.99 ± 0.78 Hz and 7.08 ± 0.50 Hz respectively which demonstrated a significant difference ($p < 0.05$). Participants were able to practice 5 minutes before each section testing commenced and rested for 5 minutes between sessions. Participants were instructed to wear flamenco footwear similar to that worn during training/performance.

Figure 12. Elaboration of the graphic sequence of the ZAP-3 Test



5.2.5. External load measurement during footwork: PlayerLoad

Trigno Avanti™ Sensors (Trigno Wireless EMG System, Delsys, USA), were used to record acceleration data with data sampling at a frequency of 150 Hz and have a built-in nine degree of freedom inertial measurement unit which can relay acceleration, rotation, and earth magnetic field information. The sensors were attached directly to the skin using medical tape and secured using elastic bandage at the position of the 7th cervical vertebrae (C7), 5th lumbar vertebrae (L5), and superior to the lateral malleolus of the dominant ankle (DA). The locations were determined by palpation. Uniaxial PlayerLoad (PLuni) was calculated as the square root of the instantaneous rate of change in acceleration in each of the medial-lateral (PLml), anterior-posterior (PLap) and vertical (PLv) planes divided by 100. Accumulated total PlayerLoad (PLtotal) defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three planes and divided by 100 was calculated at C7, L5 and the DA. The uniaxial contributions (PL%) defined as the percentage contribution of the PLuni: medial-lateral (PLml%), anterior-posterior (PLap%) and vertical (PLv%) planes were quantified by dividing the individual PLuni value by PLtotal and by multiplying that value by 100 (Barrett et al., 2014; Boyd et al., 2011).

5.2.6. Statistical analysis

SPSS statistical software package (SPSS IBM Statistics V21.0) was used for data analysis with descriptive statistics presented as mean ± standard deviation. The descriptive characteristics of age, height, mass, BMI and flamenco dance experience and the frequency of the F speed level was analysed between PRO group and AM group using a Mann–Whitney U test since the dependent variable was not normally distributed. AAROM differences between PRO group and AM group were analysed with an independent sample t-test. A Pearson correlation coefficient (r) was used to examine the correlation between active plantarflexion and PLtotal, PLuin and PL% respectively, and between active dorsiflexion and PLtotal, PLuin, PL%. Simple linear regression analysis was used to examine the effect of active dorsiflexion and plantarflexion as a predictor of PLtotal, PLuni, PL%. This analysis was performed using only variables that had a significant correlation with active dorsiflexion or plantarflexion. Independence of observations was

assessed by Durbin-Watson test. Outliers were checked by casewise diagnostics and a scatterplot was used to assess linearity between AAROM and PLtotal, PLuni, PL%. The scatterplots of standardized residuals against predicted values were used to check for the assumption of homoscedasticity. Normal P-P plots were used to assess the normal distribution. The effect size for r were calculated as follows: 0.90 to1.00 (-0.90 to -1.00) very high correlation; 0.70 to 0.90 (-0.70 to -0.90) high correlation; 0.50-0.70 (-0.50 to -0.70) moderate correlation; 0.30 to 0.50 (-0.30 to -0.50) low correlation; 0.00-0.30 (0.00 to -0.30) negligible correlation (44). Statistical significance level was set at $p < 0.05$.

5.3. RESULTS

One participant in AM group was considered left foot dominant and the other 11 participants were right foot dominant. For PRO group, dorsiflexion was 15.33 ± 6.44 degrees, Plantarflexion was 50.50 ± 5.61 degrees; for AM group dorsiflexion was 19.50 ± 5.24 degrees, Plantarflexion was 50.50±5.61 degrees. Statistical analysis via an independent sample t-test. There was no significant difference between the groups for dorsiflexion or plantarflexion ROM ($p > 0.05$).

5.3.1. The effect of Ankle active ROM on the External load in the Dominant Ankle

For the PRO group, table 8 demonstrates that both DA-PLap at F speed level ($p = 0.041$) and DA-PLap% at160 bpm ($p = 0.019$) had a high positive correlation with dorsiflexion. DA-PLv% had a very high negative correlation with plantarflexion at the F speed level ($p = 0.001$). For the AM group, table 1 demonstrates, DA-PLap had a very high positive correlation with dorsiflexion at 160 bpm ($p = 0.01$) and high positive correlation at 180 bpm ($p = 0.044$), and F speed level ($p = 0.039$). DA-PLap% had a high positive correlation with dorsiflexion at 160 bpm ($p = 0.035$) and very high positive correlation at 180 bpm ($p = 0.008$) and F speed level ($p = 0.003$). There was no correlation between DA-PL or DA-PL % and plantarflexion in the AM group.

Table 8. Correlation between AAROM and PLtotal, PLuni, PL% in the dominant ankle (n=12)

		Dorsiflexion (degrees)		Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
DA-PLtotal	160	0.357	0.809	0.099	-0.378
au	180	0.347	0.71	-0.003	-0.383
	F	0.417	0.684	-0.01	-0.006
DA-PLml	160	0.177	0.77	0.355	-0.419
au	180	0.233	0.74	0.27	-0.413
	F	0.146	0.682	0.171	0.041
DA-PLv	160	0.478	0.783	-0.227	-0.372
au	180	0.36	0.626	-0.238	-0.381
	F	0.505	0.579	-0.17	-0.021
DA-PLap	160	0.634	0.916*	-0.115	-0.294
au	180	0.603	0.824*	-0.232	-0.274
	F	0.829*	0.833*	-0.494	-0.004
DA-PLml%	160	-0.329	0.135	0.804	-0.288
	180	-0.246	0.247	0.79	-0.107
	F	-0.559	0.212	0.54	0.303
DA-PLv %	160	0.083	-0.519	-0.704	0.31
	180	0.024	-0.607	-0.748	0.331
	F	0.578	-0.788	-0.971**	0.012
DA-PLap%	160	0.884*	0.843*	-0.51	-0.241
	180	0.743	0.924**	-0.619	-0.33
	F	0.708	0.958**	-0.737	-0.158

** Correlation is significant at the 0.05 level (2-tailed). p< 0.05*

*** Correlation is significant at the 0.01 level (2-tailed). p<.001*

Ankle active range of motion (AAROM); Total Playerload (PLtotal); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Total Playerload of the dominant ankle (DA-PLtotal); PlayerLoad of the dominant ankle in three planes: medial–lateral planes (DA-PLml), vertical planes (DA-PLv), anterior–posterior planes (DA-PLap); uniaxial contribution of the dominant ankle in the three planes: medial–lateral planes (DA-PLml%), vertical planes (DA-PLv%), anterior–posterior planes (DA-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Simple linear regression analysis was performed using only DA-PL or DA-PL% values that had a significant correlation with active dorsiflexion or plantarflexion. For the PRO group, table 9 demonstrates that DA-PLap at the F speed level and DA-PLap% at 160 bpm were significantly related to dorsiflexion, DA-PLv% at F speed level was significantly related to plantarflexion. For AM group, table 10 demonstrates that DA-PLap at 160 bpm, 180 bpm and F speed level were significantly related to dorsiflexion. DA-PLap% at 160 bpm, 180b pm, and F speed level were significantly related to dorsiflexion.

Table 9. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of professional dancers (n=6)

AAROM	PLuni/PL%	r and p value	adjusted r^2 value	β coefficient
Dorsiflexion	DA-PLap F	0.829 (0.041)	0.609	1.874
	DA-PLap% 160	0.884 (0.019)	0.726	0.45
Plantarflexion	DA-PLv% F	0.971 (0.001)	0.929	-0.224

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160) and in vertical planes at the fastest speed level (DA-PLv% F).

Table 10. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of amateur dancers (n=6)

AAROM	PLuni/PL%	r and p value	adjusted r^2 value	β coefficient
Dorsiflexion	DA-PLap 160	0.916 (0.01)	0.798	5.055
	DA-PLap 180	0.824 (0.044)	0.599	5.527
	DA-PLap F	0.833 (0.039)	0.618	6.877
	DA-PLap% 160	0.843 (0.035)	0.638	0.868
	DA-PLap% 180	0.924 (0.008)	0.818	0.917
	DA-PLap% F	0.958 (0.003)	0.897	0.955

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap 160), at 180 beats per minute (DA-PLap 180) and the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160), at 180 beats per minute (DA-PLap% 180) and the fastest speed level (DA-PLap% F)

5.3.2. The effect of Ankle active ROM on the External load at the 7th cervical vertebrae

For the PRO group, table 11 demonstrates that C7-PLv% had a high positive correlation with plantarflexion at 180 bpm ($p = 0.016$) and F speed level ($p = 0.017$). For the AM group, table 4 demonstrates, C7-PLv ($p = 0.029$) had a high positive correlation with dorsiflexion at 160 bpm, C7-PLml% ($p = 0.048$) and C7-PLv% ($p = 0.033$) had a high positive correlation with dorsiflexion at 180 bpm. C7-PLap% had a high negative correlation with dorsiflexion at 180 bpm ($p = 0.019$) and F speed level ($p = 0.03$).

Table 11. Correlation between AAROM and PLtotal, PLuni, PL% in the seventh cervical vertebrae (n=12)

		AAROM Dorsiflexion (degrees)		AAROM Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
C7-PLtotal au	160	0.394	0.777	-0.023	-0.345
	180	0.289	0.713	0.087	-0.305
	F	0.05	0.654	0.021	0.321
C7-PLml au	160	0.472	0.812	-0.129	-0.365
	180	0.449	0.757	-0.092	-0.304
	F	0.07	0.763	-0.027	0.164
C7-PLv au	160	0.352	0.857*	0.197	-0.186
	180	0.16	0.788	0.452	-0.212
	F	-0.137	0.668	0.476	0.334
C7-PLap au	160	0.206	0.448	0.234	-0.225
	180	0.033	0.351	0.374	-0.325
	F	0.13	-0.083	0.067	0.808
C7-PLml%	160	-0.663	0.779	-0.731	-0.603
	180	0.637	0.816*	-0.728	-0.527
	F	0.182	0.835*	-0.318	-0.544
C7-PLv %	160	-0.15	0.347	0.787	0.286
	180	-0.225	0.849*	0.896*	0.041
	F	-0.377	0.351	0.893*	0.462
C7-PLap%	160	-0.495	-0.811	0.792	0.592
	180	-0.445	-0.885*	0.753	0.478
	F	0.256	-0.854*	0.222	0.553

** Correlation is significant at the 0.05 level (2-tailed). p< 0.05*

*** Correlation is significant at the 0.01 level (2-tailed). p<.001*

Ankle active range of motion (AAROM); Total PlayerLoad (PLtotal); uniaxial PlayerLoad (PLuni), PL%(uniaxial contribution); Total PlayerLoad of the seventh cervical vertebra (C7-PLtotal); Playerload of the seventh cervical vertebra in three planes: medial–lateral planes (C7-PLml), vertical planes (C7-PLv), anterior–posterior planes (C7-PLap); uniaxial contribution of the seventh cervical vertebra in the three planes: medial–lateral planes (C7-PLml%), vertical planes (C7-PLv%), anterior–posterior planes (C7-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Simple linear regression analysis was performed using only C7-PL or C7-PL% that had a significant correlation with active dorsiflexion or plantarflexion. For PRO group, table 12 demonstrates that C7-PLv% at 180 bpm and at the F speed level were significantly related to plantarflexion. For the AM group, table 13 demonstrates that C7-PLv at 160 bpm, C7-PLml% and C7-PLv% at 180 bpm, C7-PLap% at 180 bpm and F speed level were significantly related to dorsiflexion.

Table 12. Simple linear regression analysis of active plantarflexion of PL% and seventh cervical vertebra of professional dancers (n=6)

AAROM	PL%	r and p value	adjusted r^2 value	β coefficient
Plantarflexion	C7-PLv% 180	0.896 (0.016)	0.755	0.637
	C7-PLv% F	0.893 (0.017)	0.746	0.612

Ankle active range of motion (AAROM); uniaxial contribution (PL%); uniaxial contribution of the seventh cervical vertebra in vertical planes at 180 beats per minute (C7-PLv% 180) and the fastest speed level (C7-PLv% F).

Table 13. Simple linear regression analysis of active dorsiflexion of PLuni or PL% and seventh cervical vertebra of amateur dancers (n=6)

AAROM	PLuni/PL%	r and p value	adjusted r^2 value	β coefficient
Dorsiflexion	C7-PLv 160	0.857 (0.029)	0.667	0.418
	C7-PLml% 180	0.816 (0.048)	0.582	0.916
	C7-PLv % 180	0.849 (0.033)	0.651	0.334
	C7-PLap% 180	0.885 (0.019)	0.730	-1.261
	C7-PLap% F	0.854 (0.03)	0.662	-1.513

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni); uniaxial contribution (PL%); Playerload of the seventh cervical vertebra in vertical planes at 160 beats per minute (C7-PLv 160); uniaxial contribution of the seventh cervical vertebra in medial–lateral planes at 180 beats per minute (C7-PLml% 180), in vertical planes at 180 beats per minute (C7-PLv % 180), in anterior–posterior planes at 180 beats per minute (C7-PLap% 180) and in anterior–posterior planes at the fastest speed level (C7-PLap% F).

5.3.3. The effect of Ankle active ROM on the External load at the 5th lumbar vertebrae

There was no correlation between ankle AAROM and external load at L5 ($p > 0.05$).

5.4. DISCUSSION AND IMPLICATION

Flamenco dance is characterized by the strong emotion and rhythmic sound made by footwork, which requires dancers to use different positions of the foot, such as heel, toe, ball and whole foot, to strike the floor (Vargas-Macías et al., 2021). Some steps, such as Zap-3, requires quick alternating heel and toe strikes on the floor and dancers have to make unique adjustments to the ankle joint to fulfil the requirements of this dance style (Pedersen et al., 1999). Therefore, active dorsiflexion and plantarflexion may potentially affect the performance of this

technical step (Pedersen et al., 1999). The objectives of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during a flamenco footwork technique with consideration of accelerometer positions and dance proficiency.

Regarding the effect of AAROM on external load and the percentage contribution, the results demonstrated dorsiflexion and plantarflexion were associated with PLtotal, PLuni and PL% dependent upon the position of the accelerometer. Dorsiflexion had a positive correlation with DA-PLap, DA- PLap% for both groups, and a negative correlation with C7-PLap% for the AM group. Therefore, during the footwork, a greater active dorsiflexion may produce greater external load in the anteroposterior plane of the DA, but less in the anteroposterior plane of C7. Dorsiflexion had a positive correlation with C7-PLv, C7-PLv% and C7-PLml%, but this correlation between dorsiflexion and PLtotal, PLuni or PL% did not exist in the DA positions in the vertical and mediolateral plane for both groups. Plantarflexion had a negative correlation with DA-PLv% and a positive correlation with C7-PLv %, in the PRO group only which may indicate that greater active plantarflexion may reduce external load on the vertical plane of the DA, but increase external load on the vertical plane of C7. The location of the accelerometer at the L5 position was not influenced by dorsiflexion or plantarflexion. This could potentially be due to L5 been located closer the centre of mass of the body and enhanced stability.

Results suggested AAROM was associated with different values of PLtotal, PLuni and PL% dependent upon the dance proficiency. The demographics of the two groups were similar and the only significant finding was for dance experience. There was no significant difference in the AAROM of the dominant ankle between groups, but the frequency of the F speed level was significantly different with PRO group significantly faster likely due to their professional status. Significant differences between amateur and professional dancers at maximum speed show that the ZAP-3 test is sensitive to the level of technical execution of the dancers. The AM group were only influenced by dorsiflexion with accelerometer position at the DA and C7. In contrast, the PRO group was only influenced by plantarflexion with accelerometer position at C7 and accelerometer position at DA was influenced by both dorsiflexion and plantarflexion. This may be due to differences in training duration, dance experience and dance proficiency, which might equate to greater

injury risk due to cumulative load and the increased demands of training and rehearsal. The higher speeds in professionals at the fastest speed level when performing the test may also be a factor as normally professional dancers strike the floor harder to make a louder sound. These two reasons may lead to different mechanisms for completing the footwork technique between groups. The frequency of injuries suffered by professional dancers or athletes is greater than student or amateurs (Campoy et al., 2011; Pedersen & Wilmerding, 1998; Vetter & Symonds, 2010; Young & Paul, 2002). Eileen M. Wanke's group (2018) found a higher asymmetric load in the highest national league group than in the regional or lower groups among latin dancers and they were more often injured (Wanke et al., 2018).

In flamenco dance, professionals showed greater negative perception about pain and injuries than flamenco dance student (Baena-Chicón et al., 2021). In our study although AAROM did not significantly differ between the two groups, the mean dorsiflexion of amateurs was higher than professionals while the plantarflexion of professionals was higher than amateurs, and the external load values demonstrate that amateurs were only affected by dorsiflexion while professionals were affected by both. This may be due to the correlation between ankle stability and ROM (Armstrong et al., 2018a) and reduced ankle stability may increase external load. Therefore, it is necessary to consider if there is any difference between groups in ankle ligament strength and arch height which may be related to ankle stability. Ankle strength is influenced by postural balance in the single-leg quiet stance for athletes (Trajković et al., 2021) and a lack of strength in the muscles around the joints often limit the active ROM, which may decrease joint stability (Gannon & Bird, 1999). Ligament laxity may contribute to the high prevalence of lower limb injuries in dancers (Armstrong et al., 2020). Furthermore, increasing arch height is associated with decreased mediolateral control of single-limb stance (Cobb et al., 2014). Although joint hypermobility and associated ligament laxity is thought to be associated with reduced dynamic balance, postural control, and increased injury risk, it is possible that the required high-level proficiency of dance training may attenuate any potential reductions in dynamic balance (Armstrong, 2022).

A high level of ROM is essential for optimal dance performance (Cho et al., 2018; Deighan, 2005; Kadel et al., 2005). The changes of ROM associated with

adolescent dancers may cause an increase in injury incidence (Storm et al., 2018) and our study only used adult dancers to prevent such issues which would require a different study design with consideration of physical maturity. Dancers with decreased hip and ankle/foot joint ROM are less prone to develop patellofemoral pain syndrome (Steinberg et al., 2012). Pedersen (Pedersen et al., 1999) investigated AAROM in 23 female flamenco dancers who studied flamenco in intermediate and advanced classes by using the dynamometer. For plantarflexion, the mean ROM was 59.35° and 51.48° for the right and left ankle, and for dorsiflexion, the mean range of motion ROM was 6.57° and 12.87° for the right and left ankle, respectively. In contrast in our study, the plantarflexion DA ROM was lower for both the professional (50.50° ± 5.61°) and amateur (50.00° ± 3.58°) groups and the dorsiflexion ROM was higher (professional: 15.33 ± 6.44°; amateur: 19.50 ± 5.24°). Bejjani (Bejjani et al., 1988) reported that the mean of total ankle AAROM of 10 female flamenco dancers was 85° ± 11°. The values in our study for professional (66.83° ± 5.64°) and amateur (69.5° ± 6.16°) were lower. Castro-Méndez (Castro-Méndez et al., 2022) measured the dorsiflexion of the ankle of professional flamenco dancer with the supine position and knees extended by goniometer (right foot: 11.92° ± 0.38°; left foot: 12.00° ± 0.43°), which was lower than this study. The difference in AAROM between groups may be due to the dance experience and proficiency (Gannon & Bird, 1999; Klemp et al., 1984). The AAROM difference of flamenco dancers between studies may be due to variations in the method of measurement, such as the participant position during measurement.

Two of the ZAP- 3 steps namely the Zapateado de Tacón (T) Zapateado de Punta (PNT) are always performed with the heel striking in dorsiflexion in front of the base of support and with the foot in the plantarflexion position by the toes tapping the floor behind the supporting base. The most mobile element of the locomotor unit is the ankle joint with a 42° entire ROM (plantarflexion through dorsiflexion ROM) during the footwork, however, in everyday activities, the ROM required in the sagittal plane is significantly reduced, with a maximum of 25° for walking (Forczek-Karkosz et al., 2021) therefore highlighting the importance of ankle ROM for dance performance. Zap-3 was utilized for this study as firstly it is a representative step of flamenco technique, including the various factors of striking the floor with different parts of the foot, and it has a high choreographic correlation. Occasionally biomechanical research analyzes gestures that have no

direct correlation with sports or scenic reality and in our study the authors desired a movement of practical importance. Secondly, some research has already pointed out the risks of overuse injuries for flamenco dancers during Zap-3 footwork technique and the factors are needed to be explored (Echegoyen et al., 2013; Forczek-Karkosz et al., 2021; Forczek et al., 2016; Vargas-Macías et al., 2021). Furthermore, since Zap-3 has been used in recent biomechanical studies and allows standardization for a comparison of results.

Accelerometery was used to quantify external load as it has been widely utilized in the dance research to explore the physiological characterization of latin dance and physical activity levels during dancing (Domene & Easton, 2014; O'Neill et al., 2012). Researchers has also investigated the musculoskeletal demands of dynamic load on flamenco dancers and used accelerometer to record peak frequencies and amplitude at the tibial tuberosity and the anterior superior iliac spine (Bejjani et al., 1988; Voloshin et al., 1989). It was reported that urogenital disorders and back and neck pain may be related to the vibrations generated by flamenco dance form. Different dance genres and their varying demands limit comparison. PlayerLoad has sufficient sensitivity to quantify mechanical load during dance and can be used for injury prevention (Armstrong et al., 2019, 2020; Armstrong et al., 2018a) and has the benefit of been portable. Study limitations included the use of only the dominant ankle for ROM measurement and the relatively small sample size. Future studies could consider a larger sample and explore the effect of other dance genres. From an injury perspective the use of prospective injury surveillance would be beneficial to determine how mechanical loading might influence injury prospectively.

5.5. CONCLUSION

Our findings suggest that AAROM has a correlation with the external load at the DA and C7 during flamenco footwork techniques and the effect showed differences according to dancers' proficiency. Therefore, the external load of DA and C7 can be predicted by measuring AAROM of the DA to some extent in professional and amateur dancers. Furthermore, coaches, dancers, and practitioners with an understanding of the biomechanical characteristics of flamenco footwork can provide theoretical advice to develop technical training

programs. These programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists.

VI – STUDY 4

VI -STUDY 4: THE EFFECT OF LOWER LIMB BALANCE ABILITY AND BILATERAL ASYMMETRY ON FLAMENCO FOOTWORK

6.1. INTRODUCTION

Dance is a form of performance which requires highly physical demanding repetitive movements and difficult techniques in training, rehearsal and performance to obtain excellent artistic levels (Swain et al., 2019). Lower limb injuries and pain are reported in ballet (Biernacki et al., 2021; Swain et al., 2019), contemporary dance (van Winden et al., 2021), Irish dance (Cahalan et al., 2018), and evidence suggests different factors may cause injury according to the dancers professional level (Biernacki et al., 2021). Injury and pain are reported in flamenco dance (Baena-Chicón et al., 2020; Zhang et al., 2022) and the locations most frequently reported are the knees, ankles, feet, lumbar and cervical vertebra and flamenco dancers suffer higher incidence of injuries than other type of dance (Baena-Chicón et al., 2020; Forczek et al., 2017; Pedersen & Wilmerding, 1998). Injuries can inhibit career development for dancers and can lead to injured dancers been replaced by healthy dancers (Vassallo et al., 2018) which can influence daily life and mental state (Baena-Chicón et al., 2021). Therefore, investigating the status of flamenco dancers' lower limbs may identify injury risk factors and allow the development of injury prevention programs (Maloney, 2019). Lower limb balance ability and associated asymmetries may contribute to injury in athletes and dancers (Kiesel et al., 2014).

Balance ability is one of the key functions of a dance performance (Clarke et al., 2019) and is an important factor in dance training (Batson, 2010), dance performance (Strešková & Chren, 2009), and dance injury (Clark & Redding, 2012). The relationship between balance ability and sports injury risk has been established (Hrysomallis, 2011). For instance, poorer balance ability was related to the possibility of development of chronic injury on the right side in dancers (Wanke et al., 2018), and in female team field and court sports, the greater anterior reach distance of the Star Excursion Balance Test (SEBT) for the right leg was identified as a factor for lower limb injury risk (Collings et al., 2021). Less anterior reach on the SEBT was identified as a significant factor for ankle injury risk (Attenborough

et al., 2017; Collings et al., 2021; Hartley et al., 2018). Bilateral asymmetry of the lower limbs may affect performance and injury. Most dancers have a leg they prefer to perform movement with, which is termed as "lateral bias" or "preference" distinguishing it from the developed intuitive skill of lateral awareness (Kimmerle, 2001). The lateral profiles for pre-professional ballet dancers have been described and the dominant leg has the higher injury risk (McMahon et al., 2021). The asymmetry assessment normally measures the asymmetry index (AI) left-to-right or through statistical procedures. Bilateral AI is associated with sport performance such as jumping, kicking and cycling (Bishop et al., 2018), and fundamental movement pattern asymmetry (as measured by the Functional Movement Screen, when the right and left sides are scored differently, the lowest of the right and left scores is used in the composite and the movement is categorized as asymmetrical) is related to the time-loss injury in professional football players (Kiesel et al., 2014).

The SEBT has been used to identify injury risks in dancers and athletes (Armstrong et al., 2018b). The SEBT was reported to be the most commonly used movement screening tools (34.38%) in survey of dance companies, schools and university dance programmes (Armstrong et al., 2019). The YBT is a composite modified SEBT, which measures three components (anterior, posteromedial and posterolateral direction) of the SEBT (Junker & Stöggl, 2019) which assesses unilateral balance and neuromuscular control which are important requirements of many sports (Plisky et al., 2006) with the anterior direction the most sensitive predictor of injury risk (Stiffler et al., 2017). Asymmetrical reach distance on the YBT has been associated with increased risk of noncontact lower extremity injury (Plisky et al., 2006). The Y balance test can be combined with other screening tools to predict injury risks and used in dancer injury risk management programs (Armstrong, 2020; Misegades et al., 2020).

Regarding flamenco dance footwork techniques, there is a high physical demand for dancers (Forczek et al., 2016). Flamenco dancers are required to utilize different parts of their foot to strike the floor including the heel and tip of the toes and make a series of rhythms and loud sounds (Vargas-Macías et al., 2021) with these movements producing huge vibrations (Pedersen & Wilmerding, 1998), and the impact of the shoe is transmitted by vibrational waves from the joints of the lower limbs to the spine, which can trigger pain and overuse injuries (Baena-Chicón et al., 2020). Zap-3 is one of the most representative footwork techniques in

flamenco dance and is composed of a sequence of six steps with the right and the left foot and requires striking the floor and quickly alternating the heel and tip of the toes. When one sequence is completed, the next sequence is repeated with the other foot and repeated alternately. During the whole movement, dancers are required to maintain stability of the upper limbs and trunk (Forczek-Karkosz et al., 2021), therefore proficient balance ability is required to complete the movement and asymmetry may affect the body stability and increase injury risk.

External load as measured by Playerload has been proven reliable and sensitive to monitoring and injury screening outcomes (Armstrong et al., 2019, 2020; Brogden et al., 2018; Moulder et al., 2021; Nagy et al., 2022). The relationship between balance ability, asymmetry and external load may contribute to injury risk in flamenco dancers. The aim of this study was to investigate the effect of lower limb balance ability and asymmetry as measured by YBT on the relationship with external load during flamenco footwork with consideration of accelerometry position and dance proficiency.

6.2. METHOD

6.2.1. Participants

Ten flamenco dancers volunteered to participate in this study (5 professional dancers, PRO group and 5 amateur dancers, AM group). Descriptive characteristics of the sample are presented (Table 14). The inclusion criteria for the PRO group were that participants had to be professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves to be professional flamenco dancers. For the AM group, participants had to be amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training for at least 3 hour per week. All participants were over 18 years of age and had had no musculoskeletal injuries in the 6 months preceding the test and had at least 1-year flamenco dance experience. Participants provided informed consent in writing before the commencement of the study. A stadiometer (Ruhe, China) with used to measure height, a weighing scale (Xiaonmi, China) was used to measure weight. Body mass index (BMI) was calculated as [weight (kg)/height (m2)]. Ethical

approval was granted by the Sports Science Experiment Ethics Committee of Beijing Sport University (2022037H), and the study was completed in accordance with the Declaration of Helsinki.

Table 14. Descriptive characteristics of participants (n = 10)

Characteristics	Professional N=5	Amateur N=5	P value
Age (years)	36 ± 4.36	34.8 ± 11.9	0.841
Height (m)	1.63 ± 0.02	1.62 ± 0.034	0.507
Weight (kg)	61.6 ± 5.32	56.4 ± 17.87	0.562
BMI (kg/m2)	22.91 ± 6.28	21.43 ± 3.15	0.653
Flamenco dance experience (years)	8.2 ± 5.26	2 ± 1.22	0.033*

** Denotes a significant difference between groups at the p < 0.05 level. kg: kilograms; m: meters; m2: square meters; BMI: Body mass index.*

6.2.2. External load during footwork: Playerload

Built-in triaxial accelerometry sensors (EMG; Trigno EMG Wireless Delsys, Inc., 2000Hz, USA) were used to quantify mechanical load responses to the flamenco Zap-3 footwork performance with data sampling at 150 Hz. A unit was housed at the 7th cervical vertebrae (C7), the 5th lumbar vertebrae (L5), superior to the lateral malleolus of the ankle of the dominant foot (DA) and superior to the lateral malleolus of the ankle of the non-dominant foot (NDA). The dominant leg was determined as the leg that would be used by the participant to kick a ball (Lin et al., 2013; Wilson et al., 2018). The sensors were attached directly to the skin using medical tape and secured using elastic bandage. The PL total (PLt), defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors: medial-lateral, anterior-posterior and vertical, and divided by 100, was calculated at C7, L5, DA and NDA. The external load of PL in anteroposterior (PLap), mediolateral (PLml), and vertical (PLv) planes were calculated as the square root of the instantaneous rate of change in acceleration in each of the medial-lateral, anterior-posterior and vertical planes divided by 100.

6.2.3. Flamenco ZAP-3 footwork

Participants performed Zap-3: a sequence of 6 footwork steps with the right and the left foot. When one sequence is completed, the next sequence is repeated with the other foot and repeated alternately (Forczek-Karkosz et al., 2021; Vargas-Macías, 2006).

Participants were required to start with the dominant foot. During the entire footwork movement, participants were required to keep their upper limbs and trunk stable, while maintaining akimbo and performing smooth and coherent movements. The six Zap-3 steps were completed in the following order: Zapateado de planta (P); Zapateado de Tacón-planta (TP); Zapateado de Tacón (T); Zapateado de Tacón-planta (TP); Zapateado de Punta (PNT); and Zapateado de Tacón-planta (TP).

Subsequently, for the flamenco footwork test, each participant was asked to complete Zap-3 footwork at 3 different speed levels on the same portable flamenco dancing wood floor (92×100 cm). The speeds were 160 bpm (beats per minute), 180 bpm, and at their own the fastest speed possible (F speed level) in sequence. The sequence was performed in a dance studio and each speed was completed 3 times for a duration of 15 seconds. At 160 bpm and 180 bpm participants were required to dance while listening to an earphone which was linked to a metronome and had to strike the floor twice on each beat. At the fastest speed level (F), participants were required to perform every footwork step of Zap-3 as quickly as possible and maintain a rhythmic sound. Participants were able to practice 5 minutes before each section testing commenced and rested for 5 minutes between sessions to reduce fatigue effects. Participants were instructed to wear flamenco footwear that would be worn during training/performance.

6.2.4. Data analysis

All data were analysed using a statistical software package (Statistical Package for the Social Sciences, International Business Machines Corporation, V21.0, Armonk, New York, USA) with descriptive statistics presented as mean ± standard deviation. The descriptive characteristics of age, height, mass, BMI and flamenco dance experience and the frequency of the F speed level was analysed between PRO group and AM group using a Mann-Whitney U test since the

dependent variable was not normally distributed. The result of YBT and Zap-3 test differences between PRO group and AM group were analysed with an independent sample t-test and the differences between dominant and non-dominant legs or ankles were analysed with a dependent sample t-test. Pearson correlation coefficient (r) was used to examine the correlation between YBcom, YBant, YBpl, YBpm, AI. The size of correlation (r) was defined as: 0.90 to1.00 (-0.90 to -1.00) very high correlation; 0.70 to 0.90 (-0.70 to -0.90) high correlation; 0.50-0.70 (-0.50 to -0.70) moderate correlation; 0.30 to 0.50 (-0.30 to -0.50) low correlation; 0.00-0.30(0.00 to -0.30) negligible correlation (Mukaka, 2012). Bonferroni correction factors were used for a post-hoc comparison, to determine where any significant differences occurred between groups in YBT or PL. Statistical significance level was set at $p<0.05$.

6.3. RESULTS

During the test, PRO and AM groups performed the 160 bpm and 180 bpm at the same frequency, 5.33 Hz and 6.00Hz respectively. At F speed level, dancers tapped at 9.09 ± 0.83 Hz and 6.96 ± 0.46 Hz respectively which demonstrated a significant difference ($p = 0.002$).

6.3.1. The Y-balance and ZAP-3 test

The results of YBT are reported in Table 15 and did not reveal significant bilateral asymmetries in the participants, regardless of their groups ($p > 0.05$). There was significant difference between groups in YBpm and YBpl, which indicated that for the dominant leg, the AM group (113.21 ± 6.13; CI: 105.61 - 120.82) was higher than PRO group (104.04 ± 5.78; CI: 96.87 - 111.21; $p = 0.041$) in YBpm. The AM group (111.48 ± 6.78; CI: 103.05 - 119.90) was significantly higher than PRO group (102.27 ± 2.48; CI: 99.19 - 105.34; $p = 0.021$) in YBpl. For the non-dominant leg, the AM group (110.53 ± 4.67; CI: 104.73 - 116.32) was also significantly higher than the PRO group (105.11 ± 7.40; CI: 95.92 - 114.30; $p = 0.01$) in YBpl.

Table 15. YBT balance test performance of both dominant and non-dominant leg in professional and amateur dancers. (n=10).

	Dominant Leg		Non-Dominant Leg		Asymmetry Index	
	PRO Group	AM Group	PRO Group	AM Group	PRO Group	AM Group
YBcom	90.19±4.48	95.20±5.32	91.25±4.59	96.95±3.13	-1.17±2.61	-1.90±5.05
YBant	64.25±8.36	63.86±5.79	66.64±8.52	65.62±3.93	-3.70±5.17	-2.34±4.33
YBpm	#104.04±5.78	113.21±6.13	102.00±2.27	112.09±5.44	1.89±6.91	0.97±7.88
YBpl	#102.27±2.48	111.48±6.78	#105.11±7.40	110.53±4.67	2.57±8.30	-0.79±5.83

#Significant differences between professional dancers and amateur dancers ($p < 0.05$); YBcom: Y-balance test composite scores; YBant: Y-balance test anterior scores; YBpm: Y-balance test posteromedial scores; YBpl: Y-balance test posterolateral scores; PRO Group: professional group; AM Group: amateur group.

The results of PL during Zap-3 test are reported in Table 16. There was no difference between DA and NDA in PRO group, but for AM group there was a significant difference in PLml at 180 bpm ($p = 0.003$) and F speed level ($p = 0.032$). There was a significant group x speed ($p < 0.001$) interaction effect for PLuni. Post-hoc analyses revealed that there was a significant difference between groups at the fastest speed levels ($p < 0.05$).

6.3.2. The effect of dynamic balance and asymmetry on the external load at the ankle

There was no correlation between dynamic balance and external load in the ankle in the PRO group.

For the AM group, NDA-YBcom had negative correlation with DA-PLtotal ($r = -0.885$, $p = 0.046$) and DA-PLv ($r = -0.928$, $p = 0.023$) at the 180 bpm speed level.

6.3.3. The effect of dynamic balance and asymmetry on the external load at the 5th Lumber vertebrae

For PRO group, DA-YBpl had negative correlation with L5-PLtotal ($r = -0.956$, $p = 0.01$, L5-PLml ($r = -0.941$, $p = 0.01$, L5-PLv ($r = -0.933$, $p = 0.021$) at the F speed level. AI-YBcom had a negative correlation with L5-PLml ($r = -0.89$, $p = 0.043$) at the F speed level.

For AM group, DA-YBpm had negative correlation with L5-PLtotal ($r = -0.895$, $p = 0.04$), L5-PLv ($r = -0.932$, $p = 0.021$), at F speed level, and L5-PLv ($r = -0.927$, $p =$

0.023) at 180 bpm. NDA-YBcom had a negative correlation with L5-PLml (r = -,916, p = 0.029), L5-PLap (r = -,904, p = 0.035) at the 180 bpm speed level.

Table 16. The PL across speed of the Zapateado-3 footwork. Values are mean ± σ

	DA		NDA		L5		C7	
	PRO Group	AM Group	PRO Group	AM Group	PRO Group	AM Group	PRO Group	AM Group
PLt160	176,28± 35,44	194,63± 62,86	173,73± 30,32	213,28± 62,81	39,24± 10,65	39,38± 14,86	35,01± 12,42	33,49± 10,29
PLt180	193,56± 39,90	198,33± 79,55	197,47 ± 30,5	214,61± 76,03	42,11± 10,53	40,19± 18,85	37,17± 10,00	33,92± 15,43
PLtf	316,44± 34,03	248,48± 80,6	324,09 ± 23,87	258,23± 90,55	68,58± 14,44	49,21± 21,95	58,70± 14,01	40,85± 17,54
PLml160	93,38± 22,82	104,72± 32,48	100,66 ± 21,91	128,24± 32,39	14,62± 3,32	16,28± 4,82	25,94± 10,35	25,70± 9,61
PLml180	103,00± 23,66	*106,61± 39,23	116,00 ± 18,83	131,35± 44,79	15,85± 2,79	16,90± 7,78	27,87± 8,08	26,48± 13,75
PLmlf	172,78± 19,02	*130,17± 39,72	194,51± 17,43	155,09± 54,93	27,47± 5,69	20,50± 8,41	44,39± 11,15	31,01± 15,71
PLv160	107,53± 15,85	118,46± 36,61	102,91 ± 14,00	117,80± 34,88	21,53± 8,26	19,88± 11,08	7,45± 2,91	6,77± 2,81
PLv180	118,81± 21,88	119,41± 47,41	115,95± 14,98	117,25± 40,89	22,68± 8,35	20,19± 11,42	7,82± 2,66	7,06± 4,16
PLvf	193,27± 22,67	151,50± 45,81	186,15± 9,71	144,99± 50,27	34,71± 9,32	24,47± 13,95	13,53± 3,29	9,58± 5,43
PLap160	56,62± 16,53	63,47± 27,87	47,86± 11,35	66,68± 29,37	19,37± 3,80	20,00± 6,01	14,73± 4,88	12,52± 1,94
PLap180	60,99± 11,35	66,13± 36,24	53,86± 10,50	64,17± 29,97	21,19± 3,35	20,24± 9,23	15,54± 4,96	12,06± 3,49
PLapf	99,20± 15,80	83,59± 40,44	92,11± 17,30	76,83± 30,83	36,61± 6,85	25,32± 10,36	23,83± 6,33	15,35± 5,32

**Significant differences between dominant ankle and non-dominant ankle; PLt160: PLayerLoad total at at 160 beats per minute; PLt180: PLayerLoad Total at 180 beats per minute; PLtf: PLayerLoad Total at the fastest speed level; PLml160: PLayerLoad in mediolateral planes at at 160 beats per minute; PLml180: PLayerLoad in mediolateral planes at at 180 beats per minute; PLmlf: PLayerLoad in mediolateral planes at the fastest speed level； PLv160: PLayerLoad in vertical planes at at 160 beats per minute; PLv180: PLayerLoad in vertical planes at at 180 beats per minute;PLvf: PLayerLoad in vertical planes at the fastest speed level; PLap160: PLayerLoad in anteroposterior planes at at 160 beats per minute; PLap180: PLayerLoad in anteroposterior planes at at 180 beats per minute; PLapf: PLayerLoad in anteroposterior planes at the fastest speed level； DA: dominant ankle; NDA: non-dominant ankle; L5: the fifth lumbar vertebrae; C7: the seventh cervical vertebrae; PRO Group: professional group; AM Group: amateur group.*

6.3.4. The effect of dynamic balance and asymmetry in the external load at the 7th cervical vertebrae

There was no correlation between dynamic balance and external load at the 7th cervical vertebrae in the PRO group. For AM group, DA-YBpm had negative correlation with C7-PLap ($r = -0.936$, $p = 0.019$) at 160 bpm, NDA-YBcom had negative correlation with C7-PLtotal ($r = -0.92$, $p = 0.027$), C7-PLml ($r = -0.895$, $p = 0.04$), C7-PLap ($r = -0.966$, $p = 0.007$) at the 180 bpm speed level. AI-YBant had positive correlation with C7-PLap ($r = -0.971$, $p = 0.006$) at the F speed level.

6.4. DISCUSSION

Injury and pain in flamenco dancers may cause serious problems to a dancer's career development and affect their daily life and mental health. Previous research has identified the knees, ankles and feet and the lumbar and cervical vertebrae as the most prevalent injury locations in flamenco dancers (Baena-Chicón et al., 2021). Balance ability is one of the key functions of dance performance and bilateral asymmetry of lower limb balance ability is related to injury risk. The aim of this research was to investigate the effect of lower limb balance ability and asymmetry on the external load during flamenco footwork with consideration of accelerometry positions and dance proficiency.

The triaxial accelerometers were positioned at four different body locations and the movement was performed as a series of footwork techniques of Zap-3 test to provide information regarding external loading. Our study demonstrated there were some differences between groups. Flamenco dance experience, and the frequency of the F speed level was significantly different between the PRO group and AM group. The PRO group could reach 9.09 ± 0.83 Hz and AM group 6.96 ± 0.46 Hz. In a previous case study, one professional female flamenco dancer could perform the Zap-3 at the frequency of 11.8 steps for each second, which is higher than the speed in our study and it could be because this case study dancer had a high level of proficiency as the professional dancer had 31 years flamenco dance experience including 16 years as professional (Vargas-Macías et al., 2021). Furthermore, there was no significant difference between the lower limb in the two groups in the YBT, but with regard to the external load, there was a significant difference in PLml at 180 bpm and F speed level between DA and NDA in the AM

group. These differences between PRO group and AM group may be due to different movement patterns, years of dance training and training methods. Research in female ballet dancers has demonstrated different injury risk factors between recreational dancers and elite dancers (Biernacki et al., 2021). Therefore, it is necessary to separate the group according to the participants' dance proficiency when investigating injury factors.

Regarding the effect of lower limb balance ability on external load on Zap-3 footwork technique of professional flamenco dancers, the results demonstrated DA-YBpl had a negative correlation with PLtotal, PLml and PLv at F speed level and at the L5 position. Therefore, during footwork, a greater DA-YBpl may produce less external load at the L5 position in total external load, mediolateral and vertical plane, and vice versa. The position of L5 is closer to the centre of mass of the body, and dancers need to maintain the upper limbs and torso relatively stable while changing footwork quickly. The L5 may be affected more in the trunk position connecting the upper and lower limbs, where it needs to bear more vibrations to decrease the effect on the upper limbs and torso and better balance ability reduces the external load of the L5 position. Enhanced balance makes the body more stable and reduces the external load required to maintain stability in the L5 position. In contrast there was no correlation between YBT and external load in the DA, NDA or C7 position. This may be due to a relatively fixed movement pattern that has been developed over a long period of training for professional dancers, and thus there is less effect of YBT on PL on other body positions.

For amateur dancers, the external load during Zap-3 footwork was more affected by balance ability. Firstly, NDA-YBcom had a negative correlation with DA-PLtotal and DA-PLv at the 180 bpm speed level, which could mean the greater YBcom of the non-dominant leg may produce less the external load for DA in PLtotal and vertical plane due to the characteristics of Zap-3 footwork, that requires one leg to maintain body stability while the other foot strikes the floor and quickly alternates the heel and tip of the toes. It is possible that the better the balance ability of the non-dominant leg, the more stable the dominant foot striking the floor and the lower the external load. The relationship between YBT and PL on C7 and L5 demonstrate a negative correlation. Compared with professional dancers, amateur dancers do not control the stability of the whole body during footwork performance as well, and the instability at L5 and C7 will be more prominent and

produce more vibration. Thus, for amateur dancers, better balance ability may improve overall stability, thus reducing the external load on the spine. Some previous studies indicated that YBT score is related to ankle injury incidence in female team field and court sport (Collings et al., 2021), and ankle sprain injury in collegiate male athletes (Hartley et al., 2018), and netball participants (Attenborough et al., 2017), and therefore lower reach distance may cause higher injury incidence.

Our results demonstrated the bilateral asymmetry were associated with PL dependent upon the dance proficiency. For AM group AI-YBant had positive correlation with C7-PLap at the F speed level, which might equate to greater AI and may cause higher external load and potentially increase injury risk therefore reducing the difference between bilateral lower limbs could be favorable. However, the results for PRO group were conflicting, the correlation was negative for PRO group between AI-YBcom and L5-PLml, which means higher AI could lower externally load at the L5 position. This may be because, for professional dancers, less asymmetry or more stability may cause them to strike the floor with greater force to make a louder sound, thus producing more vibration. On the contrary, with higher asymmetry, the floor may be struck with greater force on only one side and less on the other, thus producing less vibration. Thus, lower AI could increase external load at L5 position could mean a better footwork technique because a better percussive footwork technique. Regarding the effect of AI, a systematic review has reported inconsistent findings of the effect of asymmetry on injury or physical performance in different studies (Bishop et al., 2018). Research has demonstrated that strength asymmetry of > 15% was associated with increased injury incidence compared to those who score below this threshold (Grindem et al., 2011; Impellizzeri et al., 2007). This is believed to increase the risk of sport injury because it may cause unequal force absorption or a loss of frontal plane stability (Guan et al., 2022). Asymmetry may reduce jump height (Bell et al.,2014) and result in a lower change of direction speed times (Hoffman et al.,2007). In contrast, larger asymmetries have resulted in better performance in cycling (Bini & Hume, 2015) and no relationship between asymmetry and performance has also been reported in team sports (Lockie et al., 2014).

Previous studies which investigate injury risk factors generally use self-report injury incidence or follow-up to record the times of injury, with the injury

defined as injuries leading to time loss of a day or longer and analysed if there was any relation between factors and injury incidence (Guan et al., 2022). Lower balance ability was related to chronic overload damage on the right side for junior level dancers in sport dance (Wanke et al., 2018). In this study, the external load in form of PlayerLoad was utilized during the footwork test, which can provide real-time live feedback and correlates with injury risks in different sports (Cummins et al., 2019; Drew & Finch, 2016). The concept of PlayerLoad has sufficient sensitivity to quantify mechanical load during dance and can be used for injury prevention (Armstrong et al., 2019, 2020; Armstrong et al., 2018a).

The study contained some limitations including the sample size and that only analysis footwork techniques were considered and not a choreograph routine. Future studies could consider a larger sample and explore the effect of a choreography routine. From an injury perspective the use of prospective injury surveillance would be beneficial to determine how mechanical loading over a period of rehearsal and competition might influence injury.

6.5. CONCLUSIONS

This study explored the effect of lower limb balance ability and asymmetry on external load during flamenco footwork with consideration of accelerometry positions and dance proficiency. The findings suggest that amateur dancers are more susceptible to the effect of balance ability and better balance ability may produce less external load. On the other hand, it has been proven that having good bilateral balance symmetry between both limbs is a positive effect among flamenco dancers. For amateurs it allows them to reduce overloads at the cervical level and their risk of injury, and for professionals it allows them to optimize their percussive tapping technique. Furthermore, few studies utilise amateur dancers and consider the potential differences in injury risk between them and professional dancers. This study provides further stimulus regarding how balance ability affects footwork so that training plans and injury surveillance could be optimized according to participants' dance proficiency to reduce injury risk. Even though balance is not a specific element of flamenco dance, its training is recommended, especially in the early stages of learning flamenco dance.

VII – STUDY 5

VII - STUDY 5: MONITORING FLAMENCO DANCE MOVEMENT WITH ACCELEROMETER: METHODOLOGICAL AND PRACTICAL COMMENDATIONS

7.1. INTRODUCTION

Flamenco dance has been listed as an Intangible Heritage of Humanity in become a cultural feature of Spain. It is "a dance of passion, courtship, expressing a wide range of situations ranging from sadness to joy." (UNESCO, 2010). It has gained worldwide prominence and attraction, captivating a growing community of enthusiasts in many countries (Cuellar-Moreno, 2016; De Santiago Ortega, 2018; Diamond, 2018; Ropero, 1995). Flamenco dance is distinguished by its powerful emotional expression and distinctive footwork techniques, characterized by the striking of the floor to create a resounding and rhythmic sound. This sets it apart from other dance styles (Cuellar-Moreno, 2016). The rhythm and emotional expression are two of the most important elements for performing flamenco, which is indispensable for the precise execution of this dance form (Braga, 2010). Mastering flamenco necessitates the development of motor skills that involve precise techniques and the coordination of various body parts like the feet, torso, arms among others (Cuellar-Moreno, 2016).

Accelerometers are tools specifically engineered for quantifying differences in force or acceleration over time, providing data regarding the magnitudes and frequency of movement. When utilized for monitoring physical activity, these devices have the capability to detect movement in three planes of movement (medial-lateral, anterior-posterior and vertical) and to evaluate the intensity and overall amount of movement over a given time period (Cliff et al.,2009). It has already been used in sports or physical activity monitoring, as well as dance fields, to explore the physiological characterization of dance and physical activity levels during dancing (Bejjani et al., 1988; Bowen et al., 2019; Brogden et al., 2018; Moulder et al., 2021).

Flamenco dance is a combination of physical movement and aesthetics that also requires a high level of physical demand, the physical effort demanded in

performing flamenco is similar to that of elite sports (Macías, 2006; Macías et al., 2008; Pedersen et al., 2001). Meanwhile, achieving a high level of skill and proficiency in dance also necessitates training and rehearsal, which may elevate the risk of potential injuries (Angioi et al., 2009; Bronner et al., 2003; Motta-Valencia, 2006). The injuries and pains have been already reported in flamenco dancers, which affect dancers not only their professional careers but also may have a negative effect on their daily lives (Baena-Chicón et al., 2020; Forczek et al., 2016; Pedersen & Wilmerding, 1998). On the other hand, to improve the skill and technique of dance, more theoretical studies also are necessary for the future. The instruments utilized are good for researchers to better understand how to study this field. Therefore, we would like to further emphasize the importance of using accelerometers and link it to the need for a more in-depth and comprehensive study of the technique. The aim of this study is to establish a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection and validation of accelerometers, usage protocols, and data processing and analysis.

7.2. ACCELEROMETERS SELECTION

Generally, the choice of accelerometers largely depends on the specific research objectives with consideration of factors such as product reliability, access to technical support, feasibility, and cost (Ward et al.,2005). Besides possessing adequate data processing and storage capabilities to track movement over extended periods is critical, we also have to consider if it is portable and compact for practical use in settings since in a flamenco dance test, accelerometers need to be posted on participants' body steady during performing dance for a period. We need to make sure the accelerometers do not drop during the dancers' performance and do not interfere with their dance moves during the test.

Out of the commercially accessible accelerometer brands, ActiGraph (Pensacola, FL, USA) stands out as the most commonly employed choice among researchers (Wijndaele et al., 2015). There are some examples about dance research. ActiGraph Triaxial accelerometers (GT3X+ 2.5, Actigraph LLC, Pensacola, USA) was used for describing the physical activity parameters of Latin dance (Domene & Easton, 2014). Actigraph GT33 accelerometer were used in Kelli's research group,

to record the physical activity, the intensity and time length of teenagers in different dance style classes of youth, included flamenco dance class. It was also widely used in other dance styles studies (Cain et al., 2015). Additionally, Global Positioning Systems (GPS) with triaxial accelerometry (Armstrong et al., 2018a; Nagy et al., 2022), and triaxial accelerometer Kionix KX94 (Kionix, Ithaca, New York, USA) (Brogden et al., 2018) were also utilized in other physical activity studies before.

About flamenco dance test, in 1998, Bejjani research group used two light-weight (2 g) skin-mounted unidirectional accelerometers (PCB 303; Power Supply 408), to record vibrations of hip and knee for ten flamenco dancers, indicated that vibrations generated by flamenco dancing may be linked to urogenital disorders, as well as back and neck pain, and the hip joint appears to absorb the majority of these impacts (Bejjani et al., 1988). Voloshin et al, in 1989 recorded the amplitude of dynamic loading recorded on tuberosity, antero-superior iliac spine with two light-weight (2 g) skin-mounted unidirectional accelerometers as well, and revealed that utilizing insoles appears to decrease the amplitude of dynamic loading observed on the dancer's tibial tuberosity depending on the specific dance and performer (Voloshin et al., 1989). Otherwise, in 2022, Zhang research group used Trigno Avanti™ sensors (Trigno Wireless EMG System, Delsys, Natick, MA, USA), which is a Triaxial Accelerometer having a built-in nine-degrees-of-freedom inertial measurement unit and can relay acceleration, rotation and earth magnetic field information, to record the flamenco Zap-3 footwork's external load responses. It described the external load at the dominant ankle, the 7th cervical vertebrae and the 5th lumbar, and the effect of speed, axis and the dancers' proficiency level on external load and their interaction (Zhang et al., 2022). The same research group also used the triaxial accelerometer to record the external load and analysis the correlation with ankle range of motion, and it pointed out that dorsiflexion affected the dominant ankle load in the anteroposterior axis for both professional and amateur dancers, as well as the cervical vertebrae load, which only affected amateurs. Plantarflexion only influenced the vertical axis load in professional dancers (Zhang et al.,2023).

We recommend future studies use triaxial accelerometers to monitor flamenco technique tests. Existed research reported that triaxial accelerometers

outperforms uniaxial accelerometry in capturing accelerations of sports consisting of smooth, horizontal or complex body movements (Smith et al., 2018). Also, the effectiveness of triaxial accelerometers in dance detection has been proved. Nagy investigated within-day and between-day loading responses to ballet choreography and reported that the effectiveness of triaxial accelerometers in dance monitoring (Nagy et al., 2022). In a study about flamenco dance external load, researchers identified significant effects of speed on external load (Zhang et al., 2022). To some extent, it means the accelerometer is sensitive enough to recognize the variation in the speed of flamenco footwork. Additionally, it also is better to use similar instruments as research in most recent years for comparing and discussing the results, since the difference between these devices makes it difficult to compare data between studies (Migueles et al., 2017).

7.3. MONITOR USE PROTOCOLS

Accelerometers can be fixed in many parts of the body. For example, ankles, wrists, torso, etc. The trunk position (hip or lower back) has become the most common position for monitors in general to monitor physical habitual, intensity (Ward et al., 2005). For instance, the intensity of dance classes of different dance styles was studied too, including flamenco dance, where participants wore accelerometers in the position of waist (Cain et al., 2015). Further, it has been indicated that when accelerometers are used for activity classification, the knee is the preferred sensor position for high-level activities. For transitional activities involving leg motion and posture changes, both chest and knee sensors are suitable choices (Atallah et al., 2011). However, the location of the accelerometer depends on the interest to be studied, the accelerometer can also be placed in different body positions when the study aims to record data on a specific body position. For example, in flamenco dance, the 7th cervical vertebrae, the 5th lumbar vertebrae, and superior to the lateral malleolus of the ankle were selected for quantifying the external load of the flamenco Zap-3 footwork while comparing the difference in those three body positions (Zhang et al., 2023). The accelerometers were also strapped onto the tibial tuberosity and the anterior superior iliac spine of flamenco dancers before for account acceleration amplitude, peak accelerations (Bejjani et al., 1988; Voloshin et al., 1989).

In flamenco dance experiments, the duration of wearing the accelerometer can be determined according to the needs of the interest. If studying a specific dance movement, it could be counted the time of the entire sequence of movements (usually more than 10 seconds), or the units of seconds or minutes based on the time it takes to complete the movement. If it is to estimate habitual, intensity of dancers, the time is determined according to the need, such as a dance class, a rehearsal, or a choreography. Similarly, the location of the experiment is also selected according to the needs of the experiment. The accelerometer is small and portable, the experiment can be conducted in the dance classroom, rehearsal hall or stage. The principle is to be as close as possible to the dancers' usual training, performance and class conditions, so as to ensure the authenticity and validity of the data.

7.4. DATA ANALYSIS

Frequency and amplitude recorded by accelerometers have been used to quantify results in research. Bejjani (Bejjani et al., 1988) and Voloshin (Voloshin et al., 1989) used accelerometer data to analyze the vibrations with peak frequency ranges and amplitudes of acceleration. Otherwise, MeterPlus version 4.3 could be used to summarize minutes of sedentary, light, moderate, vigorous, and MVPA (moderate + vigorous) during physical activities. The research studied physical activity in youth dance using an accelerometer. Seven different dance classes (flamenco is one of them) were investigated. Outcomes as classes' total time (minutes) and per cent of class time (minutes divided by class length) spent in each intensity level were calculated.

The PlayerLoad (PL) concept allows for the quantification of a vector-modified algorithm introduced by the tech company Catapult Sports, which utilizes a micro-electrical mechanical system. PL is calculated as the square root of the sum of the squared rates of acceleration change along each of the three vectors (medial-lateral, anterior-posterior, and vertical), divided by 100. The micro-electrical mechanical system (MEMS) device includes a triaxial piezoelectric linear accelerometer that samples movement data at a frequency of 150 Hz, allowing for the precise quantification of movement performance. Due to its low user dependence, PL has found application in numerous physical activity tests for

characterizing external load (Bowen et al., 2019; Bredt et al., 2020; Bullock et al., 2021; Scanlan et al., 2021) and is related to sports training and competition. In the field of dance research, PL has also been widely used to quantify the external load or mechanical load and its correlation with injuries (Armstrong et al., 2019, 2020; Moulder et al., 2021). Nagy's research delved into within-day and between-day loading responses to ballet choreography. The study found that PL is suitably sensitive for tracking progressive routines, and accelerometers prove effective for athlete monitoring and injury screening protocols (Nagy et al., 2022). In flamenco footwork research, Playerload was utilized as the form to calculate external load, and analyzed correlation with other factors such ankle active range of motion, and balance ability (Zhang et al., 2022, 2023; Zhang, in press)

The way to describe the acceleration data depends on the problem you are studying. The case of the above studies may give thinking of choosing the appropriate definition to describe the data. However, it does not mean they included all possibilities, the outcomes could also be other concepts with analysis acceleration. Standardizing the data with other research will facilitate comparison.

7.5. CONCLUSIONS

This study explained how to monitor flamenco dance movement with accelerometers by making a detailed introduction from aspects of accelerometer selection, monitor use protocols, and data process and analysis. Triaxial accelerometers were recommended to be used to monitor flamenco technique tests no matter what brand it is, which may better than uniaxial accelerometry for dance movement. The use of accelerometers in dance performance is often used to monitor physical conditions over a period of time, which can be days or seconds, depending on the problem to be studied. Accelerometers can be used in different settings, such as a classroom, rehearsal hall, or stage, and can also be placed in different locations on the body to obtain data. Existing studies of flamenco dance include the analysis of a dance technique movement by placing accelerometers at different locations to calculate external loads at different locations, or to describe vibrations. Another type of study looks at physical activity over time, such as the intensity and duration of exercise during a class. At present, there are many problems that can be studied by using accelerometers in flamenco dance, such as

the intensity of physical activity in different chapters of a choreographer, or the analysis of acceleration data and related factors of other variables to interpret the physiological characteristics of flamenco dance more fully. Those studies will be significantly meaningful to deeply know the flamenco movement, giving advice to improve the techniques, prevent injuries or plan the training efficiently.

VIII - GENERAL RESULTS AND DISCUSSION

VIII - GENERAL RESULTS AND DISCUSSION

The purposes of this thesis were to firstly investigate the framework of the flamenco dance research field to demonstrate the hotspots and trends; secondly, to study the accelerometer application in flamenco dance research, with aspects of describing the external load of flamenco dancers during footwork, exploring the effect of ankle range of motion, lower limb balance ability and asymmetry on the external load of dancers, with consideration of the sensors position and proficiency level of dancers, and thirdly, to establish a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection of accelerometers, usage protocols, and data processing and analysis. Results indicated that the hotspots included cultural aspects, and biomechanical and physical aspects, including body, anthropometry, and physical activity focusing on dancers. The trend of this field will be physical and psychological aspects. Regarding external load and its factors, significant effects on speed and position, the interaction between speed and position were identified, and at the dominant ankle, values were significantly higher than those at the C7 vertebrae and the L5. Significant single-axis and group effects and effects of the interactions between the position and a single axis and the group and speed were also identified. The effect of dorsiflexion on the external load of the dominant ankle of both professional and amateur dancers existed only in the anteroposterior axis while dorsiflexion was related to the external load at the C7 and only amateurs were affected. Plantarflexion only affected the uniaxial contribution of the vertical axis of professional dancers. For professionals, the balance had a negative correlation with the external load at the L5. Asymmetry had a negative correlation with PL at L5. For amateurs, the balance had a negative correlation with PL with the DA, C7 and L5. Asymmetry had a positive correlation with PL at C7.

Study 1 revealed that the hotspots and trends of flamenco dance research with a visualization analysis based on 130 articles published from 1982 to 2021 in Scopus and Web of Science Core Collection with CiteSpaceV software, which included time distribution of published papers, Co-occurrence network of scientific research authors, institutions, regions, and keywords co-occurrence and strongest

citation bursts analysis as well. Over the past two decades, research has focused on cultural aspects, including identity and art, especially in Andalusia. Cultural studies in Flamenco dance have gained prominence due to its multicultural origins in Andalucia Spain (Palma et al., 2017) being recognized as Intangible Heritage of Humanity in 2010 and symbolizing Spanish culture. While Flamenco became professionalized only in the 1980s (Millán Vázquez de la Torre et al., 2019), a number of scholars tried to improve the recognition of flamenco as heritage at a political level, and efforts to establish it as a heritage symbol began in the 1990s, notably in Andalusia. (Machin-Autenrieth, 2015)

However, in recent years, researchers have shifted more attention from cultural and historical studies to more physical studies of dancers. Physical and biomechanical aspects as hotspots and trends. Firstly, flamenco dancers are required to have a high level of physical conditions (Forczek et al., 2017), and injuries and pain have been reported in them. Also, thanks to the advancement of research in the entire dance field, people are pursuing technical and aesthetic improvement in a more scientific way, and they have increased their awareness of physical health and injury protection. On the other hand, compared with the previous family-style or mentor-apprentice-style methods (Millán Vázquez de la Torre et al., 2019; Palma et al., 2017), the official organizations and institutes of development are more capable of academic research. Professional researchers who have been trained by institutionalization are more aware of scientific training methods. Meanwhile, flamenco has reached schools and universities, which could be also the reason that the psychological aspect may also be one of the trends for future studies.

A significant discovery in Study 2 is that PLTOTAL, PLUNI, and PL% all exhibited higher values at the DA compared to C7 and L5. This suggests that in the flamenco dance, particularly during the practice of footwork techniques, the ankle experiences greater loading and this heightened loading could potentially have implications for the risk of injury. PLML was also elevated at the DA. This increase may be attributed to the inherent foot imbalance when dancers practice the Zap-3 footwork. PLV exhibited higher values at the DA, which may be related to the specific body positions required during the practice of the Zap-3 footwork in which these positions necessitate more extensive movement in the vertical plane. PLAP

displayed increased values at the DA, potentially associated with the technique known as flamenco Zapateado. This technique involves knee flexion extensions, which could contribute to the heightened anterior-posterior loading. Lastly, our study revealed a noteworthy distinction at the DA concerning different axes. This disparity may be due to the comprehensive foot movements that occur in all three axes during the Zapateado dance routine.

While the PLTOTAL and PL% values for the C7 region in the flamenco Zap-3 test were lower compared to the DA, they were notably higher than those recorded in other dance assessments. For instance, in ballet, a specific choreographed routine consisting of five stages was executed by 10 participants, and the highest PL was observed during the fifth stage of this routine (Nagy et al., 2022). However, it's worth noting that even though the speed (measured in beats per minute) in the ballet and other tests was slower, these tests spanned 4 minutes in duration, which is a slower speed and longer time recorded than the Zap-3 test, the highest uniaxial PL and PL% values in ballet were lower than what we observed in the Zap-3 test. This leads us to infer that the cervical vertebrae may potentially experience a greater load during flamenco practices, possibly increasing the risk of injury from flamenco footwork. Indeed, other studies in the realm of flamenco have also reported a notable frequency of injury or discomfort in the cervical spine (Baena-Chicón et al., 2020; Pedersen & Wilmerding, 1998).

In terms of the external load on the L5, our study uncovered that the PLTOTAL, PLV, PLV%, and PLAP values were lower when compared to the DA but higher than those recorded at C7. The PLML and PLML% contribution for L5 were found to be lower than both C7 and DA. This observation suggests that there may be a reduced risk of injury associated with lateral (ML axis) loading, although it's important to consider that different mechanisms of spine injury can occur. Factors such as the direction of force (e.g., anterior–posterior, vertical, or medial–lateral) might play a crucial role in injury development. Prior research on injuries among flamenco dancers has reported a in risk of injuries of the lumbar spine (Baena-Chicón et al., 2020).

Regarding differences between professional and amateur flamenco dancers, our study demonstrated that a difference in external load occurs only at the fastest speed level and that the professional group had more external load than the amateurs for uniaxial PL. This difference may be because the professional group

had a higher fastest speed and their movement quality was higher. Professional dancers tend to strike the floor more forcefully to create louder sounds during footwork, resulting in increased ground reaction force (Forczek-Karkosz et al., 2021). Consequently, professional dancers may face a higher risk of injury during their footwork practice. In line with dancers' experience levels, M. Elizabeth Pedersen's research showed that professional flamenco dancers experienced more injuries compared to student flamenco dancers (Pedersen & Wilmerding, 1998). Similar findings have been reported in various other dance styles and sports (Campoy et al., 2011; Vetter & Symonds, 2010; Young & Paul, 2002).

About the difference between the speed levels, our study identified a main effect of speed ($p < 0.001$) in the case of PLTOTAL or uniaxial PL, and PLTOTAL increased with speed level. Additionally, a speed x position interaction ($p \leq 0.001$) between PLTOTAL and PL was also found. Post hoc analyses revealed that the differences became more pronounced as the speed increased. Furthermore, a group x speed interaction for uniaxial PL was also proven, indicating a significant difference at the fastest level between professional and amateur dancers ($p < 0.05$). This evidence, combined with the differences existing in group, position and axis effect suggests that the accelerometry technique demonstrated sufficient sensitivity during the Zap-3 flamenco dance footwork test.

Study 3 investigated the effect of AAROM on external load and the percentage contribution, the results demonstrated dorsiflexion and plantarflexion were associated with PLtotal, PLuni and PL% dependent upon the position of the accelerometer. Dorsiflexion had a positive correlation with DA-PLap, DA- PLap% for both groups and a negative correlation with C7-PLap% for the AM group. Therefore, during the footwork, a greater active dorsiflexion may produce greater external load in the anteroposterior plane of the DA, but less in the anteroposterior plane of C7. Dorsiflexion had a positive correlation with C7-PLv, C7-PLv% and C7-PLml%, but this correlation between dorsiflexion and PLtotal, PLuni or PL% did not exist in the DA positions in the vertical and mediolateral plane for both groups. Plantarflexion had a negative correlation with DA-PLv% and a positive correlation with C7-PLv %, in the PRO group only which may indicate that greater active plantarflexion may reduce the external load on the vertical plane of the DA but increase the external load on the vertical plane of C7. The location of the

accelerometer at the L5 position was not influenced by dorsiflexion or plantarflexion. This could potentially be due to L5 being located closer to the centre of mass of the body and enhanced stability.

Two of the ZAP-3 dance steps, Zapateado de Tacón (T) and Zapateado de Punta (PNT), involve striking the heel in dorsiflexion in front of the base of support, while the toes tap the floor in plantarflexion behind the support base. The ankle joint, with a range of motion (Mathias et al.) of 42° (from plantarflexion to dorsiflexion) during footwork, is the most mobile component of the locomotor unit. In contrast, everyday activities typically require a reduced ROM in the sagittal plane, with a maximum of 25° for walking (Forczek-Karkosz et al., 2021). This underscores the significance of ankle ROM in dance performance.

Study 3 investigated the effect of lower limb balance ability and asymmetry on the external load. For professional flamenco dancers, the results demonstrated DA-YBpl had a negative correlation with PLtotal, PLml and PLv at F speed level and at the L5 position. Therefore, during footwork, a greater DA-YBpl may produce less external load at the L5 position in total external load, mediolateral and vertical plane, and vice versa. The L5 position is crucial as it's closer to the body's centre of mass, and dancers must maintain stability while performing rapid footwork. Enhanced balance seems to contribute to lower external load at the L5 position, which is important for trunk stability connecting the upper and lower limbs. In contrast, there was no correlation between YBT (balance test) and external load in the DA, NDA, or C7 positions. This lack of correlation may be because professional dancers have relatively fixed movement patterns, developed over years of training, which minimizes the influence of YBT on PL in other body positions. For amateur dancers, the external load during Zap-3 footwork was more affected by balance ability. Firstly, NDA-YBcom had a negative correlation with DA-PLtotal and DA-PLv at the 180 bpm speed level, which could mean the greater YBcom of the non-dominant leg may produce less the external load for DA in PLtotal and vertical plane due to the characteristics of Zap-3 footwork, that requires one leg to maintain body stability while the other foot strikes the floor and quickly alternates the heel and tip of the toes. It is possible that the better the balance ability of the non-dominant leg, the more stable the dominant foot striking the floor and the lower the external load. The relationship between YBT and PL on C7 and L5

demonstrates a negative correlation. Compared with professional dancers, amateur dancers do not control the stability of the whole-body during footwork performance, and the instability at L5 and C7 will be more prominent and produce more vibration.

Our results demonstrated the bilateral asymmetry were associated with PL dependent upon the dance proficiency. For AM group AI-YBant had positive correlation with C7-PLap at the F speed level, which might equate to greater AI and may cause higher external load and potentially increase injury risk therefore reducing the difference between bilateral lower limbs could be favorable. However, the results for PRO group were conflicting, the correlation was negative for PRO group between AI-YBcom and L5-PLml, which means higher AI could lower externally load at the L5 position. This may be because, for professional dancers, less asymmetry or more stability may cause them to strike the floor with greater force to make a louder sound, thus producing more vibration. On the contrary, with higher asymmetry, the floor may be struck with greater force on only one side and less on the other, thus producing less vibration. Thus, lower AI could increase external load at L5 position could mean a better footwork technique because a better percussive footwork technique.

Accelerometer has already been used in sports or physical activity monitoring, as well as dance fields, to explore the physiological characterization of dance and physical activity levels during dancing (Bejjani et al., 1988; Bowen et al., 2019; Brogden et al., 2018; Moulder et al., 2021). Study 5 explained how to monitor flamenco dance movement with accelerometers by making a detailed introduction from aspects of accelerometer selection, monitor use protocols, and data process and analysis. Triaxial accelerometers were recommended to be used to monitor flamenco technique tests no matter what brand it is, which may be better than uniaxial accelerometry for dance movement. The use of accelerometers in dance performance is often used to monitor physical conditions over a period of time, it can be placed in different locations on the body and used in different settings depending on the problem to be studied.

About the flamenco dance test, in 1998, the Bejjani research group used two light-weight (2 g) skin-mounted unidirectional accelerometers (PCB 303; Power Supply 408), to record vibrations of hip and knee for ten flamenco dancers [8].

Voloshin et al, in 1989 recorded the amplitude of dynamic loading recorded on tuberosity, ant-sup. iliac spine with two light-weight (2 g) skin-mounted unidirectional accelerometers as well (Voloshin et al., 1989). However, the triaxial accelerometers were first utilized in our studies for investigating flamenco movement in biomechanical and health perspectives. Future studies could research flamenco dance by using accelerometers, such as the intensity of physical activity in different chapters of a choreographer, or the analysis of acceleration data and related factors of other variables to interpret the physiological characteristics of flamenco dance more fully.

IX - CONCLUSIONS

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Para cumplir con los criterios especificados en el Real Decreto 99/2011 para obtener la Mención Internacional en el Doctorado, las conclusiones de la tesis se presentan en español e inglés.

9.1. CONCLUSIONES EN ESPAÑOL

Este estudio demostró el marco del campo de investigación del baile flamenco utilizando el software CiteSpaceV para explorar los puntos clave de investigación y las tendencias del baile flamenco desde una perspectiva temporal, incluyendo la red de colaboración que abarca autores, instituciones, regiones y palabras clave. Se analizaron las características biomecánicas del baile desde la perspectiva de la carga externa en forma del concepto PlayerLoad, utilizando acelerómetros triaxiales teniendo en cuenta la velocidad, posición, eje y nivel de destreza de los bailarines de flamenco, e investigando el efecto de la amplitud activa de movimiento del tobillo, la capacidad de equilibrio de las extremidades inferiores y la asimetría en la carga externa comparando bailarines profesionales y aficionados. Además, esta tesis también explicó la aplicación de los acelerómetros en la investigación del baile flamenco con recomendaciones metodológicas y prácticas.

Las conclusiones de los estudios de la presente tesis se presentan a continuación:

Estudio 1:

- Los aspectos culturales, incluyendo la identidad y la investigación artística relacionada con el baile flamenco, especialmente en Andalucía, han sido uno de los puntos destacados en los últimos 21 años. Además, los aspectos biomecánicos y físicos se han convertido en temas de interés en el campo del baile flamenco, incluyendo la investigación sobre el cuerpo, la antropometría y la actividad física enfocada en el bailarín, y se espera que desempeñen un papel cada vez más importante en el futuro. Además, palabras clave como actividad física, imaginación motora, emoción y estilo han experimentado un aumento en interés en los últimos

tres años, por lo que es posible que los futuros estudios sobre el baile flamenco se centren también en aspectos psicológicos.

Estudio 2:

- Aunque las cargas externas en el tobillo dominante fueron significativamente más altas que en la séptima vértebra cervical y la quinta lumbar, estas vértebras cervicales y lumbares también soportaron cargas externas significativas causadas por las vibraciones derivadas del zapateado..

- El zapateado realizado durante el test Zap-3 produjo unas cargas externas significativas en diferentes posiciones, viéndose afectadas por la velocidad, el eje y el nivel técnico de las bailaoras de flamenco. Además, también se registraron vinculaciones significativos cuando esos factores interactuaban entre sí.

Estudio 3:

- El efecto de la dorsiflexión sobre las cargas externas del tobillo dominante de bailaoras profesionales y amateurs solo se registraron en el eje anteroposterior. En el caso exclusivo de bailaoras amateurs, la dorsiflexión manifestó relación también con las cargas externas registradas la séptima vértebra cervical. La flexión plantar solo afectó a la contribución uniaxial del eje vertical en las bailaoras profesionales.

- Las cargas externas a nivel del tobillo dominante y la séptima vértebra cervical, pueden predecirse en cierta medida midiendo la amplitud activa de movimiento del tobillo en bailarines profesionales y aficionados.

Estudio 4:

- Un Y-Balance Test más alto podría tener una carga externa menor en el tobillo dominante, la séptima vértebra cervical y la quinta lumbar, para bailarines aficionados, y el mismo efecto en bailarines profesionales solo en la quinta lumbar.

- La asimetría tuvo una correlación negativa con PlayerLoad en la quinta lumbar para profesionales. La asimetría tuvo una correlación positiva con PlayerLoad en la séptima vértebra cervical para aficionados. Un índice de asimetría más alto puede producir una carga externa menor para profesionales en la quinta

lumbar, pero aficionados pueden producir más carga en la séptima vértebra cervical.

- Las bailaoras amateurs son más susceptibles al efecto de la capacidad de equilibrio y una mejor capacidad de equilibrio puede producir una carga externa menor. Tener una buena simetría de equilibrio bilateral entre ambas extremidades tiene un efecto positivo en las bailaoras de flamenco. A las amateurs, les permite reducir las sobrecargas a nivel cervical y su riesgo de lesiones, y a las profesionales, les permite optimizar su técnica de golpeo percusivo.

Estudio 5:

- Se recomienda el uso de acelerómetros triaxiales para monitorizar pruebas de técnica de flamenco, ya que esta tecnología ha demostrado sus aplicaciones, siendo mejor que los acelerómetros uniaxiales para análisis del baile flamenco. El uso de acelerómetros en el rendimiento del baile se utiliza con frecuencia para monitorizar las condición física a lo largo del tiempo. La duración del período y la configuración de la prueba dependerán del objeto de estudio. Los datos registrados por los acelerómetros no solo pueden cuantificarse como cargas externas, sino que también pueden calcular otros conceptos como la intensidad de la actividad física.

9.2. CONCLUSIONS IN ENGLISH

This study demonstrated the framework of the flamenco dance research field utilizing the CiteSpaceV software to explore the research hotspots and trends of the flamenco dance from the time horizon, collaborate network incorporates authors, institutions, regions, and keywords. Analysed the dance's biomechanical characteristics from the perspective of external load in the form of the PlayerLoad concept by using triaxial accelerometers with consideration of speed, position, axis and proficiency level of the flamenco dancers, and investigated the effect of the ankle active range of motion, lower limb balance ability and asymmetry on the external comparing professional and amateur dancers. Additionally, this thesis also explained the accelerometer application in flamenco dance research with methodological and practical commendations.

The conclusions of the studies of the present thesis are presented following:

Study 1:

- The cultural aspects, including identity and art research related to flamenco dance, especially in Andalusia, which is one of the hotspots in the last 21 years. Furthermore, biomechanical and physical aspects have become the hotspots in the field of flamenco dance, including body, anthropometry, and physical activity research in the last years focusing on the dancer, and it is going to act as an increasingly significant character in the future. Besides, as physical activity, motor imagery, emotion, and style as keywords showed a burst in the last three years, the attention of future studies on flamenco dance might change to psychological aspects as well.

Study 2:

- Although the external load at the dominant ankle, values were significantly higher than those at the 7th cervical vertebrae and 5th lumbar, the lumbar and cervical vertebrae also bear some external load caused by significant vibrations.

- The Zap-3 footwork produced a significant external load at different positions, which was affected by speed, axis and the proficiency level of the flamenco dancer. Significant effects of the interactions between those factors were also identified.

Study 3:

- The effect of dorsiflexion on the external load of the dominant ankle of both professional and amateur dancers existed only in the anteroposterior axis while dorsiflexion was related to the external load at the 7th cervical vertebrae and only amateurs were affected. Plantarflexion only affected the uniaxial contribution of the vertical axis of professional dancers.

- The external load of the dominant ankle and the 7th cervical vertebrae can be predicted by measuring the ankle active range of motion of the dominant ankle to some extent in professional and amateur dancers.

Study 4:

- The higher Y-Balance Test could have a less external load at the dominant ankle, the 7th cervical vertebrae and 5th lumbar for amateur dancers, and the same effect on professional dancers only at 5th lumbar.

- Asymmetry had a negative correlation with Playerload at 5th lumbar for professionals. Asymmetry had a positive correlation with Playerload at the 7th cervical vertebrae for amateurs. A higher Asymmetry index may produce less external load for professionals at 5th lumbar, but amateurs may produce more external at the 7th cervical vertebrae.

- Amateur dancers are more susceptible to the effect of balance ability and better balance ability may produce less external load. Having good bilateral balance symmetry between both limbs has a positive effect on flamenco dancers. For amateurs it allows them to reduce overloads at the cervical level and their risk of injury, and for professionals it allows them to optimize their percussive tapping technique.

Study 5:

- Triaxial accelerometers were recommended to be used to monitor flamenco technique tests, which the equipment has been validated and may be better than uniaxial for dance movement. The use of accelerometers in dance performance are often used to monitor physical conditions over a period, the length of the period and the test setting depend on the problem to be studied. The data recorded by accelerometers cannot only be quantified as external load, but it could also be calculated in other concepts such as the intensity of physical activity.

X – LIMITATIONS AND FUTURE RESEARCH PERSPECTIVES

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The limitations of the present thesis must warrant careful consideration when interpreting its findings and implications.

- The relatively small sample size in study of flamenco footwork external load and its factors. The results may not fully represent the variability that exists in the broader population or provide robust statistical support for the observed outcomes.
- The position of accelerometers, this thesis only located sensors at position of C7, L5 DA, and NDA, but consideration of the injury and pain were also existed in other parts of body such as knee, it could be more comprehensive understanding with comparing more different sensor's locations.
- The effect of lower limbs and ankle active range of motion have been investigated in this thesis, but there may be another factor effect footwork techniques.
- This thesis only records accelerator data during only one type of flamenco footwork, the Zap-3 test footwork, even this Zap-3 includes many elements of flamenco footwork, but there still many different series step in flamenco choreography.

According to the result of this thesis and also considering the limitations which need to be addressed, perspectives of future research could be the following outlines. It could contribute to a deeper comprehension of the subjects explored in this thesis.

- To study the external load on different body positions, such as upper limbs or knees. That means the accelerometers could be placed on dancers in different locations at the same time.

- To investigate the external load involving various flamenco dance techniques, choreography, a period training section, a performance, or a rehearsal, which will be more closely aligned with the practical needs of dancers, offering them more actionable guidance.
- To explore potential factors influencing dancers' performance in biomechanical aspects, such as range of motion, muscular activity, and flexibility, and not only limited physical factors but also the impact of environment end equipment, variables such as different flooring materials and dance shoes.
- The data recorded by accelerometers cannot only be quantified as external load, but it could also be calculated in other concepts such as the intensity of physical activity.
- To involve more participants. Increasing the sample size in the study would enhance the reliability of the results.

XI – MENCIÓN INTERNACIONAL

XI - MENCIÓN INTERNACIONAL

The following are documents which approved and completed the International Stay:

Resolución Trámites | EIDUCAM

Estimada Ningyi,

A continuación le detallamos información y resolución a su solicitud de trámite solicitada.

Tipo de Trámite Solicitado	Nº Identificación	Curso Académico Solicitud	Fecha Trámite
Mención Internacional	287	2020/2021	03-mar.-22
Solicitante	**Programa Doctorado del Solicitante**		
Zhang ; Ningyi	Programa de Doctorado en Ciencias del Deporte		

Le informamos que la misma ha sido resulta.

Resolución Solicitud	Fecha Resolución
ACEPTADA	05-abr.-22

Sin otro particular, reciba un cordial saludo.

Escuela Internacional de Doctorado UCAM | EIDUCAM

THE UNIVERSITY OF SYDNEY

Dr Alycia Fong Yan
Senior Lecturer, Discipline of Exercise and Sport Science, Faculty of Medicine and Health

06 September 2022

Re: Ningyi ZHANG Certificate of internship completion

To Whom it May Concern,

This letter is to certify that Ningyi ZHANG has completed her internship (23 May – 23 August 2022) under my supervision.

Ningyi was a wonderful addition to our research group. She was hard working, professional, independent, efficient, and very receptive to learning new skills. Ningyi engaged with many aspects of the research culture at The University of Sydney during her stay.

She observed and assisted other students with their 3D motion capture data collection in the Sydney Biomechanics Laboratory, volunteered as a research participant for fellow PhD students, volunteered her body to assist with researchers updating their anthropometry accreditation, and was an active participant in the Neuromusculoskeletal Research Collaborative and Dance Research Collaborative research meetings.

Ningyi contributed immensely to the Backalast project through her research of 2D motion capture methodology, Kinovea software operations, piloting the filming set up for data collection, and troubleshooting the camera setup. She has written the manual of procedures for the data collection and Kinovea data analysis for this study. She contributed her insight and experience to team discussions and helped maintain progression of this project. Ningyi also assisted me with the screening of literature exploring the effect of dance interventions on psychological and cognitive health.

Ningyi benefitted from assisting me to host a small group of high school girls on campus as part of the Biomechanics Research Innovation Challenge. Ningyi learnt quickly how to facilitate the set up and collection of EMG data and demonstrated her skill at being a wonderful tutor engaging and guiding the girls through the practical activity.

I wish Ningyi all the best with her studies. Her short internship has demonstrated that she has a bright future ahead.

Yours sincerely,

Dr Alycia Fong Yan

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XII - REFERENCES

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XIII - APPENDICES

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ANEXO 1. Journal Indexation for Articles Published in this Thesis.

As stipulated in the regulations of the University of San Antonio de Murcia (UCAM), doctoral theses by Compendium have to collect a minimum of 4 articles (at least three already published and the fourth accepted). These articles must be published in journals with impact indexes in any of the quartiles of Journal Citation Reports (SCI and/or SSCI), SCOPUS, or related databases by the Comisión Nacional Evaluadora de la Actividad Investigadora (revistas científicas con sellos de calidad FECYT o el ranking Dialnet Métricas). The doctoral student must be the first or second author, in the latter case, the first must be the Thesis supervisor.

The indexation of the journals where the articles of this thesis have been published is presented below:

Cultura, ciencia y deporte (2022): SCOPUS - SJR 0.22 - Q3

Sensors (2022): Journal Citation Reports - JCR 3.9 - Q2; SCOPUS - SJR 0.76 - Q1

Archivos de Medicina del Deporte (2023): SCOPUS - SJR 0.15 - Q4

Revista del Centro de Investigación Flamenco Telethusa (2021) - Dialnet Métricas - IDR 0.14 - Q1

ANEXO 2. Study 1. Hotspots and Trends of Flamenco Dance Research: A CiteSpace Analysis.

Reference:

Zhang, N.Y., Gómez-Lozano, S., & Vargas-Macías, A. (2022). Hotspots and trends of flamenco dance research: A CiteSpace analysis. Cultura, Ciencia y Deporte, 17(53), 99-108. https://doi.org/10.12800/ccd.v17i53.1861

CULTURA, CIENCIA Y DEPORTE

Hotspots and trends of flamenco dance research: A CiteSpace analysis

Focos de interés y tendencias sobre la investigación en el baile flamenco: Análisis CiteSpace

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Short title:
Analysis of flamenco dance

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Abstract

Flamenco dance, which is increasingly internationalized and globalized, has a huge market demand all over the world and it has been popular and valued by researchers nowadays. Thus, hotspots and trends research is essential to provide information for industrial development and further development lines. Based on 130 articles published from 1982 to 2021 (database updated on 4 December 2021) about flamenco dance in Scopus and Web of Science Core Collection, this research by using CiteSpaceV software explored the research hotspots and trends of the flamenco dance from the time horizon, collaborate network incorporates authors, institutions, regions, and keywords. Result: The number of publications shows an upward trend with fluctuations Since 2008. 9 main research groups are formed. The University of Seville is the most prolific institution and the Saint Anthony Catholic University of Murcia ranks the highest centrality. Spain is the highest yield region. The hotspots included cultural aspects, which include identity and art in Andalusia, as well as biomechanical and physical aspects, including body, anthropometry, and physical activity focusing on dancers. The trend of this field will be physical and psychological aspects. Conclusion: future research may focus on the body and psychological aspects.

Keywords: flamenco dance, visualization analysis, CiteSpace, hotspots, trends.

Resumen

El baile flamenco se encuentra cada vez más internacionalizado y globalizado, teniendo una enorme demanda de mercado a nivel mundial. Actualmente es un campo de estudio para investigadores y profesionales del arte flamenco. Así, las zonas de referencia y tendencias en la investigación sobre el baile flamenco son esenciales para proporcionar información para el desarrollo industrial y futuras líneas de desarrollo.La muestra se basó en 130 artículos publicados desde 1982 hasta 2021 (base de datos actualizada el 4 de diciembre de 2021) sobre baile flamenco en las bases de datos de Scopus y Web of Science Core Collection. El análisis se realizó mediante el uso del software CiteSpaceV. Se exploraron los focos de interés y las tendencias de investigación en el baile flamenco desde el horizonte temporal. La red de colaboración incorpora autores, instituciones, regiones y palabras clave. Resultados: el número de publicaciones muestra una tendencia al alza con fluctuaciones desde 2008. Se forman 9 grupos de investigación principales. La Universidad de Sevilla es la institución más prolífica y la Universidad Católica San Antonio de Murcia ocupa el puesto de centralidad más alto. España es la región de mayor rendimiento. Los focos de interés incluyeron aspectos culturales, que incluyen la identidad y el arte en Andalucía, así como aspectos biomecánicos y físicos, incluidos el cuerpo, la antropometría y la actividad física centrada en los bailarines. La tendencia de este campo se basa en aspectos físicos y psicológicos. Conclusión: Investigaciones futuras pueden centrarse en aspectos corporales y psicológicos.

Palabras clave: baile flamenco, análisis de visualización, CiteSpace, focos de interés, tendencias.

Introduction

"Flamenco baile is a dance of passion, courtship, expressing a wide range of situations ranging from sadness to joy." (UNESCO, 2010). It has a history of more than 200 years and it is commonly considered that it is the result of the integration of multiple cultures which have developed in Andalusia (Machin-Autenrieth, 2015; Moon, 2015; Palma et al., 2017). It was listed as Intangible Heritage of Humanity in 2010 and has become the culture feature of Spain, which has been widely spread and recognized on the world stage and has attracted an increasing number of enthusiasts all over the world like United States, the United Kingdom, France (Cuellar-Moreno, 2016; De Santiago, 2018; Diamond, 2018). The impact of flamenco dance has been increasing by the international market demand (Aoyama, 2007), it has been proofed by universities' program between different countries, and activities or festivals and cultural tourism over continents (García et al., 2019; Palma, Palma, Rodríguez, Martín, & Cascajo, 2017). It also popular in Asia, like South Korea, the Philippines, Singapore, more and more practitioners are from China, and Japan has the largest number of amateurs and dancers of flamenco (Aoyama, 2007; Diamond, 2018).

Previous research studied the biomechanical aspect of flamenco dance generally related to footwork technique analysis with professional dancers as subjects described the average values of the vertical component of ground reaction force, analyzed the range of motion in lower limbs joints and pelvis (Forczek-Karkosz et al., 2021), demonstrated the smooth oscillations of the centre of mass in all three trajectory planes, which provide theoretical information to flamenco dancers and teachers (Forczek, Chicón, & Vargas-Macías, 2016). In terms of injury research, pains and injuries have been reported in professional flamenco dancers and students, and indicated knees, lumbar and cervical spine shows high incidence (Baena-Chicón et al., 2020). Already early studies such as those by Bejjani et al., 1988 suggested it may be caused by the huge vibrations accompanying the flamenco dance form. Considering physiological aspects, previous studies described the energy requirements of flamenco dancers by testing aerobic and anaerobic capacities, indicating flamenco dancers have those two both and have a substantial anaerobic power output, which is meaningful for developing training strategy (Pedersen, Wilmerding, Kuhn, & Enciñias-Sandoval, 2001). Meanwhile, the data on the average heart rate and maximal oxygen consumption of professional flamenco dancers have been described. It proved great physical workloads requirement in flamenco dance (González et al., 2011). However, there are still many limitations to applying flamenco in biomechanics or physiology, and fewer studies covered the holistic perspective of flamenco movement (Forczek et al., 2017). Some articles involved psychological analysis of flamenco participants. There is evidence that shows both students and professionals displayed higher levels of helplessness than those who were only students, and anxiety states which can be triggered by the artistic professional development on stage before spectators may relate to the levels of catastrophism (Baena-Chicón, Gómez-Lozano, Cano, & Vargas-Macías, 2021). Meanwhile, there is research that studied Brazilian female flamenco dancers and indicated 64.7% of participants were not satisfied with their bodies though they had high self-esteem (Nakamura, Juzwiak, de Almeida, & Montesano, 2012). Relating to the perspective of flamenco culture, tourists use the dance expression as a positive factor for self-esteem self-expression, and self-exploration, also, as a way to differentiate themselves from other groups (Matteucci, 2014). One empirical study focused on ethnography recorded from a martial arts club and a flamenco class, observing, recording filming and participating in the classes they found trans-situational practice, matching and combining situations and communications, can explain ethnography to some extent, for better understanding other social practices for sociological reasons, and being able to reconstruct it (Schindler, 2018). However, there is few studies have looked at review of flamenco's academic research field which could enable us to better understand the development and phenomenon of flamenco dance.

Through Citespace software, we can make a comprehensive review of the academic research status and hotspot of flamenco field and infer future research trends and what we can see more clearly than other types of review is that this software shows the hotspots and trend in visualized analysis. CiteSpace, commonly advanced by Dr Chen Chaomei, is an intellectual visualization software for analysing and visualizing co-citation networks (Chen, 2006). It was designed to behaviour the visualization electric network. The collaborate networks incorporate authors, institutions, and regions; the co-occurrence network includes terminology, keywords, and categories. The collaborate network is to manifest the community connection with author, organization, and district in a study field; the co-occurrence network is to uncover the development of study hotspots and trends (Chen et al. 2014; Chen, 2005).

Therefore, the objective of this study, with using of the CiteSpaceV software is to analyse and review the flamenco researches, which enables the development of flamenco dance research since 1982 to 2021 to be reported precisely and visually and provides reference information for the further research of flamenco dance in the future.

Materials and methods

The information was gathered from the Scopus and Web of Science Core Collection. This study strategy is used for the research without publishing time limitation: TOPIC: (flamenco) AND TOPIC: (danc* OR baile) AND LANGUAGE: (English OR Spanish) AND DOCUMENT TYPES: (Article OR Review). After the initial screening, 114 related documents were retrieved in WOS, 107 in the Scopus. After removing duplicates and screening records, there are 130 publications in total, database updated on 4 December 2021.

CiteSpace# were used to parse the literature in this research. It is an intellectual visualization software commonly advanced by Dr Chen Chaomei. It was made use for behaviour visualization electric network. The collaborate network incorporates authors, institutions, and regions; the co-occurrence network includes terminology, keywords, and categories. The collaborate network is to manifest the community connection with author, organization, district in a study field; the co-occurrence network is to uncover the development of study hotspots and trends (Chen et al. 2014). Co-citation is defined as the third article citing two references, it can be one case of co-occurrence, which can include co-occurrence words, as well as co-author, co-region. A reference may be cited for many purposes or for different reasons (Chen, 2013; White & McCain, 1998). However, the cited literature may be cited in a manner similar to the function of citing underlying concepts. Therefore, the visualized map from CiteSpace can identify the structure of patterns and trends and the dynamics of the underlying scientific literature (Braam, Moed, & Van Raan, 1991). The citation tree rings show the

citation history of an article. The ring's colour indicates the corresponding citation time. The thickness of the ring is proportional to the number of references in a given period (Chen, 2013).

The 130 documentations downloaded were inputted into the CiteSpace 5.5.R2 software for bibliographic analysis with the time spacing set from 1982 to 2021 (130 records), and content analysis with the time span set 2000 to 2021 (114 records), both with the time part of a place as one piece each year. The nodes of the author, organization, region, and keyword were selected. Selection criteria were g-index, k=15.

Results

Bibliographic analysis

1 Time distribution of published papers

The relationship between the number and time of published papers can reveal the research history and development speed in this field and predict its development trend. The time distribution of published papers in the field of flamenco dance research is shown in Figure 1.

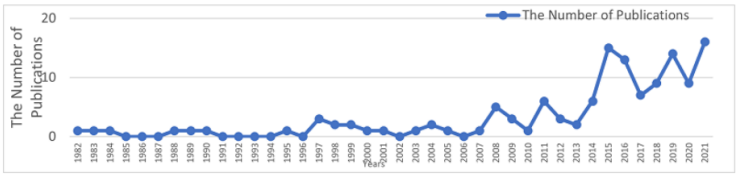

Figure1. The number of publications on flamenco dance per year from 1982 to 2021

It can be seen that the research papers on flamenco dance were first published in 1982. However, before 2008, researchers did not pay enough attention in this field, there are at most 3 articles published a year. Since 2008, it shows an upward trend with fluctuations even though the most was only 16 articles in 2021. While it also saw a surge in 2015 with 15 records and in 2019 with 14 records.

2 The co-occurrence network of scientific research authors

CiteSpace is only being equipped with use of counting the quantity of the first writers, so the writer is referred to underneath all first writers. Table 1 lists the authors with further than 2 articles. Alfonso Vargas-Macías, with 5 articles. Luis Gadea-Mateos, Alba Paris-Alemany and F.J. Bejjani with 3 articles, respectively.

Table 1. High-yield authors in the flamenco dance research

Author	Frequency
Alfonso Vargas-Macias	5
Luis Gadea-Mateos	3
Albea Paris-Alemany	3
F.J. Bejjani	3

As shown in Figure 2, 179 researchers (N = 179) participate in the related researches of flamenco dance, and they have 242 (N = 242) research cooperation of varying degrees, showing that 24 groups with at least 3 members are formed in the field, 9 of them have more than 2 publications and show relatively stable.

Hotspots and trends of flamenco dance research: A CiteSpace analysis

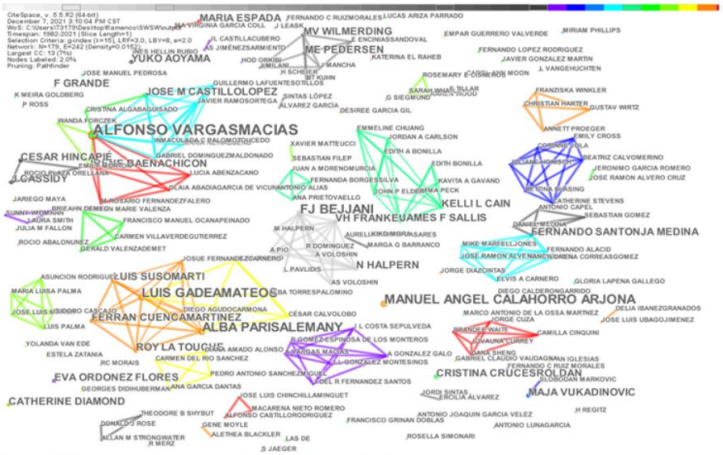

Figure 2. The co-occurrence network of authors in the flamenco dance research

It also can be seen from Figure 2, Alfonso Vargas-Macías, as a professor at the Telethusa Centre for Flamenco Research, has involved three teams and formed the largest research cooperation network in the field of flamenco dance. They focused on the aspects of biomechanics, podiatry, and injury of flamenco dance. One of the most cited articles is Metatarsal Pain and Plantar Hyperkeratosis in the Forefeet of Female Professional Flamenco Dancers (Castillo-López et al.,2014). The group of Fernando Santonja Medina did researches in the same area as well, such as Magnetic Resonance Study of Lumbar Disks in Female Dancers (Capel et al.,2009) and Comparison of two field methods for estimating body fat in different Spanish Dance disciplines (Alvero-Cruz et al., 2014). F.J. Bejjani with other members as a team also focused on the biomechanics aspects, publishing articles such as Musculoskeletal demands on flamenco dancers: a clinical and biomechanical study (Bejjani et al., 1988). Cain, K.L group studied on the physiological aspects, such as Physical activity in youth dance classes (Cain et al., 2015), as well as ME Pedersen group, which did research about energy requirement, plantar flexion and dorsiflexion strength in flamenco, such as Energy requirements of the American professional flamenco dancer (Pedersen et al., 2001) and Measures of plantar flexion and dorsiflexion strength in flamenco dancers (Pedersen et al., 1999). Alba Paris-Alemany with other researchers as a group focused on the motor image published, such as Visual-motor imagery predominance in professional Spanish dancers (Paris-Alemany et al., 2019). It can be seen that most of these groups focus on biomechanical and physical research.

3 The co-occurrence network of scientific research institutions

The authors' institutions which have more than 3 articles are listed in Table 2. The University of Seville with 8 articles are the most prolific institution, followed by the University of Granada with 7, Saint Anthony Catholic University has 6 publications as well as International University of La Rioja. And Telethusa Centre for Flamenco Research has 5, University of Malaga and Rey Juan Carlos University published 4 articles respectively. It shows the main research institutions are universities in different regions.

Table 2. High-yield institutions in the flamenco dance research

Institution	Frequency	Centrality
Univ Seville	8	0.05
Univ Granada	7	0
Univ Int La Rioja	6	0
Univ Catolica San Antonio Murcia	6	0.14
Ctr Invest Flamenco Telethusa	5	0.02
Univ Malaga	4	0.02
Univ Rey Juan Carlos	4	0.09

According to Figure 3, there are 82 (N=82) institutions involved in flamenco dance research, and these research institutions have 91 cooperations (E = 91). In the network, the density is 0.0274, which shows the cooperation network of scientific research institutions is relatively stable. However, as table 2 shows, in the largest groups, the centrality value of Saint Anthony Catholic University is 0.14, Rey Juan Carlos University with 0.09, The University of Seville with 0.05, University of Malaga and Telethusa Centre for Flamenco Research with 0.02, the rest all as 0.00

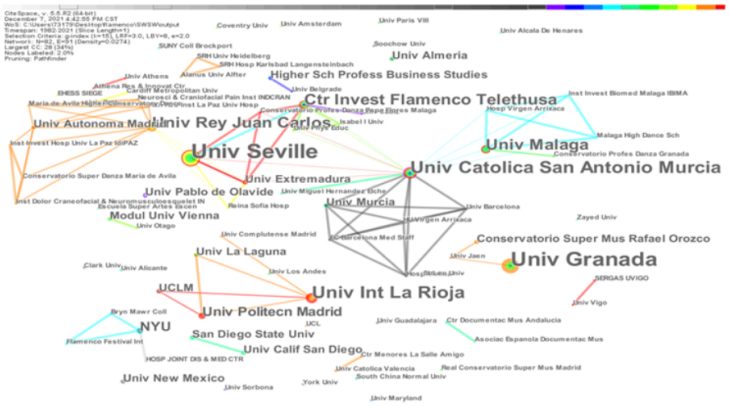

Figure 3. The co-occurrence network of institutions in the flamenco dance research

4 The co-occurrence network of scientific research region

As Table 3, Spain, as a place where flamenco developed, ranks the top with 60 publications. The second is the USA with 15. France and England with 3, respectively. Other regions which did not list on the table made little contribution. As Figure 4 shows, there is less cooperation research between regions.

Table 3. High-yield regions in the flamenco dance research

Region	Frequency
Spain	60
USA	15
France	3
England	3

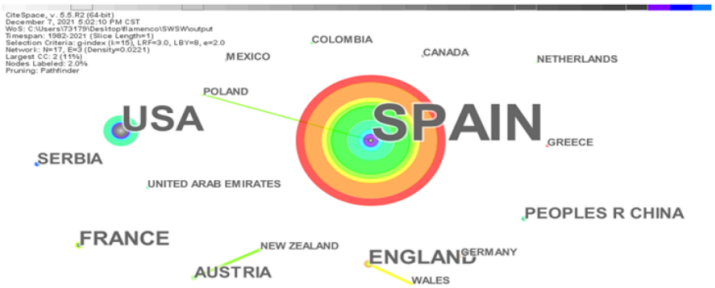

Figure 4. The co-occurrence network of regions in the flamenco dance research

Content analysis

1 Keywords co#occurrence analysis: thematic hotspots

As shown in Table 4 and Figure 5, "flamenco" has the largest nodes with 25 frequencies in the co-occurrence network, which is closely related to the keyword "dance", "flamenco dance". "Physical activity" is the 3rd on the list with 8 frequencies as well as "dancer". Followed with "body" with 7 frequencies. Other keywords whose frequency is more than 3 and less than 6 in the field are "culture" "identity" "pain" "Andalusia" "biomechanics" and "art".

The High-centrality keywords in the flamenco dance research. "Flamenco" (0.43) "dance" (0.42) and "dancer" (0.24) ranked the top 3 of the high-centrality keywords, while "art" (0.22) "body" (0.15) "anthropometry" (0.15) "physical activity" (0.12) are also the keywords whose centrality is more than 0.10. "injury" (0.09) "flamenco dance" (0.06) "Andalusia" (0.06) and "motor

imagery" (0.05) are also high-centrality keywords but less than 0.10 and more than 0.04. Combining with Tables 4 and Figure 5, it can be seen that there are two main hotspots in the last 21 years.

1) Biomechanical and physical aspects, as related keywords are "body", "anthropometry" "physical activity" "injury" "pain" and "biomechanics", focusing on "dancer", such as articles Physical Activity in Youth Dance Classes (Cain et al., 2015), Comparison of two field methods for estimating body fat in different Spanish Dance disciplines (Alvero-Cruz et al., 2014), Analysis of selection criteria in the access tests to official Dance Studies (Parent et al., 2016), Algias as a predisposing factor of injury in flamenco dance students (Baena-Chicón et al., 2020), Receptiveness of Spanish and Flamenco Professional Dancers in Their Training and Development (De las Heras-Fernández et al., 2020).

2) Cultural aspects, including related keywords "culture", "identity" "art" and related about "flamenco dance", especially in "Andalusia". Such as Domains of public activity in touristic flamenco shows (Wieczorek, 2017), Identity, Migration, and the Arts: Three Case Studies of Translocal Communities (Smith et al., 2011), Artists, Tourists, and the State: Cultural Tourism and the Flamenco Industry in Andalusia, Spain (Aoyama, 2009)

Table 4. High frequency and centrality keywords in the flamenco dance research

Frequency	Centrality	Keyword
25	0.43	flamenco
19	0.42	dance
8	0.12	physical activity
8	0.24	dancer
7	0.06	flamenco dance
7	0.15	body
5	0.01	culture
5	0.01	identity
5	0.01	pain
4	0.06	Andalusia
4	0.02	biomechanics
4	0.22	art

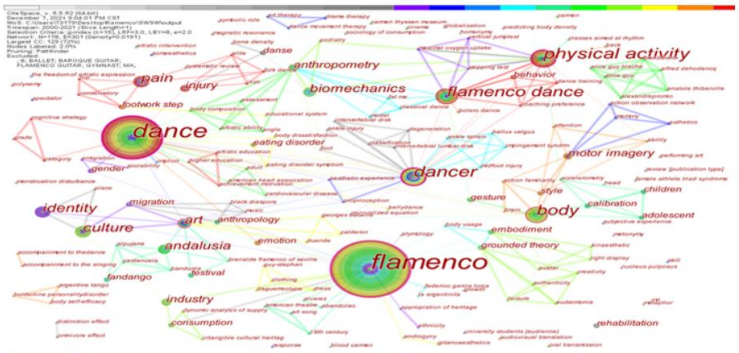

Figure 5. The co-occurrence network of keywords in the flamenco dance research

2 Strongest citation burst analysis: thematic trends

As Table 5 shows the strongest citation bursts of keywords in the field of flamenco dance, it can be seen that "body" shows the strongest burst from 2015 to 2021. "Physical activity", "motor imagery", "emotion" and "style", show a burst in the last three years. It indicated that the attentions of future studies on flamenco dance may pay to physical and psychological research.

Table 5. The keywords with the strongest citation bursts in the flamenco dance research

Keywords	Year	Strength	Begin	End	2000 - 2021
rehabilitation	2000	1.1761	2008	2010	
pain	2000	1.1672	2008	2011	
danse	2000	1.1761	2008	2010	
migration	2000	1.088	2009	2011	
identity	2000	2.76	2009	2011	
gender	2000	1.2439	2011	2011	
biomechanics	2000	1.1397	2014	2014	
Andalusia	2000	1.8822	2015	2016	
fandango	2000	1.1558	2015	2015	
body	2000	1.3214	2015	2021	
flamenco	2000	1.2649	2015	2016	
festival	2000	1.1558	2015	2015	
calibration	2000	1.1558	2015	2015	
adolescent	2000	1.1558	2015	2015	
children	2000	1.1558	2015	2015	
dance	2000	2.133	2016	2021	
gesture	2000	1.1761	2016	2016	
industry	2000	1.1001	2017	2017	
culture	2000	1.6147	2017	2017	
physical activity	2000	1.3459	2019	2021	
motor imagery	2000	1.1205	2019	2021	
emotion	2000	1.21	2019	2021	
style	2000	1.21	2019	2021	

Discussion

This study revealed that the hotspots and trends of flamenco dance research with a visualization analysis based on 130 articles published from 1982 to 2021 in Scopus and Web of Science Core Collection with Citespace# software, which included time distribution of published papers, Co-occurrence network of scientific research authors, institutions, regions, and keywords co-occurrence and strongest citation bursts analysis as well.

"Cultural", "physical" and "biomechanical" researches as hotspots and trend over the world in the flamenco field

It is not difficult to predict that "cultural" study is one of the hotspots. First of all, it is a multi-cultural background art product integrated and developed in the Andalucia region in Spain with various elements (Palma et al., 2017) and it was listed as Intangible Heritage of Humanity in 2010 and has become the culture feature of Spain. Secondly, even though flamenco was considered a marginal art for Spanish society and it is not until the 1980s that the form was professionalized (de la Torre, Lara, & Arjona-Fuentes, 2019), a number of scholars tried to improve the recognition of flamenco as heritage at a political level since 1990s, and it was chosen as a symbol of regional cultural development and a prominent symbol of Andalusian identity (Machin-Autenrieth, 2015). Therefore, the cultural aspects, including identity and art research related to flamenco dance, especially in Andalusia, is one of the hotspots in the last 21 years. Furthermore, Flamenco promotes tourism in Spain, as an important part of cultural tourism, it has attracted many people and creates a huge global market demand (de la Torre et al., 2019; García et al., 2019). So, to find the way to improve the experience to the tourists, bringing the emotion and also living it (García et al., 2019), some researches about "cultural" aspect was studied.

We can also notice that these researches are not only in Spain, there are also some from different regions. It is widely popular in the United States, the United Kingdom, France, and other Europe countries (Machin-Autenrieth, 2015; Palma et al., 2017). as well included regions like Mexico, Poland, Canada according to results of this research. Except for tourism, emigration could also be a reason of this popularization. Some of emigrants from Spain developed flamenco where they stayed. They devised training program, run restaurants, bars and related activities which is a medium to bonds between them (Ruiz-Morales, 2011). Activities are formed through individual groups, universities and communities related to flamenco dance, which not only expands social identity and strengthens regional identity, but also developed the flamenco culture world widely (Crespi#Vallbona & Richards, 2007; García et al., 2019). Eva Encinias Sandoval, who built the flamenco program at the the University of New Mexico, could be a great example. She wove flamenco into the cultural fabric of New Mexico and started Festival called "Flamenco de Alburquerque" which draws audiences and dancers. Additionally, in both the United States and Canada in the first half of the century also the intangible cultural heritage such as the art of flamenco has been moved (Briseno, 2021). Flamenco dance is popular in Asia as well, South Korea, the Philippines, Singapore, more and more practitioners are from China, and Japan has the largest number of amateurs and dancers of flamenco (Aoyama, 2007). This phenomenon may be caused by globalization. There were universities' program between different countries, and activities or festivals and cultural tourism over continents. On the contrary, unlike emigration or social identity, the main reason why it became popular in Japan is that it has a completely different culture from flamenco. The culture of Japan is opaque with its highly codified gestures in the observance of which propriety represses emotion to preserve a calm exterior of social harmony (Diamond, 2018). In the 21st century

in Japan, although many women have achieved economic independence, they still suffer from gender discrimination. Therefore, flamenco can express strong emotions and it does not necessary a partner, which is also a reason for its popularity in Japan (Diamond, 2018).

About "physical" and "biomechanical" aspect as hotspots, there are some main reasons. Flamenco dance has its unique characteristics with strong emotion and the footwork technique (Baena-Chicón, Gómez-Lozano, Cano, & Vargas-Macías, 2021), which requires dancers strike the floor to make a loud and rhythm voice (Vargas-Macías et al., 2021). Therefore, dancers were usually required to have a high level of physical conditions (Forczek, Baena-Chicon, & Vargas-Macias, 2017), there is research indicate that the require is similar to those of elite sports (Pedersen, Wilmerding, Kuhn, & Enciñias-Sandoval, 2001). Meanwhile, some research investigated as well the injury frequency of flamenco dancers and deduced that the pain and injuries on lower limbs and back may be caused by the model of footwork movement (Castillo-López et al., 2014; Pedersen, Wilmerding, & Science, 1998). Therefore, the biochemical and physical descriptions and relevant studies have been demanded to be researched, in order to prevent the injury or pain and improving dance performance. On the other hand, thanks for the advancement of research in the entire dance field, people are pursuing technical and aesthetic improvement in a more scientific way, and they have increased their awareness of physical health and injury protection. Also, compared with the previous family-style or mentor-apprentice-style methods (de la Torre et al., 2019; Palma et al., 2017), the official organizations and institute of development are more capable of academic research. The professional researchers who have been trained by institutionalization are more aware of scientific training methods. Meanwhile, flamenco has reached schools and universities, that could be also the reason that "psychological" aspect may be one of the trends for future studies. Therefore, biomechanical and physical aspects have become the hotspots in the field, including body, anthropometry, and physical activity research focusing on dancers, and it is going to act as an increasingly significant character in the future.

Comparing with related researches with Citespace software

There is limited research currently existing on research hotspots and trends in flamenco dance, but some articles have been reported to explore hotspots and trends related to other style dance fields. For instance, the article Quantitative Analysis on Research Trends of Dance Sport at Home and Abroad (Ma & Huang, 2019) studied on the hotspots and trends of DanceSport (Latin dance and Ballroom dance) research, including 61 records (1990-2018) with Citespace# as well, which has been found that the number of articles related to DanceSport published in Web of Science database, shows a skipping trend of rising since 2007, which is similar with flamenco dance time range in this article. Furthermore, another similar result is that in co-occurrence network of scientific research authors and institutions aspects, both of DanceSport and flamenco dance research show that although the number of research groups is less, there are some groups relatively stable, and the main research institutions are universities in different regions.

By contrast, the difference between DanceSport and flamenco dance researches is that the main research regions, Spain and the USA ranked the top of flamenco research, while the UK and the USA were the main regions in DanceSport research area. It may be due to the origin and level of development of those two styles of dance. Additionally, in terms of hotspots and trends, DanceSport researchers focused on the exercise, health, and disease interventions of adolescence and the elderly, while flamenco researchers draw more attention to the biomechanical and physical aspects as well as the psychological aspects of dancers.

Comparing with related researches with other statistical methods

Some bibliometric analysis about the dance field has been documented with other statistical methods: information was downloaded into spreadsheet software (Microsoft Office Excel), and additional coding was manually performed for all analysis. For example, Publications in dance field in Arts & Humanities Citation Index: a bibliometric analysis (Ho & Ho, 2015) and A bibliometric analysis of dance performance reviews in the dance category of the Web of Science (Wang & Ho, 2019), these two with this method analysis about dance research and dance reviews respectively, based on Arts & Humanities Citation Index database of the Clarivate Analytics' Web of Science Core Collection.

According to the results in the face of the authors, they all indicated that most of the authors are single-authors. Interestedly, comparing with this study of flamenco dance research that the number of relatively stable groups was few to 9. That might mean researchers in the dance area should strengthen cooperation in the future. Furthermore, Huei-Chen Ho has also found that "body" and "education" were new popular words in article titles. Similarly, "body" is also one of the high-frequency keywords with high-centrality in flamenco dance research. Simultaneously, a common result of those two above articles about dance research and review is that "Ballets" is the main area for current dance researches and reviews, which may partially indicate that other dance style research needs to be studied in the future. Even though those above two pieces of research included more records of the data, they had limited to the bibliometric analysis including aspects of publication language, output, authors, journals, and distribution of words in the article title. Rather, this article, researching flamenco dance with Citespace#, can more clearly show the bibliographic and visual analysis evolution, hotspots, trends in Co-occurrence network and keywords with the strongest citation bursts.

Conclusion

CiteSpace software applies to fix quantify analyse added apparently, intuitionistic, and objective. Precise algorithms can analyse the hotspots, trends, knowledge base, and high-quality literature. Although the data recorded in this study are only 130 publications, hotspots and trends in the field of flamenco dance could be detected, this research could manifest the start, bursts, high-centrality and frequency reveal the evolutionary trends of hotspots. Based on the above analyse, the following conclusions can be drawn:

From the bibliographic analysis, the number of announced works in this field shows a growing trend in 2008 and reaches its peak by 2021. From the scientific research authors, Alfonso Vargas-Macías is the highest yield author in flamenco dance research, followed by Luis Gadea-Mateos, Alba Paris-Alemany and F.J. Bejjani. 9 research cooperative groups which have more than 2 publications and at least 3 authors are formed in the field of flamenco dance research, and most of these groups focus on biomechanical and physical research. In terms of scientific research institutions, The University of Seville with 8 articles is the most prolific institution and Saint Anthony Catholic University ranks the highest centrality value. Main research institutions are universities in different regions.

The cooperation network of scientific research institutions is relatively stable. Spain and the United States are high yield regions.

From the content analysis, the cultural aspects, including identity and art research related to flamenco dance, especially in Andalusia, which is one of the hotspots in the last 21 years. Furthermore, biomechanical and physical aspects have become the hotspots in the field of flamenco dance, including body, anthropometry, and physical activity research in the last years focusing on the dancer, and it is going to act as an increasingly significant character in the future. Besides, as physical activity, motor imagery, emotion, and style as keywords showed a burst in the last three years, the attention of future studies on flamenco dance might change to psychological aspects as well.

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ANEXO 3. Study 2. External Load of Flamenco Zap-3 Footwork Test: Use of PlayerLoad Concept with Triaxial Accelerometry.

Reference:

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sensors

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Article

External Load of Flamenco Zap-3 Footwork Test: Use of PlayerLoad Concept with Triaxial Accelerometry

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Abstract: The intense footwork required in flamenco dance may result in pain and injury. This study aimed to quantify the external load of the flamenco Zapateado-3 (Zap-3) footwork via triaxial accelerometry in the form of PlayerLoad (PL), comparing the difference in external loads at the fifth lumbar vertebra (L5), the seventh cervical vertebra (C7) and the dominant ankle (DA), and to explore whether the speed, position, axis and proficiency level of the flamenco dancer affected the external load. Twelve flamenco dancers, divided into professional and amateur groups, completed a 15-s Zap-3 footwork routine at different speeds. Triaxial accelerometry sensors were positioned at the DA, L5 and C7 and were utilized to calculate the total PlayerLoad (PLTOTAL), uniaxial PlayerLoad (PLUNI) and uniaxial contributions (PL%). For both PLTOTAL and PLUNI, this study identified significant effects of speed and position ($p < 0.001$), as well as the interaction between speed and position ($p \leq 0.001$), and at the DA, values were significantly higher ($p < 0.001$) than those at C7 and L5. Significant single axis and group effects ($p < 0.001$) and effects of the interactions between the position and a single axis and the group and speed ($p \leq 0.001$) were also identified for PLUNI. Medial-lateral PL% represented a larger contribution compared with anterior-posterior PL% and vertical PL% ($p < 0.001$). A significant interaction effect of position and PL% ($p < 0.001$) also existed. In conclusion, the Zap-3 footwork produced a significant external load at different positions, and it was affected by speed, axis and the proficiency level of the flamenco dancer. Although the ankle bears the most external load when dancing the flamenco, some external load caused by significant vibrations is also borne by the lumbar and cervical vertebrae.

Keywords: triaxial accelerometry; dance; flamenco footwork; external load; PlayerLoad

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1. Introduction

Flamenco dance is performed with strong emotional expression, and its footwork techniques, which include striking the floor with a loud and rhythmic sound, make it different from other dance genres [1,2]. The physical effort demanded in performing flamenco is similar to that of elite sports [3–6]. Therefore, practicing the required footwork in flamenco may cause chronic repetitive pain and injuries of the feet, knees and spine, mainly at the lumbar and cervical levels [4,7–12]. Previous studies regarding flamenco's technical movements have focused on analyzing them from the perspective of electromyography, kinematics and epidemiology [9,13–15]. However, questionnaires and labor-intensive methods were often used in these studies. Normally, labor-intensive methods test one subject and cannot provide real-time live feedback [16]. These shortcomings, along with the vast amounts of data downloaded and analyzed in a single study [17], have raised questions about the ability of these technologies to influence everyday dance practices.

Triaxial accelerometers are motion sensors used to detect movement in three planes of movement (medial-lateral, anterior-posterior and vertical) and therefore to provide data regarding the magnitudes and frequency of movement. The concept of PlayerLoad (PL) enables the measurement of a vector modified algorithm proposed by the technological company Catapult Sports, utilizing a micro-electrical mechanical system. It is expressed as the square root of the sum of the squared instantaneous rates of change in acceleration for each of the three vectors (medial-lateral, anterior-posterior and vertical) divided by 100. This technology requires highly responsive motion sensors to record movement along these vectors. The micro-electrical mechanical system device contains a triaxial piezoelectric linear accelerometer that samples at a frequency of 150 Hz, therefore providing the opportunity to quantify movement performance. Due to its low user dependence, PL has been used in various physical activity tests to describe the external load [18–21] and is associated with sports training and competition for a broad range of athletes. Within dance research, PL has also been used extensively to quantify the external load or mechanical load and the relationship with dance injuries [22–24]. Nagy [25] investigated within-day and between-day loading responses to ballet choreography and reported that PL is sufficiently sensitive for use with a progressive routine and that accelerometers are effective for athlete monitoring and injury screening protocols, supporting previous work indicating that triaxial PL was sensitive enough to detect the increased loading associated with increases in exercise intensity when quantifying PL, PLUNI and PL% [17].

In summary, future research regarding the external load during the footwork routines of flamenco dance is required to provide medical practitioners, coaches and dancers with a theoretical basis for the effective management of training programs, to reduce injury risk in accordance with the proficiency levels of dancers and to provide a feasible method for assessing flamenco footwork techniques. Furthermore, Zapateado-3 (Zap-3) is a topical issue surrounding flamenco footwork. It is widely used to analyze flamenco technique and associated movements [4,13,20]. Therefore, this study aimed to quantify the external load during performance of the Zap-3 footwork technique via triaxial accelerometry in the form of PL values, comparing the difference in external load at a lumbar vertebra, a cervical vertebra and the dominant ankle, and to explore whether speed, position, axis and the proficiency level of the flamenco dancer affected the external load.

2. Materials and Methods

2.1. Participants

Twelve flamenco dancers volunteered for this study. They were recruited by via posters promoting the study in three dance institutions that included flamenco dance training and performance. The participants' demographics are reported in Table 1. The procedures, risks and benefits of the test were explained to the participants in advance. Participants provided informed consent prior to testing. Ethical approval was granted by the Sports Science Experiment Ethics Committee of Beijing Sport University (2022037H), and the study was completed in accordance with the Declaration of Helsinki.

Table 1. Descriptive characteristics of participants (n = 12).

Characteristics	Group P n = 6	Group A n = 6	*p*
Age (years)	38.83 ± 7.96	34.50 ± 10.67	0.148
Height (m)	1.67 ± 0.10	1.62 ± 0.03	0.681
Mass (kg)	63.33 ± 6.38	56.17 ± 15.99	0.055
BMI (kg/m^2)	22.79 ± 1.95	21.36 ± 6.00	0.078
Flamenco dance experience (years)	7.67 ± 4.89	1.83 ± 1.17	* **0.009**

* Denotes a significant difference between groups at the $p < 0.05$ level. kg: kilograms; m: meters; m^2: square meters.

The participants consisted of a professional group (group P, 6 participants) and an amateur group (group A, 6 participants). The inclusion criteria for group P were that participants had to be professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves to be professional flamenco dancers with a minimum of 3 years' experience. For group A, participants had to be amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training for at least 3 h per week. All participants were over 18 years of age and had had no musculoskeletal injuries in the 6 months preceding the test.

2.2. Procedures

All participants were informed about the experimental methods and procedures, and the flamenco techniques were demonstrated by a teacher with 12 years' experience as a qualified flamenco dance teacher. Accelerometer application was performed by a laboratory technician with 5 years' experience and training in the use of accelerometers. The process order was fixed for each participant. Each participant was required to perform the Zap-3 footwork at 160 bpm (beats per minute), 180 bpm and the fastest (as fast as they could) speed level, in sequence, on the same flamenco dance folding portable floor (measuring 0.92 × 1 m^2, made of wood) in a dance studio. Each speed level was presented 3 times for a duration of 15 s. At 160 bpm and 180 bpm, participants had to strike the floor twice on each beat, utilizing earphones that played a metronome. At the fastest level (F), the sound had to be rhythmic, and the frequency at each speed level is reported in Table 2. Group P demonstrated a significantly higher speed than Group A ($p < 0.05$). Participants were allowed to practice 3 times before the data were recorded, to facilitate adaptation to the next speed level, and they were allowed a 3-min rest between recordings to reduce fatigue. Participants were asked to perform wearing flamenco shoes that were similar to those they wore during performances, rehearsals or daily training. During the entire footwork movement, participants were required to maintain an akimbo posture with their hands (Figure 1), to keep their upper limbs and trunk stable and to perform smooth and coherent movements. Figure 2 provides a flowchart of the procedure for the Zap-3 footwork test.

Table 2. Descriptive speed levels for professional and amateur groups (n = 12).

Speed	**160 BPM**		**180 BPM**		*** F**	
Group	**Group P**	**Group A**	**Group P**	**Group A**	**Group P**	**Group A**
Frequency (Hz)	5.33	5.33	6.00	6.00	8.99 ± 0.78	7.08 ± 0.50

* Denotes a significant difference between groups at $p < 0.05$. F: the fastest speed level; Hz: Hertz; BPM: beats per minute.

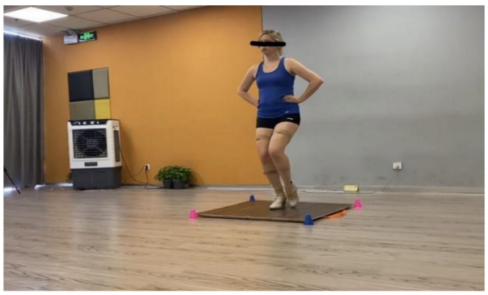

Figure 1. Akimbo posture required for completing the footwork test.

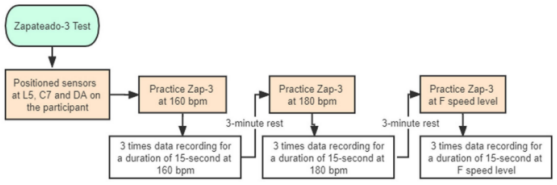

Figure 2. The procedure for the footwork test. L5: the 5th lumbar vertebra; C7: the 7th cervical vertebra; D: the dominant ankle; bpm: beats per minute; F: the fastest speed level.

2.3. Flamenco Zap-3 Footwork

Participants completed the sequence of flamenco Zap-3 footwork, which is a sequence of 6 steps completed bilaterally. When one sequence is completed, it is repeated with the other foot, and this repetition continues with alternating feet [4,13]. The 6 steps are:

(1) Zapateado de planta (P);
(2) Zapateado de Tacón-planta (TP);
(3) Zapateado de Tacón (T);
(4) Zapateado de Tacón-planta (TP);
(5) Zapateado de Punta (PNT);
(6) Zapateado de Tacón-planta (TP).

2.4. Data Processing

Trigno Avanti™ sensors (Trigno Wireless EMG System, Delsys, Natick, MA, USA), which have a built-in nine-degrees-of-freedom inertial measurement unit and can relay acceleration, rotation and earth magnetic field information, were utilized to record the flamenco Zap-3 footwork's external load responses, with data sampling at 150 Hz. The sensors were positioned at the 5th lumbar vertebra (L5), the 7th cervical vertebra (C7) and the dominant ankle (DA) [10,17,25–29]. The dominant foot was defined as the foot which participants would most often use to kick a ball [29,30]. The sensors were attached directly to the skin using medical tape and secured using elastic bandage. The locations were determined by palpation, and the ankle location was 1cm proximal to the lateral malleolus.

The uniaxial PlayerLoad (PLUNI) was calculated as the square root of the instantaneous rate of change in acceleration in each of the medial-lateral (PLML), anterior-posterior (PLAP) and vertical (PLV) planes divided by 100. The accumulated total PlayerLoad (PLTOTAL) was defined as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes divided by 100 and was calculated at L5, C7 and the DA. The uniaxial contributions (PL%), defined as the percentage contributions of the PLUNI in the medial-lateral (PLML%), anterior-posterior (PLAP%) and vertical (PLV%) planes, was also quantified by dividing the individual PLUNI value by PLTOTAL and by multiplying that value by 100.

2.5. Statistical Analysis

Data were analyzed using SPSS (SPSS IBM Statistics V21.0, IBM, Armonk, New York, NY, USA). Descriptive statistics are reported as means ± standard deviations. The descriptive characteristics of age, height, mass, body mass index (BMI) and years of experience dancing flamenco, together with the frequency of the F speed level, were analyzed between group P and group A using a Mann-Whitney U test, as the dependent variable was not normally distributed. The assumptions of normality were verified using the Shapiro-Wilk test. Differences in each dependent variable during the Zap-3 footwork were quantified using a general linear model (GLM). Bonferroni correction factors were used for a post hoc comparison, to determine where any significant differences occurred. The 95% confidence intervals (CIs) and Cohen's *d* effect sizes were as follows: small, 0.20–0.49; moderate, 0.50–0.79; large > 0.80 [31,32]. Statistical significance was set at the $p < 0.05$ level.

3. Results

3.1. Zap-3 Footwork Load Responses—Total PlayerLoad

Figures 3 and 4 report the results for different speed levels for PLTOTAL for the Zap-3 footwork in the professional and amateur groups. A significant main effect was identified for speed ($p < 0.001$), and the value of PLTOTAL increased with speed level. There was no significant main effect for the groups ($p > 0.05$). There was also no significant group x speed interaction ($p > 0.05$).

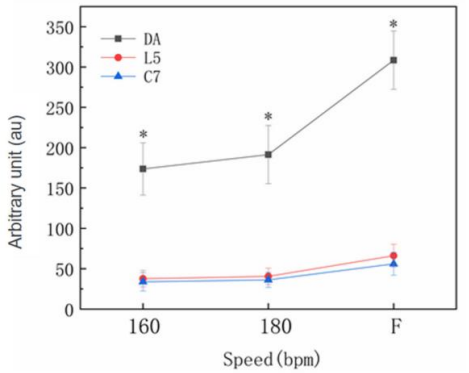

Figure 3. The professional group total PlayerLoad responses to the Zapateado-3 footwork at 160 bpm, 180 bpm and the fastest speed level (F) for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7). * Denotes a significant main effect for the unit position.

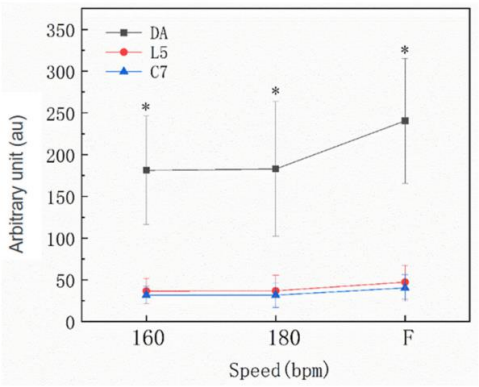

Figure 4. The amateur group total PlayerLoad responses to the Zapateado-3 footwork at 160 bpm, 180 bpm and the fastest speed level (F) for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7). * Denotes a significant main effect for the unit position.

Significant main effects for unit position ($p < 0.001$) as well as for the speed x position interaction ($p \leq 0.001$) were identified. PLTOTAL values were higher for the DA (212.98 ± 72.27 au; CI = 201.30–224.66 au) compared with C7 (38.27 ± 14.70 au; CI = 26.59–49.95 au; $p < 0.001$; $d = 3.35$) and L5 (44.15 ± 17.68 au; CI = 32.47–55.83 au; $p < 0.001$; $d = 3.21$),

with the differences becoming more pronounced as the speed increased. There was no significant difference between L5 and C7 ($p > 0.05$). There was a significant difference for the DA at different speed levels ($p < 0.001$), but this difference was not identified in the L5 and C7 positions ($p > 0.05$). There was no significant interaction between group and position ($p > 0.05$) or between group, speed and position ($p > 0.05$).

3.2. Zap-3 Footwork Load Responses—Uniaxial PlayerLoad

Significant main effects for unit position ($p < 0.001$) and a single axis ($p < 0.001$) were identified (Figure 5), and there was also a position x single axis interaction effect ($p < 0.001$). The PLML values were higher at the DA (113.33 ± 39.20 au; CI = 107.28–119.38 au) compared with C7 (28.94 ± 12.14 au; CI = 22.89–34.99 au; $p < 0.001$; $d = 2.91$) and L5 (18.17 ± 6.80 au; CI = 12.12–24.22 au; $p < 0.001$; $d = 3.38$). A significant difference existed between L5 and C7 ($p < 0.05$; $d = 1.09$).

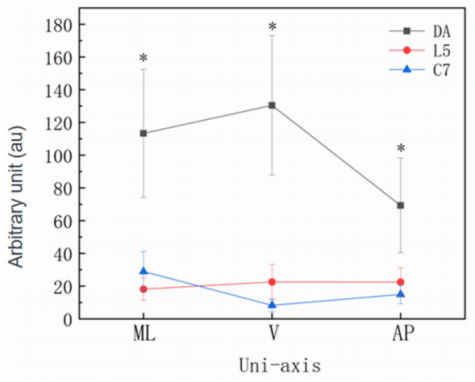

Figure 5. The differences in PlayerLoad responses between the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7) for the Zapateado-3 footwork in three planes: medial-lateral (ML), vertical (V) and anterior-posterior (AP). * Denotes a significant main effect for the unit position.

The PLV values were higher at the DA (130.49 ± 42.62 au; CI = 124.44−136.54 au) compared with C7 (8.31 ± 3.95 au; CI = 2.26–14.36 au; $p < 0.001$; $d = 4.04$) and L5 (22.57 ± 10.71 au; CI = 16.52–28.62 au; $p < 0.001$; $d = 3.47$). There was a significant difference between L5 and C7 ($p < 0.01$; $d = 1.77$).

The PLAP values were higher at the DA (69.31 ± 28.85 au; CI = 63.26–75.36 au) compared with C7 (15.02 ± 5.72 au; CI = 8.97–21.07 au; $p < 0.001$; $d = 2.61$) and L5 (22.14 ± 8.93 au; CI = 16.36–28.46 au; $p < 0.001$; $d = 2.21$). There was no significant difference between L5 and C7 ($p > 0.05$).

There was a significant different in the DA position for different axes ($p < 0.001$), but this difference was not identified in L5 ($p > 0.05$). At C7, there was a significant difference between PLML and PLV ($p < 0.001$) and between PLML and PLAP ($p < 0.01$) but no difference between PLV and PLAP ($p > 0.05$).

Significant main effects were identified for the speed ($p < 0.001$) and group ($p < 0.01$). There was significant group x speed interaction effect ($p \leq 0.001$). Post hoc analyses revealed that there was a significant difference between groups at the fastest speed levels ($p < 0.05$), but this difference was not found at the 160 bpm or 180 bpm speed levels ($p > 0.05$). There was a difference in group P at different speeds ($p < 0.001$), as well as in group A ($p < 0.001$).

A speed x position interaction ($p < 0.001$) was also identified. There was a significant difference in ankle loading at different speed levels ($p < 0.001$), but this difference was not

identified in L5 and C7 ($p > 0.05$), and there was a significant difference between DA and L5 ($p < 0.001$) and between DA and C7 ($p < 0.001$) but no significant difference between L5 and C7 ($p > 0.05$) at any speed level.

3.3. Zap-3 Footwork Load Responses—Uniaxial Contributions

There was no significant main effect for group ($p = 0.841$) or speed ($p = 0.739$) for any axis. Although the statistical significance value indicated a significant difference ($p < 0.001$), the Cohen's d effect sizes between positions were smaller than 0.2, showing no significant main effect differences for the position.

There was a significant main effect identified for PL% ($p < 0.001$), with PLML% (56.75 ± 14.59%; CI = 55.70–57.80) representing a significantly larger contribution compared with PLV% (44.25 ± 17.92%; CI = 43.20–45.30; $p < 0.001$; $d = 0.76$) and PLAP% (41.97 ± 9.47; CI = 39.90–42.00; $p < 0.001$; $d = 1.20$). The PLAP% values were lower than the PLV values ($p < 0.001$; $d = 0.16$). Although the difference between PLAP% and PLV% was statistically significant ($p < 0.001$), the Cohen's d effect sizes ($d = 0.16$) were smaller than 0.2, which demonstrates that there was no significant difference.

Post hoc analysis of a significant unit position x uniaxial interaction contribution ($p < 0.001$) demonstrated that the PLML% at C7 (74.87 ± 5.28%; CI = 73.00–76.70) was significantly greater than that at both L5 (42.26 ± 6.51%; CI = 40.40–44.10; $p < 0.001$; $d = 5.50$) and DA (53.13 ± 3.59%; CI = 51.30–55.00; $p < 0.001$; $d = 4.82$). Moreover, there was a significant difference between DA and L5 ($p < 0\ 001$; $d = 2.07$) (Figure 6).

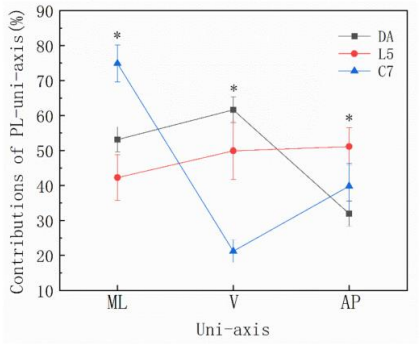

Figure 6. The different uniaxial contributions to the total PlayerLoad responses for the dominant ankle (DA), the fifth lumbar vertebra (L5) and the seventh cervical vertebra (C7) for the Zapateado-3 footwork in three planes: medial-lateral (ML), vertical (V) and anterior-posterior (AP). * Denotes a significant main effect for the position.

The PLV% values at the DA (61.63 ± 3.66%; CI = 59.80–63.50) were significantly higher than at both C7 (21.22 ± 3.26%; CI = 19.40–23.10; $p < 0.001$; $d = 11.66$) and L5 (49.92 ± 8.27%; CI = 48.10–51.80, $p < 0.001$; $d = 1.83$), and those at L5 were significantly higher than those at C7 ($p < 0\ 001$; $d = 4.57$). The PLAP% values at L5 (51.13 ± 5.40%; CI = 49.30–53.00) were significantly higher than at both DA (31.96 ± 3.60%; CI = 30.10–33.80; $p < 0\ 001$; $d = 4.18$) and C7 (39.82 ± 6.42; CI = 38.00–41.70; $p < 0.001$; $d = 1.91$), and there was a difference between DA and C7 ($p < 0.001$; $d = 1.51$) (Figure 6). There was no interaction among other effects in uniaxial contributions.

4. Discussion

This study aimed to quantify the external load in flamenco Zap-3 footwork via triaxial accelerometry in the form of PlayerLoad (PL), comparing the differences in external load

at a lumbar vertebra, a cervical vertebra and the dominant ankle, with consideration of speed, position, axis and the proficiency level of the flamenco dancer. The triaxial PlayerLoad is sensitive enough to detect a load change associated with the intensity of the dance movement [22,33,34] and it is hypothesized that an increase in cumulative accelerometer load may cause injury [17,35]. Consequently, the results of this study could have implications for potential injury risk, from the perspective of variables such as position, speed and the proficiency level of flamenco dancers.

An important finding of this study is that PLTOTAL, PLUNI and PL% were all higher at the DA compared with C7 and L5, suggesting that in flamenco, when practicing footwork techniques, the ankle is subject to higher loading, which consequently might have implications for injury risk. Furthermore, the PLML was higher at the DA, which is potentially due to the normal foot imbalance when practicing the Zap-3 footwork. The PLV was higher at the DA, which may be due to the body positions required while practicing the Zap-3 footwork, which requires more movement in the vertical plane. The PLAP was higher at the DA, which may be due to the flamenco Zapateado technique being performed with knee flexion extensions. Additionally, our study found a significant difference for the DA for different axes, potentially because, during the Zapateado, the foot performs movements on all three axes [11]. Previous studies that used triaxial accelerometry in other dance genres have reported that lower limbs bear higher loads on the three axes than C7, specifically in both dance aerobic fitness tests and ballet choreography [17,25]. Flamenco dance injury studies have reported that the frequency of injury or pain in the foot is higher than in the spine or in other body locations and have highlighted the fact that that the amount of time spent practicing footwork may affect the rate of injury incidence [2,10]. Foot disorders such as metatarsal pain and hyperkeratosis in the forefoot are not an uncommon phenomenon for female flamenco dancers and may be caused by chronic repetitive trauma suffered during footwork practice [8]. Therefore, the higher loads observed at the DA in this study may potentially increase injury risk.

Although the PLTOTAL and PL% values for C7 were lower than for the DA in flamenco Zap-3, they were comparatively higher than in other dance tests. In ballet, a specific choreographed routine test with five stages was performed by 10 participants [25], and the routine's fifth stage had the highest PL. The highest uniaxial PL and PL% values were lower than our results for the Zap-3 test, and we found that the PLTOTAL and PL% values at C7 were lower than at the DA and L5 for the flamenco Zap-3 footwork test with the fastest speed level in both the professional and amateur groups. Although the speed (beats per minute) in these two tests was slower, they were performed for 4 min; in contrast, the Zap-3 lasted for just 15 s. Therefore, we can deduce that potentially the cervical vertebrae can be loaded to a greater extent during flamenco and could therefore potentially be injured by practicing flamenco footwork. Other flamenco studies have reported a high frequency of injury or pain in the cervical spine [2,10].

For the external load in the lumbar vertebrae, this study found that the PLTOTAL, PLV, PLV% and PLAP values were lower than at the DA but greater than at C7. The PLML and PLML% contribution for L5 was lower than for both C7 and DA, which indicates that increased loading and the potential for injury risk on the ML axis may potentially be less, if load is directly related to injury occurrence. However, consideration of the different mechanisms of injury that can occur at the spine is required, as loading directions might potentially influence injury development. For example, the L4/5 level is the most common location for lumbar spine injury; however, the influence of the direction of force, e.g., anterior-posterior, vertical or medial-lateral is not known, and therefore this could be an important consideration for future research. Previous injury studies of flamenco dancers stated that the lumbar spine is associated with a high risk of injury [10] and that the highest prevalence of spinal injury in flamenco dancers occurs in the lumbar spine [2]. To the best of our knowledge, limited research exists using accelerometer placement at L5 to determine injury risk in dance. However, L5 has been proven to have sufficient sensitivity to detect the external load in this region [26,28,29].

Zap-3 is a symbolic flamenco dance training footwork technique that does not require much movement of the upper limbs or trunk. The displacements of the center of gravity are minuscule: 0.136 m in anteroposterior movement, 0.105 m in lateral and 0.018 m in vertical displacement [36]. In our study, participants were asked to keep their hands in an akimbo posture and to keep their upper limbs and trunk stable; however, we found that significant external loads were recorded at the cervical and lumbar positions. It should be noted that this Zap-3 movement model, which does not engage the upper body, could be the fundamental reason why the spinal structures are forced to absorb vibrations that have not been dissipated during tilts [10]. The biomechanical stomping mechanisms have a similar impact on the musculo-articular kinetic chain. Vibrational waves transmit the impact of the shoe from the joints of the lower body to the spine, which can trigger vertebral pain [37] and overload the spinal muscles [38]. A survey of the injury frequency of 75 flamenco dancers demonstrated that 16% and 22.7% suffered from lumbar and cervical spine injury, respectively. In other forms of percussive dance, back injury was not as prevalent, e.g., in Irish dancers (5% of 159 dancers) [39] and tap dancers (15% of 104 dancers) [12]. Furthermore, cervical injury was not as prevalent in Irish dancers (1% of 159 dancers). Such differences could be due to different performance characteristics and could be explained by jumping during percussions with the foot, which more effectively dissipates the large vibrations.

Regarding differences between professional and amateur flamenco dancers, our study demonstrated that a difference in external load occurs only at the fastest speed level and that the professional group had more external load than the amateurs for uniaxial PL. This difference may be because the professional group had a higher fastest speed and their movement quality was higher. Professional dancers tended to strike the floor firmly to make a louder sound while performing the footwork, producing more ground reaction force [13]. Therefore, professional dancers may have higher injury risk when practicing their footwork. Considering the dancers' experience, M. Elizabeth Pedersen reported that the number of injuries sustained by professional flamenco dancers was greater than the number sustained by student flamenco dancers [2]. Similar findings have been reported for other dance styles and sports [40–42]. Eileen M. Wanke's group reported a greater asymmetric load in the highest national league group of Latin dancers than in the regional or lower groups, and they were injured more often in their right hands and shoulders [43].

Regarding the difference between the speed levels, our study identified a main effect of speed ($p < 0.001$) in the case of PLTOTAL or uniaxial PL, and PLTOTAL increased with speed level. Additionally, a speed x position interaction ($p \leq 0.001$) between PLTOTAL and PL was also found. Post hoc analyses revealed that the differences became more pronounced as the speed increased. Furthermore, a group x speed interaction for uniaxial PL was also proven, indicating a significant difference at the fastest level between professional and amateur dancers ($p < 0.05$). This evidence, combined with the differences existing in group, position and axis effect suggests that the accelerometry technique demonstrated sufficient sensitivity during the Zap-3 flamenco dance footwork test.

Accelerometry has been used infrequently in flamenco footwork tests. Literature searches identify only one article, which explored musculoskeletal demands on flamenco dancers more than thirty years ago [9]. In this study, ten dancers performed dance steps with accelerometry sensors located at their tibial tuberosity and the anterior superior iliac spine. Data from these accelerometry sensors were recorded as peak frequencies and amplitudes. The current study involved the concept of PlayerLoad, which is a more modern concept allowing for greater reliability and standardization. Additionally, the use of triaxial accelerometry allowed us to analyze the details of each plane. Furthermore, the triaxial accelerometry sensor used in this study provided a non-invasive way to measure the external loads encountered by a dancer's body, which helps dancers, teachers and medical staff improve performance quality, adapt training loads and programs and inform on rehabilitation strategies. These are practices that are currently observed in sports with high injury incidence. One of the main contributions of this biomechanical study was the involvement

of six professional flamenco dancers, while a previous study analyzed the case of professional flamenco dancers with only one participant, as a case study [13,15,36]. The second contribution was the comparison between the professional and amateur groups, which allowed the assessment of the association between technical progression and biomechanical variables. The last relevant contribution of this research compared to previous studies was that triaxial accelerometers were used for the first time to determine the external load in the form of PlayerLoad in flamenco dance. Study limitations included the relatively small sample size and the fact that only one type of footwork was investigated. Future studies could consider a larger sample and explore the external load at other positions such as the knees and upper limbs and could analyze a complete flamenco dance choreography.

5. Conclusions

This study quantified the mechanical demands of the footwork required of flamenco dancers and explored whether speed, position, axis and the proficiency level of the flamenco dancer affected the external load. In conclusion, the Zap-3 footwork produced a significant external load at different positions, which was affected by speed, axis and the proficiency level of the flamenco dancer. Although the ankle bears the highest external load when dancing the flamenco, some external load is also experienced by the lumbar and cervical vertebrae, caused by significant vibrations. This study provides medical practitioners, coaches and dancers with a theoretical basis for the development of an appropriate training program to reduce injury risk and to provide a feasible method for assessing flamenco footwork techniques in future studies.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Faculty Ethics Committee at Beijing Sport University (2022037H), Beijing, China.

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

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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ANEXO 4. Study 3. Ankle Active Range of Motion as an Essential Factor of Footwork Technique in the Prevention of Overuse Injuries in Flamenco Dancers.

Reference:

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Artículo original

Ankle Active Range of Motion as an Essential Factor of Footwork Technique in the Prevention of Overuse Injuries in Flamenco Dancers

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Summary

Flamenco dance is a performing art which is based on footwork technique where the foot and ankle play an important role. The objective of this study was to investigate the effect of ankle active range of motion on external load and its efficacy as a predictor during a flamenco footwork technique, with consideration of accelerometer positions and dance proficiency. Twelve flamenco dancers composed of 6 professional and 6 amateurs participated voluntarily in this study for whom no significant differences were detected regarding age, mass or height. Participants completed a 15-second Zap-3 footwork test at a speed of 160 bpm (beats per minute), 180 bpm and as fast as they could. Triaxial accelerometers were positioned at the dominant ankle, 5th lumbar vertebrae and 7th cervical vertebrae to calculate accumulated PlayerLoad and uniaxial PlayerLoad of the 3 planes (anteroposterior, mediolateral and vertical) for each speed level. Percentage contributions were also calculated. The effect of dorsiflexion on the external load of the dominant ankle of both professional and amateur dancers existed only in the anteroposterior axis while dorsiflexion was related to the external load at the 7th cervical vertebrae and only amateurs were affected. Plantarflexion only affected the uniaxial contribution of the vertical-axis of professional dancers. These programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists.

Key words:
Ankle active range of motion. External load. Playerload. Triaxial accelerometery. Overuse injuries.

Rango de movimiento activo del tobillo como factor esencial de la técnica de zapateado en la prevención de lesiones por sobreuso en bailarinas de flamenco

Resumen

El baile flamenco es un arte en el que el zapateado tiene un papel muy relevante. El objetivo de este estudio fue investigar el efecto del rango de movimiento activo del tobillo sobre la carga externa y su eficacia como predictor durante la realización de un zapateado flamenco, en función de las posiciones del acelerómetro y el dominio técnico de los participantes. Un total de doce bailaoras de flamenco, 6 profesionales y 6 amateurs, participaron voluntariamente en este estudio y en los que no se encontraron diferencias significativas respecto a edad, peso o estatura. Los participantes realizaron un test de zapateado denominado Zap-3 durante 15 segundos a una velocidad de 160 pulsos por minuto, 180 y tan rápido como pudieron. Se colocaron acelerómetros triaxiales en el tobillo del pie dominante, en la 5ª vértebra lumbar y en la 7ª vértebra cervical para calcular la PlayerLoad acumulada y la PlayerLoad uniaxial de los 3 planos (anteroposterior, medio-lateral y vertical) en función de cada nivel de velocidad, así como sus contribuciones porcentuales. Solamente se ha encontrado relación entre la flexión dorsal del tobillo dominante y la carga externa en el eje anteroposterior, tanto en profesionales como amateurs, mientras que a nivel de la 7ª vértebra cervical sólo se ha encontrado relación entre la dorsiflexión y la carga externa en el grupo de amateurs. Respecto a la flexión plantar solo se ha encontrado relación a nivel uniaxial con el eje vertical de los bailarines profesionales. Estos programas podrían servir de ayuda a desarrollar un sistema de retroalimentación de la técnica para que el practicante de baile flamenco pueda seguir su propio modelo respecto al ideal. Esto permitiría intervenir en la prevención de las lesiones por sobreuso en los artistas de baile flamenco.

Palabras clave:
Rango de movimiento activo del tobillo. Carga externa. Carga de jugadores. Acelerómetro triaxial. Lesiones por sobrecarga.

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Introduction

Dance performance is a combination of physical movement and aesthetics, it demands a high level of physical conditioning, excellent artistic, and proficient techniques and dancers are also required to reach a similar demand for training and rehearsal, which could contribute to potential injury risk[1-3]. Injuries have been reported in various styles of dance[4-8], including flamenco dance and a high incidence of injuries is prevalent in the lower limbs, lumbar and cervical vertebrae[9-11]. Injuries can have serious consequences for a dancer's career and can impact on their daily life[12,13], and result in psychological suffering[14,15]. Injury can be caused by various factors including demographic characteristics, such as the body mass index, gender, age, and the level of proficiency of dancers[7]. Previous studies have demonstrated that the injury frequency suffered by professional dancers or athletes is greater than student or amateurs[11,12,16-18]. Furthermore, the correlation between external load and injury risk has been proven in different sports and highlighted the importance of monitoring external workload metrics routinely for reducing injury risks[19-21].

Previous studies indicated that range of motion (ROM) is an important contributor to dance performance[22]. Efficient ankle function is fundamental to success in dance and is an important factor in establishing low extremity stability between the leg and the foot[23] and can improve dance performance[24]. Ankle ROM is related to the injury development[25-27], and research has suggested that reduced right ankle plantarflexion is a risk factor for injury between injured and non-injured pre-professional dancers[28] and hyper ankle plantarflexion is related to increased injury rate[15,26,29]. Dancers with decreased hip and ankle/foot joint ROM are less prone to developing patellofemoral pain syndrome[30].

Research investigating injury risk factors in contemporary dance students demonstrated that limited ankle dorsiflexion during a single-leg squat was significantly associated with the occurrence of substantial lower extremity injury[31]. These injuries may occur due to the aesthetic requirement of dance which require dancers to increase the ROM to sometimes excessive levels and can relate to injury[26,32]. Ankle ROM could also affect joint stability and static balance performance[33], which could also be a potential injury risk. Currently the majority of research investigating the effect of ROM on dance performance and injury involves ballet or contemporary dancers with some research failing to specify dance genre.

There is a high loading demand of flamenco dancers on the foot and ankle joints[10]. The footwork technique requires dancers to use different foot locations to strike the floor and produce a rhythmic and loud sound[34], and the huge vibration produced during this time[11], the impact of the shoe is transmitted by vibrational waves from the joints of the lower body to the spine, which can trigger pains and overuse injuries[9]. For instance, the Zapateado-3 (Zap-3) flamenco footwork technique, utilized in this study requires striking the floor and quickly alternating the heel and tip of the toes. The heel striking occurs with the foot in dorsiflexion in front of the base of support and toes striking with the foot in plantarflexion by tapping the floor behind the supporting base[35]. Furthermore, the frequency of this step can reach 11.8 steps for each second[34]. This requirement of ankle active ROM (AAROM) and frequency for floor tapping may increase external load and reduce body stability.

Consideration of potential factors that may contribute to overusing injury risk in dance and specifically the relationship between ankle active ROM and external load is required. The aims of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during the flamenco footwork technique with consideration of accelerometer positions and dance proficiency. We hypothesis that the ankle active range of motion significantly affects the external load and its efficacy as a predictor could be proved during a flamenco footwork technique, the effects may show difference between different dance proficiency and body positions.

Material and method

Participants

Twelve flamenco dancers were recruited by asking for volunteers via posters in three flamenco dancing training institutions or performance company. Participants were composed of a professional group (PRO group, 6 participants, age: 38.83 ± 7.96 years; height: 1.67 ± 0.10 m; mass: 63.33 ± 6.38 kg; BMI: 22.79 ± 1.95 kg/m^2; flamenco dance experience: 7.67 ± 4.89 years) and an amateur group (AM group, 6 participants, age: 34.50 ± 10.67 years; height: 1.62 ± 0.03 m; mass: 56.17 ± 15.99 kg; BMI: 21.36 ± 6.00 kg/m^2; flamenco dance experience: 1.83 ± 1.17 years). Only flamenco dance experience years shows significant difference between groups ($p = 0.09$). The inclusion criteria for the PRO group were that participants were professional flamenco dancers who received paid work for teaching, rehearsing or performing in the flamenco dance field and who primarily considered themselves as a professional flamenco dancer. For the AM group, participants were amateur flamenco dancers who engaged in dance for recreational purposes only and attended flamenco dance training at least 3 hours per week. Participants completed a self-reported questionnaire before the study, and those who under 18 years of age and had a minimum of 1-year flamenco dance experience and/or reported heart disease and/or were pregnant and/or had musculoskeletal injuries in the 6 months preceding the study were excluded. No participants reported they had been diagnosed with either Ehlers-Danlos syndrome, Marfan syndrome, or osteogenesis imperfecta. The dancers provided informed consent in writing before commencing the study. Ethical approval was granted by the Faculty Ethics Committee at Beijing Sport University (2022037H), and the study was conducted in accordance with the Declaration of Helsinki.

General Procedures

Participants were informed regarding the experimental methods and procedures. Firstly, AAROM was measured, and then accelerometer data was recorded during performing the Zap-3 footwork. The order of progress was fixed for each participant. One professional dance teacher who experienced at 12-years flamenco dance teaching demonstrated the Zap-3 footwork technique. Laboratory technicians who have at least 5-year of lab experience and are trained were responsible for data collection.

Ankle active ROM measurement

AAROM were measured prior to the Zap-3 footwork test to prevent any potential warm-up effects. Participants adopted a sitting position with their feet off the ground and legs relaxed with their knee joints flexed at 90°. AAROM was measured for dorsiflexion and plantarflexion using a goniometer (Mitutoyo, Jiangsu, China) by a physiotherapist with 5 years' experience. The angle was measured at the maximum extent[15,30,36,37] with the measurement axis set to the lateral malleolus. While measuring, the fixed arm was parallel to the lateral aspect of the gastrocnemius and the moving arm was parallel to the lateral aspect of the 5th metatarsal bone[33].

Flamenco zapateado-3 footwork technique

Participants were asked to perform the Zap-3 composed of a sequence of 6 footwork steps with the right and the left foot (figure 1). When one sequence was completed, participants repeated the next sequence with the other foot and then repeated alternately with each foot[35,38]. Participants were required to start with the dominant foot which was defined as that the foot they would kick a ball with[39-41]. During the entire footwork movement, participants were required to keep their upper limbs and trunk stable, with maintaining in akimbo, and to perform smooth and coherent movements. The six Zap-3 steps were included and followed in this order: Zapateado de planta (P); Zapateado de Tacón-planta (TP); Zapateado de Tacón (T); Zapateado de Tacón-planta (TP); Zapateado de Punta (PNT); snd Zapateado de Tacón-planta (TP).

Subsequently, for the flamenco footwork test, each participant was asked to complete Zap-3 footwork at 3 different speed levels on the same portable flamenco dancing wood floor (92×100 cm), respectively at 160 bpm (beats per minute), 180 bpm, and at their own the fastest speed possible (F speed level) in sequence. The sequence was performed in a dance studio and each speed was completed 3 times for a duration of 15 seconds. At 160 bpm and 180 bpm participants were required to dance while listening to an earphone which was linked to a metronome and had to strike the floor twice on each beat. At the fastest speed level (F), participants were required to perform every footwork step of Zap-3 as quickly as possible and maintain a rhythmic sound[34,35]. During the test, PRO and AM groups performed the 160 bpm and 180 bpm at the same frequency, 5.33 and 6.00 respectively. At F speed level, dancers tapped at 8.99 ± 0.78 Hz and 7.08 ± 0.50 Hz respectively which demonstrated a significant difference (P <0.05). Participants were able to practice 5 minutes before each section testing commenced and rested for 5 minutes between sessions. Participants were instructed to wear flamenco footwear similar to that worn during training/performance (Figure 1).

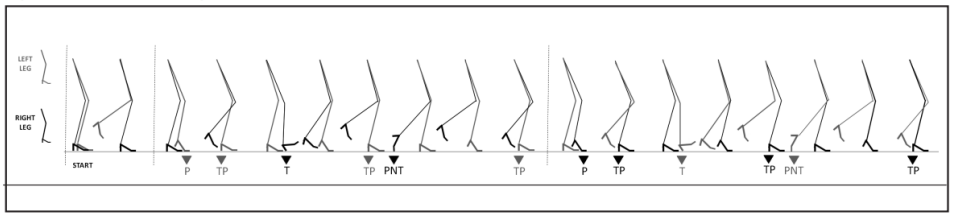
External load measurement during footwork: Playerload

Trigno Avanti™ Sensors (Trigno Wireless EMG System, Delsys, USA), were used to record acceleration data with data sampling at a frequency of 150 Hz and have a built-in nine degree of freedom inertial measurement unit which can relay acceleration, rotation, and earth magnetic field information. The sensors were attached directly to the skin using medical tape and secured using elastic bandage at the position of the 7th cervical vertebrae (C7), 5th lumbar vertebrae (L5), and superior to the lateral malleolus of the dominant ankle (DA). The locations were determined by palpation. Uniaxial PlayerLoad (PLuni) was calculated as the square root of the instantaneous rate of change in acceleration in each of the medial-lateral (PLml), anterior-posterior (PLap) and vertical (PLv) planes divided by 100. Accumulated total PlayerLoad (PLtotal) defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three planes and divided by 100 was calculated at C7, L5 and the DA. The uniaxial contributions (PL%) defined as the percentage contribution of the PLuni: medial-lateral (PLml%), anterior-posterior (PLap%) and vertical (PLv%) planes were quantified by dividing the individual PLuni value by PLtotal and by multiplying that value by 100[42,43].

Statistical analysis

SPSS statistical software package (SPSS IBM Statistics V21.0) was used for data analysis with descriptive statistics presented as mean ± standard deviation. The descriptive characteristics of age, height, mass, BMI and flamenco dance experience and the frequency of the F speed level was analysed between PRO group and AM group using a Mann–Whitney U test since the dependent variable was not normally distributed. AAROM differences between PRO group and AM group were analysed with an independent sample t-test. A Pearson correlation coefficient (r) was used to examine the correlation between active

Figure 1. Elaboration of the graphic sequence of the ZAP-3 Test.



plantarflexion and PLtotal, PLuin and PL% respectively, and between active dorsiflexion and PLtotal, PLuin, PL%. Simple linear regression analysis was used to examine the effect of active dorsiflexion and plantarflexion as a predictor of PLtotal, PLuni, PL%. This analysis was performed using only variables that had a significant correlation with active dorsiflexion or plantarflexion. Independence of observations was assessed by Durbin-Watson test. Outliers were checked by casewise diagnostics and a scatterplot was used to assess linearity between AAROM and PLtotal, PLuni, PL%. The scatterplots of standardized residuals against predicted values were used to check for the assumption of homoscedasticity. Normal P-P plots were used to assess the normal distribution. The effect size for r were calculated as follows: 0.90 to1.00 (-0.90 to -1.00) very high correlation; 0.70 to 0.90 (-0.70 to -0.90) high correlation; 0.50-0.70 (-0.50 to -0.70) moderate correlation; 0.30 to 0.50 (-0.30 to -0.50) low correlation; 0.00-0.30 (0.00 to -0.30) negligible correlation[44]. Statistical significance level was set at P <0.05.

Results

One participant in AM group was considered left foot dominant and the other 11 participants were right foot dominant. For PRO group, dorsiflexion was 15.33±6.44 degrees, Plantarflexion was 50.50±5.61 degrees; for AM group dorsiflexion was 19.50±5.24 degrees, Plantarflexion was 50.50±5.61 degrees. Statistical analysis via an independent sample t-test. There was no significant difference between the groups for dorsiflexion or plantarflexion ROM (P >0.05).

The effect of ankle active rom on the external load in the dominant ankle

For the PRO group, Table 1 demonstrates that both DA-PLap at F speed level (P = 0.041) and DA-PLap% at160 bpm (P= 0.019) had a high positive correlation with dorsiflexion. DA-PLv% had a very high negative correlation with plantarflexion at the F speed level (P = 0.001). For the AM group, table 1 demonstrates, DA-PLap had a very high positive correlation with dorsiflexion at 160 bpm (P = 0.01) and high positive correlation at 180 bpm (P = 0.044), and F speed level (P = 0.039). DA-PLap% had a high positive correlation with dorsiflexion at 160 bpm (P = 0.035) and very high positive correlation at 180 bpm (P = 0.008) and F speed level (P = 0.003). There was no correlation between DA-PL or DA-PL % and plantarflexion in the AM group.

Simple linear regression analysis was performed using only DA-PL or DA-PL% values that had a significant correlation with active dorsiflexion or plantarflexion. For the PRO group, Table 2 demonstrates that DA-PLap at the F speed level and DA-PLap% at 160 bpm were significantly related to dorsiflexion, DA-PLv% at F speed level was significantly related to plantarflexion. For AM group, Table 3 demonstrates that DA-PLap

Table 1. Correlation between AAROM and PLtotal, PLuni, PL% in the dominant ankle (n=12).

		Dorsiflexion (degrees)		Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
DA-PLtotal	160	0.357	0.809	0.099	-0.378
au	180	0.347	0.71	-0.003	-0.383
	F	0.417	0.684	-0.01	-0.006
DA-PLml	160	0.177	0.77	0.355	-0.419
au	180	0.233	0.74	0.27	-0.413
	F	0.146	0.682	0.171	0.041
DA-PLv	160	0.478	0.783	-0.227	-0.372
au	180	0.36	0.626	-0.238	-0.381
	F	0.505	0.579	-0.17	-0.021
DA-PLap	160	0.634	0.916*	-0.115	-0.294
au	180	0.603	0.824*	-0.232	-0.274
	F	0.829*	0.833*	-0.494	-0.004
DA-PLml%	160	-0.329	0.135	0.804	-0.288
	180	-0.246	0.247	0.79	-0.107
	F	-0.559	0.212	0.54	0.303
DA-PLv %	160	0.083	-0.519	-0.704	0.31
	180	0.024	-0.607	-0.748	0.331
	F	0.578	-0.788	-0.971**	0.012
DA-PLap%	160	0.884*	0.843*	-0.51	-0.241
	180	0.743	0.924**	-0.619	-0.33
	F	0.708	0.958**	-0.737	-0.158

* Correlation is significant at the 0.05 level (2-tailed). P< 0.05
** Correlation is significant at the 0.01 level (2-tailed). P<.001
Ankle active range of motion (AAROM); Total Playerload (PLtotal); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Total Playerload of the dominant ankle (DA-PLtotal); Playerload of the dominant ankle in three planes: medial–lateral planes (DA-PLml), vertical planes (DA-PLv), anterior–posterior planes (DA-PLap); uniaxial contribution of the dominant ankle in the three planes: medial–lateral planes (DA-PLml%), vertical planes (DA-PLv%), anterior–posterior planes (DA-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Table 2. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of professional dancers (n=6).

AAROM	PLuni/PL%	*r* and *P* value	adjusted r^2 value	β coefficient
Dorsiflexion	DA-PLap F	0.829 (0.041)	0.609	1.874
	DA-PLap% 160	0.884 (0.019)	0.726	0.45
Plantarflexion	DA-PLv% F	0.971 (0.001)	0.929	-0.224

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160) and in vertical planes at the fastest speed level (DA-PLv% F).

at 160 bpm, 180 bpm and F speed level were significantly related to dorsiflexion. DA-PLap% at 160 bpm, 180b pm, and F speed level were significantly related to dorsiflexion.

The effect of ankle active rom on the external load at the 7th cervical vertebrae

For the PRO group, table 4 demonstrates that C7-PLv% had a high positive correlation with plantarflexion at 180 bpm ($P = 0.016$) and F speed level ($P = 0.017$). For the AM group, Table 4 demonstrates, C7-PLv ($P = 0.029$) had a high positive correlation with dorsiflexion at

Table 3. Simple linear regression analysis of AAROM of PLuni or PL% in the dominant ankle position of amateur dancers (n=6).

AAROM	PLuni/PL%	*r* and *P* value	adjusted r^2 value	β coefficient
Dorsiflexion	DA-PLap 160	0.916 (0.01)	0.798	5.055
	DA-PLap 180	0.824 (0.044)	0.599	5.527
	DA-PLap F	0.833 (0.039)	0.618	6.877
	DA-PLap% 160	0.843 (0.035)	0.638	0.868
	DA-PLap% 180	0.924 (0.008)	0.818	0.917
	DA-PLap% F	0.958 (0.003)	0.897	0.955

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni), uniaxial contribution (PL%); Playerload of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap 160), at 180 beats per minute (DA-PLap 180) and the fastest speed level (DA-PLap F); uniaxial contribution of the dominant ankle in anterior–posterior planes at 160 beats per minute (DA-PLap% 160), at 180 beats per minute (DA-PLap% 180) and the fastest speed level (DA-PLap% F).

160 bpm, C7-PLml% ($P = 0.048$) and C7-PLv% ($P = 0.033$) had a high positive correlation with dorsiflexion at 180 bpm. C7-PLap% had a high negative correlation with dorsiflexion at 180 bpm ($P = 0.019$) and F speed level ($P = 0.03$).

Simple linear regression analysis was performed using only C7-PL or C7-PL% that had a significant correlation with active dorsiflexion or plantarflexion. For PRO group, Table 5 demonstrates that C7-PLv% at

Table 4. Correlation between AAROM and PLtotal, PLuni, PL% in the seventh cervical vertebrae (n=12).

		AAROM Dorsiflexion (degrees)		AAROM Plantarflexion (degrees)	
		Group PRO	Group AM	Group PRO	Group AM
C7-PLtotal	160	0.394	0.777	-0.023	-0.345
au	180	0.289	0.713	0.087	-0.305
	F	0.05	0.654	0.021	0.321
C7-PLml	160	0.472	0.812	-0.129	-0.365
au	180	0.449	0.757	-0.092	-0.304
	F	0.07	0.763	-0.027	0.164
C7-PLv	160	0.352	0.857*	0.197	-0.186
au	180	0.16	0.788	0.452	-0.212
	F	-0.137	0.668	0.476	0.334
C7-PLap	160	0.206	0.448	0.234	-0.225
au	180	0.033	0.351	0.374	-0.325
	F	0.13	-0.083	0.067	0.808
C7-PLml%	160	-0.663	0.779	-0.731	-0.603
	180	0.637	0.816*	-0.728	-0.527
	F	0.182	0.835	-0.318	-0.544
C7-PLv %	160	-0.15	0.347	0.787	0.286
	180	-0.225	0.849*	0.896*	0.041
	F	-0.377	0.351	0.893*	0.462
C7-PLap%	160	-0.495	-0.811	0.792	0.592
	180	-0.445	-0.885*	0.753	0.478
	F	0.256	-0.854*	0.222	0.553

* Correlation is significant at the 0.05 level (2-tailed). $P< 0.05$
** Correlation is significant at the 0.01 level (2-tailed). $P<.001$
Ankle active range of motion (AAROM); Total Playerload (PLtotal); uniaxial PlayerLoad (PLuni), PL%(uniaxial contribution); Total Playerload of the seventh cervical vertebra (C7-PLtotal); Playerload of the seventh cervical vertebra in three planes: medial–lateral planes (C7-PLml), vertical planes (C7-PLv), anterior–posterior planes (C7-PLap); uniaxial contribution of the seventh cervical vertebra in the three planes: medial–lateral planes (C7-PLml%), vertical planes (C7-PLv%), anterior–posterior planes (C7-PLap%); the professional group (Group PRO), the amateur group (Group AM). Performed Zap-3 at 160 beats per minute (160), 180 beats per minute (180) and at the fastest speed level (F).

Table 5. Simple linear regression analysis of active plantarflexion of PL% and seventh cervical vertebra of professional dancers (n=6).

AAROM	PL%	*r* and *P* value	adjusted r^2 value	β coefficient
Plantarflexion	C7-PLv% 180	0.896 (0.016)	0.755	0.637
	C7-PLv% F	0.893 (0.017)	0.746	0.612

Ankle active range of motion (AAROM); uniaxial contribution (PL%); uniaxial contribution of the seventh cervical vertebra in vertical planes at 180 beats per minute (C7-PLv% 180) and the fastest speed level (C7-PLv% F).

Table 6. Simple linear regression analysis of active dorsiflexion of PLuni or PL% and seventh cervical vertebra of amateur dancers (n=6).

AAROM	PLuni/PL%	*r* and *P* value	adjusted r^2 value	β coefficient
Dorsiflexion	C7-PLv 160	0.857 (0.029)	0.667	0.418
	C7-PLml% 180	0.816 (0.048)	0.582	0.916
	C7-PLv % 180	0.849 (0.033)	0.651	0.334
	C7-PLap% 180	0.885 (0.019)	0.730	-1.261
	C7-PLap% F	0.854 (0.03)	0.662	-1.513

Ankle active range of motion (AAROM); uniaxial PlayerLoad (PLuni); uniaxial contribution (PL%); Playerload of the seventh cervical vertebra in vertical planes at 160 beats per minute (C7-PLv 160); uniaxial contribution of the seventh cervical vertebra in medial–lateral planes at 180 beats per minute (C7-PLml% 180), in vertical planes at 180 beats per minute (C7-PLv % 180), in anterior–posterior planes at 180 beats per minute (C7-PLap% 180) and in anterior–posterior planes at the fastest speed level (C7-PLap% F).

180 bpm and at the F speed level were significantly related to plantarflexion. For the AM group, Table 6 demonstrates that C7-PLv at 160 bpm, C7-PLml% and C7-PLv% at 180 bpm, C7-PLap% at 180 bpm and F speed level were significantly related to dorsiflexion.

The effect of ankle active ROM on the external load at the 5th lumbar vertebrae

There was no correlation between ankle AAROM and external load at L5 ($P > 0.05$).

Discussion

Flamenco dance is characterized by the strong emotion and rhythmic sound made by footwork, which requires dancers to use different positions of the foot, such as heel, toe, ball and whole foot, to strike the floor[34]. Some steps, such as Zap-3, requires quick alternating heel and toe strikes on the floor and dancers have to make unique adjustments to the ankle joint to fulfil the requirements of this dance style[45]. Therefore, active dorsiflexion and plantarflexion may potentially affect the performance of this technical step[45]. The objectives of this study were to investigate the effect of AAROM on external load and the efficacy of the AAROM as a predictor of external loading during a flamenco footwork technique with consideration of accelerometer positions and dance proficiency.

Regarding the effect of AAROM on external load and the percentage contribution, the results demonstrated dorsiflexion and plantarflexion were associated with PLtotal, PLuni and PL% dependent upon the position of the accelerometer. Dorsiflexion had a positive correlation with DA-PLap, DA- PLap% for both groups, and a negative correlation with C7-PLap% for the AM group. Therefore, during the footwork, a greater active dorsiflexion may produce greater external load in the anteroposterior plane of the DA, but less in the anteroposterior plane of C7. Dorsiflexion had a positive correlation with C7-PLv, C7-PLv% and C7-PLml%, but this correlation between dorsiflexion and PLtotal, PLuni or PL% did not exist in the DA positions in the vertical and mediolateral plane for both groups. Plantarflexion had a negative correlation with DA-PLv% and a positive correlation with C7-PLv %, in the PRO group only which may indicate that greater active plantarflexion may reduce external load on the vertical plane of the DA, but increase external load on the vertical plane of C7. The location of the accelerometer at the L5 position was not influenced by dorsiflexion or plantarflexion. This could potentially be due to L5 been located closer the centre of mass of the body and enhanced stability.

Results suggested AAROM was associated with different values of PLtotal, PLuni and PL% dependent upon the dance proficiency. The demographics of the two groups were similar and the only significant finding was for dance experience. There was no significant difference in the AAROM of the dominant ankle between groups, but the frequency of the F speed level was significantly different with PRO group significantly faster likely due to their professional status. Significant differences between amateur and professional dancers at maximum speed show that the ZAP-3 test is sensitive to the level of technical execution of the dancers. The AM group were only influenced by dorsiflexion with accelerometer position at the DA and C7. In contrast, the PRO group was only influenced by plantarflexion with accelerometer position at C7 and accelerometer position at DA was influenced by both dorsiflexion and plantarflexion. This may be due to differences in training duration, dance experience and dance proficiency, which might equate to greater injury risk due to cumulative load and the increased demands of training and rehearsal. The higher speeds in professionals at the fastest speed level when performing the test may also be a factor as normally professional dancers strike the floor harder to make a louder sound. These two reasons may lead to different mechanisms for completing the footwork technique between groups. The frequency of injuries suffered by professional dancers or athletes is greater than student or amateurs[11,16-18]. Eileen M. Wanke's group (2018) found a higher asymmetric load in the highest national league group than in the regional or lower groups among latin dancers and they were more often injured[46].

In flamenco dance, professionals showed greater negative perception about pain and injuries than flamenco dance student[14]. In our study although AAROM did not significantly differ between the two groups, the mean dorsiflexion of amateurs was higher than professionals while the plantarflexion of professionals was higher than amateurs, and the external load values demonstrate that amateurs were only affected by dorsiflexion while professionals were affected by both. This may be due to the correlation between ankle stability and ROM[47] and reduced ankle stability may increase external load. Therefore, it is necessary to

consider if there is any difference between groups in ankle ligament strength and arch height which may be related to ankle stability. Ankle strength is influenced by postural balance in the single-leg quiet stance for athletes[48] and a lack of strength in the muscles around the joints often limit the active ROM, which may decrease joint stability[49]. Ligament laxity may contribute to the high prevalence of lower limb injuries in dancers[50]. Furthermore, increasing arch height is associated with decreased mediolateral control of single-limb stance[51]. Although joint hypermobility and associated ligament laxity is thought to be associated with reduced dynamic balance, postural control, and increased injury risk, it is possible that the required high-level proficiency of dance training may attenuate any potential reductions in dynamic balance[52].

A high level of ROM is essential for optimal dance performance[22,24,53]. The changes of ROM associated with adolescent dancers may cause an increase in injury incidence[27] and our study only used adult dancers to prevent such issues which would require a different study design with consideration of physical maturity. Dancers with decreased hip and ankle/foot joint ROM are less prone to develop patellofemoral pain syndrome[30]. Pedersen[45] investigated AAROM in 23 female flamenco dancers who studied flamenco in intermediate and advanced classes by using the dynamometer. For plantarflexion, the mean ROM was 59.35° and 51.48° for the right and left ankle, and for dorsiflexion, the mean range of motion ROM was 6.57° and 12.87° for the right and left ankle, respectively. In contrast in our study, the plantarflexion DA ROM was lower for both the professional (50.50° ± 5.61°) and amateur (50.00° ± 3.58°) groups and the dorsiflexion ROM was higher (professional: 15.33 ± 6.44°; amateur: 19.50 ± 5.24°). Bejjani[54] reported that the mean of total ankle AAROM of 10 female flamenco dancers was 85° ± 11°. The values in our study for professional (66.83° ± 5.64°) and amateur (69.5° ± 6.16°) were lower. Castro-Méndez[55] measured the dorsiflexion of the ankle of professional flamenco dancer with the supine position and knees extended by goniometer (right foot: 11.92° ± 0.38°; left foot: 12.00° ± 0.43°), which was lower than this study. The difference in AAROM between groups may be due to the dance experience and proficiency[49,56]. The AAROM difference of flamenco dancers between studies may be due to variations in the method of measurement, such as the participant position during measurement.

Two of the ZAP- 3 steps namely the Zapateado de Tacón (T) Zapateado de Punta (PNT) are always performed with the heel striking in dorsiflexion in front of the base of support and with the foot in the plantarflexion position by the toes tapping the floor behind the supporting base. The most mobile element of the locomotor unit is the ankle joint with a 42° entire ROM (plantarflexion through dorsiflexion ROM) during the footwork, however, in everyday activities, the ROM required in the sagittal plane is significantly reduced, with a maximum of 25° for walking[35] therefore highlighting the importance of ankle ROM for dance performance. Zap-3 was utilized for this study as firstly it is a representative step of flamenco technique, including the various factors of striking the floor with different parts of the foot, and it has a high choreographic correlation. Occasionally biomechanical research analyzes gestures that have no direct correlation with sports or scenic reality and in our study the authors desired a movement of practical importance. Secondly, some research has already pointed out the risks of overuse injuries for flamenco dancers during Zap-3 footwork technique and the factors are needed to be explored[10,34,35,57]. Furthermore, since Zap-3 has been used in recent biomechanical studies and allows standardization for a comparison of results.

Accelerometery was used to quantify external load as it has been widely utilized in the dance research to explore the physiological characterization of latin dance and physical activity levels during dancing[58,59]. Researchers has also investigated the musculoskeletal demands of dynamic load on flamenco dancers and used accelerometer to record peak frequencies and amplitude at the tibial tuberosity and the anterior superior iliac spine[54,60]. It was reported that urogenital disorders and back and neck pain may be related to the vibrations generated by flamenco dance form. Different dance genres and their varying demands limit comparison. PlayerLoad has sufficient sensitivity to quantify mechanical load during dance and can be used for injury prevention[47,50,61] and has the benefit of been portable. Study limitations included the use of only the dominant ankle for ROM measurement and the relatively small sample size. Future studies could consider a larger sample and explore the effect of other dance genres. From an injury perspective the use of prospective injury surveillance would be beneficial to determine how mechanical loading might influence injury prospectively.

Conclusion

Our findings suggest that AAROM has a correlation with the external load at the DA and C7 during flamenco footwork techniques and the effect showed differences according to dancers' proficiency. Therefore, the external load of DA and C7 can be predicted by measuring AAROM of the DA to some extent in professional and amateur dancers. Furthermore, coaches, dancers, and practitioners with an understanding of the biomechanical characteristics of flamenco footwork can provide theoretical advice to develop technical training programs. These programs would be applied to develop a technique feedback system for the flamenco dancer to follow their own model with respect to the ideal. This would allow intervention in the prevention of overuse injuries in flamenco dance artists.

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Conflict of interest

The authors do not declare a conflict of interest.

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ANEXO 5. Study 4. The Effect of Lower Limb Balance Ability and Bilateral Asymmetry on Flamenco Footwork.

Reference:

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ANEXO 6. Study 5. Monitoring Flamenco Dance Movement with Accelerometer: Methodological and Practical Commendations.

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Monitoring Flamenco Dance Movement with Accelerometers: Methodological and Practical Commendations

Monitorización de Movimientos del Baile Flamenco con Acelerómetros: Recomendaciones Metodológicas y Prácticas

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Abstract

Accelerometers are tools specifically engineered for quantifying differences in force or acceleration over time, providing data regarding the magnitudes and frequency of movement. It could be utilized in the flamenco dance study field for monitoring the movement to reduce the risks of injuries or pain, as well as to give recommendations for making a reasonable and scientific training plan for dancers to improve their technique. The aim of this study is to introduce how to monitor flamenco dance movement with accelerometers, and suggestions for future studies. This study makes a detailed introduction from the following aspects: accelerometer selection, monitor use protocols, and data process and analysis.

Key words

External load, dancer, biomechanics, acceleration, vibration.

Resumen

Los acelerómetros son herramientas diseñadas para cuantificar las variaciones en las fuerzas o aceleraciones en un período de tiempo, proporcionando datos sobre las magnitudes y frecuencia del movimiento. Pueden ser utilizados en el campo de estudio del baile flamenco para monitorizar el movimiento y reducir las dolencias y riesgos de lesiones, además de ofrecer recomendaciones para elaborar un plan de entrenamiento eficiente y con base científica para mejorar la técnica de los bailarines. El objetivo de este estudio es establecer unas pautas básicas sobre cómo monitorizar el movimiento del baile flamenco utilizando acelerómetros, y ofrecer sugerencias para futuras investigaciones. Este estudio profundiza en los siguientes aspectos: selección de acelerómetros, protocolos de uso del monitor y procesamiento, así como del análisis de los datos obtenidos.

Palabras clave

Cargas externas, bailaor, biomecánica, aceleración, vibración.

Introduction

Flamenco dance has been listed as an Intangible Heritage of Humanity in become a cultural feature of Spain, It is "a dance of passion, courtship, expressing a wide range of situations ranging from sadness to joy." [1]. It has gained worldwide prominence and attraction, captivating a growing community of enthusiasts in many countries. [2-5]. Flamenco dance is distinguished by its powerful emotional expression and distinctive footwork techniques, characterized by the striking of the floor to create a resounding and rhythmic sound. This sets it apart from other dance styles [2]. The rhythm and emotional expression are two of the most important elements for performing flamenco, which is indispensable for the precise execution of this dance form [6]. Mastering flamenco necessitates the development of motor skills that involve precise techniques and the coordination of various body parts like the feet, torso, arms among others [2].

Accelerometers are tools specifically engineered for quantifying differences in force or acceleration over time, providing data regarding the magnitudes and frequency of movement. When utilized for monitoring physical activity, these devices have the capability to detect movement in three planes of movement (medial-lateral, anterior-posterior and vertical) and to evaluate the intensity and overall amount of movement over a given time period [7]. It has already been used in sports or physical activity monitoring, as well as dance fields, to explore the physiological characterization of dance and physical activity levels during dancing [8-11].

Flamenco dance is a combination of physical movement and aesthetics that also requires a high level of physical demand, the physical effort demanded in performing flamenco is similar to that of elite sports [12-14]. Meanwhile, achieving a high level of skill and proficiency in dance also necessitates training and rehearsal, which may elevate the risk of potential injuries [15-17]. The injuries and pains have been already reported in flamenco dancers, which affect dancers not only their professional careers but also may have a negative effect on their daily lives [18-20]. On the other hand, to improve the skill and technique of dance, more theoretical studies also are necessary for the future. The instruments utilized are good for researchers to better understand how to study this field. Therefore, we would like to further emphasize the importance of using accelerometers and link it to the need for a more in-depth and comprehensive study of the technique. The aim of this study is to establish a specific proposal for monitoring flamenco dance movement with accelerometers, including the selection and validation of accelerometers, usage protocols, and data processing and analysis.

Accelerometers Selection

Generally, the choice of accelerometers largely depends on the specific research objectives with consideration of factors such as product reliability, access to technical support, feasibility, and cost [21]. Besides possessing adequate data processing and storage capabilities to track movement over extended periods is critical, we also have to consider if it is portable and compact for practical use in settings since in a flamenco dance test, accelerometers need to be posted on participants' body steady during performing dance for a period. We need to make sure the accelerometers do not drop during the dancers' performance and do not interfere with their dance moves during the test.

Out of the commercially accessible accelerometer brands, ActiGraph (Pensacola, FL, USA) stands out as the most commonly employed choice among researchers [22]. There are some examples about dance research. ActiGraph Triaxial accelerometers (GT3X+ 2.5, Actigraph LLC, Pensacola, USA) was used for describing the physical activity parameters of Latin dance [23]. Actigraph GT33 accelerometers were used in Kelli's research group, to record the physical activity, the intensity and time length of teenagers in different dance style classes of youth, including flamenco dance class. It was also widely used in other dance styles studies [24]. Additionally, Global Positioning Systems (GPS) with triaxial accelerometry [25,26], and triaxial accelerometer Kionix KX94 (Kionix, Ithaca, New York, USA) [9] were also utilized in other physical activity studies before.

About flamenco dance test, in 1998, Bejjani research group used two light-weight (2 g) skin-mounted unidirectional accelerometers (PCB 303; Power Supply 408), to record vibrations of hip and knee for ten flamenco dancers, indicated that vibrations generated by flamenco dancing may be linked to urogenital

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disorders, as well as back and neck pain, and the hip joint appears to absorb the majority of these impacts [8]. Voloshin et al, in 1989 recorded the amplitude of dynamic loading recorded on tuberosity, antero-superior iliac spine with two light-weight (2 g) skin-mounted unidirectional accelerometers as well, and revealed that utilizing insoles appears to decrease the amplitude of dynamic loading observed on the dancer's tibial tuberosity depending on the specific dance and performer [27]. Otherwise, in 2022, Zhang research group used Trigno Avanti™ sensors (Trigno Wireless EMG System, Delsys, Natick, MA, USA), which is a Triaxial Accelerometer having a built-in nine-degrees-of-freedom inertial measurement unit and can relay acceleration, rotation and earth magnetic field information, to record the flamenco Zap-3 footwork's external load responses. It described the external load at the dominant ankle, the 7th cervical vertebrae and the 5th lumbar, and the effect of speed, axis and the dancers' proficiency level on external load and their interaction [28]. The same research group also used the triaxial accelerometer to record the external load and analysis the correlation with ankle range of motion, and it pointed out that dorsiflexion affected the dominant ankle load in the anteroposterior axis for both professional and amateur dancers, as well as the cervical vertebrae load, which only affected amateurs. Plantarflexion only influenced the vertical axis load in professional dancers [29].

We recommend future studies use triaxial accelerometers to monitor flamenco technique tests. Existed research reported that triaxial accelerometers outperforms uniaxial accelerometry in capturing accelerations of sports consisting of smooth, horizontal or complex body movements [30]. Also, the effectiveness of triaxial accelerometers in dance detection has been proved. Nagy investigated within-day and between-day loading responses to ballet choreography and reported the effectiveness of triaxial accelerometers in dance monitoring [25]. In a study about flamenco dance external load, researchers identified significant effects of speed on external load [28]. To some extent, it means the accelerometer is sensitive enough to recognize the variation in the speed of flamenco footwork. Additionally, it also is better to use similar instruments as research in most recent years for comparing and discussing the results, since the difference between these devices makes it difficult to compare data between studies [31].

Monitor Use Protocols

Accelerometers can be fixed in many parts of the body. For example, ankles, wrists, torso, etc. The trunk position (hip or lower back) has become the most common position for monitors in general to monitor physical habitual, intensity [21]. For instance, the intensity of dance classes of different dance styles was studied too, including flamenco dance, where participants wore accelerometers in the position of waist [24]. Further, it has been indicated that when accelerometers are used for activity classification, the knee is the preferred sensor position for high-level activities. For transitional activities involving leg motion and posture changes, both chest and knee sensors are suitable choices [32]. However, the location of the accelerometer depends on the interest to be studied, for example, the accelerometer can also be placed in different body positions when the study aims to record data on a specific body position. For example in flamenco dance, the 7th cervical vertebrae, the 5th lumbar vertebrae, and superior to the lateral malleolus of the ankle were selected for quantifying the external load of the flamenco Zap-3 footwork while comparing the difference in those three body positions [29]. The accelerometers were also strapped onto the tibial tuberosity and the anterior superior iliac spine of flamenco dancers before for account acceleration amplitude, peak accelerations [8,27].

In flamenco dance experiments, the duration of wearing the accelerometer can be determined according to the needs of the interest. If studying a specific dance movement, it could be counted the time of the entire sequence of movements (usually more than 10 seconds), or the units of seconds or minutes based on the time it takes to complete the movement. If it is to estimate habitual, intensity of dancers, the time is determined according to the need, such as a dance class, a rehearsal, or a choreography. Similarly, the location of the experiment is also selected according to the needs of the experiment. The accelerometer is small and portable, the experiment can be conducted in the dance classroom, rehearsal hall or stage. The principle is to be as close as possible to the dancers' usual training, performance and class conditions, so as to ensure the authenticity and validity of the data.

Data analysis

Frequency and amplitude recorded by accelerometers have been used to quantify results in research. Bejjani [8] and Voloshin [27] used accelerometer data to analyze the vibrations with peak frequency ranges and amplitudes of acceleration. Otherwise, MeterPlus version 4.3 could be used to summarize minutes of sedentary, light, moderate, vigorous, and MVPA (moderate + vigorous) during physical activities. The research studied physical activity in youth dance using an accelerometer. Seven different dance classes (flamenco is one of them) were investigated. Outcomes as classes' total time (minutes) and per cent of class time (minutes divided by class length) spent in each intensity level were calculated.

The PlayerLoad (PL) concept allows for the quantification of a vector-modified algorithm introduced by the tech company Catapult Sports, which utilizes a micro-electrical mechanical system. PL is calculated as the square root of the sum of the squared rates of acceleration change along each of the three vectors (medial-lateral, anterior-posterior, and vertical), divided by 100. The micro-electrical mechanical system (MEMS) device includes a triaxial piezoelectric linear accelerometer that samples movement data at a frequency of 150 Hz, allowing for the precise quantification of movement performance. Due to its low user dependence, PL has found application in numerous physical activity tests for characterizing external load [10, 33-35] and is related to sports training and competition. In the field of dance research, PL has also been widely used to quantify the external load or mechanical load and its correlation with injuries [11,36, 37]. Nagy's research delved into within-day and between-day loading responses to ballet choreography. The study found that PL is suitably sensitive for tracking progressive routines, and accelerometers prove effective for athlete monitoring and injury screening protocols [25]. In flamenco footwork research, Playerload was utilized as the form to calculate external load, and analyzed correlation with other factors such ankle active range of motion, and balance ability [28,29,38].

The way to describe the acceleration data depends on the problem you are studying. The case of the above studies may give thinking of choosing the appropriate definition to describe the data. However, it does not mean they included all possibilities, the outcomes could also be other concepts with analysis acceleration. Standardizing the data with other research will facilitate comparison.

Conclusions

This study explained how to monitor flamenco dance movement with accelerometers by making a detailed introduction from aspects of accelerometer selection, monitor use protocols, and data process and analysis. Triaxial accelerometers were recommended to be used to monitor flamenco technique tests no matter what brand it is, which may better than uniaxial accelerometry for dance movement. The use of accelerometers in dance performance is often used to monitor physical conditions over a period of time, which can be days or seconds, depending on the problem to be studied. Accelerometers can be used in different settings, such as a classroom, rehearsal hall, or stage, and can also be placed in different locations on the body to obtain data. Existing studies of flamenco dance include the analysis of a dance technique movement by placing accelerometers at different locations to calculate external loads at different locations, or to describe vibrations. Another type of study looks at physical activity over time, such as the intensity and duration of exercise during a class. At present, there are many problems that can be studied by using accelerometers in flamenco dance, such as the intensity of physical activity in different chapters of a choreographer, or the analysis of acceleration data and related factors of other variables to interpret the physiological characteristics of flamenco dance more fully. Those studies will be significantly meaningful to deeply know the flamenco movement, giving advice to improve the techniques, prevent injuries or plan the training efficiently.

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