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Quantifying the External Joint Workload and Safety of Latin Dance in Older Adults: Potential Benefits for Musculoskeletal Health

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Featured Application: Latin dance presents a safe, engaging form of weight-bearing exercise for older adults that could help to mitigate age-related physical decline. Quantifying limb impacts during dance using wearable sensors informs guidelines for an appropriate workload to strengthen lower extremity bones and muscles in older populations vulnerable to sarcopenia and falls.

Abstract: As global aging rises, identifying strategies to mitigate age-related physical decline has become an urgent priority. Dance represents a promising exercise modality for older adults, yet few studies have quantified the external loads older dancers experience. This study aimed to characterize the impacts accumulated across lower limb and spinal locations in older adults during Latin dance. Thirty older Latin dancers (age = 66.56 ± 6.38 years; female = 93.3%) wore inertial sensors on the scapulae, lumbar spine, knees, and ankles during a 1 h class. A distal-to-proximal gradient emerged in the total impacts (F = 429.29; $p < 0.01$; $\omega_p{}^2$ = 0.43) and per intensities (F = 103.94-to-665.55; $p < 0.01$; $\omega_p{}^2$ = 0.07-to-0.54), with the highest impacts sustained in the ankles (≈9000 total impacts) from 2 g to >10 g ($p < 0.01$; d = 1.03-to-4.95; ankles > knees > lower back > scapulae) and knees (≈12,000 total impacts) when <2 g ($p < 0.01$, d = 2.73-to-3.25; knees > ankles > lower back > scapulae). The majority of the impacts remained below 6 g across all anatomical locations (>94%). The impacts also increased in lower limb locations with faster tempos (r = 0.10-to-0.52; $p < 0.01$), while subtly accumulating over successive songs rather than indicating fatigue (r = 0.11-to-0.35; $p < 0.01$). The mild ankle and knee loads could strengthen the dancers' lower extremity bones and muscles in a population vulnerable to sarcopenia, osteoporosis, and falls. Quantifying the workload via accelerometry enables creating personalized dance programs to empower healthy aging. With global aging rising, this work addresses a timely public health need regarding sustainable lifelong exercise for older people. Ranging from low to moderate, the measured impact magnitudes suggest that dance lessons may provide enough osteogenic stimulus without overloading structures.

Keywords: older adults; accelerometry; inertial sensors; exercise prescription; injury prevention

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1. Introduction

The world's population is aging rapidly. According to the United Nations [1], by 2050, one in six people will be over the age of 65 years globally, triple the number of 2019. This demographic shift comes with substantial health and economic challenges, as aging is associated with an increased risk for chronic diseases, like heart disease, diabetes,

osteoporosis, arthritis, and sarcopenia [2–4]. Age-related losses of muscle mass, strength, and function, also known as sarcopenia, negatively impact the quality of life and ability to live independently [5]. Thus, identifying strategies to mitigate sarcopenia and its related consequences is an urgent public health priority.

Exercise participation helps to prevent and manage age-related decline, like sarcopenia, osteoporosis, and loss of balance, in older adults [6–9]. While the benefits of dancing are promising, understanding its specific workload implications is crucial for prescribing it safely and effectively. Recent systematic reviews have explored the risks and benefits of other physical activities, like judo [10,11] and sport participation [12], in older populations. Palumbo et al. [10] found that appropriately dosed judo training can improve muscle strength, flexibility, and fall prevention in middle-aged and older adults, though the risk of injury must be carefully managed. Ciaccioni et al. [11] reported judo's dynamic throwing and grappling movements provide osteogenic benefits. Oliveira et al. [12] concluded in their meta-analysis that sport participation reduces the risk of falls and functional limitations, while enhancing the quality of life in older adults. Like these activities, dancing integrates physical challenges within a socially enriching context that appeals to older exercisers [13,14]. Researchers have demonstrated that dancing produces various benefits among older people, such as better balance, gait, endurance, strength, and quality of life, compared to non-dancing controls [15–17].

While the benefits of dancing for older adults are promising, few studies have quantified the specific external loads that older dancers experience to guide programing. Evaluating a dance's workload profile can shed light on its safety and potential to mitigate age-related musculoskeletal decline. Wearable inertial measurement units (IMUs) enable the objective quantification of external loads via the impacts accumulated [18]. High volumes of repeated impact may fatigue structures and heighten injury risks [19]. Thus, monitoring the musculoskeletal load distribution can inform guidelines for safe, sustainable dance programing for older adults [20]. Factors like music and fatigue across a dance session can influence impact accumulation, though this has not been explored in older dancers.

Therefore, this study aimed to: (1) characterize the external workload experienced by older people across various anatomical locations during a 60 min Latin dance class and (2) examine whether factors like music genre and session duration influence the workload. We hypothesized the participants would accumulate the greatest workload at the ankle, followed by the knee, lumbar region, and scapulae. We also predicted faster, more rhythmic genres would elicit higher impacts than slower songs and that fatigue would provoke decreased impacts from the first to the last songs. The findings from this study can guide the prescription of safe, optimal dance programing for older adults, while shedding light on how music genre and fatigue may modulate the external dance workload. With global aging rising, this work addresses a timely public health need regarding sustainable lifelong exercise.

2. Materials and Methods

2.1. Design

This study protocol used a non-randomized cross-sectional approach [21]. We aimed to quantify and characterize the external workload experienced by older individuals across six designated anatomical locations (scapulae, lower back, right knee, left knee, right ankle, and left ankle) during a dance class composed of 16 songs of different styles (kizomba, roots, cumbia, vallenato, bachata, salsa, merengue, and chachacha). The participants visited the sports pavilion on two occasions (first for familiarization with the equipment and second for the evaluation) for about 90 min during each session. The monitorization of the external workload suffered by older people during the Latin dance class was performed by six WIMU PRO^{TM} inertial devices that registered the total impact suffered and per intensities.

2.2. Participants

A non-probabilistic sample [18] was established to determine the external workload in older adults. A total of 30 older participants (men: $n = 2$; women: $n = 28$) were selected to participate in the present study (mean ± SD; age: 66.56 ± 6.38 years; body mass: 67.21 ± 13.73 kg; height: 1.50 ± 5.67 m; body mass index: 28.39 ± 4.97 kg/m^2; and fat mass percentage: 36.44 ± 6.25%). To participate in the study, the participants were selected according to accessibility, availability, and meeting different inclusion and exclusion criteria: (a) a minimum of 6 months of experience in Latin dance classes, (b) participating at least in two classes per week ascribed to the institutionalized program, and (c) no health problems or discomforts that influenced the assessment. In addition, all participants provided their consent to participate in the protocol with full freedom and autonomy. The assessment was conducted according to the Declaration of Helsinki and was approved by the National Council of Health Research, which belongs to the Costa Rican Ministry of Health (register number: 2432-2019; approval date: 02/10/2019).

To determine the sample size, a power analysis test was performed with G-Power version 3.1.9.7, considering an a priori alpha (α) of 0.05 and an a priori test power ($1 - \beta$) of 0.80 in a mixed ANOVA analysis scheme of 4 measurements for 3 conditions with confidence intervals of 1.96, which resulted in a sample size of 30 participants and a critical F-value of 2.17 [22].

2.3. Variables and Instruments

The external workload was registered through the impacts suffered by the participants during the dance lesson. The impacts were calculated using the magnitude of the 3-dimensional accelerometer values at any time point and were identified as the maximum accelerometer magnitude values above a g-force value in a 0.1 s period, according to the manufacturers' specifications [18]. Depending on the intensity of the impact, it was classified into six ranges based on the g forces detected: (1) very low, <2 g; (2) low, 2–4 g; (3) moderate, 4–6 g; (4) high, 6–8 g; (5) very high, 8–10 g; and (6) severe, >10 g. In addition, the sum of all impacts in their different ranges also was considered as the total impacts.

All variables were registered by WIMU PRO^{TM} inertial devices (RealTrack Systems, Almeria, Spain). The device features four triaxial accelerometers responsible for measuring and detecting movement (±16 gravity (g), ±16 g, ±32 g, ±400 g). It is supported by an electromechanical system with sampling frequencies ranging from 10 to 1000 Hz, being configured at 100 Hz in this research because it is sufficiently sensitive to detect sports movements [23]. The device contains a 1 GHz microprocessor, 8 GB of internal memory, a USB port for data download, and a battery allowing over 4 h of use. This enables the inertial measurement unit to record, store, and download the movement data. The device weighed 70 g and had dimensions of 81 × 45 × 16 mm. The reliability (CV = 0.23-to-2.20%; r > 0.86; $p > 0.46$; t < 0.73) and convergent validity (average heart rate: r = 0.99; muscle oxygen saturation: r = −0.69) of the accelerometer measures were proved in previous research for the four anatomical locations evaluated in the present study [24,25].

2.4. Procedures

The study comprised two sessions in one week. The first session was for familiarization with the equipment and the second session was for registering the external workload during the dance class. The first session allowed the participants to become familiar with the equipment during the activity.

Firstly, the participants arrived 30 min previous to the start of the dance class to attach the inertial devices in six anatomical locations: (1) scapulae (in the T2–T4 vertebrae), (2) lower back (L2–L4 vertebrae), (3 and 4) knees (one to the right (RK) and the other to the left (LK) of the vastus lateralis muscle insertion point), and (5 and 6) ankles (3 cm above the right (RA) and left (LA) peroneal malleolus). The lower back sensor was placed at L3 due to this region having been recommended for capturing representative kinematics and loading

during dynamic activities [26,27] and not being influenced by the rotational movements of the sacrum [28].

The devices were secured using fitted tops and leggings with pockets designed to prevent unwanted vibrations or device movements during testing [24] (see Figure 1a,b). Before device placement, the accelerometers were calibrated per the manufacturer's (RealTrack Systems, Almeria, Spain) recommendations to avoid four potential sources of error: offset error, scaling error, orthogonal error, and random error [29]. Additionally, to ensure correct data collection at device initiation, three key recommendations from Gomez Carmona et al. [24] were followed: (1) leave the device motionless for 30 s, (2) on a flat surface, and (3) away from magnetic devices.

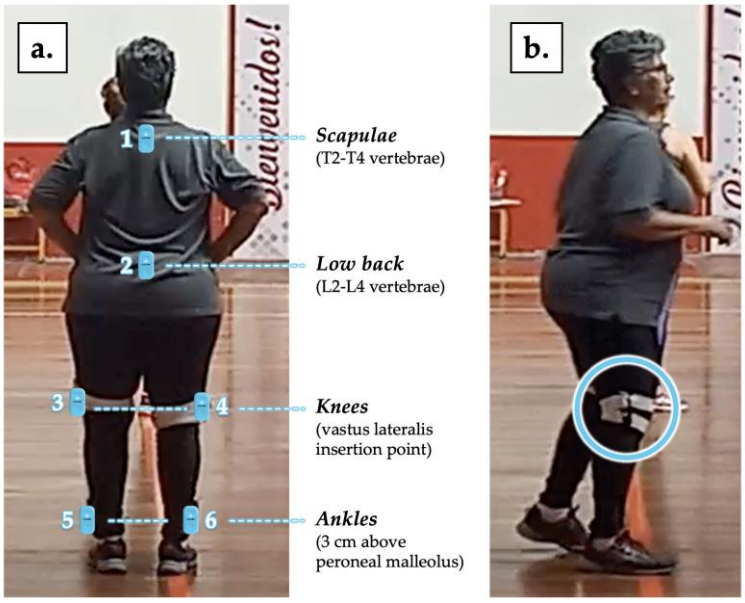


Figure 1. Inertial device placement. (**a**) 1: Scapulae, 2: lower back, 3: left knee, 4: right knee, 5: left ankle, and 6: right ankle. (**b**) Fixing system of the inertial devices to avoid movement during the assessments.

Then, the 60 min dance class was performed. The dance class consisted of group choreographies and movements performed individually, without the need for partner work or couple dances. This allowed all 30 participants (28 women and 2 men) to perform the same movements and follow the instructor's guidance without being paired up. This session was designed by an expert in dance and physical activity with older people, as well as followed the recommendations for aerobic fitness and safety provided by Rodrigues-Krause et al. [30]. This class was composed of 16 songs with a great variety of Latin rhythms and an Angolan rhythms (kizomba, for the first song as a warm-up). Dance movements included walking forward and backward, side-to-side steps, turns, pivots, foot drags, small jumps, and knee flexions. The dance routine was pre-recorded and edited to standardize the intervention session across all participants. The routine was projected in TV screens to enable proper viewing and the execution of the moves. The television screens were positioned to be clearly visible and to allow the music to be heard adequately. Table 1 shows the description of the order of songs, duration, and dance rhythms.

At the conclusion of each session, the inertial device data were downloaded to a computer and imported into the SPRO^{TM} analysis software (version 989, RealTrack Systems, Almeria, Spain). This software enabled the configuration of impact intensity thresholds. It also allowed for the data extraction of impacts for each participant, anatomical location, and individual song. The aggregated data were compiled into an Excel spreadsheet formatted as a database. To enable comparisons of workload between songs with varying durations, the absolute impact counts extracted for each song were normalized by expressing them relative to the song length as impacts per minute.

Table 1. Description of the order, music style, music velocity, and song duration.

Order	Music Style	Beats per Minute	Duration
1	Kizomba	80	4 min
2	Roots	85	4 min 26 s
3	Cumbia	124	4 min 6 s
4	Vallenato	114	3 min 3 s
5	Bachata	110	3 min 14 s
6	Cumbia	93	3 min 44 s
7	Salsa	124	3 min 22 s
8	Merengue	136	4 min 9 s
9	Cumbia	125	3 min 8 s
10	Bachata	110	4 min 3 s
11	Merengue	142	4 min 52 s
12	Bolero	100	2 min 47 s
13	Cumbia	126	2 min 53 s
14	Chachacha	114	3 min 51 s
15	Cumbia	94	4 min 19 s
16	Bolero	103	4 min
		Total	59 min 57 s

2.5. Statistical Analysis

Firstly, there were no missing data in this study. All 30 participants completed the full 60 min dance class while wearing the inertial sensors at all six anatomical locations. The data from the inertial devices were successfully downloaded and processed for each participant across all 16 songs of the dance routine. No data points had to be excluded or imputed. The Kolmogorov–Smirnov and Levene tests were then performed, confirming normal data distribution and homoscedasticity [31]. Mean and standard deviations were conducted to characterize the total impacts and per intensities in the different anatomical locations. To calculate the data of songs in each variable, the separate average of each song performed during the dance lesson was calculated. In addition, the total workload of the session was obtained as the sum of the session's songs. A multivariant analysis of variance (MANOVA) was conducted to identify the mean of differences between the rhythm of the songs and the anatomical locations of the inertial devices. Bonferroni correction was used for 2-by-2 comparisons [31]. In addition, the magnitude of the differences for MANOVA was calculated using the partial omega-squared (ω_p^2) that was classified as <0.01 as trivial, 0.01–0.06 as small, 0.06–0.14 as medium, and >0.14 as large, following Cohen [32], and for 2-by-2 comparisons using Cohen's d following Hopkins et al. [33], classified as very low (<0.2), low (0.2–0.6), moderate (0.6–1.2), high (1.2–2.0), and very high (>2.0), with mean differences and CIs. In addition, to identify the fatigue throughout the dance lesson, the relationship between the songs' order and the external workload was studied using the Pearson correlation coefficient. The magnitude of the correlation coefficients was deemed trivial ($r^2 < 0.1$), small ($0.1 > r^2 < 0.3$), moderate ($0.3 > r^2 < 0.5$), large ($0.5 > r^2 < 0.7$), very large ($0.7 > r^2 < 0.9$), nearly perfect ($r^2 < 0.9$), and perfect ($r^2 = 1.0$) [33]. All analyses were conducted using the SPSS 24.0 software (SPSS, Inc., Chicago, IL, USA). Statistical significance was established at $p < 0.05$.

3. Results

Table 2 shows the descriptive and inferential analyses of the total impacts suffered and per intensities regarding the music style and the body location where the inertial devices were attached. Older people had a total sum of 2805.92 impacts on the scapulae, 6013.09 on the lower back, 11,822.79 on the left knee, 12,127.90 on the right knee, 8912.86 on the left ankle, and 8615.49 on the right ankle during the dance lesson. The majority of impacts were at very low ($Imp_{<2G}$; scapulae: 98.60%; lower back: 99.09%; left knee: 87.73%; right knee: 87.45%; left ankle: 69.09%; and right ankle: 67.37%) or low intensities ($Imp_{2–4G}$; scapulae: 1.34%; lower back: 0.82%; left knee: 10.59%; right knee: 10.67%;

left ankle: 21.16%; and right ankle: 22.36%). Impacts at moderate (4–6 g), high (6–8 g), and very high (8–10 g) intensities only were found on the knees ($Imp_{4–6G}$: 1.43–1.58%; $Imp_{6–8G}$: 0.19–0.23%; and $Imp_{8–10G}$: 0.03–0.04%) and ankles ($Imp_{4–6G}$: 6.85–7.17%; $Imp_{6–8G}$: 2.16–2.23%; and $Imp_{8–10G}$: 0.55–0.62%), with a very reduced frequency. Finally, severe impacts (>10 g) only were registered on the ankles, being in the range from 16-to-21 impacts in the total session (0.18–0.25%).

Regarding body locations, statistical differences with a large effect size were found for the total impacts ($F = 429.29$; $p < 0.01$; $\omega_p^2 = 0.43$) and per intensities ($F = 103.94$-to-665.55; $p < 0.01$; <2 g, $\omega_p^2 = 0.40$; 2–4 g, $\omega_p^2 = 0.54$; 4–6 g, $\omega_p^2 = 0.35$; 6–8 g, $\omega_p^2 = 0.25$; and 8–10 g, $\omega_p^2 = 0.15$), except for a medium effect size for severe impacts (>10 g; $F = 40.70$; $p < 0.01$; $\omega_p^2 = 0.07$). Specifically, most of the impacts at a very low intensity (<2 g) were received by the knees ($p < 0.01$, $d = 2.73$-to-3.25, very high; knees > ankles > lower back > scapulae). Instead, most of the impacts at low, moderate, high, and very high intensities were suffered by the ankles ($p < 0.01$; $d = 1.03$-to-4.95, moderate to very high; ankles > knees > lower back > scapulae). At a severe intensity (>10 g), only differences were found between the ankles and the rest of the locations ($p < 0.01$, $d = 0.41$-to-0.71, low to moderate; ankles > knees = lower back = scapulae). The location that registered lower impacts in the total impacts at all intensity levels was the scapulae, followed by the lower back. No differences were found regarding laterality both at the knees ($p = 0.94$, $d < 0.02$) and ankles ($p > 0.74$, $d < 0.27$) in the total impacts and per intensities.

Considering music style, statistical differences were found with a large effect size for the total impacts ($F = 532.57$; $p < 0.01$; $\omega_p^2 = 0.60$), very low impacts (<2 g; $F = 416.64$; $p < 0.01$; $\omega_p^2 = 0.54$), low impacts (2–4 g; $F = 295.92$; $p < 0.01$; $\omega_p^2 = 0.45$), and moderate impacts (4–6 g; $F = 118.24$; $p < 0.01$; $\omega_p^2 = 0.25$); with a medium effect size for high impacts (6–8 g; $F = 52.55$; $p < 0.01$; $\omega_p^2 = 0.13$) and very high impacts ($F = 24.48$; $p < 0.01$; $\omega_p^2 = 0.06$); and with a small effect size for severe impacts ($F = 11.14$; $p < 0.01$; $\omega_p^2 = 0.03$). Cumbia and salsa obtained the highest total impacts and at very low (<2 g), low (2–4 g) and moderate (4–6 g) intensities ($p < 0.01$, $d = 0.33$-to-4.53, low to very high; cumbia = salsa > vallenato = merengue > bachata = chachacha > bolero > roots > kizomba). At high (6–8 g) and very high (8–10 g) intensities, salsa, cumbia, chachacha, and vallenato presented the highest impacts ($p < 0.01$, $d = 0.73$-to-1.18, moderate; salsa = cumbia = chachacha = vallenato > merengue > bachata > bolero > roots > kizomba). For severe impacts, the highest values were found for chachacha ($p < 0.01$, $d = 0.22$-to-0.73, low to moderate; chachacha > salsa = vallenato > cumbia > merengue > bachata > bolero = roots > kizomba).

Finally, the interaction between the music style and body locations presented statistical differences with a large effect size for the total impacts, very low impacts, low impacts, moderate impacts, and high impacts ($F = 12.78$-to-28.14; $p < 0.01$; $\omega_p^2 = 0.14$-to-0.27); with a medium effect size for the very high impacts ($F = 7.55$; $p < 0.01$; $\omega_p^2 = 0.08$); and with a small effect size for severe impacts ($F = 3.98$; $p < 0.01$; $\omega_p^2 = 0.04$).

The relationships between the total impacts and per intensity levels performed by the older people concerning the order of the songs throughout the dance lesson and the rhythm of the music (beats per minute) at each anatomical location are shown in Table 3. The analysis indicated that a faster music rhythm produced higher impacts with moderate correlations in the total impacts and at a very low intensity in the lower limb locations and at a low intensity in the ankles. In addition, small correlations were found in the knees at a low intensity and in the ankles at moderate, high, and very high intensities. No correlations were found between music rhythm and impacts in the upper limbs (scapulae and lower back). On the other hand, the order of the songs throughout the dance lesson produced greater impacts in the lower limb locations with small correlations in the total impacts and very low, low, and moderate impacts in the knees and ankles and in high and very high intensity impacts in the ankles.

Table 2. MANOVA for the body location and music style of the total impacts and impacts per intensity levels.

External Workload	Music Style	Body Location						F (p)	ω_p^2 (*Effect*)
		Scapulae	Lower Back	Left Knee	Right Knee	Left Ankle	Right Ankle		
		M ± SD	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD		
TImp/min	Bachata	42.40 ± 48.90	108.62 ± 66.74	261.78 ± 63.17	270.91 ± 38.96	202.55 ± 24.50	203.13 ± 22.06		
	Bolero	14.03 ± 36.88	27.05 ± 37.07	133.36 ± 59.19	133.89 ± 51.93	122.85 ± 39.58	120.92 ± 37.99		
	Chachacha	49.62 ± 57.89	104.68 ± 77.10	257.47 ± 57.53	258.56 ± 33.76	199.49 ± 22.75	191.55 ± 23.50	429.29 (<0.01)	0.43 (large)
	Cumbia	114.72 ± 95.50	202.32 ± 101.44	291.01 ± 67.13	301.01 ± 51.64	203.06 ± 43.32	196.96 ± 40.16		
	Kizomba	7.53 ± 5.67	2.93 ± 3.65	4.91 ± 5.15	4.29 ± 4.87	3.50 ± 4.07	3.40 ± 3.70		
	Merengue	59.08 ± 58.36	132.45 ± 75.13	265.04 ± 62.00	270.87 ± 39.56	200.57 ± 28.02	193.00 ± 27.58		
	Roots	14.74 ± 20.72	21.43 ± 32.62	44.39 ± 42.79	46.53 ± 44.31	21.05 ± 27.10	21.10 ± 27.40		
	Salsa	68.60 ± 67.28	174.08 ± 103.70	278.50 ± 60.36	292.76 ± 44.26	210.26 ± 43.92	195.59 ± 29.80		
	Vallenato	60.96 ± 63.45	151.53 ± 86.42	282.43 ± 61.34	287.01 ± 37.98	207.88 ± 28.09	199.81 ± 30.32		
	F (p)			532.57 (<0.01)				*F interaction (p); ω_p^2 (effect)*	
	ω_p^2 (*effect*)			0.60 (large)				16.63 (<0.01); 0.18 (large)	
$Imp_{<2G}$/min	Bachata	41.88 ± 46.82	108.52 ± 66.57	233.65 ± 56.07	240.83 ± 32.02	146.56 ± 25.14	145.25 ± 23.46		
	Bolero	13.85 ± 36.00	26.30 ± 33.05	126.30 ± 53.15	126.09 ± 46.03	97.64 ± 29.10	96.35 ± 29.29		
	Chachacha	48.90 ± 55.53	104.06 ± 75.93	220.60 ± 46.59	220.38 ± 24.97	129.38 ± 19.82	121.68 ± 21.76	375.43 (<0.01)	0.40 (large)
	Cumbia	112.61 ± 91.65	197.47 ± 96.40	248.68 ± 54.09	255.68 ± 40.86	132.98 ± 33.55	123.99 ± 31.56		
	Kizomba	7.52 ± 5.67	2.91 ± 3.64	4.77 ± 5.08	4.12 ± 4.73	3.14 ± 3.55	3.04 ± 3.22		
	Merengue	58.32 ± 55.91	131.79 ± 74.13	234.51 ± 54.08	238.98 ± 36.15	146.82 ± 26.13	138.02 ± 26.46		
	Roots	14.56 ± 20.51	21.38 ± 32.51	42.31 ± 38.47	43.89 ± 39.09	17.30 ± 18.66	17.41 ± 18.88		
	Salsa	67.71 ± 64.69	173.72 ± 103.13	236.10 ± 51.03	251.39 ± 36.88	127.98 ± 27.26	113.66 ± 22.44		
	Vallenato	60.27 ± 61.12	150.50 ± 85.24	248.83 ± 51.24	250.35 ± 28.32	145.54 ± 20.98	133.51 ± 22.48		
	F (p)			416.64 (<0.01)				*F interaction (p); ω_p^2 (effect)*	
	ω_p^2 (*effect*)			0.54 (large)				18.89 (<0.01); 0.20 (large)	
$Imp_{2–4G}$/min	Bachata	0.52 ± 2.73	0.10 ± 0.28	26.04 ± 13.70	27.65 ± 12.54	42.70 ± 8.65	44.15 ± 8.39		
	Bolero	0.18 ± 0.96	0.71 ± 5.33	6.39 ± 7.54	6.99 ± 6.76	20.46 ± 10.07	20.31 ± 8.63		
	Chachacha	0.71 ± 3.00	0.48 ± 1.71	31.19 ± 16.18	31.84 ± 14.17	45.78 ± 9.64	45.74 ± 10.20		
	Cumbia	2.05 ± 7.02	4.16 ± 10.23	35.11 ± 18.28	37.05 ± 17.63	45.57 ± 14.05	47.00 ± 12.25		
	Kizomba	0.01 ± 0.05	0.03 ± 0.08	0.13 ± 0.43	0.17 ± 0.40	0.31 ± 0.64	0.30 ± 0.59	665.55 (<0.01)	0.54 (large)
	Merengue	0.68 ± 3.25	0.62 ± 2.03	27.25 ± 13.58	28.00 ± 12.95	36.70 ± 8.06	36.15 ± 7.98		
	Roots	0.17 ± 0.78	0.05 ± 0.14	1.94 ± 4.70	2.20 ± 4.37	2.60 ± 6.02	2.68 ± 6.74		
	Salsa	0.79 ± 4.17	0.36 ± 0.86	35.64 ± 19.40	34.45 ± 16.65	53.42 ± 16.20	55.47 ± 13.62		
	Vallenato	0.69 ± 3.29	1.03 ± 2.13	29.02 ± 15.92	30.90 ± 13.91	42.58 ± 10.69	44.57 ± 10.69		
	F (p)			295.92 (<0.01)				*F interaction (p); ω_p^2 (effect)*	
	ω_p^2 (*effect*)			0.45 (large)				28.14 (<0.01); 0.27 (large)	
$Imp_{4–6G}$/min	Bachata	0.01 ± 0.04	0.00 ± 0.00	1.96 ± 3.11	2.22 ± 3.23	10.03 ± 4.70	10.74 ± 5.19		
	Bolero	0.00 ± 0.00	0.04 ± 0.28	0.63 ± 2.21	0.65 ± 2.51	3.54 ± 3.36	3.38 ± 3.83		
	Chachacha	0.01 ± 0.05	0.11 ± 0.62	5.00 ± 5.41	5.56 ± 5.83	16.41 ± 7.72	14.86 ± 6.59		
	Cumbia	0.06 ± 0.33	0.51 ± 3.48	6.08 ± 6.98	6.99 ± 7.64	17.96 ± 9.54	18.54 ± 10.13		
	Kizomba	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.05	0.01 ± 0.05	0.03 ± 0.09	0.05 ± 0.14	303.92 (<0.01)	0.35 (large)
	Merengue	0.08 ± 0.49	0.04 ± 0.16	3.04 ± 4.23	3.53 ± 3.82	11.64 ± 5.29	12.97 ± 5.96		
	Roots	0.02 ± 0.08	0.00 ± 0.00	0.14 ± 0.44	0.41 ± 1.97	0.93 ± 3.24	0.59 ± 1.76		
	Salsa	0.10 ± 0.54	0.00 ± 0.00	5.48 ± 8.39	5.53 ± 8.08	19.50 ± 10.11	18.72 ± 9.42		
	Vallenato	0.00 ± 0.00	0.00 ± 0.00	3.70 ± 4.20	4.66 ± 5.53	13.88 ± 7.31	15.17 ± 7.36		
	F (p)			118.24 (<0.01)				*F interaction (p); ω_p^2 (effect)*	
	ω_p^2 (*effect*)			0.25 (large)				19.06 (<0.01); 0.20 (large)	
$Imp_{6–8G}$/min	Bachata	0.00 ± 0.00	0.00 ± 0.00	0.12 ± 0.43	0.20 ± 0.49	2.40 ± 1.95	2.30 ± 2.27		
	Bolero	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.16	0.15 ± 0.98	1.00 ± 1.48	0.76 ± 1.18		
	Chachacha	0.00 ± 0.00	0.03 ± 0.14	0.55 ± 1.25	0.66 ± 0.93	5.54 ± 4.36	6.05 ± 4.56		
	Cumbia	0.00 ± 0.03	0.17 ± 1.38	0.97 ± 2.11	1.11 ± 2.06	5.04 ± 3.94	5.57 ± 4.57		
	Kizomba	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.09	0.01 ± 0.05	192.80 (<0.01)	0.25 (large)
	Merengue	0.00 ± 0.03	0.00 ± 0.03	0.22 ± 0.46	0.33 ± 0.70	4.22 ± 3.25	4.33 ± 3.17		
	Roots	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.04	0.03 ± 0.10	0.08 ± 0.23	0.32 ± 1.28		
	Salsa	0.00 ± 0.00	0.00 ± 0.00	1.02 ± 3.96	1.12 ± 2.98	6.96 ± 5.67	5.63 ± 5.28		
	Vallenato	0.00 ± 0.00	0.00 ± 0.00	0.56 ± 1.28	0.71 ± 1.28	4.46 ± 2.98	4.61 ± 3.78		
	F (p)			52.55 (<0.01)				*F interaction (p); ω_p^2 (effect)*	
	ω_p^2 (*effect*)			0.13 (medium)				12.78 (<0.01); 0.14 (large)	

Table 2. *Cont.*

External Workload	Music Style	Body Location: Scapulae	Lower Back	Left Knee	Right Knee	Left Ankle	Right Ankle	*F* (*p*)	ω_p^2 (*Effect*)
		M ± SD	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD		
$Imp_{8–10G/}$min	Bachata	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.08	0.01 ± 0.05	0.64 ± 0.77	0.53 ± 0.87		
	Bolero	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.05	0.17 ± 0.50	0.09 ± 0.26		
	Chachacha	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.62	0.07 ± 0.20	1.64 ± 1.76	2.06 ± 2.56		
	Cumbia	0.00 ± 0.00	0.01 ± 0.06	0.14 ± 0.46	0.15 ± 0.38	1.16 ± 1.24	1.40 ± 1.67	103.94 (<0.01)	0.15 (large)
	Kizomba	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00		
	Merengue	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.05	0.03 ± 0.08	0.97 ± 1.08	1.15 ± 1.36		
	Roots	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.54	0.08 ± 0.37		
	Salsa	0.00 ± 0.00	0.00 ± 0.00	0.24 ± 1.03	0.21 ± 0.73	1.81 ± 2.34	1.50 ± 2.18		
	Vallenato	0.00 ± 0.00	0.00 ± 0.00	0.13 ± 0.51	0.28 ± 1.37	1.08 ± 1.52	1.43 ± 2.00		
	F (*p*)	24.48 (<0.01)						*F interaction (p)*; ω_p^2 (*effect*)	
	ω_p^2 (*effect*)	0.06 (medium)						7.55 (<0.01); 0.08 (medium)	
$Imp_{>10G/}$min	Bachata	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.22 ± 0.63	0.15 ± 0.31		
	Bolero	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.18	0.03 ± 0.12		
	Chachacha	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.05	0.06 ± 0.16	0.74 ± 1.19	1.15 ± 2.38		
	Cumbia	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.16	0.04 ± 0.19	0.35 ± 0.64	0.47 ± 0.82	40.70 (<0.01)	0.07 (medium)
	Kizomba	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00		
	Merengue	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.03	0.01 ± 0.04	0.22 ± 0.36	0.38 ± 0.78		
	Roots	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.16	0.02 ± 0.12		
	Salsa	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.16	0.07 ± 0.28	0.58 ± 1.76	0.60 ± 0.88		
	Vallenato	0.00 ± 0.00	0.00 ± 0.00	0.19 ± 1.02	0.11 ± 0.54	0.34 ± 0.99	0.52 ± 1.14		
	F (*p*)	11.14 (<0.01)						*F interaction (p)*; ω_p^2 (*effect*)	
	ω_p^2 (*effect*)	0.03 (small)						3.98 (<0.01); 0.04 (small)	

Note. TImp/min: total impacts per minute; $Imp_{<2G/}$min: total impacts lower than 2 g per minute; $Imp_{2–4G/}$min: total impacts between 2 and 4 g per minute; $Imp_{4–6G/}$min: total impacts between 4 and 6 g per minute; $Imp_{6–8G/}$min: total impacts between 6 and 8 g per minute; $Imp_{8–10G/}$min: total impacts between 8 and 10 g per minute; $Imp_{>10G/}$min: total impacts over 10 g per minute; F: F-value of the MANOVA test; *p*: *p*-value (significance); ω_p^2: partial omega-squared.

Table 3. Correlation analysis between the total impacts and per intensities concerning music rhythm and the order of the songs throughout the dance lesson at the different anatomical locations.

		TImp/min	$Imp_{<2G/}$min	$Imp_{2–4G/}$min	$Imp_{4–6G/}$min	$Imp_{6–8G/}$min	$Imp_{8–10G/}$min	$Imp_{>10G/}$min
Scapulae	Music Rhythm							
	Order of songs							
Lower back	Music Rhythm							
	Order of songs							
Left knee	Music Rhythm	0.379	0.405	0.229				
	Order of songs	0.219	0.226	0.119	0.131			
Right knee	Music Rhythm	0.410	0.445	0.231				
	Order of songs	0.226	0.232	0.128	0.126			
Left ankle	Music Rhythm	0.485	0.505	0.390	0.173	0.202	0.111	
	Order of songs	0.295	0.335	0.167	0.111			
Right ankle	Music Rhythm	0.492	0.516	0.383	0.181	0.150	0.101	
	Order of songs	0.309	0.352	0.168	0.120			

Note. Only significant ($p < 0.05$) correlations are included in the table. TImp/min: total impacts per minute; $Imp_{<2G/}$min: total impacts lower than 2 g per minute; $Imp_{2–4G/}$min: total impacts between 2 and 4 g per minute; $Imp_{4–6G/}$min: total impacts between 4 and 6 g per minute; $Imp_{6–8G/}$min: total impacts between 6 and 8 g per minute; $Imp_{8–10G/}$min: total impacts between 8 and 10 g per minute; $Imp_{>10G/}$min: total impacts over 10 g per minute.

4. Discussion

The present study aimed to characterize the external workload experienced by older people across various anatomical locations during a 60 min Latin dance class. We also examined whether factors like music genre, rhythm, and session duration influenced the mechanical loading. The main findings show that the impacts were the highest at the knees, followed by the ankles, lower back, and scapulae. The impacts also increased with faster tempos, while accumulating subtly over successive songs. These results provide initial evidence that Latin dance presents a safe, sustainable aerobic activity for older adults that engages lower body musculature in a population vulnerable to age-related decline.

Our data align with research highlighting the potential sensorimotor and musculoskeletal benefits of activities like judo, dance, and sport participation for older populations. Perrin et al. [34] reported judo's dynamic throwing techniques and falls better develop balance control versus dance. However, the multi-planar choreographies chal-

lenged our older participants' stability through lateral travels, turns, and small jumps. The greater volume of knee and ankle impacts likely stemmed from needing to continuously adjust foot placements and shift weight during step sequences. Such repeated stabilizations over the base of support could enhance proprioceptive abilities and musculoskeletal conditioning beneficial for strength, balance, and fall prevention [9,13]. While less overtly destabilizing than judo falls, dance may still tax sensorimotor systems in ways that mitigate age-related decline.

Indeed, reviews identify the promising effects of judo [10,11] and sport participation [12] on strength, bone health, balance, and functionality in older adults when properly prescribed. Our mild-to-moderate dance impact magnitudes could provide similar musculoskeletal stimulus without excessive loading. Examining potential neuromuscular and skeletal adaptations to chronic dance training represents an avenue for future study in aging populations. Quantifying multi-joint workloads and fatigue effects could elucidate dose–response relationships for programing purposes.

4.1. Effect of Body Location on External Load

Contrary to our hypothesis, the knees registered the highest impacts (11,800 per limb over the hour), with 98% $\leq$4 g. The ankles suffered the second highest overall workload, accumulating over 8800 impacts on average, with 90% $\leq$4 g. Far lower total impacts were observed in the lumbar spine ($\approx$6000) and scapulae ($\approx$2800), nearly all $\leq$2 g (98–99%). This distal-to-proximal gradient in the dance load is likely owed to the foot–floor contacts underlying the steps and movements, which transmit attenuated forces up the athletes' kinetic chain [35]. The multi-joint coordination fundamental to dance techniques may also explain the greater impacts measured at the ankles and knees compared to more proximal sites [36]. Indeed, dance utilizes ankle plantarflexion/dorsiflexion, knee flexion/extension, and hip abduction/adduction to perform steps, transfers, and bounces [37]. As dancers dynamically shift their center of mass over the base of support, distal joints likely bear and dissipate these forces before they reach the lumbar spine [38].

Notably, most impacts remained below 6 g across all sites. Light (2–4 g) walking gait impacts fall in the range of 2–5 g, while runners' > 8 g impacts increase injury likelihood [39]. No definitive loading thresholds exist for safe dance [36]. However, based on running research, the observed loads likely pose minimal harm, though perhaps still enough stimulus to strengthen the dancers' lower extremity bones and muscles. Since aging reduces lower extremity muscle mass and strength critical for movement [5], dance could offer an osteogenic, muscle-building activity for older adults [14]. Indeed, interventions report dance helps older people to improve gait speed, balance, leg strength, and fall risk versus education or social programs [15–17]. The mild-to-moderate impacts dance elicits could mediate such functional benefits by loading musculoskeletal and neuromuscular tissues.

4.2. Effect of Music Style and Rhythm on the External Load

As predicted, faster songs (cumbia and salsa) provoked the highest acute impacts in the dance session. In contrast, slower styles like rumba, bolero, and bachata yielded lower loads. This agrees with past findings that quicker music tempos elicit a greater exertion and arousal versus slower genres [30,40]. Upbeat rhythms likely energize dancers, driving faster steps/transitions that produce greater impacts [41]. Our data indicate that music selection marks an easy way for instructors to modulate session intensity for older people. For example, teachers could program salsa and cumbia to challenge fitter older adults desiring higher intensity intervals, while sequencing occasional slower rumbas for variation. This nuanced programing would accommodate older adults' varying fitness while preventing boredom, discomfort, or injury.

The analyses also uncovered moderate correlations between the songs' beats per minute and the impacts accumulated in the lower limb locations. Specifically, quicker tempos were associated with higher ankle and knee impacts, predominantly at lighter intensities. This contrasts with the between-song results that absolute salsa impacts ex-

ceeded its slower counterparts. Potentially, the fastest rhythms (>130 bpm) hindered older adults' ability to cleanly synchronize steps, thereby increasing foot contacts and eliciting more exertion. An optimal workout tempo likely balances energizing dancers without overloading coordination capabilities. Instructors should factor the perceived intensity and observed synchronization alongside the songs' rhythms when programing older classes over training cycles.

4.3. Effect of Fatigue throughout the Dance Lesson on Impacts

Contrary to predictions, successive songs moderately correlated with increased ankle and knee impacts, suggesting that cumulative fatigue failed to suppress the workload over the hour. Rather, later songs subtly produced more very light ($\leq$2 g), light (2–4 g), and moderate (4–6 g) impacts on the lower limbs. This upward trend opposes the acceleration in decline observed during intense team sport matches, indicating substantial metabolic taxation [42,43]. Dance may alternatively boost slight potentiation versus fatigue in older people's leg musculature. Dancers could leverage repetitive contractions to enhance power output over time [44]. Warming connective tissues may also enable a greater joint mobility and shock attenuation as the session progresses [45]. Nevertheless, the mild positive song correlations imply that recreational Latin dance dynamically overloads the lower extremities without excessively exhausting older students. Teachers can structure 60+ minute lessons knowing that most older adults are unlikely to tire significantly by the end. However, offering occasional low-impact tracks between higher-exertion songs could allow rest for those requiring it.

4.4. Limitations and Future Research

This exploratory analysis provides preliminary evidence that Latin dance offers a safe, dynamic form of weight-bearing exercise for older adults that engages lower body musculature in a population vulnerable to age-related decline. Several limitations prompt future work to extend these early insights. Firstly, we quantified impacts using accelerometry. While accelerometers accurately measure dance impacts [36], force plates could validate the intensity magnitudes and distribution profiles thought to indicate injury likelihood [46]. Applying this approach to older adults' dance can further establish safety.

It is important to acknowledge that, while accelerometers enable the objective quantification of the external workload via impacts, the measurements may not directly reflect the true internal joint loads experienced by the participants. The direct in vivo measurement of joint forces and moments is challenging, especially in natural dance settings. However, previous research has established relationships between accelerometer-derived impacts and joint loading rates [47,48]. The strong distal-to-proximal gradient observed, with the highest impacts on the ankles/knees versus the lower back/scapulae, aligns with the expected force attenuation up the kinetic chain during weight-bearing activities, like basketball [35] or running [25]. While future work is warranted, the findings provide initial insights into lower extremity musculoskeletal demands using a validated, non-invasive approach ideal for quantifying workload in older adult populations.

Secondly, we recorded acute Latin dance responses in a modest sample of experienced dancers (n = 32) unaccustomed to wearing sensors during normal practice. Monitoring training adaptations over cycles in larger cohorts could clarify impact trends while determining sensor interference. Comparing older adults versus young dancers would also reveal normative loading patterns by age, informing prescriptions accordingly. Finally, reproducing the findings across styles, like ballet or ballroom dance, can elucidate genre-specific dose responses.

Overall, while preliminary, the results demonstrate that Latin dance challenges older adults' lower body musculature while unlikely overloading the dancers. Set to spirited Latin music, the dance could boost older people's physical function and prevent fall risks while protecting against sarcopenia and osteoporosis. Our impact quantification and early

multi-site data help to inform safe, sustainable dance programing parameters to empower healthy aging.

4.5. Practical Applications

The present findings provide quantitative insights into the biomechanical loading experienced during Latin dance, which could guide programing to harness its potential osteogenic and neuromuscular benefits for mitigating age-related decline, like sarcopenia and fall risk, in older adults. The observed distal-to-proximal gradient of impact magnitudes, with the highest loads on the knees and ankles, but remaining predominantly low to moderate ($\leq$4 g), suggests that Latin dance could strengthen lower extremity bones and muscles without excessively overloading the joints or soft tissues.

For practical implementation, dance instructors can strategically manipulate music characteristics, like tempo and genre, to modulate the session intensity according to the older participants' fitness levels and desired training stimuli. Programing faster, rhythmic styles, like salsa and cumbia, interspersed with occasional slower genres, like rumba and bolero, can offer a high exertion variability within a single session. The use of wearable inertial sensor technology enables the practitioners to objectively monitor external workloads, which could inform personalized programing and recovery prescription. For instance, a higher sustained ankle load could signify an appropriate osteogenic stimulus for some, but potentially excessive strain for others struggling with choreography or balance. An understanding of normative multi-joint impact profiles could facilitate exercise modification for safe yet effective person-centered training.

Alongside Latin dance's documented cognitive and social enrichment benefits, its dynamic, multi-planar choreography purposefully challenges older adults' musculoskeletal and neuromuscular systems in ways known to enhance strength, balance, and physical function. Continued research efforts to establish dose–response relationships and delineate acute versus chronic workload effects in larger older cohorts will enable the development of definitive guidelines. Such evidence could position Latin dance as a sustainable, lifelong training modality to empower healthy, active aging through integrating the physical and psychosocial exercise domains.

5. Conclusions

The present article provides preliminary evidence that Latin dance offers a safe, dynamic form of weight-bearing exercise for older adults that engages lower body musculature in a population vulnerable to age-related decline. The participants experienced the highest impact forces at the knees and ankles, with impact magnitudes remaining relatively mild (90% $\leq$ 4 g). The faster music styles elicited greater ankle and knee loads compared to the slower styles, while subtle impact accumulation rather than decay was observed over the course of the session, suggesting fatigue potentiation rather than diminished capacity.

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