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).

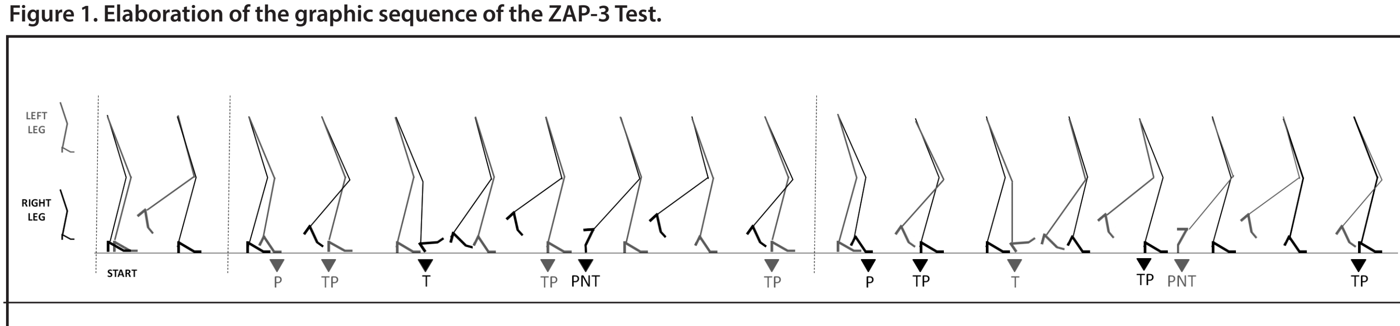
External load measurement during footwork: Playerload

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 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 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).

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 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).

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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