Control Group

The CG followed their regular dance class schedule of three 90-minute ballet classes and two one-hour modern classes per week. The warm-up for the CG was a self-directed warm-up consisting of static stretching and mobilization exercises.

Statistical Analysis

An exploratory analysis was conducted to investigate the effects of the 11+ Dance on jump height and lower extremity biomechanics. The analysis was focused on jump height as well as angles and moments of the hip and knee in the sagittal and frontal plane. After taking the absolute value for each variable, a contrast analyses was performed by subtracting the measured values of baseline from the outcomes measured after the intervention (Post – Pre) to obtain a measure of change for the IG and CG (Δ scores).[33] Thus, positive values indicate an increase in the outcome variables while negative values indicate a decrease at the end of the intervention. Since normal distribution was not given in the change of jump height, Wilcoxon's rank sum tests were used to compare the change in jump height between the IG and CG and Wilcoxon's signed rank test to compare the change of jump height against a median of zero. For all other outcome measures, one-sample t-tests or independent t-tests were used to compare the Δ scores against zero or between the IG and CG, respectively. Due to multiple comparisons (IG vs. CG, IG vs. zero, CG vs. zero), the alpha-level threshold was adjusted from 0.05 to 0.0167 based on the Bonferroni correction. A trend towards significance was defined as α=0.05-0.0167. Test statistics and p-values were reported in the results. The statistical analysis was performed in MATLAB.

Results

Of the twenty participants, one dancer in each group dropped out due to scheduling issues or sustaining a non-dance related injury. For more details of the trial flowchart please see Figure 1. The mean (SD) age of the participants was 14.6 (0.7) years (IG) and 16.0 (0.9) years (CG) representing a statistically significant difference in age ($t(18)=-3.90$, $p=0.0010$) between the groups. No statistically significant differences were found for height ($t(18)=0.94$, $p=0.3578$) or body mass ($t(18)=1.79$, $p=0.0894$) between the CG (height, 162.8 (2.7) cm; body mass, 57.9 (6.3) kg) and IG (height, 164.8 (6.5) cm; body mass, 62.4 (4.3) kg).

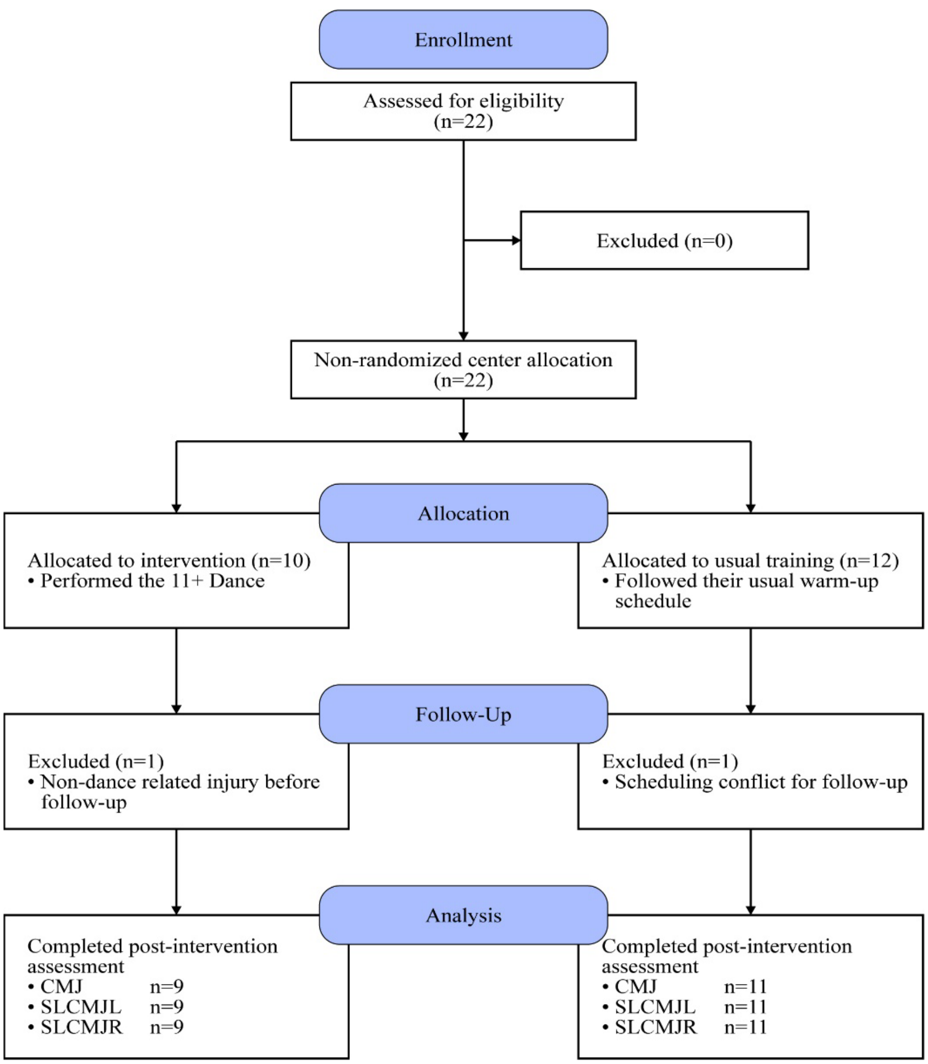

Figure 1: Flowchart of the two-centered non-randomized controlled trial. CMJ: Countermovement Jump, SLCMJL: Single Leg Countermovement Jump Left, SLCMJR: Single Leg Countermovement Jump Right.

Jump Height

There was no statistically significant change in jump height of the intervention group compared to the control group in all three jumping tasks (Z=0.38-1.22, p=0.1121-0.3520; Figure 2 & Table 2). However, both groups statistically increased their jump height in the CMJ (IG: Z=2.37, p=0.0089; CG: Z=2.58, p=0.0099) and in the SLCMJR (IG: Z=2.49, p=0.006; CG: Z=2.76, p=0.0058). During the SLCMJL, a trend towards increased jump height in the IG (Z=1.89, p=0.0290) and a statistical increase in the CG (Z=2.18, p=0.0147) was observed.

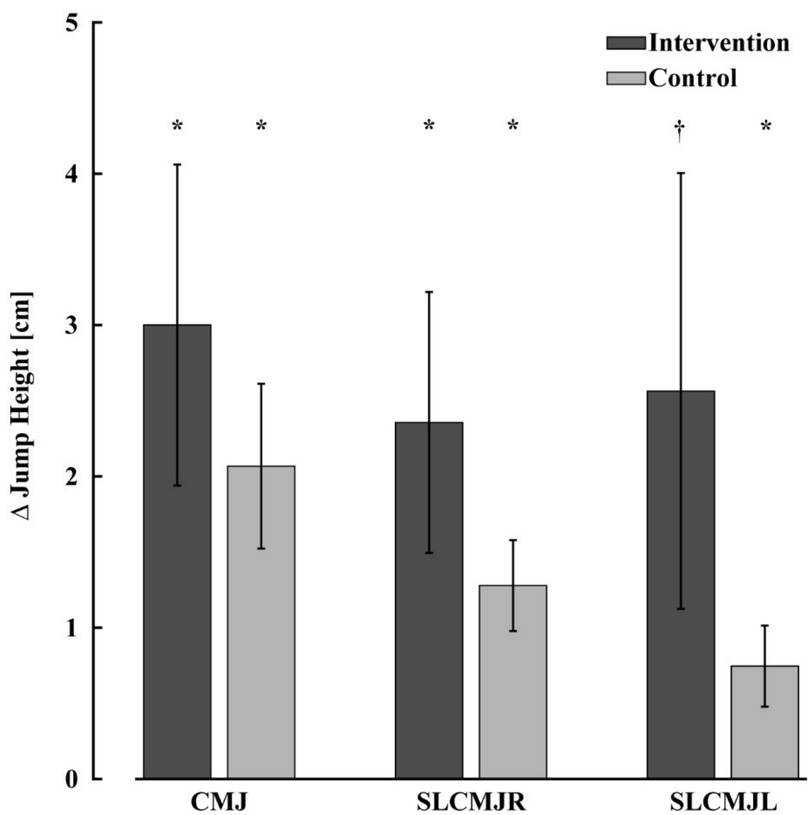

Figure 2: Change in jump height between Post and Pre for the Countermovement Jump (CMJ), Single Leg Countermovement Jump Right (SLCMJR), and Single Leg Countermovement Jump Left (SLCMJL). * indicates a statistically significant difference (p<0.0167). † indicates a trend (p=0.05-0.0167). Error bars indicate SE.

Table 2: Mean scores and Standard Error (SE) of jump height for the intervention and control groups and statistical outputs. Statistically significant differences and trends were marked **bold**.

		Pre	Post	Post - Pre			Group Comparison	
Task	Group	Mean (SE)	Mean (SE)	Mean (SE)	Statistics	p	Statistics	p-value
CMJ	Intervention	21.89 (0.76)	24.89 (1.29)	3.00 (1.06)	Z=2.37	**0.0089**	Z=0.46	0.3243
	Control	21.62 (1.02)	23.69 (1.37)	2.07 (0.54)	Z=2.58	**0.0099**		
SLCMJR	Intervention	7.34 (0.43)	9.69 (1.05)	2.36 (0.86)	Z=2.49	**0.0064**	Z=0.38	0.3520
	Control	8.04 (0.65)	9.32 (0.74)	1.28 (0.29)	Z=2.76	**0.0058**		
SLCMJL	Intervention	7.42 (0.53)	9.98 (1.25)	2.56 (1.44)	Z=1.89	**0.0290**	Z=1.22	0.1121
	Control	9.62 (1.11)	10.37 (1.18)	0.75 (0.27)	Z=2.18	**0.0147**		

Takeoff Biomechanics

Knee Moments

Throughout the intervention, the IG showed a statistically significant smaller change in the knee extension moments in the CMJ (Right: $t(18)=-3.77$, p=0.0014, Left: $t(18)=-3.79$, p=0.0014) and SLCMJL ($t(18)=-3.04$, p=0.0070) compared to the CG (Figure 3 & Table 3). The IG exhibited a statistically significant decrease in knee extension moments in the SLCMJR compared to zero ($t(8)=-3.71$, p=0.0060), and a statistically significant decrease in knee adduction moments of the left leg during the CMJ compared to the CG (Figure 4, $t(18)=-2.91$, p=0.0093). A statistically significant decrease in knee adduction moments were observed in the right and left leg of the IG during the CMJ compared to zero while the CG group did not statistically change the knee adduction moment (see Table 3).

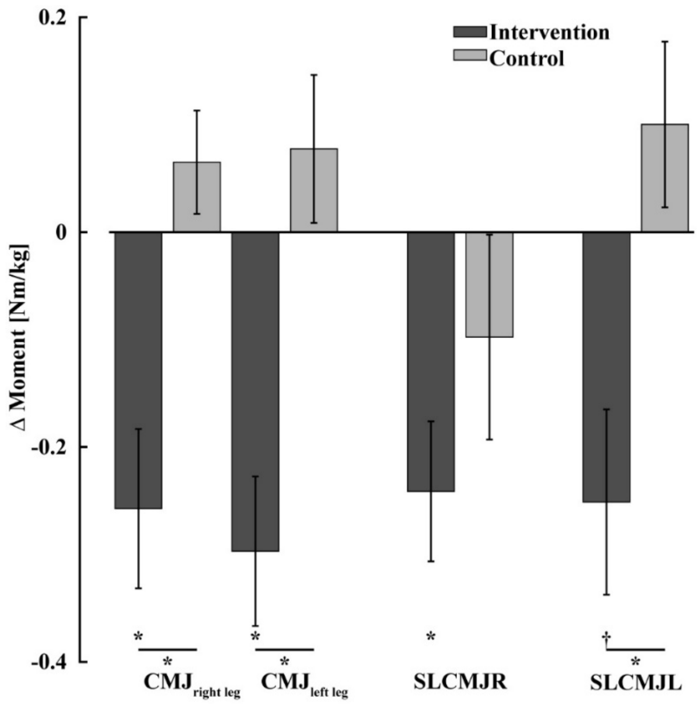

Figure 3: Change in knee extension moment between Post to Pre for the Countermovement Jump (CMJ), Single Leg Countermovement Jump Right (SLCMJR), and Single Leg Countermovement Jump Left (SLCMJL) during takeoff. * indicates a statistically significant difference ($p<0.0167$). † indicates a trend ($p=0.05-0.0167$). Error bars indicate SE.

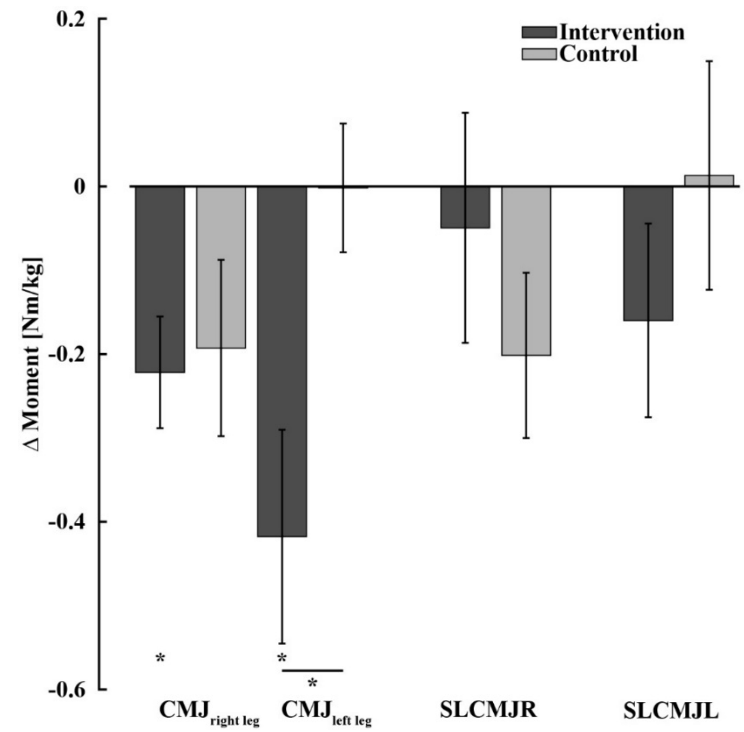

Figure 4: Change in knee adduction moment between Post to Pre for the Countermovement Jump (CMJ), Single Leg Countermovement Jump Right (SLCMJR), and Single Leg Countermovement Jump Left (SLCMJL) during takeoff.

Landing Biomechanics

Knee Moments

No statistically significant differences in peak knee extension moments were observed in the CMJ and SLCMJR during the landing phase (Table 4). In the SLCMJL, the CG statistically increased the peak knee extension moments compared to zero ($t(10)=3.45$, $p=0.0062$), resulting in a statistically significant increase compared to the IG ($t(18)=-3.45$, $p=0.0029$). Moreover, there were no statistically significant differences between the IG and CG of the change in peak knee adduction moment during landing in all jumps. However, there was a statistically significant reduction in the peak knee adduction moment of the right leg for the CG during the CMJ ($t(10)=-2.94$, $p=0.0147$), while the CG increased the peak knee adduction moment during the SLCMJR ($t(10)=3.25$, $p=0.0087$) with a trend towards increased peak knee adduction moment during the SLCMJL ($t(10)=2.58$, $p=0.0274$).

Knee Angles

A trend towards an increased change in peak knee flexion angles was observed in the IG compared to the CG during the SLCMJR ($t(18)=2.21$, $p=0.0405$) with a statistically significant increase of the peak knee flexion angle in the IG compared to zero ($t(8)=3.48$, $p=0.0084$). Additionally, a trend towards an increased change in peak knee abduction angle during the SLCMJR was observed comparing the IG to the CG ($t(18)=2.59$, $p=0.0182$). Additionally, the CG tended to decrease the peak knee abduction angle in the right leg during the CMJ ($t(10)=-2.68$, $p=0.0231$). No further statistical differences were observed.

Hip Moments

No statistically significant differences in the change of peak hip extension and abduction moments of the CMJ and SLCMJR during landing were observed comparing the IG to the CG. However, trends towards increased peak hip extension moments during the SLCMJR for both groups (IG: $t(8)=2.58$, $p=0.0325$, CG: $t(10)=2.78$, $p=0.0194$) and a statistically significant increase of the peak hip extension moment in the SLCMJL of the CG ($t(10)=2.95$, $p=0.0146$) were observed. Furthermore, a statistically significant increase of the peak hip abduction moment during the SLCMJR ($t(10)=4.18$, $p=0.0019$) and SLCMJL ($t(10)=2.95$, $p=0.0145$) in the CG compared to zero was detected. The changes in the SLCMJL resulted in a trend towards an increased peak hip abduction moment in the CG compared to the IG ($t(18)=-2.63$, $p=0.0170$) at the end of the intervention.

Hip Angles

Similar to takeoff, the IG indicated a statistically significant increase in the change of the hip flexion angle during landing in all jumping tasks compared to the CG ($t(18)=2.78$-5.13, $p=0.0001$-0.0123). Considering the hip adduction angle, only a trend towards a decreased change in hip adduction angle in the IG compared to the CG ($CMJ_{left\text{-}leg}$: $t(18)=2.13$, $p=0.0475$) was noted, with a statistically significant increase of the left hip adduction angle of the IG compared to zero ($t(8)=3.47$, $p=0.0085$). No other statistical differences were found in the hip adduction angle during landing.

Table 4: Mean (SE) Δ scores of landing performance for the intervention and control groups and statistical outputs. Statistically significant differences and trends were marked **bold**.

		Intervention Group (IG)			Control Group (CG)			IG vs CG	
Task	Outcome Variable	Mean (SE)	Statistics	p-value	Mean (SE)	Statistics	p-value	Statistics	p-value
CMJ	Right Leg								
	Δ Peak Hip Flexion Angle [°]	15.78 (3.72)	t(8)=4.24	**0.0028**	-1.77 (1.98)	t(10)=-0.86	0.4103	t(18)=4.33	**0.0004**
	Δ Peak Hip Adduction Angle [°]	0.43 (2.36)	t(8)=0.18	0.8612	-0.06 (1.51)	t(10)=-0.04	0.9663	t(18)=0.18	0.8601
	Δ Peak Knee Flexion Angle [°]	-3.69 (2.49)	t(8)=-1.48	0.1776	-2.33 (2.06)	t(10)=-1.13	0.2848	t(18)=-0.42	0.6761
	Δ Peak Knee Abduction Angle [°]	-0.28 (1.42)	t(8)=-0.19	0.8501	-2.64 (0.99)	t(10)=-2.68	**0.0231**	t(18)=1.41	0.1764
	Δ Peak Hip Extension Moment [Nm/kg]	0.19 (0.22)	t(8)=0.92	0.3845	-0.03 (0.27)	t(10)=-0.10	0.9195	t(18)=0.64	0.5301
	Δ Peak Hip Abduction Moment [Nm/kg]	-0.02 (0.12)	t(8)=-0.18	0.8645	-0.17 (0.11)	t(10)=-1.59	0.1410	t(18)=0.94	0.3580
	Δ Peak Knee Extension Moment [Nm/kg]	-0.14 (0.15)	t(8)=-0.94	0.3746	-0.06 (0.08)	t(10)=-0.69	0.5037	t(18)=-0.50	0.6231
	Δ Peak Knee Adduction Moment [Nm/kg]	-0.02 (0.04)	t(8)=-0.46	0.6552	-0.13 (0.05)	t(10)=-2.94	**0.0147**	t(18)=1.77	0.0944
	Left Leg								
	Δ Peak Hip Flexion Angle [°]	16.21 (3.06)	t(8)=5.29	**0.0007**	-0.74 (1.65)	t(10)=-0.45	0.6621	t(18)=5.13	**<0.0001**
	Δ Peak Hip Adduction Angle [°]	4.22 (1.22)	t(8)=3.47	**0.0085**	0.13 (1.42)	t(10)=0.09	0.9278	t(18)=2.13	**0.0475**
	Δ Peak Knee Flexion Angle [°]	-2.09 (3.02)	t(8)=-0.69	0.5070	-0.97 (1.92)	t(10)=-0.50	0.6252	t(18)=-0.33	0.7480
	Δ Peak Knee Abduction Angle [°]	-4.06 (2.66)	t(8)=-1.52	0.1664	-0.75 (1.41)	t(10)=-0.53	0.6059	t(18)=-1.16	0.2631
	Δ Peak Hip Extension Moment [Nm/kg]	-0.11 (0.34)	t(8)=-0.34	0.7431	0.27 (0.21)	t(10)=1.27	0.2317	t(18)=-1.00	0.3289
	Δ Peak Hip Abduction Moment [Nm/kg]	0.16 (0.19)	t(8)=0.82	0.4345	0.01 (0.11)	t(10)=0.01	0.9948	t(18)=0.76	0.4590
	Δ Peak Knee Extension Moment [Nm/kg]	-0.12 (0.17)	t(8)=0.49	0.4948	0.03 (0.16)	t(10)=0.22	0.8291	t(18)=-0.67	0.5091
	Δ Peak Knee Adduction Moment [Nm/kg]	-0.09 (0.05)	t(8)=-1.69	0.1279	0.04 (0.06)	t(10)=0.62	0.5493	t(18)=-1.53	0.1434
SLCMJR	Right Leg								
	Δ Peak Hip Flexion Angle [°]	16.99 (3.21)	t(8)=5.29	**0.0007**	5.50 (2.65)	t(10)=2.07	0.0650	t(18)=2.78	**0.0123**
	Δ Peak Hip Adduction Angle [°]	-0.08 (1.53)	t(8)=-0.05	0.9599	-1.09 (1.46)	t(10)=-0.74	0.4765	t(18)=0.47	0.6437
	Δ Peak Knee Flexion Angle [°]	5.89 (1.69)	t(8)=3.48	**0.0084**	0.47 (1.73)	t(10)=0.27	0.7928	t(18)=2.21	**0.0405**
	Δ Peak Knee Abduction Angle [°]	3.06 (1.89)	t(8)=1.59	0.1487	-2.51 (1.16)	t(10)=-2.17	0.0550	t(18)=2.59	**0.0182**
	Δ Peak Hip Extension Moment [Nm/kg]	0.43 (0.17)	t(8)=2.58	**0.0325**	0.78 (0.27)	t(10)=2.78	**0.0194**	t(18)=-0.93	0.3629
	Δ Peak Hip Abduction Moment [Nm/kg]	0.27 (0.13)	t(8)=1.99	0.0821	0.42 (0.10)	t(10)=4.18	**0.0019**	t(18)=-0.96	0.3477
	Δ Peak Knee Extension Moment [Nm/kg]	0.07 (0.09)	t(8)=0.68	0.5161	0.04 (0.09)	t(10)=0.45	0.6631	t(18)=0.16	0.8711
	Δ Peak Knee Adduction Moment [Nm/kg]	0.06 (0.08)	t(8)=0.81	0.4398	0.17 (0.05)	t(10)=3.25	**0.0087**	t(18)=-1.16	0.2623
SLCMJL	Left Leg								
	Δ Peak Hip Flexion Angle [°]	15.95 (1.95)	t(8)=8.17	**<0.0001**	-1.28 (4.06)	t(10)=-0.32	0.7579	t(18)=3.57	**0.0022**
	Δ Peak Hip Adduction Angle [°]	-1.84 (1.80)	t(8)=-1.02	0.3366	-0.78 (1.86)	t(10)=-0.42	0.6824	t(18)=-0.40	0.6916
	Δ Peak Knee Flexion Angle [°]	2.52 (3.02)	t(8)=0.83	0.4286	0.59 (2.86)	t(10)=0.21	0.8412	t(18)=0.46	0.6497
	Δ Peak Knee Abduction Angle [°]	-0.44 (2.00)	t(8)=-0.22	0.8330	0.01 (1.89)	t(10)=0.01	0.9954	t(18)=-0.16	0.8732
	Δ Peak Hip Extension Moment [Nm/kg]	0.25 (0.18)	t(8)=1.38	0.2064	0.65 (0.22)	t(10)=2.95	**0.0146**	t(18)=-1.35	0.1927
	Δ Peak Hip Abduction Moment [Nm/kg]	-0.09 (0.12)	t(8)=-0.75	0.4777	0.39 (0.13)	t(10)=2.95	**0.0145**	t(18)=-2.63	**0.0170**
	Δ Peak Knee Extension Moment [Nm/kg]	-0.21 (0.13)	t(8)=-1.65	0.1371	0.32 (0.09)	t(10)=3.45	**0.0062**	t(18)=-3.45	**0.0029**
	Δ Peak Knee Adduction Moment [Nm/kg]	0.02 (0.09)	t(8)=0.19	0.8506	0.17 (0.07)	t(10)=2.58	**0.0274**	t(18)=-1.44	0.1662

Discussion

Multi-faceted neuromuscular training programs are designed to decrease associated injury risk factors and ultimately prevent lower extremity injuries by changing biomechanical outcomes while improving athletic performance.[14, 21, 22] To the authors' knowledge, this is the first study to examine changes in biomechanical outcomes and jump height in a female adolescent recreational dance population. Therefore, the objective of the current study was to determine if the 11+ Dance, a dance-specific neuromuscular training program, improves jump height and reduces peak knee extension and adduction moments during takeoff and landing in female recreational adolescent dancers.

Jump Height

There is currently no normative data for recreational dancers available for direct comparison with our study's sample group. Mean scores for the jump height pre and post the intervention were similar to previously reported scores of pre-professional ballet dancers with no supplementary resistance training experience.[8] Throughout the 8-week intervention period, jump height statistically increased in both groups in all jumping tasks. The intervention group did not statistically improve jump height compared to the control group. However, it should be noted that the change in jump height for both bilateral and single leg tasks was higher in the intervention group (CMJ: IG: 13.7% vs. CG: 9.5%, SLCMJR: IG:32.1% vs. CG: 15.9%, SLCMJL: IG: 34.5% vs. CG: 7.7%). These results are consistent with other studies in pre-adolescent and adolescent football players, after the implementation of a both short-term (10 weeks)[23] and a longitudinal (30 weeks)[34] neuromuscular injury prevention intervention. Both studies, however, were conducted with male participants and indicated superior results to the control group due to greater training volumes, frequencies, intensities and/or the type of intervention.[23, 34, 35] An important consideration is that the 11+ Dance was specifically designed to promote ankle, knee, and hip alignment, and local muscular endurance to promote jumping and landing technique.[27] Less focus was placed on maximal jump training in the first four weeks of the 11+ Dance, which may further explain the lack of statistically significant changes in jump height between groups. Moreover, our intervention replaced the first thirty minutes of the dancers' regular class time. Only thirty minutes per week were additional training for a total of four hours over the eight-week period, therefore, higher volume and frequency of training could potentially have a bigger effect on the adaptations.

In addition to the neuromuscular training characteristics, the improvements in jump height of the control group may have related to the timing of the study and the increased training load due to competition rehearsals. Our study was performed during the latter part of the dancers' season (March-June). For the final four weeks of the trial, the control groups training load was increased from 6.5 hours of technical class time (including self-directed static stretching warm-up) to 9.5 hours in response to additional rehearsals. As the intervention group was not involved in competitions, their training load remained at 6.5 hours per week of technical training (including 2, 11+Dance sessions) and 1 additional hour of 11+ Dance training for a total of 7.5 hours per week. With an increase of 2 hours of training per week leading up to the post-test, the control group may have improved their jumping ability due to more practice time which may have been a confounding variable for jump height. The timing as well as the dance schedule of the control group was not controlled for and may have further confounded the changes in jump height. More evidence is required to elucidate the effects of the 11+ Dance on jump height.

Takeoff Biomechanics

Considering takeoff biomechanics, the intervention group increased the peak hip flexion angle and peak hip extension moment and reduced the peak knee extension and adduction moments. These findings were stronger in the bilateral countermovement jump, compared to the single leg jumps. The 11+ Dance focuses on increasing muscle activation of the lumbopelvic hip musculature, quadriceps, and hamstrings to improve dynamic joint control for takeoff and landing. The putative increase in hip muscle strength could have resulted in greater forces of the involved musculature increasing joint moments at the hip and subsequently improved jump height.[36] Thus, the dancers seemed to use a more hip-dominant movement strategy to execute CMJ jumping tasks.[20] Research suggests that increasing the hip extension moments during takeoff can have a positive effect on jump height.[20, 36] It is unclear, however, whether this effect is associated with the movement strategy change, strength improvements, or both.[20] Moreover, strengthening the muscles surrounding the hip has been shown to contribute to the prevention of both acute and overuse knee injuries,[37, 38] which is reinforced by numerous investigations studying benefits of neuromuscular training in adolescents to improve dynamic alignment of the lower extremity.[15, 22, 24] Interestingly, the intervention group also decreased the knee adduction and extension moments during takeoff. Due to the use of a rather hip dominant movement strategy, the dancers were able to reduce the moments surrounding the knee while increasing jump height.[20] The importance of reduced knee moments during the takeoff phase is highlighted by a recent study suggesting that the strains occurring at the patellar tendon are similar during takeoff and landing of a countermovement jump and that large patellar tendon strains during takeoff are detrimental causing overuse injuries.[19] The authors further emphasize that even small changes in patellar tendon strains that are largely affected by the moments occurring at the knee could result in reduced overuse injuries.[19] Thus, the reduced knee moments observed in this study support the idea that the 11+ Dance may be beneficial in reducing the risk of overuse injury. This conclusion is further supported by a recent systematic review and meta-analysis (n=18 articles, 704 participants) that suggests even small to moderate changes in neuromuscular performance parameters can be sufficient to reduce associated injury risk factors and, thus, are clinically meaningful.[39] The effects seen in this study and their clinical relevance with regards to injuries in adolescent dancers need further investigation.

Landing Biomechanics

Since a greater jump height increases the peak joint moments during landing,[40] a greater peak hip and knee moments was expected following the improved jump height in both the IG and CG. In contrast to our expectation, our results did not show a change in the IG's landing moments following improved jump height. The intervention may have increased hip strength to improve control of lower limb alignment.[41] However, it is unclear whether this finding reflects a prophylactic training effect of the 11+ Dance. In line with this idea, the control group seemed to increase the knee adduction, knee extension, and hip adduction moments in the single leg countermovement jumps. Those adverse outcomes might be a result of the small improvements in jump height. However, it should be noted that the control group also reduced the peak knee adduction moment of the right leg during the CMJ, which contrasts our initial expectation.

Finally, the 11+ Dance encouraged "soft landings",[14, 42] with greater hip and knee flexion, which has been suggested as a strategy to reduce the risk of lower extremity injury.[43] Although "soft landings" are also encouraged in dance, the traditional aesthetic of ballet requires a more vertical alignment of the torso with minimal displacement of the pelvis from the center position. The observed increase in hip flexion angle without altering the knee flexion angle suggests that the dancers' torsos were less vertically aligned. Therefore, the altered movement pattern during takeoff and landing may not be aesthetically pleasing in dance. However, it is unclear whether the 11+ Dance altered movement patterns of dance-specific jumping task and will benefit from further study. The 17% reduction in knee extension moments observed in this study may be clinically relevant for reducing overuse injuries. This is supported by a recent systematic review and metanalysis (n= 18 articles, 704 participants) that suggests even small to moderate reduction of forces and moments on muscles and ligaments can be sufficient to reduce associated injury risk factors.[39] Subsequently, the effects seen in this study and their clinical relevance with regards to injuries in adolescent dancers need further investigation.

Strengths and Limitations

To the authors' knowledge this is the first controlled trial that has investigated the effects of a neuromuscular program on jump height as well as takeoff and landing biomechanics in recreational adolescent dancers. The trial was two-centered and therefore there was no intervention contamination for the control group. All sessions were supervised for the intervention group. This trial, however, is characterized by some limitations. It was not randomized, which may have introduced potential selection bias or motivational bias. This was inevitable as the principal investigator was the owner of the one center. To protect the data from potential confirmation bias from the principal investigator, the data was analyzed by an independent researcher (PM). Not all the exercises were progressed to Level 3, as the principal investigator did not deem it appropriate. Even though this may have affected the results, it is unclear whether longer exposure and/or higher intensity/difficulty would produce better results or not. The control group was not monitored over the 8-week period. However, it is unlikely that the group engaged in any form of structured training during the intervention. Practitioners who wish to conduct a two-centered study need to take this factor into consideration. The collaboration with another practitioner/teacher may be essential for the integrity of the intervention fidelity. Lastly, the two groups indicated statistically significant difference in their age. Even though there may be an inherent difference in ability due to age difference, there is currently no evidence to suggest that recreational dancers have statistical or clinical differences in ability or skill level when there an approximately one-year difference in age. In addition, the effect of the intervention was not assessed on both groups, therefore, the age is not an influential factor for the results.

Conclusion

The 11+ Dance is a neuromuscular dance-specific training program that simply replaced the first part of a dance session. Moreover, the intervention was performed without utilizing any materials or tools and specifically adjusted to match dancers' requirements. Considering the simplicity of this neuromuscular training, together with the potential prophylactic effect against injuries, this intervention could compliment regular training in recreational dance practice. In addition, the change in movement patterns to a more hip-dominant strategy and the decreased loads at the knee need further investigation as they may be associated with the reduction of lower extremity injury risk factors. However, since this study was conducted as a pilot study, our results need to be considered with caution. Further research is required to assess the effects of the 11+ Dance on jump performance, the risk of dance-related injuries, and its aesthetical aspects for dance.

Acknowledgments

The authors would like to acknowledge the support of Crossings Dance School, Elite Dance Academy, the participants who volunteered for this study, and Sandro Rajic for his contribution to data collection and exercise supervision. This work was presented at the 29th Annual Conference of the International Association for Dance Medicine and Science Annual Meeting held in Montreal, Canada 2019.

Conflict of Interest

The authors report no potential conflicts of interest.

References

1 Macintyre J, Joy E. Foot and ankle injuries in dance. Clinics in sports medicine. 2000;19(2):351-68.

2 Emery CA, Meeuwisse WH, McAllister JR. Survey of sport participation and sport injury in Calgary and area high schools. Clin J Sport Med. 2006;16(1):20-6.

3 Caine DG, J. B. , Caine C, Bergeron G. Epidemiological Review of Injury in Pre-Professional Ballet Dancers. Journal of Dance Medicine & Science 2015;19(4):140-8.

4 Roberts KJ, Nelson NG, McKenzie L. Dance-Related Injuries in Children and Adolescents Treated in US Emergency Departments in 1991–2007. Journal of Physical Activity and Health. 2013;10:143-50.

5 Black AM, Meeuwisse DW, Eliason PH, Hagel BE, Emery CA. Sport participation and injury rates in high school students: a Canadian survey of 2029 adolescents. Journal of safety research. 2021;78:314-21.

6 Ekegren CL, Quested R, Brodrick A. Injuries in pre-professional ballet dancers: Incidence, characteristics and consequences. Journal of Science & Medicine in Sport. 2014 2014/5;17(3):271-5.

7 Gamboa JM, Roberts LA, Maring J, Fergus A. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. J Orthop Sports Phys Ther. 2008 2008/3;38(3):126-36.

8 Kolokythas N, Metsios GS, Galloway SM, Allen N, Wyon MA. The Relationship of Year Group and Sex on Injury Incidence and Countermovement Jump in Adolescent Ballet Dancers: a cross-sectional analysis. J Dance Med Sci. in print.

9 Liederbach M, Richardson M, Rodriguez M, Compagno J, Dilgen F, Rose D. Jump exposures in the dance training environment: a measure of ergonomic demand. J Athl Train. 2006;41(2):S85.

10 Simpson KJ, Kanter L. Jump distance of dance landings influencing internal joint forces: I. Axial forces. Med Sci Sports Exerc. 1997;29(7):916-27.

11 Allen N, Nevill A, Brooks J, Koutedakis Y, Wyon M. Ballet injuries: injury incidence and severity over 1 year. J Orthop Sports Phys Ther. 2012 2012/9;42(9):781-90.

12 Mattiussi AM, Shaw JW, Williams S, Price PD, Brown DD, Cohen DD, et al. Injury epidemiology in professional ballet: a five-season prospective study of 1596 medical attention injuries and 543 time-loss injuries. Br J Sports Med. 2021:bjsports-2020-103817.

13 Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes: decreased impact forces and increased hamstring torques. Am J Sports Med. 1996;24(6):765-73.

14 Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. Am J Sports Med. 1999;27(6):699-706.

15 Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. Am J Sports Med. 2006;34(3):490-8.
16 Hewett TE, Myer GD. The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury. Exerc Sport Sci Rev. 2011;39(4):161-6.
17 Özkaya N, Leger D, Goldsheyder D, Nordin M. *Fundamentals of biomechanics: equilibrium, motion, and deformation*. Springer 2016.
18 Murphy DF, Connolly DAJ, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. Br J Sports Med. 2003 2003/2;37(1):13-29.
19 Firminger CR, Bruce OL, Wannop JW, Stefanyshyn DJ, Edwards WB. Effect of shoe and surface stiffness on lower limb tendon strain in jumping. Med Sci Sports Exerc. 2019;51(9):1895-903.
20 Rajic S, Legg HS, Maurus P, Nigg SR, Cleather DJ. The effects of a 9-week hip focused weight training program on hip and knee kinematics and kinetics in experienced female dancers. Journal of Human Kinetics. 2020;75(1):29-39.
21 Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. J Strength Cond Res. 2005 2005/2;19(1):51-60.
22 Chappell JD, Limpisvasti O. Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. Am J Sports Med. 2008;36(6):1081-6.
23 Rössler R, Donath L, Bizzini M, Faude O. A new injury prevention programme for children's football–FIFA 11+ Kids–can improve motor performance: a cluster-randomised controlled trial. J Sports Sci. 2016;34(6):549-56.
24 Noyes F, Barber-Westin S. Neuromuscular retraining in female adolescent athletes: effect on athletic performance indices and noncontact anterior cruciate ligament injury rates. Sports. 2015;3(2):56-76.
25 Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. J Athl Train. 2006;41(4):450.
26 Sadigursky D, Braid JA, De Lira DNL, Machado BAB, Carneiro RJF, Colavolpe PO. The FIFA 11+ injury prevention program for soccer players: a systematic review. BMC Sports Sci Med Rehabil. 2017 November 28;9(1):18.
27 Kolokythas N, Metsios GS, Galloway SM, Allen N, Wyon MA. 11+ Dance: A Neuromuscular Injury Prevention Exercise Program for Dancers. Strength & Conditioning Journal. 2021.
28 Jamnik VK, Warburton DE, Makarski J, McKenzie DC, Shephard RJ, Stone JA, et al. Enhancing the effectiveness of clearance for physical activity participation: background and overall process. Applied physiology, nutrition, and metabolism. 2011;36(S1):S3-S13.
29 Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR. Hop Testing Provides a Reliable and Valid Outcome Measure During Rehabilitation After Anterior Cruciate Ligament Reconstruction. Physical Therapy. 2007;87(3):337-49.
30 Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. Measurement in Physical Education and Exercise Science. 2008;12(4):207-18.
31 Vanezis A, Lees A. A biomechanical analysis of good and poor performers of the vertical jump. Ergonomics. 2005;48(11-14):1594-603.
32 Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. Bmj. 2008;337:a2469.
33 Cumming G, Calin-Jageman R. *Introduction to the new statistics: Estimation, open science, and beyond*. Routledge 2016.

34 Zarei M, Abbasi H, Daneshjoo A, Barghi TS, Rommers N, Faude O, et al. Long-term effects of the 11+ warm-up injury prevention programme on physical performance in adolescent male football players: a cluster-randomised controlled trial. J Sports Sci. 2018 Apr 11:1-8.

35 Chimera NJ, Swanik KA, Swanik CB, Straub SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. J Athl Train. 2004;39(1):24.

36 Lees A, Vanrenterghem J, De Clercq D. The maximal and submaximal vertical jump: implications for strength and conditioning. The Journal of Strength & Conditioning Research. 2004;18(4):787-91.

37 Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain. J Orthop Sports Phys Ther. 2003;33(11):671-6.

38 Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. journal of orthopaedic & sports physical therapy. 2010;40(2):42-51.

39 Faude O, Rössler R, Petushek EJ, Roth R, Zahner L, Donath L. Neuromuscular Adaptations to Multimodal Injury Prevention Programs in Youth Sports: A Systematic Review with Meta-Analysis of Randomized Controlled Trials. Front Physiol. 2017 2017-October-12;8(791).

40 Zhang S-N, Bates BT, Dufek JS. Contributions of lower extremity joints to energy dissipation during landings. Med Sci Sports Exerc. 2000;32(4):812-9.

41 Myer G, Brent J, Ford K, Hewett T. A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength. Br J Sports Med. 2008;42(7):614-9.

42 Orishimo KF, Kremenic IJ, Pappas E, Hagins M, Liederbach M. Comparison of landing biomechanics between male and female professional dancers. Am J Sports Med. 2009;37(11):2187-93.

43 Sinsurin K, Vachalathiti R, Jalayondeja W, Limroongreungrat W. Different sagittal angles and moments of lower extremity joints during single-leg jump landing among various directions in basketball and volleyball athletes. Journal of physical therapy science. 2013;25(9):1109-13.