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Article

Long-term dance trainings alter gait; mechanical work and joint kinematics

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Abstract: Background: Dancers undergo extensive training, resulting in enhanced lower extremity muscle function, flexibility, and stability compared to the general population. However, research on joint loading mechanisms in professional dancers during walking is limited. **Objective:** This study aimed to investigate the gait characteristics of professional dancers and compare them with non-dancers from a biomechanical perspective. **Methods:** A comparative gait analysis was performed on 30 dancers (10 each of modern, ballet, and Korean dance) and 10 non-dancers. The study assessed peak joint moment, peak joint power, and joint work at the knee and ankle joints while walking on a flat surface. **Results:** Ballet group showed longer step cycles (1.30 ± 0.06 s), whereas modern group had shorter cycles (1.11 ± 0.07 s) but higher walking speeds (1.07 ± 0.04 s). Ballet group also had a longer stance phase (64.53% ± 3.46%), while Korean (41.53% ± 4.66%) and modern (41.93% ± 2.95%) groups had larger swing phases. Modern group displayed significantly higher negative ankle joint work (−0.059 ± 0.022 J/kg), ballet (1.49 ± 0.11 Nm/kg) and Korean group (1.53 ± 0.41 Nm/kg) showed higher peak knee joint moments compared to normal group. **Conclusion:** These findings highlight the distinct gait patterns of dancers, with ballet and Korean dancers showing greater knee joint loading and modern dancers exhibiting unique ankle joint dynamics. Tailored rehabilitation and injury prevention strategies are crucial for their long-term health and performance sustainability.

Keywords: dance; gait analysis; joint loading; rehabilitation; performance metrics

1. Introduction

Dance is an art through the expression of body movements, and it is important to perform aesthetic movements [1,2]. In order to achieve aesthetic movements, dancers consider coordination of the muscular system, functional flexibility, body coordination, and sense of rhythm important [3]. Dance has a characteristic movement according to its genre. Korean dance mainly steps on the heel and has a lot of knee flexion [4], and modern dance has intense movement characteristics through strong muscle contraction [5]. In ballet, the turn-out posture and extension of the knees and ankles are prominent, and there are many movements of standing on tiptoe [6]. And in dance, the lower limbs play an important role in maintaining propulsion, stability, and equilibrium and moving the center of the body while improving the efficiency of walking, jumping, leaping, hopping, and twisting movements [7,8]. While these movements are integral to dance artistry, it is important to consider their potential impact on dancers' musculoskeletal health, particularly within the context of gait.

Advancements in motion capture and data analysis have greatly enhanced the study of human biomechanics [9,10]. Previous research has delved into the biomechanics of dancers, revealing unique gait characteristics and joint loading patterns distinct from non-dancers. For instance, Latin dance training has been shown to effectively strengthen lower limb and core muscles, leading to enhanced coordination, gait performance, and balance [11]. Additionally, studies on Korean dance have reported significant improvements in gait evaluation and leg strength following training [12]. Similarly, long-term intensive ballet training has been found to alter the movement patterns of specific joints during gait [13]. These findings emphasize the necessity for further research to explore how various dance styles influence gait mechanics and joint health, highlighting a gap in our understanding of the long-term effects of dance training on lower extremity biomechanics.

The pursuit of artistic excellence in dance demands exceptional lower extremity muscle function. Dancers undergo extensive training, which results in excellent lower extremity muscle strength, setting them apart from the general population [14,15]. The rigorous dance routines, characterized by frequent squats, abrupt turns and stops, and unpredictable knee movements, place significant demands on the dancer's knee joints [16–18]. Additionally, movements like deep squats, side kicks, and rotations impose considerable stress on the dancer's hip joints. To execute such extreme lower limb movements effectively, dancers must attain proper joint limit posture and matching muscle strength through long-term training [3]. Consequently, understanding the effects of these movements on dancers' gait patterns and the potential resultant joint loading becomes paramount.

Besides muscle function, dancers are renowned for their remarkable flexibility and stability, which are crucial attributes in dance performance. The unique nature of dance as an exercise form necessitates specific techniques and skills, demanding greater flexibility in the lower limbs compared to ordinary individuals [3]. Maintaining proper stability during dance performances requires precise joint movements at the ankle, knee, and hip [7,19]. Muscle activity plays a pivotal role in preventing excessive joint movement and ensuring controlled and graceful dance movements [20]. An individual's physical functions can be reflected through their gait. Professional athletes exhibit differences in their gait compared to non-athletes. Although normal walking does not require conscious thought, the control of the nervous and various systems is quite complex, involving the coordination of multiple systems. Any dysfunction or excessive functionality in any aspect should affect gait [21,22]. Yet, prolonged training effects on lower extremity joint loading mechanisms of dancers is lacking. Understanding the changes in gait due to dance is useful because it can guide assessment, treatment, and rehabilitation using dance as an intervention to improve gait of special populations.

Given the intricate relationship between flexibility, stability, muscle activation, and joint health, it is pertinent to explore how these components interplay within the context of gait. The study aimed to investigate the impact of long-term dance training on gait and hypothesized that professional dancers would show different lower limb joint loading characteristics compared to general population.

2. Materials and methods

2.1. Subjects

Forty female participants aged 19–23 were recruited for this study. Among them, 10 had never received any dance training and formed the normal group. The remaining 30 participants were divided into three distinct dance categories: 10 modern dancers, 10 ballet dancers, and 10 Korean dancers. All dancers had a minimum of ten years of dance experience and trained for a minimum of 4 hours per session, five times per week. The characteristics of the four groups are summarized in **Table 1**. There were no statistically significant differences in age, height, and weight among the groups. All participants re-ported no history of injury in the past six months, no strenuous activity or sports training within the last 24 h, and normal joint mobility. Participants were thoroughly briefed about the study's purpose and procedures, comprehended the intent of the experiment, and willingly consented to participate by signing the consent form. This research protocol received approval from the institutional review board of the university (JBNU2022-04-008-002). This study complies with the Declaration of Helsinki and was conducted in accordance with relevant guidelines and regulations.

Table 1. Comparison of the basic physical characteristics.

	Normal	Modern	Ballet	Korean	*p*
Height (cm)	166.31 ± 4.03	165.30 ± 4.12	165.51 ± 3.15	164.2 ± 4.45	0.85
Weight (kg)	49.67 ± 5.07	48.53 ± 4.22	46.93 ± 3.45	48.93 ± 3.65	0.89
Age (years)	20.73 ± 0.83	20.60 ± 1.84	20.33 ± 1.05	20.76 ± 1.55	0.93

All values are expressed in degrees as mean ± standard deviation. Notice: $p < 0.001$ (***highly significant); $p < 0.01$ (**moderately significant); $p < 0.05$ (*significant); $p > 0.05$ (not significant).

2.2. Preparation for testing

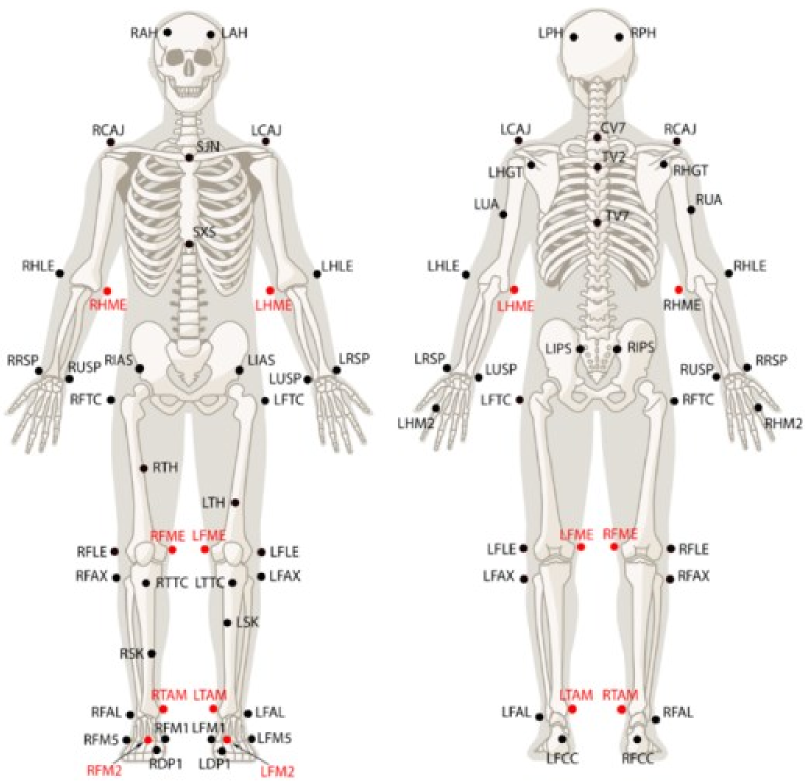


Figure 1. Anatomical Location of Reflective Markers (Motive by optitrack).

For three-dimensional motion data, a motion capture analysis system (OptiTrack, LEYARD, USA) including 13 high-speed infrared cameras was used to collect all trial data for each subject at a sampling frequency of 120 Hz. **Figure 1** showed 57 reflective marker points on anatomical landmarks of each subject (**Figure 1**). The ground reaction force was collected by a force plate (OR6-6-2000 force platform (AMTI Inc.) embedded in the floor at a sampling frequency of 1200 Hz. The motion analysis system and force plate were built synchronously before the test. After each experiment, the 3D motion data was transferred to Visual 3D software (C-Motion, Inc., Germantown, MD, USA) for subsequent data analysis of joint angles and other features.

2.3. Test procedure

This study was conducted in a laboratory setting with a 5 m × 1 m walkway. Two three-dimensional force platforms with a sampling frequency of 1200 Hz were embedded in the walkway at ground level. **Figure 2** showed an 8 m × 2 m × 2 m motion capture space with 13 motion capture cameras with a sampling frequency of 120 Hz. Participants' height and weight were measured before the experiment. They were asked to walk at their natural speed in the experimental environment without any external interference. The experimenters evaluated each trial's data. The collected data were processed using a low-pass 4th-order Butterworth filter with a cutoff frequency of 6 Hz and exported in C3D file format for kinematic and kinetic analysis using the Visual 3D (Professional 6.0, C-Motion Inc., USA) software [23]. The software enabled the definition of seven segments (shoulder, trunk, arm, pelvis, thigh, shank, and foot).

Figure 3 shows data processing and analysis in this study focused on one complete gait cycle of the right leg of the subjects, which encompass both the stance phase and the swing phase. The stance phase was operationally defined as the period starting from the moment the right heel of the foot made contact with the force platform and extending until the right toe left the force platform. The initial contact of the foot during the stance phase was identified using a ground reaction force threshold. The swing phase, on the other hand, was defined as the interval from the moment the right toe left the force platform until the same foot made contact with the force platform again, as per established criteria [24]. The mechanical parameters selected for this study included sagittal plane joint moments (extension(+) & plantarflexion(+), flexion(-) & dorsiflexion(-)), joint power, and joint work. The joint moments were calculated employing the inverse dynamics method, which al-lowed for the standardization of these measures with respect to body mass. Joint work refers to the mechanical work done by muscles and soft tissues through a joint during its movement, obtained by integrating the joint power curve over time. Joint power describes the rate of energy production or absorption at the joint, calculated as the product of joint moment and joint angular velocity. Positive joint power indicates energy generation (e.g., during muscle concentric contractions), while negative joint power indicates energy absorption (e.g., during muscle eccentric contractions). These parameters were standardized to body weight to facilitate comparisons between individuals. Detailed analysis of these parameters provides insight into the energy exchange and functional performance of each joint throughout different phases of the gait cycle.

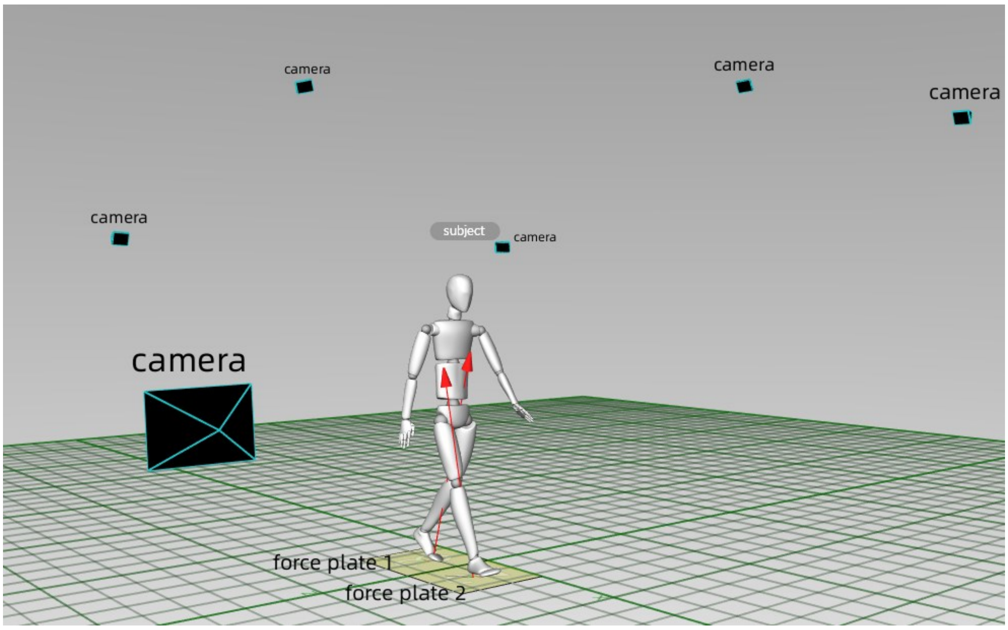


Figure 2. Experimental environment.

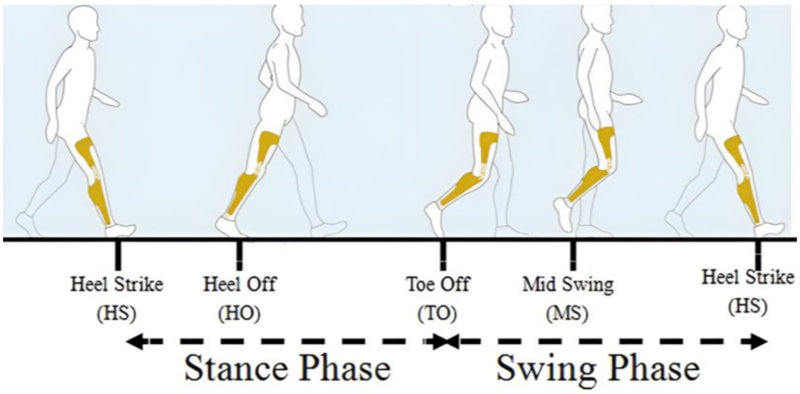


Figure 3. Phases of a gait cycle [24].

2.4. Data processing and analysis

To assess the impact of dance training on these mechanical parameters, a one-way analysis of variance (ANOVA) was conducted, with the participants grouped into four distinct categories: the control group (Normal), as well as the three dance groups (modern, ballet, and Korean dancers). Prior to conducting the ANOVA, both assumptions of normality and homogeneity of variances were assessed. Normality was checked using the Shapiro-Wilk test, and homogeneity of variances was assessed using Levene's test. Following the one-way ANOVA, post-hoc pairwise comparisons were carried out to identify specific differences between the groups. The significance level was set at less than 0.05 to determine statistical significance. Additionally, to evaluate whether there were significant differences within each group before and after any potential interventions, paired *t*-tests or non-parametric tests (if assumptions were not met) were applied. All statistical analyses were performed using Prism 9.0 (GraphPad Software, San Diego, CA), and the results were considered significant if *p*-values were less than 0.05.

3. Results

Table 2 presents gait parameter comparisons across four groups: normal, modern dancers, ballet dancers, and Korean dancers. **Figure 4** shows the post-hoc results. This is to show which particular groups differ significantly (**Figure 4**). Normal group and modern dancers showed a significant advantage in step length, surpassing Korean dancers and ballet dancers. Meanwhile, modern dancers showed significant characteristics in step length, surpassing ballet and Korean dancers. In terms of step width, Korean dancers showed wider step width compared to the average person and ballet dancers. Regular people had relatively long step cycles, while ballet dancers presented longer cycles, in contrast to the relatively shorter cycles of modern dancers. In terms of speed, modern dancers exhibited significantly higher characteristics than ballet dancers. In terms of stance phase, ballet dancers showed significantly larger cycles than modern and Korean dancers. In terms of swing phase, both Korean dancers and modern dancers exhibited larger swing phase.

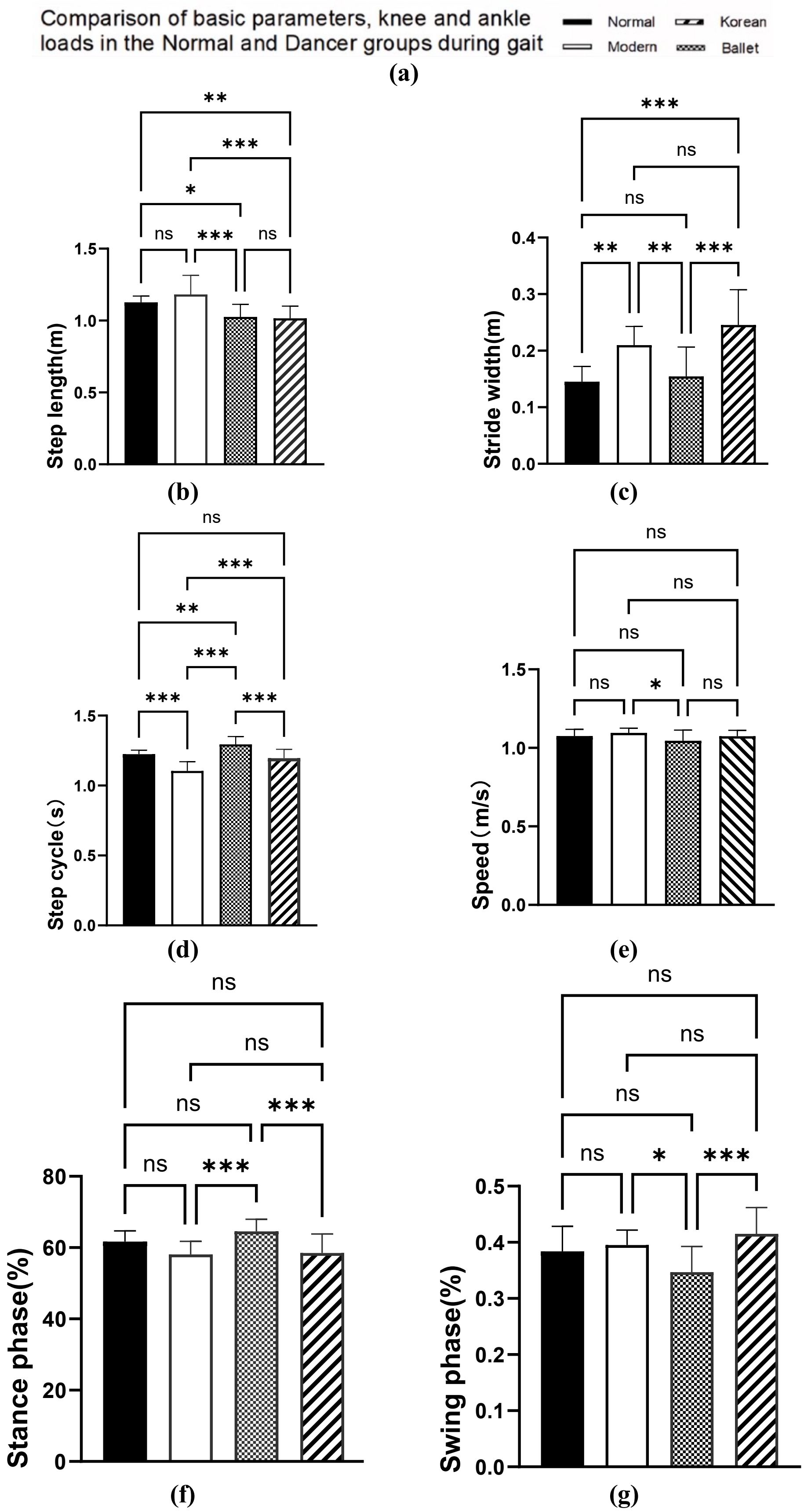
In ankle loading (**Figure 4**), Modern dancers demonstrated significantly higher negative joint work compared to the normal group, with no significant distinctions in joint peak power or positive joint work at the ankle. These results highlight biomechanical differences in knee and ankle loading patterns across dance styles, suggesting potential influences of dance training on knee loading dynamics and unique ankle loading patterns in different dance styles.

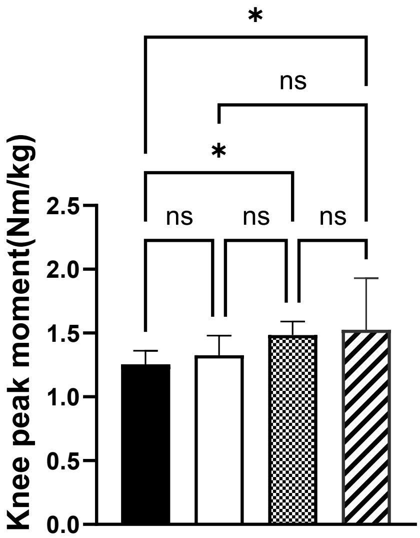
In knee loading (**Figure 4**), Ballet and Korean dancers showed significantly higher joint peak moments compared to the Normal group. The Modern dancer group exhibited a non-significant increase. No significant differences were found in joint peak power or negative joint work at the knee joint among groups.

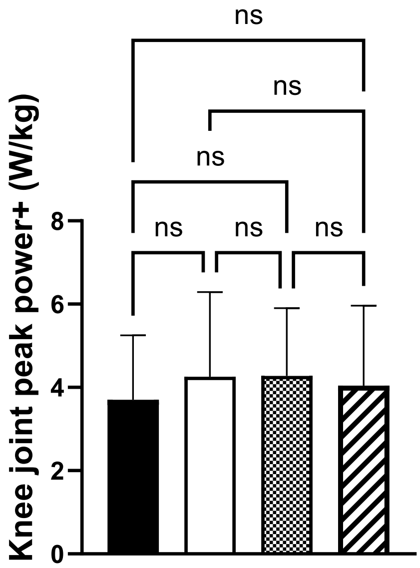
Table 2. Comparison of gait parameter.

	Normal	Modern	Ballet	Korean	*p*
Step length (m)	1.13 ± 0.04	1.18 ± 0.13	1.03 ± 0.09	1.03 ± 0.08	<0.001***
Stride width (m)	0.15 ± 0.03	0.21 ± 0.03	0.15 ± 0.05	0.25 ± 0.06	<0.001***
Step cycle (s)	1.23 ± 0.03	1.11 ± 0.07	1.30 ± 0.06	1.20 ± 0.03	<0.001***
Speed (m/s)	1.08 ± 0.04	1.07 ± 0.04	1.05 ± 0.04	1.10 ± 0.04	0.03*
Stance phase (%)	61.67 ± 3.04	58.07 ± 3.73	64.53 ± 3.46	58.47 ± 5.40	<0.001***
Swing phase (%)	38.33 ± 4.47	41.93 ± 2.95	35.47 ± 4.61	41.53 ± 4.66	<0.001***
Knee joint peak moment (Nm/kg)	1.26 ± 0.11	1.33 ± 0.15	1.49 ± 0.11	1.53 ± 0.41	0.027*
Knee joint peak power + (W/kg)	3.71 ± 1.54	4.25 ± 2.03	4.28 ± 1.64	4.05 ± 1.92	0.813
Knee joint peak power − (W/kg)	−0.85 ± 0.21	−0.95 ± 0.31	−0.94 ± 0.29	−0.97 ± 0.22	0.563
Knee joint work + (J/kg)	0.257 ± 0.071	0.285 ± 0.072	0.323 ± 0.045	0.315 ± 0.013	0.013*
Knee joint work − (J/kg)	−0.143 ± 0.053	−0.159 ± 0.033	−0.163 ± 0.041	−0.168 ± 0.059	0.523
Ankle joint peak moment (Nm/kg)	0.28 ± 0.09	0.32 ± 0.06	0.36 ± 0.04	0.33 ± 0.11	0.076
Ankle joint peak power + (W/kg)	2.11 ± 0.43	2.35 ± 1.05	2.66 ± 0.93	2.27 ± 0.41	0.262
Ankle joint peak power− (W/kg)	−1.03 ± 0.28	−1.35 ± 0.36	−1.13 ± 0.51	−1.19 ± 0.55	0.553
Ankle joint work + (J/kg)	0.044 ± 0.009	0.053 ± 0.021	0.042 ± 0.015	0.054 ± 0.017	0.457
Ankle joint work − (J/kg)	−0.041 ± 0.015	−0.059 ± 0.022	−0.047 ± 0.009	−0.037 ± 0.016	0.007**

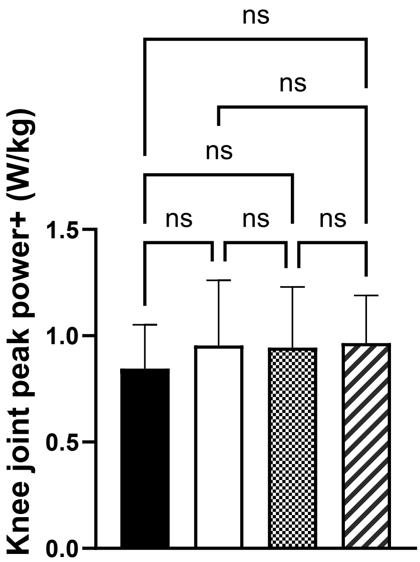
All values are expressed in degrees as mean ± standard deviation. Notice: $p < 0.001$ (***highly significant); $p < 0.01$ (**moderately significant); $p < 0.05$ (*significant); $p > 0.05$ (not significant).

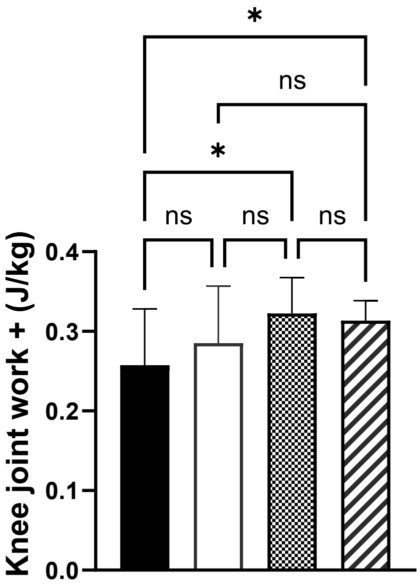

Comparison of basic parameters, knee and ankle loads in the Normal and Dancer groups during gait
Normal
Modern
Korean
Ballet
(a)
Step length(m)
(b)
Stride width(m)
(c)
Step cycle(s)
(d)
Speed（m/s)
(e)
Stance phase(%)
(f)
Swing phase(%)
(g)


Knee peak moment(Nm/kg)
0.0 0.5 1.0 1.5 2.0 2.5
ns
ns
*
*
ns

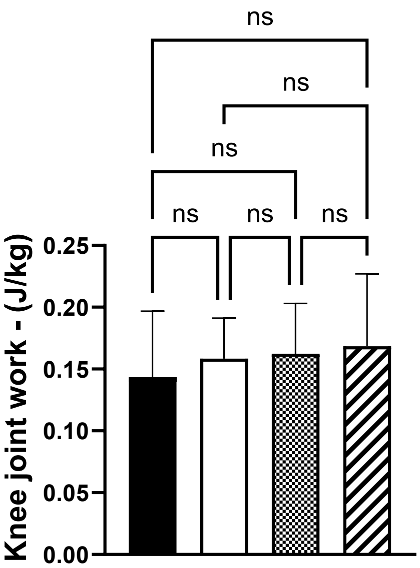

Knee joint peak power+ (W/kg)
0 2 4 6 8
ns
ns
ns
ns

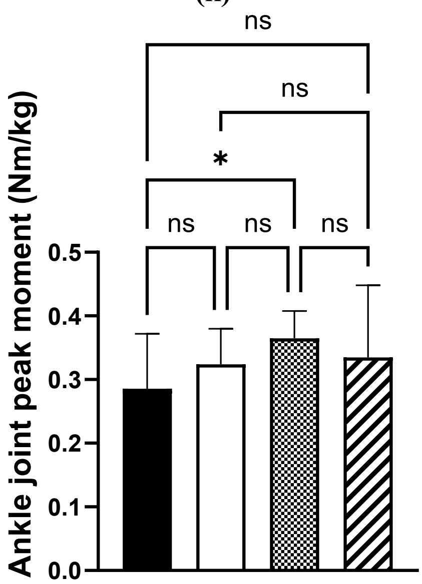
(h) (i)


Knee joint peak power+ (W/kg)
0.0 0.5 1.0 1.5
ns
ns
ns
ns


Knee joint work + (J/kg)
0.0 0.1 0.2 0.3 0.4
ns
ns
*
*
ns

(j) (k)


Knee joint work - (J/kg)
0.00 0.05 0.10 0.15 0.20 0.25
ns
ns
ns
ns


Ankle joint peak moment (Nm/kg)
0.0 0.1 0.2 0.3 0.4 0.5
ns
ns
*
ns

(l) (m)

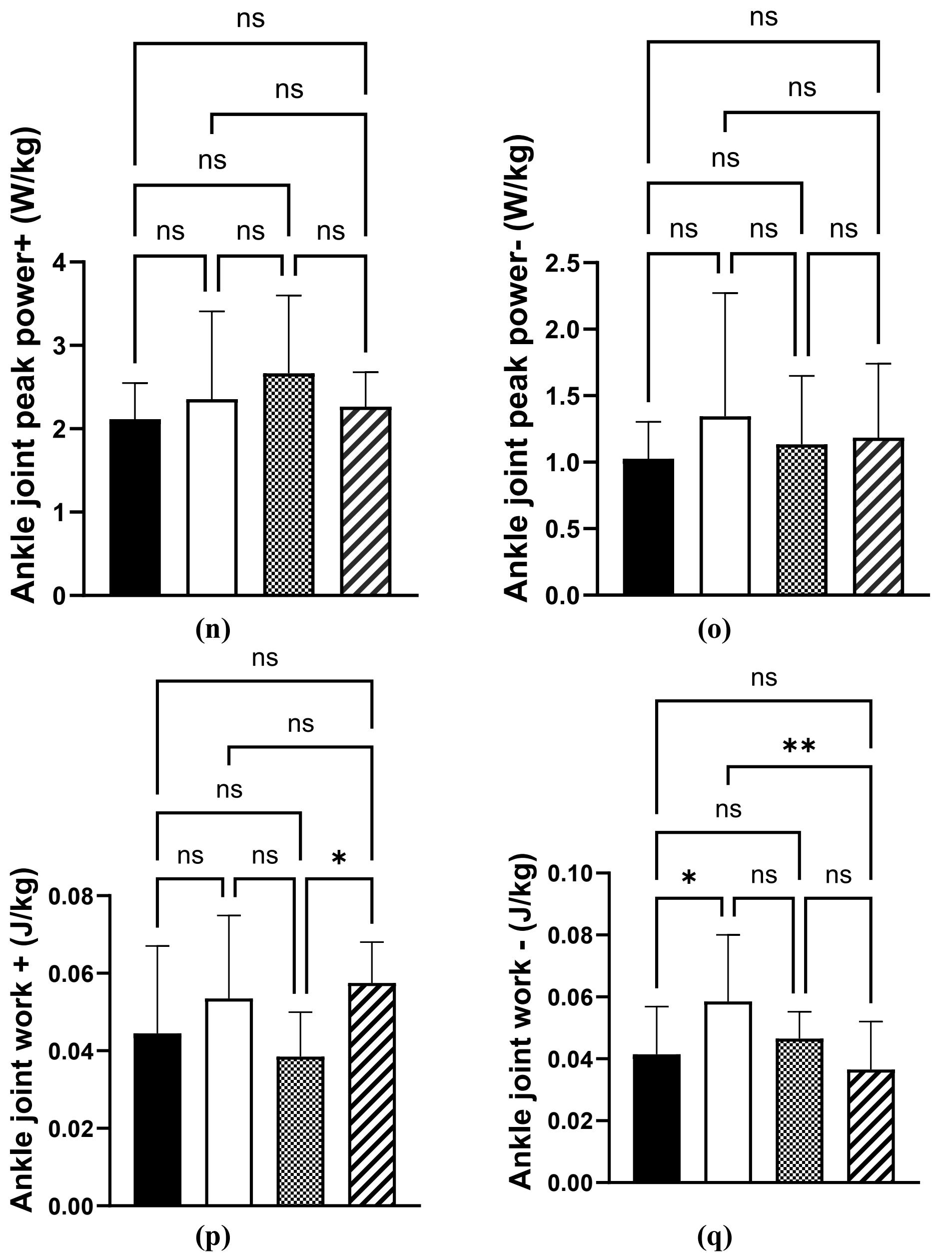


Figure 4. Post-hoc analysis of basic parameters, knee, and ankle loads. This figure shows the lower limb loads during gait across different groups **(a)**: the normal, modern, ballet, and Korean group. The subfigures (b–q) detail specific parameters: **(b)** step length, **(c)** stride width, **(d)** step cycle, **(e)** speed, **(f)** stance phase, **(g)** swing phase, **(h)** knee peak moment, **(i)** knee joint peak power+, **(j)** knee joint peak power-, **(k)** knee joint work+, **(l)** knee joint work-, **(m)** ankle joint peak moment, **(n)** ankle joint peak power+, **(o)** ankle joint peak power-, **(p)** ankle joint work+, and **(q)** ankle joint work-. The bars represent the mean values for each group, with error bars indicating the standard deviation. Significant differences between groups are marked.

4. Discussion

This study delves into the intricate relationship between long-term dance training and its potential impact on health, particularly within the context of lower extremity joint loading. Among the most fascinating discoveries in this research is the exceptional power generation capacity demonstrated by dancers during various phases of joint motion. From a biomechanical perspective, power generation relies on a finely orchestrated combination of muscle contractions, joint mechanics, and energy transfer [25]. These findings underscore the painstaking conditioning and training regimens dancers undergo to harness and project power with finesse during gait. The realm of dance artistry hinges on the seamless execution of dynamic movements, and the ability to generate power with precision is the cornerstone of their performances [26]. However, this heightened power generation capacity, essential for artistic expression, also carries inherent health risks. The repetitive and demanding nature of dance can place significant stress on the lower extremities, particularly the knee and ankle joints, potentially leading to overuse injuries, joint stress, and the development of musculoskeletal imbalances over time. These risks highlight the critical need for targeted interventions and injury prevention strategies to safeguard the well-being of dancers as they practice their respective dance styles.

Significant disparities in knee loading parameters, particularly joint peak moment and positive joint work, were observed across different dance groups. Ballet and Korean dancers exhibit notably higher joint peak moments compared to the Normal group. This finding aligns with the distinctive movement characteristics of these dance styles: Ballet, known for its turnout posture and knee extension, places considerable stress on the knee joint, while Korean dance, with its focus on knee flexion and heel-based steps, also results in increased knee loading. These observations highlight how specific dance techniques influence knee joint loading. The ability of dancers to control eccentric muscle contractions during gait is crucial for absorbing ground reaction forces and ensuring smooth transitions between movements [27]. This skill supports both the aesthetic and functional demands of dance while aiding in injury prevention. Although no significant differences were found in joint peak power or positive joint work at the ankle, Modern dancers showed a marked increase in negative joint work compared to the Normal group. This reflects the unique demands of Modern dance, which often involves abrupt movements, deep squats, and rotational actions requiring substantial negative work at the ankle joint [28].

The findings emphasize the need for targeted interventions and injury prevention strategies to protect dancers’ health. Customizing training protocols to address the biomechanical demands of each dance style, such as enhancing ankle joint resilience for Modern dancers and managing knee joint stress for ballet and Korean dancers, can provide significant benefits. Incorporating motion analysis technologies for real-time feedback and developing comprehensive injury prevention programs, including dynamic warm-ups and flexibility exercises, are also essential. Additionally, applying insights from this study to rehabilitation strategies can facilitate smoother recovery and optimize performance.

This study has several limitations, including a relatively small sample size and a focus on female participants. Future research should include larger and more diverse samples, encompassing both male and female dancers, to gain a more comprehensive understanding of dance-related gait mechanics. Additionally, exploring the nuances of specific dance genres and considering factors such as years of training could provide deeper insights into variations in joint loading patterns. This holistic approach will contribute to a more nuanced understanding of the potential health risks associated with long-term dance training, particularly in the context of gait mechanics.

5. Conclusions

This study has explored the influence of long-term dance training on gait. This study has shown that long-term dance training significantly affects gait, dancers exhibiting distinctive gait patterns compared to the general population. Furthermore, dancers exhibit remarkable power generation abilities, which are essential for their performances but also underscore the importance of tailored rehabilitation and injury prevention strategies to safeguard their health. In summary, long-term dance training has a profound impact on dancers' gait, underlining the critical need for health considerations. Future research should expand sample size and encompass diverse dance styles for a more comprehensive understanding of the relationship between dance training and gait.

Author contributions: Conceptualization, XT and SK; methodology, XT and SK; software, YK and CW; validation, YK and CW; formal analysis, XT and CW; investigation, XT, YK and CW; resources, XT and SK; data curation, XT and CW; writing—original draft preparation, XT and YK; writing—review and editing, CW and SK; visualization, SK; supervision, SK; project administration, YK. All authors have read and agreed to the published version of the manuscript.

Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Jeonbuk National University (JBNU2022-01-004-002, August, 2022).

Conflict of interest: The authors declare no conflict of interest.

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