University of Cumbria

Zhang, Ningyi ORCID: https://orcid.org/0000-0002-2282-7960 , Gomez-Lozano, Sebastián ORCID: https://orcid.org/0000-0003-4888-2930 , Armstrong, Ross ORCID: https://orcid.org/0000-0002-8424-6854 , Liu, Hui ORCID: https://orcid.org/0000-0002-1793-0015 and Vargas-Macias, Alfonso (2023) The effect of lower limb balance ability and bilateral asymmetry on flamenco footwork. Cultura, Ciencia y Deporte, 18 (58). pp. 119-128.

Downloaded from: http://insight.cumbria.ac.uk/id/eprint/7544/

Usage of any items from the University of Cumbria's institutional repository 'Insight' must conform to the following fair usage guidelines.

Any item and its associated metadata held in the University of Cumbria's institutional repository Insight (unless stated otherwise on the metadata record) may be copied, displayed or performed, and stored in line with the JISC fair dealing guidelines (available here) for educational and not-for-profit activities

provided that

- the authors, title and full bibliographic details of the item are cited clearly when any part of the work is referred to verbally or in the written form
- a hyperlink/URL to the original Insight record of that item is included in any citations of the work
- the content is not changed in any way
- all files required for usage of the item are kept together with the main item file.

You may not

- sell any part of an item
- refer to any part of an item without citation
- amend any item or contextualise it in a way that will impugn the creator's reputation
- remove or alter the copyright statement on an item.

The full policy can be found here.
Alternatively contact the University of Cumbria Repository Editor by emailing insight@cumbria.ac.uk.

The effect of lower limb balance ability and bilateral asymmetry on flamenco footwork

El efecto de la capacidad de equilibrio de las extremidades inferiores y la asimetría bilateral en el zapateado flamenco

***Ningyi Zhang*[1]**
***Sebastián Gómez-Lozano*[1]**
***Ross Armstrong*[2]**
***Hui Liu*[3]**
***Alfonso Vargas-Macías*[4]**

[1] Performing Arts Research Group-Faculty of Sport, San Antonio Catholic University. Murcia, Spain
[2] Institute of Health, University of Cumbria, Carlisle, England
[3] Biomechanics Laboratory, Beijing Sport University, Beijing, China
[4] Telethusa Centre for Flamenco Research, Cádiz, Spain

Correspondence:
Sebastián Gómez-Lozano
sglozano@ucam.edu

Short title:
Balance ability and bilateral asymmetry effect on flamenco footwork

How to cite this article:
Zhang, N., Gómez-Lozano, S., Armstrong, R., Liu, H., & Vargas-Macías, A. (2023). The effect of lower limb balance ability and bilateral asymmetry on Flamenco footwork. *Cultura, Ciencia y Deporte, 18*(58), 119-128. https://doi.org/10.12800/ccd.v18i58.2093

Received: 26 July 2023 / **Accepted**: 11 September 2023

Abstract

The aim of this study was to investigate the effect of lower limb balance ability and asymmetry on external load during flamenco footwork. Five professional and five amateur flamenco dancers completed the flamenco Zap-3 footwork at 160, 180 beats per minute, and at their own the fastest speed possible while wearing triaxial accelerometry (at the dominant ankle, non-dominant ankle, 5th lumbar and 7th cervical vertebrae). The external load was calculated in the form of Playerload. The Y-Balance test was used to assess the balance ability, anterior, posteromedial, posterolateral, composite scores and the asymmetry index were calculated. 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 is a positive effect among flamenco dancers: it reduces overloads at the cervical level and injury risks and could optimize their percussive tapping technique.

Keywords: Postural balance, workload, dancing, accelerometry, professional, amateur.

Resumen

El objetivo del estudio es investigar las cargas externas, la capacidad de equilibrio y la asimetría en extremidades inferiores durante el zapateado flamenco. Cinco bailaoras profesionales y cinco amateurs realizaron el test de zapateado Zap-3 a 160, 180 pulsos por minuto, y a la mayor velocidad posible mientras portaban acelerometría triaxial (en el tobillo dominante, el tobillo no dominante, la 5ª vértebra lumbar y la 7ª cervical). Las cargas externas se calcularon mediante Playerload. El equilibrio fue evaluado con la prueba Y-Balance, se calcularon los resultados a nivel anterior, posteromedial, posterolateral, compuesto y el índice de asimetría. Las bailaoras amateurs son más sensibles a la capacidad de equilibrio, consecuentemente un mejor equilibrio puede reducir las cargas externas. Una correcta equilibración bilateral entre ambas extremidades es positivo para los bailaores de flamenco: reduce las sobrecargas a nivel cervical, los riesgos de lesiones y podría optimizar su técnica de zapateado.

Palabras clave: Equilibrio postural, carga de trabajo, baile, acelerometría, profesional, aficionado.

This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

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 (Wildermuth et al., 2021; 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). Vargas-Macías found female professional flamenco dancer: 3.37% right foot more than left foot (Vargas-Macías, 2016). The Forczek research group indicated that within the time parameters observed during the flamenco footwork ZAP-3 period, there were indications of low variability and high symmetry, but a lack of perfect symmetry in the movements performed with both lower limbs by the flamenco dancer has also been revealed (Forczek et al., 2022). Cromie's research group revealed that in Irish dance, which is a type of percussive dance and is a dance form where asymmetry is required, the rigidity of its training influences lower limb asymmetries as observed by comparing one hundred dancers and one hundred non-dancers (Cromie et al., 2007). 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., 2018a). 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 a very 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.

External load as measured by Playerload has been proven reliable and sensitive to monitoring and injury screening outcomes (Armstrong et al., 2019; Armstrong et al., 2020; Brogden et al., 2018; Moulder et al., 2021; Nagy et al., 2021). 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.

Method

Participants

Ten flamenco dancers volunteered to participate in this study (Five professional dancers, PRO group and five amateur dancers, AM group). Descriptive characteristics of the sample are presented (Table 1). 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 three hours per week. All participants were over 18 years of age and had had no musculoskeletal injuries in the six months preceding the test and had at least one year flamenco dance experience. Participants provided informed consent in writing before the commencement of the study. A stadiometer (Ruhe, China) used to measure height, a weighing scale (Xiaonmi, China) was used to measure weight. Body mass index (BMI) was calculated as [weight (kg)/height (m^2)]. Ethical approval was granted by the Faculty Ethics Committee at Beijing Sport University (2022037H), and the study was completed in accordance with the Declaration of Helsinki.

Table 1. Descriptive characteristics of participants (n = 10)

Characteristics	Professional n = 5	Amateur n = 5	p value
Age (years)	36 ± 4.36	34.8 ± 11.9	.841
Height (m)	1.63 ± 0.02	1.62 ± 0.034	.507
Weight (kg)	61.6 ± 5.32	56.4 ± 17.87	.562
BMI (kg/m2)	22.91 ± 6.28	21.43 ± 3.15	.653
Flamenco dance experience (years)	8.2 ± 5.26	2 ± 1.22	.033*

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; Benjamin 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.

Flamenco ZAP-3 footwork

Participants performed Zap-3: a sequence of six 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: Ball of the Foot / Zapateado de planta (P); Heel Drop / Zapateado de Tacón-planta (TP); Heel Tap / Zapateado de Tacón (T); Heel Drop / Zapateado de Tacón-planta (TP); Tip of the Toe Tap / Zapateado de Punta (PNT); and Heel Drop / 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 three 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.

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 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: .90 to 1.00 (-0.90 to -1.00) very high correlation; 0.70 to 0.90 (-0.70 to -0.90) high correlation; 0.50 to 0.70 (-0.50 to -0.70) moderate correlation; 0.30 to 0.50 (-0.30 to -0.50) low correlation; 0.00 to 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 $p < .05$.

Results

During the test, PRO and AM groups performed the 160 bpm and 180 bpm at the same frequency, 5.33 Hz and 6.00 Hz 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 ($p = .002$).

The Y-balance and ZAP-3 test

The results of YBT are reported in Table 2 and did not reveal significant bilateral asymmetries in the participants, regardless of their groups ($p > .05$). 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; $p = .041$) 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; $p = .021$) 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; $p = .01$) in YBpl.

Table 2. 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 ($p < .05$); 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 3. 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 ($p = .003$) and F speed level ($p = .032$). There was a significant group x speed ($p < .001$) interaction effect for PLuni. Post-hoc analyses revealed that there was a significant difference between groups at the fastest speed levels ($p < .05$).

Table 3. 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 ($p < .05$); 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; Lv160: 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.

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 = .046) and DA-PLv (r = -0.928, p = .023) at the 180 bpm speed level.

The effect of dynamic balance and asymmetry on the external load at the 5th Lumbar vertebrae

For PRO group, DA-YBpl had negative correlation with L5-PLtotal (r = -0.956, p = .01, L5-PLml (r = -0.941, p = .01, L5-PLv (r = -0.933, p = .021) at the F speed level. AI-YBcom had a negative correlation with L5-PLml (r = -0.89, p = .043) at the F speed level.

For AM group, DA-YBpm had negative correlation with L5-PLtotal (r = -0.895, p = .04), L5-PLv (r = -0.932, p = .021), at F speed level, and L5-PLv (r = -0.927, p = .023) at 180 bpm. NDA-YBcom had a negative correlation with L5-PLml (r = -0.916, p = .029), L5-PLap (r = -0.904, p = .035) at the 180 bpm speed level.

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 = .019) at 160 bpm, NDA-YBcom had negative correlation with C7-PLtotal (r = -0.92, p = .027), C7-PLml (r = -0.895, p = .04), C7-PLap (r = -0.966, p = .007) at the 180 bpm speed level. AI-YBant had positive correlation with C7-PLap (r = -0.971, p = .006) at the F speed level.

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 were 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. There are also articles similar to this study that describe the external load of flamenco dance, in which it is pointed out that there was a significant difference between groups when the Zap-3 footwork was performed at the fastest speed level for PLuni (Zhang, 2022), which is the same as the result in this study. This indicates that the professional dancer will generate a higher external load when striking the floor quickly, possibly because the fastest speed of the professional dancer is faster than the fastest speed of the amateur dancer, and the percussion is louder and more powerful. Otherwise, other study from the same group revealed that the effect of ankle active range of motion on the amateurs and professionals was different (Zhang, 2023), this point is similar to this study in that the effect of balance and asymmetry on dancers was different depending on their proficiency. For the ankle position amateurs were affected by dorsiflexion, but professionals were affected by both dorsiflexion and plantarflexion, For the C7 position, amateurs were affected by dorsiflexion while professionals were affected by plantarflexion (Zhang, 2023). In this study, amateurs were affected by YBT at the ankle, L5, and C7, and the YBT effect on professionals only at L5. Additionally, for amateurs, the AI-YBant had a positive correlation, but the correlation between AI-YBcom and L5 for professionals was negative. 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 of a better percussive footwork technique. The Forczek-Karkosz research group has also investigated rhythm and symmetry in flamenco footwork, which uses a 3D motion system to record and analyse the time of successive taps of the feet in the cycle, joint angular changes throughout the cycle, and lower limb joint angles at the time during flamenco footwork. They also chose Zap-3 flamenco footwork for the test and pointed out that within the time parameters observed during the Zap-3 period, there were indications of low variability and high symmetry. This study by Forczek-Karkosz proved a lack of perfect symmetry in the movements performed with both lower limbs by the flamenco dancer has also been revealed (Forczek et al., 2022). However, in our research, we studied the effect of lower limb balance ability and asymmetry on external load during flamenco footwork. Further studies could investigate if they have a correlation or if the balanced asymmetry of lower limbs causes imperfect asymmetry during performing footwork. 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).

In addition, regarding the effect of flamenco footwork factors, previous research has studied if ankle active range of motion affects the external load. The AAROM only affects the position of the ankle and the C7, but it does not affect the L5 lumbar, in contrast, in this study there was no correlation between balance ability and external load in the ankle or the C7 position for professionals (Zhang, 2023). This may be due to the movement pattern of Zap-3, where balance is responsible more for keeping upper limbs and trunk stable during performing, and AAROM is more for tapping the floor to keep the sound and rhythm.

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; Armstrong et al., 2020; Armstrong et al., 2018b).

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.

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.

References

Armstrong, R. (2020). The relationship between the functional movement screen, star excursion balance test and the Beighton score in dancers. *The Physician*

and Sportsmedicine, 48(1), 53-62. https://doi.org/10.1080/00913847.2019.1624658

Armstrong R. (2019). Dance Screening practices in dance companies, dance schools and university dance programmes: an international survey of current practices. *Journal of Clinical Case Reports, 1*(7), 1-14. https://doi.org/10.33118/oaj.clin.2019.01.007

Armstrong, R., Brogden, C., & Greig, M. (2019). The Star Excursion Balance Test as a predictor of mechanical loading and performance in dancers. *Gazzetta Medica Italiana Archivio per le Scienze Mediche, 178*(3), 98-105. https://doi.org/10.23736/S0393-3660.18.03733-6

Armstrong, R., Brogden, C. M., & Greig, M. (2020). Joint Hypermobility as a Predictor of Mechanical Loading in Dancers. *Journal of Sport Rehabilitation, 29*(1), 12-22. https://doi.org/10.1123/jsr.2018-0216

Armstrong, R., Brogden, C. M., Milner, D., Norris, D., & Greig, M. (2018a). The influence of fatigue on star excursion balance test performance in dancers. *Journal of Dance Medicine & Science, 22*(3), 142-147. https://doi.org/10.12678/1089-313X.22.3.142

Armstrong, R., Brogden, C. M., Milner, D., Norris, D., & Greig, M. (2018b). Functional movement screening as a predictor of mechanical loading and performance in dancers. *Journal of Dance Medicine & Science, 22*(4), 203-208. https://doi.org/10.12678/1089-313X.22.4.203

Attenborough, Alison S., Sinclair, P. J., Sharp, T., Greene, A., Stuelcken, M., Smith, R. M., & Hiller, C. E. (2017). The identification of risk factors for ankle sprains sustained during netball participation. *Physical Therapy in Sport,* 23, 31-36. https://doi.org/10.1016/j.ptsp.2016.06.009

Baena-Chicón, I., Gómez-Lozano, S., Abenza-Cano, L., de Vicuña, O. A.-G., Fernández-Falero, M. R., & Vargas-Macías, A. (2020). Las algias como factor predisponente de lesión en estudiantes de baile flamenco.(Algias as a predisposing factor of injury in flamenco dance students). *Cultura, Ciencia y Deporte, 15*(44), 245-253. https://doi.org/10.12800/ccd.v15i44.1466

Baena-Chicón, I., Gómez-Lozano, S., Cano, L. A., & Vargas-Macías, A. (2021). Pain catastrophizing in Flamenco dance students at professional dance conservatories. *Archivos de Medicina del Deporte,* 86-90. https://doi.org/10.18176/archmeddeporte.00030

Batson, G. (2010). Validating a dance-specific screening test for balance: preliminary results from multisite testing. *Medical Problems of Performing Artists, 25*(3), 110-115. https://doi.org/10.21091/mppa.2010.3023

Bell, D. R., Sanfilippo, J. L., Binkley, N., & Heiderscheit, B. C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of Strength and Conditioning research/ National Strength & Conditioning Association, 28*(4), 884. https://doi.org/10.1519/JSC.0000000000000367

Biernacki, J. L., Stracciolini, A., Fraser, J., Micheli, L. J., & Sugimoto, D. (2021). Risk factors for lower-extremity injuries in female ballet dancers: A systematic review. *Clinical Journal of Sport Medicine, 31*(2), e64-e79. https://doi.org/10.1097/JSM.0000000000000707

Bini, R. R., & Hume, P. (2015). Relationship between pedal force asymmetry and performance in cycling. *Journal of Sports Medicine and Physical Fitness, 55*(9), 892-898. https://www.minervamedica.it/en/journals/sports-med-physical-fitness/article.php?cod=R40Y2015N09A0892

Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: A systematic review. *Journal of Sports Sciences, 36*(10), 1135-1144. https://doi.org/10.1080/02640414.2017.1361894

Brogden, C. M., Armstrong, R., Page, R., Milner, D., Norris, D., & Greig, M. (2018). Use of triaxial accelerometry during the dance aerobic fitness test: Considerations for unit positioning and implications for injury risk and performance. *Journal of Dance Medicine & Science, 22*(3), 115-122. https://doi.org/10.12678/1089-313X.22.3.115

Cahalan, R., Kearney, P., Bhriain, O. N., Redding, E., Quin, E., McLaughlin, L. C., & O'Sullivan, K. (2018). Dance exposure, wellbeing and injury in collegiate Irish and contemporary dancers: A prospective study. *Physical Therapy in Sport,* 34, 77-83. https://doi.org/10.1016/j.ptsp.2018.09.006

Clark, T., & Redding, E. (2012). The relationship between postural stability and dancer's past and future lower-limb injuries. *Medical Problems of Performing Artists, 27*(4), 197-204. https://doi.org/10.21091/mppa.2012.4037

Clarke, F., Koutedakis, Y., Wilson, M., & Wyon, M. (2019). Associations between balance ability and dance performance using field balance tests. *Medical Problems of Performing Artists, 34*(3), 154-160. https://doi.org/10.21091/mppa.2019.3026

Collings, T. J., Bourne, M. N., Barrett, R. S., du Moulin, W., Hickey, J. T., & Diamond, L. E. (2021). Risk factors for lower limb injury in female team field and court sports: a systematic review, meta-analysis, and best evidence synthesis. *Sports Medicine, 51*(4), 759-776. https://doi.org/10.1007/s40279-020-01410-9

Cromie, S., Greenwood, J. G., & McCullagh, J. F. (2007). Does Irish-dance training influence lower-limb asymmetry?. *Laterality, 12*(6), 500-506. https://doi.org/10.1080/13576500701575140

Cummins, C., Welch, M., Inkster, B., Cupples, B., Weaving, D., Jones, B., King, D., & Murphy, A. (2019). Modelling the relationships between volume, intensity and injury-risk in professional rugby league players. *Journal*

of Science and Medicine in Sport, 22(6), 653-660. https://doi.org/10.1016/j.jsams.2018.11.028

Drew, M. K., & Finch, C. F. (2016). The relationship between training load and injury, illness and soreness: a systematic and literature review. *Sports Medicine, 46*(6), 861-883. https://doi.org/10.1007/s40279-015-0459-8

Forczek-Karkosz, W., Michnik, R., Nowakowska-Lipiec, K., Macías, A. V., Chicón, I. B., Lozano, S. G., & Gorwa, J. (2022). Rhythm or symmetry? What matters more in flamenco footwork?. *Journal of Kinesiology and Exercise Sciences, 32*(99), 35-46. https://doi.org/10.5604/01.3001.0016.0121

Forczek-Karkosz, W., Michnik, R., Nowakowska-Lipiec, K., Vargas-Macias, A., Baena-Chicón, I., Gómez-Lozano, S., & Gorwa, J. (2021). Biomechanical description of Zapateado technique in flamenco. *International Journal of Environmental Research and Public Health, 18*(6), 2905. https://doi.org/10.3390/ijerph18062905

Forczek, W., Baena-Chicon, I., & Vargas-Macias, A. (2017). Movement concepts approach in studies on flamenco dancing: A systematic review. *European Journal of Sport Science, 17*(9), 1161-1176. https://doi.org/10.1080/17461391.2017.1359680

Forczek, W., Chicón, I. B., & Vargas-Macías, A. (2016). Variación de la posición del centro de gravedad en una bailaora profesional durante el zapateado flamenco. *Revista del Centro de Investigación Flamenco Telethusa, 9*(10), 30-36. https://dialnet.unirioja.es/servlet/articulo?codigo=7653389

Grindem, H., Logerstedt, D., Eitzen, I., Moksnes, H., Axe, M. J., Snyder-Mackler, L., Engebretsen, L., & Risberg, M. A. (2011). Single-legged hop tests as predictors of self-reported knee function in nonoperatively treated individuals with anterior cruciate ligament injury. *The American journal of sports medicine, 39*(11), 2347-2354. https://doi.org/10.1177/0363546511417085

Guan, Y., Bredin, S. S., Taunton, J., Jiang, Q., Wu, N., & Warburton, D. E. (2022). Association between inter-limb asymmetries in lower-limb functional performance and sport injury: a systematic review of prospective cohort studies. *Journal of Clinical Medicine, 11*(2), 360. https://doi.org/10.3390/jcm11020360

Hartley, E. M., Hoch, M. C., & Boling, M. C. (2018). Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. *Journal of Science and Medicine in Sport, 21*(7), 676-680. https://doi.org/10.1016/j.jsams.2017.10.014

Hoffman, J. R., Ratamess, N. A., Klatt, M., Faigenbaum, A. D., & Kang, J. (2007). Do bilateral power deficits influence direction-specific movement patterns? *Research in Sports Medicine, 15*(2), 125-132. https://doi.org/10.1080/15438620701405313

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Medicine, 41*(3), 221-232. https://doi.org/10.2165/11538560-000000000-00000

Impellizzeri, F. M., Rampinini, E., Maffiuletti, N., & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Medicine and Science in Sports and Exercise, 39*(11), 2044. https://doi.org/10.1249/mss.0b013e31814fb55c

Junker, D., & Stöggl, T. (2019). The training effects of foam rolling on core strength endurance, balance, muscle performance and range of motion: a randomized controlled trial. *Journal of Sports Science & Medicine, 18*(2), 229. https://pubmed.ncbi.nlm.nih.gov/31191092/

Karim, A., Roddey, T., Mitchell, K., Ortiz, A., & Olson, S. (2019). Immediate effect of whole body vibration on sauté height and balance in female professional contemporary dancers a randomized controlled trial. *Journal of Dance Medicine & Science, 23*(1), 3-10. https://doi.org/10.12678/1089-313X.23.1.3

Kiesel, K. B., Butler, R. J., & Plisky, P. J. (2014). Prediction of injury by limited and asymmetrical fundamental movement patterns in American football players. *Journal of Sport Rehabilitation, 23*(2), 88-94. https://doi.org/10.1123/jsr.2012-0130

Kimmerle, M. (2001). Lateral bias in dance teaching. *Journal of Physical Education, Recreation & Dance, 72*(5), 34-37. https://doi.org/10.1080/07303084.2001.10605750

Lin, C.W., Su, F. C., Wu, H. W., & Lin, C. F. (2013). Effects of leg dominance on performance of ballet turns (pirouettes) by experienced and novice dancers. *Journal of Sports Sciences, 31*(16), 1781-1788. https://doi.org/10.1080/02640414.2013.803585

Lockie, R. G., Callaghan, S. J., Berry, S. P., Cooke, E. R., Jordan, C. A., Luczo, T. M., & Jeffriess, M. D. (2014). Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. *The Journal of Strength & Conditioning Research, 28*(12), 3557-3566. https://doi.org/10.1519/JSC.0000000000000588

Long, K. L., Milidonis, M. K., Wildermuth, V. L., Kruse, A. N., & Parham, U. T. (2021). The Impact of Dance-Specific Neuromuscular Conditioning and Injury Prevention Training on Motor Control, Stability, Balance, Function and Injury in Professional Ballet Dancers: A Mixed-Methods Quasi-Experimental Study. *International Journal of Sports Physical Therapy, 16*(2), 404. https://doi.org/10.26603/001c.21150

Maloney, S. J. (2019). The relationship between asymmetry and athletic performance: A critical review. *The Journal of Strength & Conditioning Research, 33*(9), 2579-2593. https://doi.org/10.1519/JSC.0000000000002608

McMahon, E., Pope, R., & Freire, K. (2021). Relationships Between Lateral Limb Bias, Turnout, and Lower Limb

Injury in a Female Pre-Professional Ballet Dancer Population. *Journal of Dance Medicine & Science, 25*(2), 139-146. https://doi.org/10.12678/1089-313X.061521i

Misegades, J., Rasimowicz, M., Cabrera, J., Vaccaro, K., Kenar, T., DeLuccio, J., & Stapleton, D. (2020). Functional movement and dynamic balance in entry level university dancers. *International Journal of Sports Physical Therapy, 15*(4), 548. https://doi.org/10.26603/ijspt20200548

Moulder, S., Armstrong, R., Greig, M., & Brogden, C. (2021). Effect of Kinesiology tape on tri-axial accelerometry during the Dance Aerobic Fitness Test. *Journal of Dance Medicine & Science, 25*(3), 191-199. https://doi.org/10.12678/1089-313X.091521d

Mukaka, M. M. (2012). A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal, 24*(3), 69-71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3576830/

Nagy, P., Brogden, C., Orr, G., & Greig, M. (2021). Within-and between-day loading response to ballet choreography. *Research in Sports Medicine, 30*(6), 616-627. https://doi.org/10.1080/15438627.2021.1929223

Pedersen, M. E., & Wilmerding, V. (1998). Injury profiles of student and professional flamenco dancers. *Journal of Dance Medicine & Science, 2*(3), 108-114. https://www.ingentaconnect.com/content/jmrp/jdms/1998/00000002/00000003/art00004

Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy, 36*(12), 911-919. https://doi.org/10.2519/jospt.2006.2244

Stiffler, M. R., Bell, D. R., Sanfilippo, J. L., Hetzel, S. J., Pickett, K. A., & Heiderscheit, B. C. (2017). Star excursion balance test anterior asymmetry is associated with injury status in division I collegiate athletes. *Journal of Orthopaedic & Sports Physical Therapy, 47*(5), 339-346. https://doi.org/10.2519/jospt.2017.6974

Strešková, E., & Chren, M. (2009). Balance ability level and sport performance in Latin-American dances. *Facta universitatis-series: Physical Education and Sport, 7*(1), 91-99. http://facta.junis.ni.ac.rs/pe/pe200901/pe200901-09.pdf

Swain, C. T., Bradshaw, E. J., Ekegren, C. L., & Whyte, D. G. (2019). The epidemiology of low back pain and injury in dance: a systematic review. *Journal of Orthopaedic & Sports Physical Therapy, 49*(4), 239-252. https://doi.org/10.2519/jospt.2019.8609

Van Winden, D., Van Rijn, R. M., Savelsbergh, G. J., Oudejans, R. R., & Stubbe, J. H. (2021). The association between stress and injury: a prospective cohort study among 186 first-year contemporary dance students. *Frontiers in Psychology,* 12, 770494. https://doi.org/10.3389/fpsyg.2021.770494

Vargas-Macías, A. (2006). *El baile flamenco: estudio descriptivo, biomecánico y condición física.* Universidad de Cádiz

Vargas-Macías, A. (2016). El baile flamenco desde la perspectiva de las Ciencias de la Actividad Física y del Deporte. *Revista del Centro de Investigación Flamenco Telethusa, 9*(11), 6-10. https://dialnet.unirioja.es/servlet/articulo?codigo=7653314

Vargas-Macías, A., Baena-Chicón, I., Gorwa, J., Michnik, R. A., Nowakowska-Lipiec, K., Gómez-Lozano, S., & Forczek-Karkosz, W. (2021). Biomechanical Effects of Flamenco Footwork. *Journal of Human Kinetics, 80*(1), 19-27. https://doi.org/10.2478/hukin-2021-0086

Vassallo, A. J., Pappas, E., Stamatakis, E., & Hiller, C. E. (2018). Differences in the occurrence and characteristics of injuries between full-time and part-time dancers. *BMJ Open Sport & Exercise Medicine, 4*(1), e000324. https://doi.org/10.1136/bmjsem-2017-000324

Wanke, E. M., Schreiter, J., Groneberg, D. A., & Weisser, B. (2018). Muscular imbalances and balance capability in dance. *Journal of Occupational Medicine and Toxicology, 13*(1), 1-8. https://doi.org/10.1186/s12995-018-0218-5

Wilson, B. R., Robertson, K. E., Burnham, J. M., Yonz, M. C., Ireland, M. L., & Noehren, B. (2018). The relationship between hip strength and the Y balance test. *Journal of Sport Rehabilitation, 27*(5), 445-450. https://doi.org/10.1123/jsr.2016-0187

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. https://doi.org/10.3390/s22134847

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. https://doi.org/10.18176/archmeddeporte.00121