



## CLINICAL TRIAL

# An Intervention Program Based on Motor Coordination Principles Improves Knee Alignment in Pre-Professional Ballet Dancers

Mônica de Oliveira Melo<sup>1</sup> , Kaanda Nabilla Souza Gontijo<sup>2</sup> , Claudia Tarragô Candotti<sup>2</sup> , Gabriela Cristina dos Santos<sup>2</sup> , Stephanie dos Santos Cardoso<sup>2</sup> , Bruna Soares<sup>2</sup> , Isis Juliene Leite Navarro<sup>2\*</sup>  and Jefferson Fagundes Loss<sup>2</sup> 

<sup>1</sup>Núcleo de Pesquisa em Ciências e Artes do Movimento Humano, University of Caxias do Sul, Brazil

<sup>2</sup>Exercise Research Laboratory, School of Physical Education, Universidade Federal do Rio Grande do Sul, Brazil

\*Corresponding author: Isis Juliene Rodrigues Leite Navarro, Exercise Research Laboratory, School of Physical Education, Universidade Federal do Rio Grande do Sul, Rua Felizardo, 750, bairro Jardim Botânico. Porto Alegre, RS, Brazil, Zip-code: 90690-200, Tel: +55-51-9981545545



## Abstract

**Background:** The practice of classical ballet requires constant, prolonged physical training periods, and the repetition of aesthetic movements that exceed anatomical limits. Joint misalignment during sustained posture or movement execution is one of the principal risk factors for injury in the dance world. Injury prevention strategies based on correcting altered movement patterns need to be targeted by health professionals during the teaching-learning-training process. The aim of this study was to determine the effects of an intervention program based on Piret and Beziers' Motor Coordination principles on knee alignment, foot arch stability and pelvic position in pre-professional ballet dancers.

**Methods:** Twenty dancers from 7<sup>th</sup> year of the Bolshoi Theatre School in Brazil underwent an intervention program based on Motor Coordination principles. The intervention program was composed of three different types of sessions (individual home-based sessions, supervised group sessions and "life lessons") focusing on exercises that organize the lower limb torsion, torso stabilization and proprioception. The outcomes included knee center alignment (patella related to 2<sup>nd</sup> toe), pelvic position (tilt) and foot arch stability (stable/unstable). They were assessed using the Dynamic Evaluation Method of Lower Limb Joint Alignment (MADAAMI) during one sequential execution of classical ballet steps (demi-plié, grand plié, and fondu), in three feet positions: Parallel, 180° En dehor, and self-select En dehor. The Friedman test was used to determine the time-effects on dependent variables and the Wilcoxon test was used to identify differences between two consecutive

periods (pre- and post-control, pre- and post-intervention, pre- and post-follow-up). The effect size was calculated to examine the practical significance of the results.

**Results:** Small and medium effects were identified in knee center alignment during several sequential execution phases of the feet in self-selected and 180° turnout positions. Regarding knee center alignment, during the feet in parallel position, changes in the number of occurrences from lowest to highest scores following the intervention period were only identified during the fondu step with medium effect size. No differences were observed between post-intervention and follow-up period for any of the variables.

**Conclusions:** The intervention promoted knee center alignment, which persisted after 24 weeks, beyond supervised sessions. No effects in the pelvic position or in the foot arch were observed.

## Keywords

Dancing, Clinical trial, Exercise therapy

## Abbreviations

MADAAMI: Dynamic Evaluation Method of Lower Limb Joint Alignment in Portuguese Método de Avaliação Dinâmica do Alinhamento Articular dos Membros Inferiores; PSIS: Posterior Superior Iliac Spine; ASIS: Anterior Superior Iliac Spine; SK1: Extended Knees before Demi-Plié; DPD: Demi-Plié Descent; DP: Demi-Plié; DPA: Demi-Plié Ascent; SK2: Extended Knees before Grand Plié; GPD: Grand Plié Descent; GP: Grand Plié; GPA: Grand Plié ascent; SK3: Extended Knees before Fondu; FOD: Fondu Descent; FO: Fondu; FOA: Fondu Ascent; ES: Effect Size

## Introduction

The practice of classical ballet requires constant, prolonged physical training periods, choreographic technical complexity and the repetition of aesthetic movements with a wide range of motion that exceed the anatomical limits [1,2]. Thus, unsurprisingly there is a high prevalence of lower-limb injuries among classical ballet dancers due to overuse [3-6] and multifactorial causes, such as muscle fatigue, inadequate flooring or insufficient rest time [4,7].

Furthermore, there seems to be a consensus that joint misalignment during sustained posture or movement execution is one of the principal risk factors for injury in the dance world [3,4,8,9]. This approach is based on the premise that these joint misalignments generate compensatory movements, reduce the body's capacity to absorb forces and exceed the mechanical threshold of musculoskeletal tissues [3,10-12]. It is believed injury prevention strategies based on correcting altered movement patterns need to be targeted by health professionals during the teaching-learning-training process [13-15]. The Motor Coordination principles, as described by Piret and Béziers [16], represent an alternative physiotherapeutic approach which envisages posture and movement re-education [16-18].

We believe that the alignment of the joint structures dictates how forces are absorbed and transferred throughout the body. Based on this, it is hypothesized that an intervention program with therapeutic exercises that emphasize a physiological joint alignment during technical ballet steps could be an effective strategy for decreasing injury risk factors [17]. Thus, the aim of this study was to determine the effects of an intervention program based on Piret and Beziers' Motor Coordination principles on the knee alignments, foot arch stability and pelvic position in pre-professional ballet dancers.

## Material and Methods

### Study design

This experimental study was approved by the

Research Ethics Committee of the university. All participants were recruited from the Bolshoi Theatre School in Brazil and provided written consent before data collection. Thirty hours per week is the average training time at this school, and this training lasts 8 years. This study was conducted between 2014 and 2016. During this period, 39 participants were recruited, evaluated and submitted to a 4-week intervention program. The intervention was conducted when the participants were in the 7<sup>th</sup> grade level of the ballet school. Twenty participants were submitted to a control period during 2014 when no intervention was conducted, and they were oriented to maintain their normal routine of ballet classes. These participants were evaluated at four different time points: pre-control, pre-intervention, post-intervention and post-follow-up. For these participants, the intervention occurred during the year 2015 (Figure 1). Another 19 participants were recruited in 2016, which are not submitted to a control period, and they were evaluated at only three different time points (pre-intervention, post-intervention and post-follow-up) during the 2016 year (Figure 1).

### Participants

Thirty-nine dancers were initially recruited to participate in the present study, 20 in 2014 and 19 in 2016. The sample was intentional, and the participants were recruited via advertisements published on murals in the ballet school. The inclusion criteria required candidates to be regularly matriculated in the 7<sup>th</sup>-grade level of Bolshoi Theatre School during the intervention period and aged between 15 and 21 years. The following exclusion criteria were observed: musculoskeletal injury during the study period and surgery performed in the previous six months.

Participants were excluded from the data analysis in the case of absence during the evaluation protocol, less than 100% adherence to the supervised sessions or less than 75% adherence to the home-based exercises. The researchers responsible for data collection and data analysis, with 3 years of experience in postural

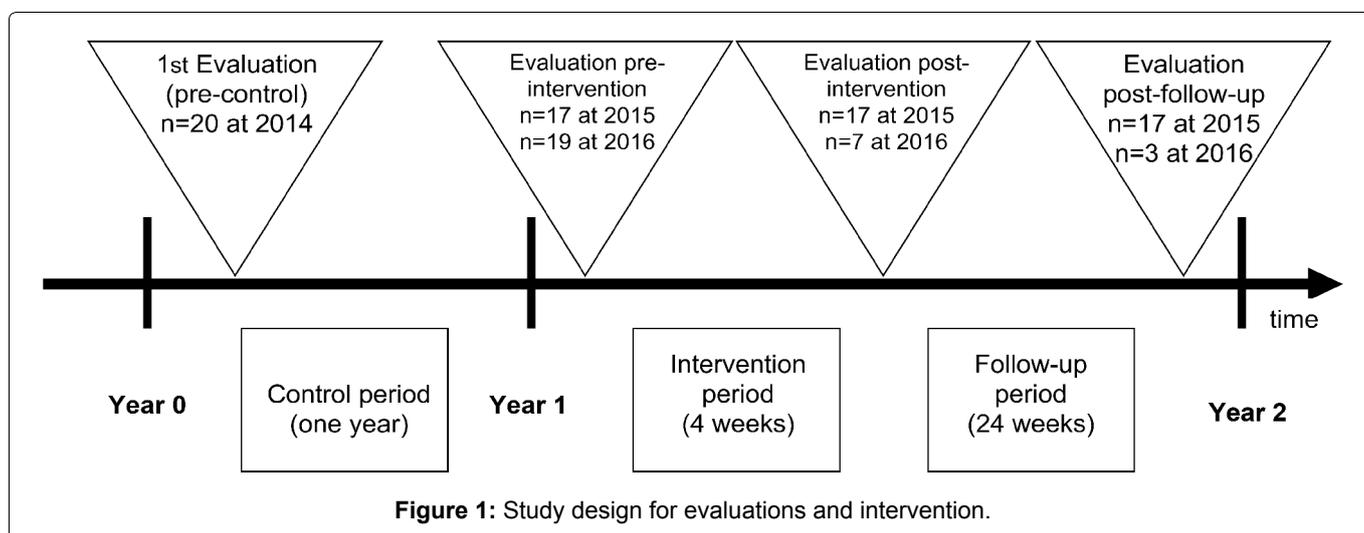


Figure 1: Study design for evaluations and intervention.

evaluation, were blinded in relation to the program intervention.

### Evaluation protocol

Knee center alignment, pelvic position and foot arch stability were assessed using the Dynamic Evaluation Method of Lower Limb Joint Alignment (MADAAMI) by one researcher with experience in the use of this method, who was blinded to the data analysis and to intervention. Details of the MADAAMI protocol were reported in previous studies that confirmed the validity and reliability of this method [19-21]. MADAAMI consist of: (i) Digital video recording of the lower limbs during sequential execution of classical ballet steps; and (ii) Checklist which helps the professional to measure change in knee alignment, foot arch stability and pelvic position based on pre-determined criteria and scores [20].

During the evaluation protocol, participants were required to be barefoot and wearing clothes that allowed the hips, knees, ankles, and feet to be clearly viewed [21]. Before the test, reflective markers were attached to the following anatomical points: the right posterior superior iliac spine (PSIS) and right anterior superior iliac spine (ASIS), the right foot second toe, the right navicular bone, the first metatarsophalangeal joint medial region, the fifth metatarsophalangeal joint lateral region and the anterior tibial tuberosity [21]. First, each participant was positioned at a previously prepared location based on the protocol proposed by MADAAMI [21]. They then performed the step sequence proposed [21] (a *demi-plié*, a *grand plié*, and a *fondu*) (Figure 2) three times, twice for familiarization and once

for the digital video recording. The foot position order was randomly defined: (1) Feet in parallel position, (2) Feet in the 180-degree *En dehor* position and (3) Feet in self-selected *En dehor* position. When in the parallel position, the feet were hip width apart. A one-minute interval was used between the tested positions. During the control period, only the feet in self-selected *En dehor* position were evaluated.

The resulting data were analyzed by one researcher, blinded to data acquisition and the intervention, who was asked to rate the score sheet based on observation of the video recordings. The content of MADAAMI score sheet was also previously validated [21]. Briefly, the MADAAMI score sheet is divided into three criteria that are used to analyze each one of the executed steps (*demi-plié*, *grand-plié*, and *fondu*): 1) Foot arch stability, 2) Pelvic position and 3) Knee center alignment. Each criterion was evaluated in the following step phases: Extended knees before *Demi-plié* (SK1), *Demi-plié* descent (DPD), *Demi-plié* (DP), *Demi-plié* ascent (DPA), Extended Knees before *Grand plié* (SK2), *Grand plié* descent (GPD), *Grand plié* (GP), *Grand plié* ascent (GPA), Extended Knees before *Fondu* (SK3), *Fondu* Descent (FOD), *Fondu* (FO), *Fondu* Ascent (FOA) [21]. Thus, the foot arch stability was assessed as “Unstable toward the fifth toe”, “Stable”, or “Unstable toward the first toe”; the knee center alignment was assessed with the ipsilateral foot in static phase as “Above the fourth and fifth toe or beyond the fifth toe”, “Above the second and third toes”, or “Above or beyond out the first toe (femur internal rotation)”, and dynamic phases as “Stable (starts and ends in the same position)”, “Unstable (starts with internal rotation and ends above the second and



**Figure 2:** Ballet movements analyzed *demi-plié*, *grand plié*, and *fondu*, respectively.

third toes)", or "Unstable (starts with internal rotation and ends above or beyond the first toe)"; and the pelvic position (i.e., anterior and posterior pelvic tilt) was assessed in both the static and dynamic phases. The pelvic position was only assessed in the 180° and self-selected turnout foot positions.

In short, each of these criteria includes descriptive categories that are scored from 1 to 4 for the knee alignment, where the scores 1 and 2 indicate a performance that deviates from the theoretical norm, while scores 3 and 4 indicate a performance that conforms to the theoretical norm. For foot arch stability and pelvic position, the scores are from 1 to 3, where the scores 1 and 2 indicate a performance that deviates from the theoretical norm, while scores 3 indicate a performance that conforms to the theoretical norm. Therefore, the higher the MADAAMI score, the better the alignment [21].

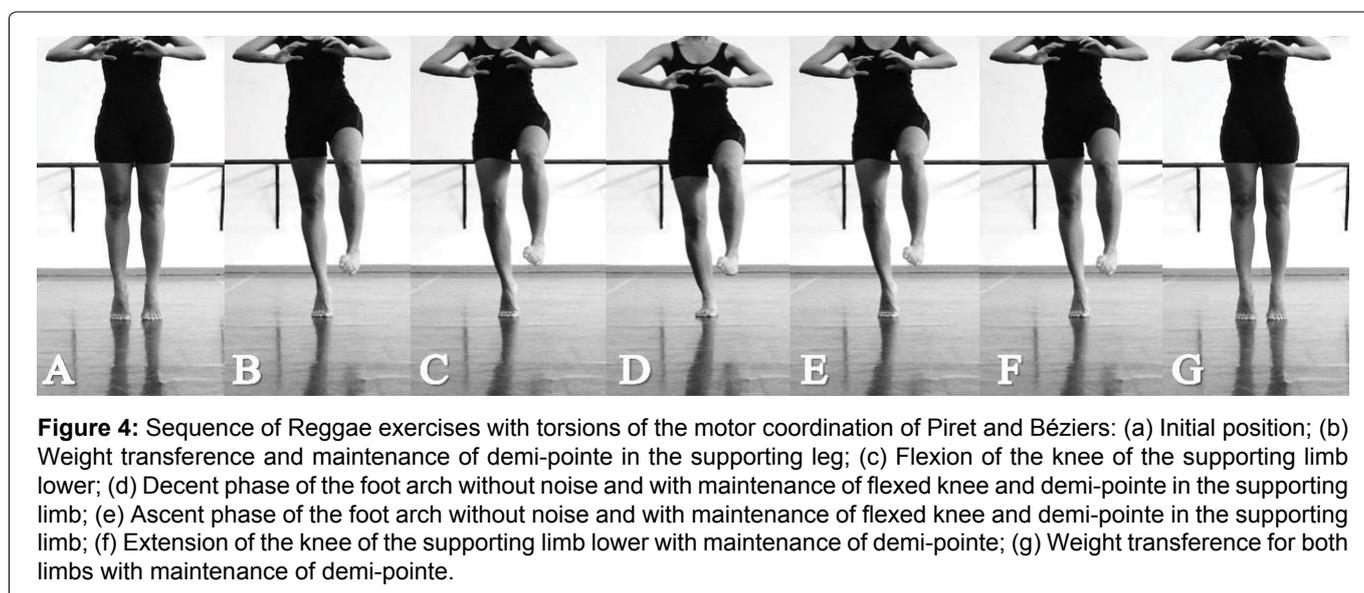
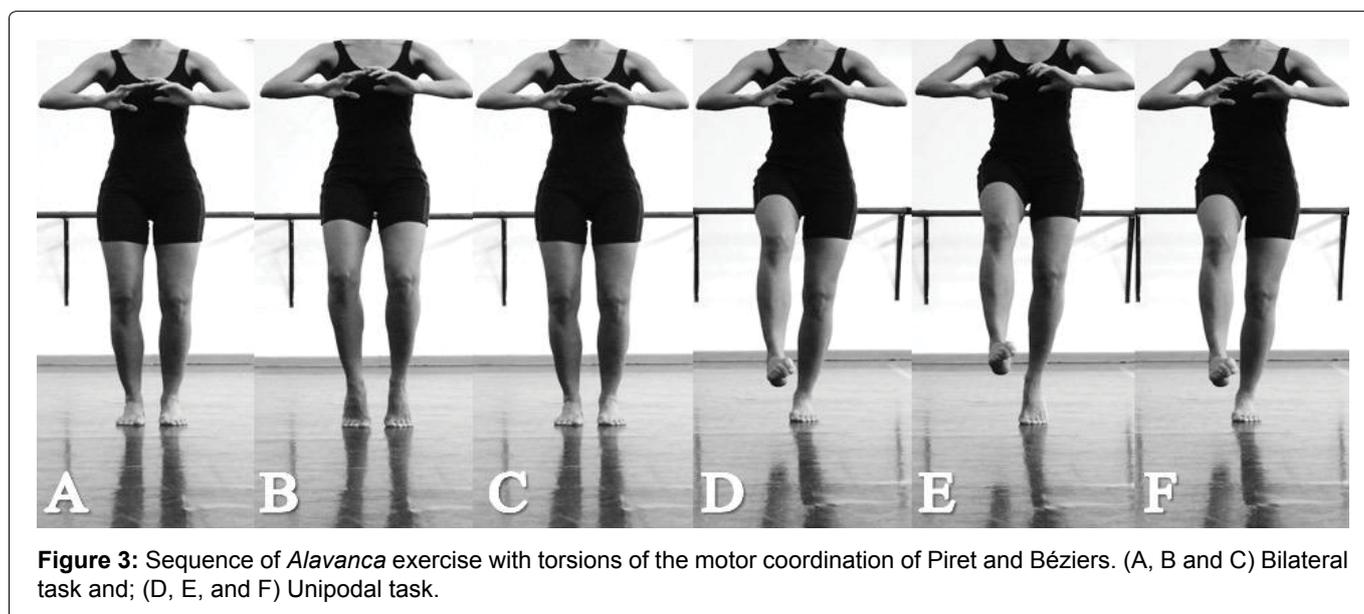
### Intervention protocol

A physiotherapist with 5 years of experience and

blinded to the data acquisition and data analysis conducted the intervention protocol. The intervention program was based on the Motor Coordination principles (i.e. adequate proprioceptivity, motor control and balance between the tension produced by antagonist muscles) [16-18].

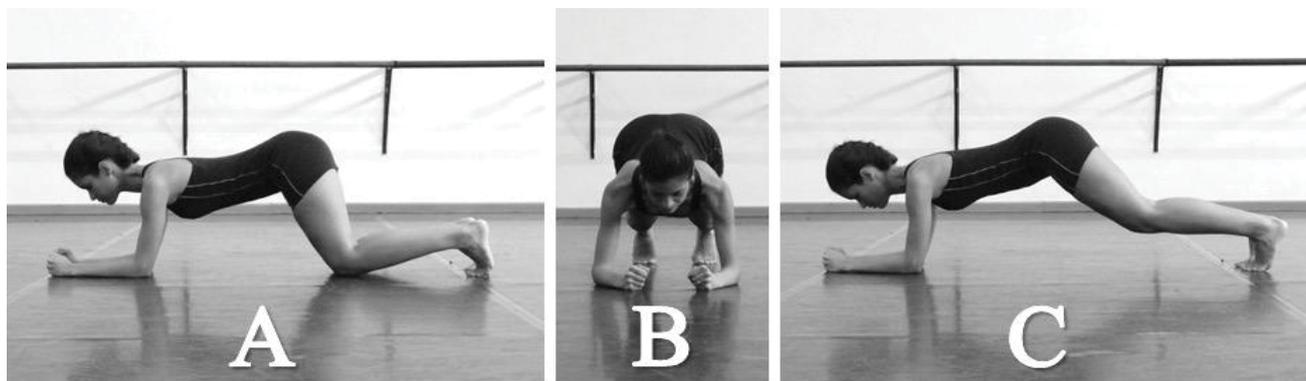
For the creators of the Motor Coordination principles, the knee joint is the central point between the external femoral rotation and the internal tibial rotation produced by the iliopsoas, the sartorius and the tibialis anterior muscles. In other words, this antagonistic opposition between rotations is brought about by "organizational tension" that keeps the tibia rotating internally, as opposed to the tension for external rotation exerted on the femur. This condition ensures alignment of the bone segments and knee stabilization, which is essential for dancers since the injuries can be caused by the loss of tibial internal rotation when performing the maximal turnout position [11-13] (Figure 3 and Figure 4).

The intervention program focused on exercises that

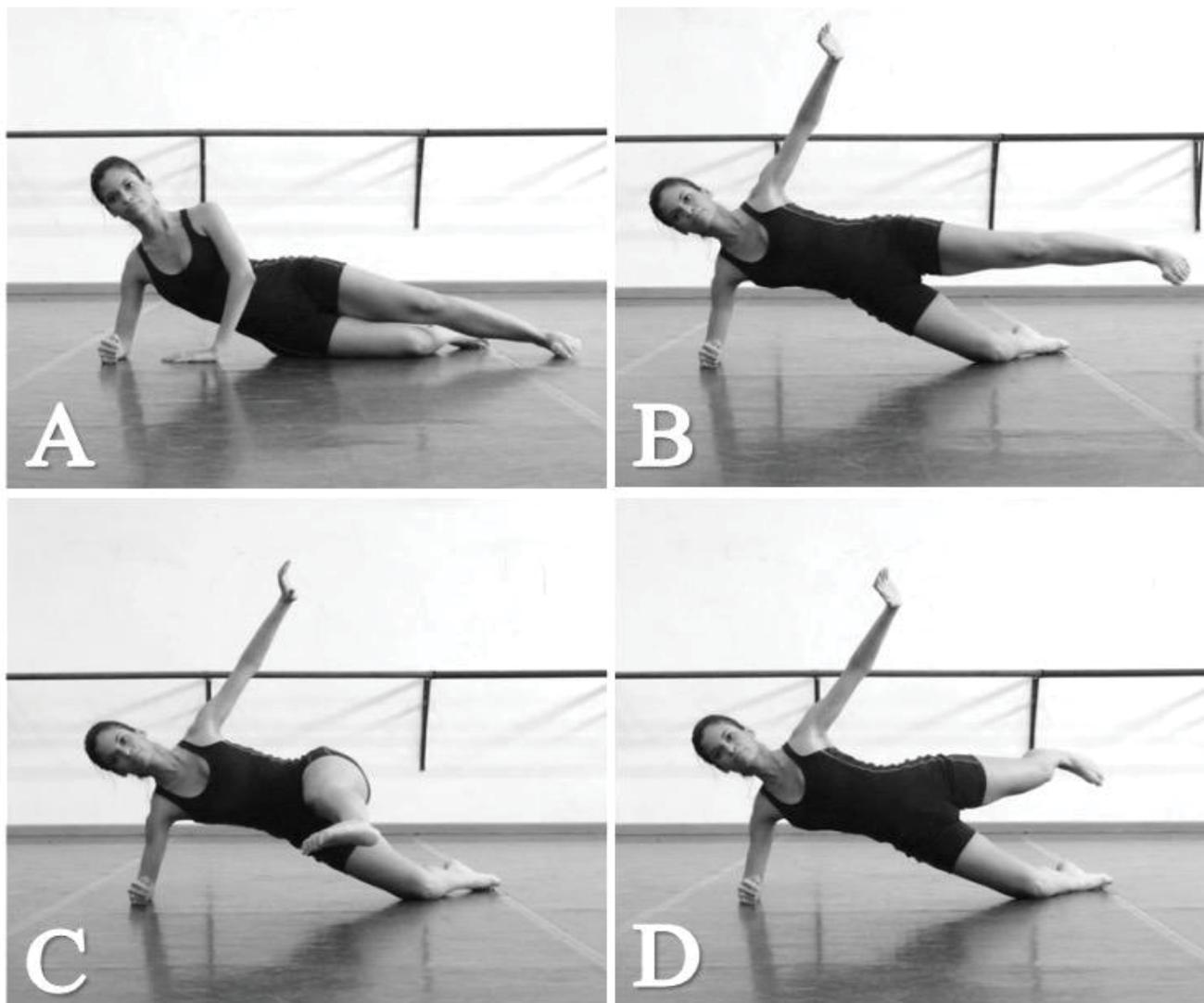


organize the lower limb torsions, torso stabilization and proprioception, involving the use of planks in different positions and on different support surfaces (Figure 5 and Figure 6). In practice, the program consisted

of three different types of session: individual home-based sessions, supervised group sessions and sessions called by “life lessons”, in which the participants were instructed regarding specific self-care tips and



**Figure 5:** Frontal plank exercise: (a) Initial position, maintaining the lumbar region neutral while simultaneously activating the abdominal and pelvic floor muscles; (b) Note the knee and foot alignment while maintaining Piret and Béziers' Motor Coordination torsions; (c) Final position.



**Figure 6:** Lateral plank exercise with pendulum: (a) Initial position for organizing the neutral lumbar region and maintaining Piret and Béziers' Motor Coordination torsions (coordination position) during simultaneous activation of the abdominal and pelvic floor muscles; (b) Intermediate pendulum position where inhalation should be performed; (c) Anterior pendulum balance phase; (d) Posterior pendulum balance phase.

exercises they could do at home at any time during the intervention period (Table 1).

Thus, the participants attended 4 supervised group sessions, once a week, over a one-month period.

**Table 1:** Summary of the main contents and exercises used in the intervention protocol.

	<b>Supervised group exercises sessions</b>	<b>Home based-exercise</b>	<b>Life lessons</b>
Session 1	<p>Practicing the static and dynamic self- evaluation of the lower member alignments in front of the mirror.</p> <p>Understanding the Motor Coordination' principles with focus about how tensions are generated by muscles that causes alignment (anterior tibialis, sartorius and iliopsoas).</p> <p>Understanding the effects of misalignments on injuries development.</p> <p>Practicing of Motor Coordination' torsions (learning how to promote tibia and fibula internal rotation together with calcaneus external rotation, ankle flexion and femur external rotation).</p> <p>Understanding and practicing the self- alignment evaluation during pli�, fondu with feet different positions: Acquiring personal knowledge of the torsions, self-evaluation and control of foot arch, pelvic position and knee alignment.</p> <p>Practicing of <i>Alavanca e Reggae</i> exercises.</p> <p>Explanation about home based-exercise sessions and "life lessons".</p>	<p>Execution of 4 sets of <i>Alavanca</i> (unilaterais and bilaterais) and <i>Reggae</i> exercises using different board superficies.</p>	<p>Observation of the knee alignment during the walking, stair climbing and when standing up.</p> <p>Observation of the noise produced by feet (heel or feet) during the contact with the ground in walking.</p>
Session 2	<p>Talk about home-based exercises and life lessons.</p> <p>Practice and correction of the routine home-based exercises session 1 in small groups.</p> <p>Practice and self-evaluation of the walking using the Motor Coordination' torsions.</p> <p>Understanding body structures: acquiring personal knowledge of the columna vertebralis and pelvic floor.</p> <p>Practicing of <i>Frontal Plank and Lateral Plank with pendulum</i> exercises.</p>	<p>Execution of the session 1 home-based exercises more quickly. Practicing of 1 or 2 sets of <i>Frontal Plank and Lateral Plank with pendulum</i> exercises</p>	<p>Walking using <i>Alavanca</i> technique and torsions and <i>pendulum</i> technique.</p> <p>Observing the noise produced by feet (heel or feet) during the contact with the ground in walking.</p>
Session 3	<p>Talk about home-based exercises and life lessons.</p> <p>Understanding body structures: Acquiring personal knowledge of the correct position of shoulder blade.</p> <p>Practicing of the routine of 1 and 2 sessions home-based exercises.</p> <p>Practicing of the sequence of steps from MADAAMI with feet parallel and self <i>en dehors</i> in front of the mirror.</p> <p>Practicing of the <i>Petit Saut�</i> exercise without any noise during the jump landing.</p> <p>Practicing of the <i>pendulum</i> exercise in stand-up position.</p> <p>In small groups and in front of the mirror, practicing of the walking with large steps and with maintenance of motor coordination torsions and using <i>pendulum technique</i> by different proprioceptive challenge.</p>	<p>Execution of number reduced of sets of session 1, 2 and 3 home-based exercises. Practicing of exercises: <i>Alavanca, Reggae</i>, Frontal and Lateral Plank exercises</p>	<p><i>Walking with long steps</i> using motor coordination torsions and different proprioceptive challenges (different boards and speeds).</p> <p>Observation of the noise produced by feet (heel or feet) during the contact with the ground in walking.</p>
Session 4	<p>Talk about home-based exercises and life lessons.</p> <p>Practice and correction of the routine home-based exercises session 3 in front of the mirror.</p> <p>Practicing the sequence of steps ballet (<i>fondu relev�, petit saut�s</i> with �paulement <i>glissades</i> and <i>pointe</i> shoes) using all acquired technical knowledge.</p> <p>Explanation of the importance of "think before doing" a movement or exercise.</p> <p>Understanding the importance of maintenance of alignments and torsions during the daily day and the before or after the ballet classes.</p>	<p>For maintenance of results acquired: Practicing <i>Alavanca, Reggae</i>, Frontal and Lateral Plank exercises.</p>	<p><i>Walking with long steps</i> using motor coordination torsions and different proprioceptive challenges (different boards and speeds).</p> <p>Observation of the noise produced by feet (heel or feet) during contact with the ground in walking.</p>

Between sessions, the participants were expected to perform the home-based exercises twice a week and the life lessons as often as possible. In addition, in each session the participants were inquired about the frequency of home-bases and life lessons exercises.

At the end of intervention period, the participants were oriented to maintain the home-based exercises and the life lessons as part of their life and ballet classes. [Table 1](#) summarises the content and main exercises developed during the intervention period. [Figure 2](#), [Figure 3](#), [Figure 4](#) and [Figure 5](#) show the typical exercises used in the intervention protocol.

### Statistical analysis

Using the knee center alignment as the main variable, the G\*Power v.3.1.7 was used to estimate the sample size. Based on the Wilcoxon test (matched pairs), two tails, estimating the effect size in 0.5,  $\alpha = 0.05$  and power of 80%, a sample size of 35 subjects was obtained.

The Friedman test was used to determine the time-effects on the dependent variables. The Wilcoxon test, with the Bonferroni correction, was used to identify differences between two consecutive periods (pre- and post-control, pre- and post-intervention, pre- and post-follow-up). Magnitude-based inference analyses were also used to examine the results practical application. The magnitude of differences between pre- and post-intervention was calculated [22] and was interpreted using the following scale, which was proposed by Cohen [23]: Trivial effect ( $< 0.10$ ), small effect (0.10-0.30), medium effect (0.30-0.50), and large effect (above 0.50). The significance level was  $\alpha < 0.05$  for all statistical analyses. The results are expressed as absolute and relative frequencies in tables when significant differences were detected.

## Results

### Anthropometric and baseline characteristics

Twenty participants (female = 8 and male = 12) completed the full protocol, (age =  $18.5 \pm 0.9$  years, height =  $1.7 \pm 0.1$  m and total body mass =  $56.1 \pm 8.5$  kg). Six dropped out due to personal reasons or injury, one participant was dismissed from the School, and 12 participants failed to reach the required percentage of adherence to the intervention program sessions during the study ([Figure 1](#)). All the participants had more than 9 years of experience in classical ballet and more than 5 years dancing in the School of Bolshoi Theatre, in Brazil.

### Control period

There were no significant differences between the pre-control and pre-intervention tests for the knee center alignment, foot arch stability or pelvic position in any of the assessed phases during each step (*demi-plié*, *grand plié* and *fondue*) performed with feet in the *En dehor* self-selected position ( $p > 0.05$  for all).

### Intervention and follow-up periods

**Knee center alignment:** Regarding the knee center alignment during the feet in the self-selected *En dehor* position, a treatment effect was observed for the SK1 [ $X^2(2) = 6.400$ ,  $p = 0.041$ ], DPD [ $X^2(2) = 9.250$ ,  $p = 0.010$ ], DPA [ $X^2(2) = 13.188$ ,  $p = 0.001$ ], SK2 [ $X^2(2) = 6.400$ ,  $p = 0.041$ ], GPA [ $X^2(2) = 11.000$ ,  $p = 0.004$ ], SK3 [ $X^2(2) = 6.400$ ,  $p = 0.041$ ] and FO [ $X^2(2) = 6.333$ ,  $p = 0.042$ ]. In addition, the adjusted Bonferroni test identified improvement in knee center scores following the intervention period for DPD ( $p = 0.014$ ), DPA ( $p = 0.006$ ), GPA ( $p = 0.016$ ), a FOD ( $p = 0.017$ ) and FO ( $p = 0.025$ ). No differences were observed between post-intervention and follow-up ( $p > 0.05$  for all, [Table 2](#)). The effect size between the pre-intervention and post-intervention tests were small for DP (ES = 0.22), GPD (ES = 0.27) and FOA (ES = 0.29) and medium for SK1 (ES = 0.31), DPD (ES = 0.38), DPA (ES = 0.43), SK2 (ES = 0.31), GP (ES = 0.33), GPA (ES = 0.37), SK3 (ES = 0.31), FOD (ES = 0.37) and FO (ES = 0.35).

When the knee center alignment was investigated during the feet in the  $180^\circ$  *En dehor* position, a treatment effect was observed on the knee center for the SK1 [ $X^2(2) = 1.333$ ,  $p = 0.006$ ], DPA [ $X^2(2) = 14.000$ ,  $p = 0.00$ ], SK2 [ $X^2(2) = 10.333$ ,  $p = 0.006$ ], GPA [ $X^2(2) = 6.059$ ,  $p = 0.048$ ], SK3 [ $X^2(2) = 10.333$ ,  $p = 0.006$ ], FOD [ $X^2(2) = 9.000$ ,  $p = 0.011$ ] and FOA ( $X^2(2) = 17,077$ ,  $p < 0.001$ ). The Bonferroni test showed an increased number of occurrences in the highest knee center scores following the intervention period for SK1 ( $p = 0.025$ ), DPA ( $p = 0.006$ ), SSK2 ( $p = 0.025$ ), GPA ( $p = 0.009$ ), SK3 ( $p = 0.025$ ) and FOA ( $p = 0.003$ ) ([Table 3](#)). No differences were found between post intervention and follow-up ( $p > 0.05$ , for all, [Table 3](#)). Trivial (DP, ES = 0.10), small (GDP, ES = 0.17; GP, ES = 0.12 and FO, ES = 0.15) and medium effect size (SK1, ES = 0.35; DPA, ES = 0.43; SK2, ES = 0.35; GPA, ES = 0.41; SK3, ES = 0.35; FOD, ES = 0.38 and FO, ES = 0.47) were found between the pre-intervention and post-intervention tests.

Regarding the knee center alignment during feet in the parallel position, a treatment effect was observed for FOD [ $X^2(3) = 12.019$ ,  $p = 0.007$ ] and FO [ $X^2(3) D = 14.455$ ,  $p = 0.002$ ]. The Bonferroni test identified changes in the number of occurrences from lowest to highest knee center scores following the intervention period for FO ( $p = 0.015$ ) ([Table 4](#)). No differences were observed between post-intervention and follow-up period ( $p > 0.05$  for all, [Table 4](#)). The effect size was trivial (SK1, ES = 0.05; DDP, ES = 0.08; DPA, ES = 0.05; GPD and ES = 0.09), small (DP, ES = 0.17; SK2, ES = 0.15; GP, ES = 0.13; SK3, ES = 0.15 and FOA, ES = 0.17) and medium (GPA, ES = 0.31; FOD, ES = 0.31; FO, ES = 0.38) between the pre-intervention and post-intervention tests.

**Foot arch stability:** With respect to arch foot stability during the feet in self-selected *En dehor* position, a

**Table 2:** Number of occurrences absolute (and relative) for the knee center alignment scores in each phase of the feet in *En dehors* self-selected position during the study evaluation times.

Phases of step	Pre-intervention				Post-intervention				Follow-up			
	Scores				Scores				Scores			
	1	2	3	4	1	2	3	4	1	2	3	4
Extended Knees before <i>demi-plié</i>	18 (90)	0 (0)	2 (10)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)
<i>Demi-plié</i> Descent*	18 (90)	1 (5)	1 (5)	0 (0)	12 (60)	0 (0)	1 (5)	7 (35)	15 (75)	0 (0)	2 (10)	3 (15)
<i>Demi-plié</i>	17 (85)	0 (0)	3 (15)	0 (0)	15 (75)	0 (0)	5 (25)	0 (0)	15 (75)	0 (0)	5 (25)	0 (0)
<i>Demi-plié</i> Ascent*	18 (90)	0 (0)	1 (5)	1 (5)	10 (50)	0 (0)	2 (10)	8 (40)	13 (65)	0 (0)	4 (20)	3 (15)
Extended Knees before <i>grand plié</i>	18 (90)	0 (0)	2 (10)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)
<i>Grand plié</i> Descent	12 (60)	2 (10)	6 (30)	0 (0)	7 (35)	2 (10)	9 (45)	2 (10)	11 (55)	0 (0)	6 (30)	3 (15)
<i>Grand plié</i>	5 (25)	7 (35)	8 (40)	0 (0)	3 (15)	4 (20)	13 (65)	0 (0)	5 (25)	5 (25)	10 (50)	0 (0)
<i>Grand plié</i> Ascent*	16 (80)	1 (5)	3 (15)	0 (0)	12 (60)	1 (5)	3 (15)	4 (20)	14 (70)	0 (0)	5 (25)	1 (5)
Extended Knees before <i>fondus</i>	18 (90)	0 (0)	2 (10)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)
<i>Fondus</i> Descent	17 (85)	0 (0)	1 (5)	2 (10)	10 (50)	0 (0)	4 (20)	6 (30)	15 (75)	0 (0)	1 (5)	4 (20)
<i>Fondus</i>	19 (95)	0 (0)	1 (5)	0 (0)	14 (70)	0 (0)	6 (30)	0 (0)	17 (85)	0 (0)	3 (15)	0 (0)
<i>Fondus</i> Ascent*	17 (85)	0 (0)	0 (0)	3 (15)	10 (50)	0 (0)	4 (20)	6 (30)	12 (60)	0 (0)	3 (15)	5 (25)

\*Indicates differences between pre-intervention and post intervention. Legends for scores at extended knees phases: 1 = above or beyond out the 1<sup>st</sup> toe (femur internal rotation, 2 = above the 4<sup>th</sup>/5<sup>th</sup> toe or beyond the 5<sup>th</sup> toe, 3= above the 2<sup>nd</sup>/3<sup>rd</sup> toes. Legends for scores at dynamic knee phases: 1 = unstable, starts with internal rotation and ends above or beyond the 1<sup>st</sup> toe, 2 = unstable, starts with internal rotation and ends above the 4<sup>th</sup>/5<sup>th</sup> toes or beyond the 5<sup>th</sup> toe, 3 = unstable, starts with rotation and ends above the 2<sup>nd</sup>/3<sup>rd</sup> toes, 4 = stable, starts and ends in the same position.

treatment effect for FO was observed [ $X^2(2) = 8.000$ ,  $p = 0.018$ ]. However, no difference between pre- and post-intervention ( $p > 0.05$  for all) or between post-intervention and follow-up periods ( $p > 0.05$  for all) was found using the adjusted Bonferroni test.

For arch foot stability during the feet in the 180° *En dehors* position, a treatment effect was observed for GPD [ $X^2(2) = 7.538$ ,  $p = 0.023$ ]. The adjusted Bonferroni test did not identify differences between the pre- and post-intervention periods ( $p > 0.05$  for all).

Regarding arch foot stability during feet in parallel position, a treatment effect was observed for GPD [ $X^2(3) = 9.923$ ,  $p = 0.019$ ]. However, the adjusted Bonferroni test did not identify difference between pre-intervention

and post-intervention ( $p > 0.05$  for all) or between post-intervention and follow-up periods ( $p > 0.05$  for all).

**Pelvic position:** Regarding the pelvic position during the feet in self-selected *En dehors* position, a treatment effect was observed for the SK3 [ $X^2(2) = 8.000$ ,  $p = 0.018$ ]. The Bonferroni test showed fewer occurrences in the highest pelvic scores following the intervention period ( $p = 0.021$ ) between pre- and post-intervention ( $p > 0.05$  for all). No difference was found between the post-intervention and follow-up periods ( $p > 0.05$  for all).

In the analysis of the feet in 180° *En dehors* position, no treatment effect was observed and the effect size between the pre- and post-intervention periods was trivial for all the analyzed phases.

**Table 3:** Number of occurrences (absolute and relative) for knee center alignment in each phase of the feet in *En dehors* 180° position during the study evaluation times.

Phases of step	Pre-intervention				Post-intervention				Follow-up			
	Scores				Scores				Scores			
	1	2	3	4	1	2	3	4	1	2	3	4
Extended Knees before <i>demi-plié</i> *	16 (80)	0 (0)	4 (20)		11 (55)	0 (0)	9 (45)		17 (85)	0 (0)	3 (15)	
<i>Demi-plié</i> Descent*	0 (0)	0 (0)	20 (100)	0 (0)	17 (85)	0 (0)	0 (0)	3 (15)	20 (100)	0 (0)	0 (0)	0 (0)
<i>Demi-plié</i>	0 (0)	0 (0)	20 (100)	0 (0)	20 (100)	0 (0)	0 (0)	0 (0)	20 (100)	0 (0)	0 (0)	0 (0)
<i>Demi-plié</i> Ascent*	16 (80)	0 (0)	4 (20)	0 (0)	7 (35)	0 (0)	9 (45)	4 (20)	16 (80)	0 (0)	3 (15)	1 (5)
Extended Knees before <i>grand plié</i> *	16 (80)	0 (0)	4 (20)		11 (55)	0 (0)	9 (45)		17 (85)	0 (0)	3 (15)	
<i>Grand plié</i> Descent	18 (90)	0 (0)	0 (0)	2 (10)	15 (75)	0 (0)	0 (0)	5 (25)	15 (75)	0 (0)	0 (0)	5 (25)
<i>Grand plié</i>	14 (70)	0 (0)	6 (30)	0 (0)	12 (60)	0 (0)	8 (40)	0 (0)	16 (80)	0 (0)	4 (20)	0 (0)
<i>Grand plié</i> Ascent*	16 (80)	0 (0)	2 (10)	2 (10)	8 (40)	0 (0)	8 (40)	4 (20)	13 (65)	0 (0)	2 (10)	5 (25)
Extended Knees before <i>fondue</i> *	16 (80)	0 (0)	4 (20)		11 (55)	0 (0)	9 (45)		17 (85)	0 (0)	3 (15)	
<i>Fondue</i> Descent	20 (100)	0 (0)	0 (0)	0 (0)	14 (70)	0 (0)	0 (0)	6 (30)	17 (85)	0 (0)	0 (0)	3 (15)
<i>Fondue</i>	20 (100)	0 (0)	0 (0)	0 (0)	19 (95)	0 (0)	1 (5)	0 (0)	19 (95)	0 (0)	1 (5)	0 (0)
<i>Fondue</i> Ascent*	16 (80)	0 (0)	4 (20)	0 (0)	7 (35)	0 (0)	6 (30)	7 (35)	17 (85)	0 (0)	1 (5)	2 (10)

\*Indicates differences between pre-intervention and post intervention. Legends for scores at extended knees phases: 1 = above or beyond out the 1<sup>st</sup> toe (femur internal rotation, 2 = above the 4<sup>th</sup>/5<sup>th</sup> toe or beyond the 5<sup>th</sup> toe, 3 = above the 2<sup>nd</sup>/3<sup>rd</sup> toes. Legends for scores at dynamic knee phases: e.

**Table 4:** Number of occurrences (absolute and relative) for knee center alignment in each phase of the feet in parallel position during the study evaluation times.

Phases of step	Pre-intervention				Post-intervention				Follow-up			
	Scores				Scores				Scores			
	1	2	3	4	1	2	3	4	1	2	3	4
Extended Knees before <i>demi-plié</i>	3 (15)	2 (10)	15 (75)	0 (0)	3 (15)	4 (20)	13 (65)	0 (0)	4 (20)	2 (10)	14 (70)	0 (0)
<i>Demi-plié</i> Descent	2 (10)	1 (5)	4 (20)	13 (65)	0 (0)	2 (10)	5 (25)	13 (65)	0 (0)	3 (15)	5 (25)	12 (60)
<i>Demi-plié</i>	2 (10)	3 (15)	15 (75)	0 (0)	0 (0)	4 (20)	16 (80)	0 (0)	1 (5)	3 (15)	16 (80)	0 (0)
<i>Demi-plié</i> Ascent	1 (5)	4 (20)	15 (75)	0 (0)	1 (5)	0 (0)	2 (10)	17 (85)	3 (15)	2 (10)	3 (15)	12 (60)

Extended Knees before <i>grand plié</i>	1 (5)	2 (10)	17 (85)	0 (0)	2 (10)	4 (20)	14 (70)	0 (0)	4 (20)	3 (15)	13 (65)	0 (0)
<i>Grand plié</i> Descent	1 (5)	7 (35)	3 (15)	9 (45)	0 (0)	6 (30)	5 (25)	9 (45)	0 (0)	6 (30)	7 (35)	7 (35)
<i>Grand plié</i>	2 (10)	10 (50)	8 (40)	0 (0)	0 (0)	11 (55)	9 (45)	0 (0)	0 (0)	10 (50)	10 (50)	0 (0)
<i>Grand plié</i> Ascent	3 (15)	3 (15)	6 (30)	8 (40)	1 (5)	1 (5)	4 (20)	14 (70)	2 (10)	1 (5)	9 (45)	8 (40)
Extended Knees before <i>fondus</i>	1 (5)	2 (10)	17 (85)	0 (0)	0 (0)	2 (10)	14 (70)	0 (0)	4 (20)	2 (10)	14 (70)	0 (0)
<i>Fondus</i> Descent	8 (40)	2 (10)	4 (25)	6 (30)	2 (10)	3 (15)	7 (35)	8 (40)	5 (25)	1 (5)	4 (20)	10 (50)
<i>Fondus</i>	8 (40)	2 (10)	10 (50)	0 (0)	1 (5)	4 (20)	15 (75)	0 (0)	5 (25)	2 (10)	13 (65)	0 (0)
<i>Fondus</i> Ascent	1 (5)	2 (10)	11 (55)	6 (30)	2 (10)	1 (5)	4 (20)	13 (65)	2 (10)	7 (35)	11 (55)	0 (0)

\*Indicates differences between pre-intervention and post intervention. Legends for scores at extended knees phases: 1 = above or beyond out the 1st toe (femur internal rotation, 2 = above the 4<sup>th</sup>/5<sup>th</sup> toe or beyond the 5<sup>th</sup> toe, 3= above the 2<sup>nd</sup>/3<sup>rd</sup> toes. Legends for scores at dynamic knee phases: 1 = unstable, starts with internal rotation and ends above or beyond the 1st toe, 2 = unstable, starts with internal rotation and ends above the 4<sup>th</sup>/5<sup>th</sup> toes or beyond the 5<sup>th</sup> toe, 3 = unstable, starts with rotation and ends above the 2<sup>nd</sup>/3<sup>rd</sup> toes, 4 = stable, starts and ends in the same position.

## Discussion

This study aimed to determine the effects of an intervention program based on Piret and Beziere's Motor Coordination principles on the knee alignments, foot arch stability and pelvic position in pre-professional ballet dancers. Based on this aim the main findings were the following: (1) An intervention program based on Piret and Beziere's Motor Coordination principles results in improved knee center alignment, but has no effect on the foot arch stability or pelvic position; (2) The improved knee alignment was maintained for 24 weeks after the conclusion of the supervised sessions.

Our results support the hypothesis that an intervention program with exercises that emphasize the balance between muscles that perform antagonistic twist actions and the alignment of the lower limbs can be an effective strategy to achieve knee alignment in pre-professional dancers. Some studies suggest that improving knee alignment decreases the risk factors for lower extremity injury in dancers [4-6].

The major novelty of the present study resides in testing the application of an intervention program based on exercises designed to reduce misalignment in the lower limbs through "knee torsional stabilization" [17]. Considering that classical ballet requires dancers to repeatedly adopt the turnout position, which involves extreme lower-limb external rotation, and that to achieve this position, dancers frequently turn the tibia out externally beyond the physiological internal rotation, the exercises selected in this study were

focused on achieving knee stabilization and alignment through the application of the Motor Coordination principles (Chart 1). In practical terms, it is believed that the exercises applied in this study, such as *Alavanca* and *Reggae*, executed on different surfaces and at different execution speeds, which focused on the dancers' lower-limb torsional organization and on proprioceptive gains, helped the dancers transfer these Motor Coordination principles into the execution of basic ballet movements such as the *plié*, *grand-plié* and *fondus*.

Our results showed that during the control period, when no intervention was performed, no differences in knee alignment were found, but during the intervention period, differences were detected for this criterion in several phases of the *plié*, *demi-plié* and *grand plié* steps. Thus, post-intervention improvements seem to be related to the real effects caused by the tested intervention. The most meaningful result of our study for knee alignment was observed during the feet in the 180° *En dehor* position, which is considered the most fundamental position in classical ballet. For this position, we found consistent improvements with a medium effect magnitude at two static extended knee phases, where, generally, the participants had increased scores from above or beyond the 1<sup>st</sup> toe (femur internal rotation) to above the 2<sup>nd</sup>/3<sup>rd</sup> toes (knee aligned). In addition, a significant effect with a medium magnitude was also found for the ascent phase of the *demi plié* and *grand plié*, where a larger percent change from unstable knee center (starts with internal rotation and ends above or beyond the 1<sup>st</sup> toe) to stable (starts and ends

in the same position) was noted. When the findings of the feet in self-selected position were explored, a larger percentage increase in the highest scores of the knee center in the ascent phase of *demi-plié* and *grand-plié* and the descent phase of the *demi-plié* and *fondus* was observed after the intervention period. Thus, the fact that the participants presented increased MADAAMI' scores in several phases during the evaluated steps after the intervention period suggests the tested intervention is effective in minimizing the effects of the misalignments resulting from altered movements and can help reduce this important risk factor of lower-limb injury in dancers.

Our results can be attributed to the fact the three types of sessions (supervised, home-based and life sessions) involved the participants actively learning how the nervous system automatically executes aligned body movements to avoid the internal rotation of the femur associated with the exaggerated external rotation of the tibia and the eversion of the subtalar joint during basic ballet steps. In theory, a better afferent somatosensory input coupled with adequate efferent muscle force generation could influence neuromuscular control of the synergist muscles, ultimately improving their function in dancers [24-26]. The central argument given by Piret and Beziers [16] is that the re-education of the antagonism between muscles with opposite actions through exercises could optimize neuromuscular control and proprioceptive function. Future interventional studies and clinical trials are needed to test these hypotheses.

Unfortunately, the evidence for the effectiveness of applying the Motor Coordination principles in the prevention or treatment of lower-limb injury is current circumstantial [16,17]. Previous studies involving areas other than dance provide evidence to show improvement in patients with, for example, patellofemoral syndrome subjected to treatment methods that incorporate physical exercises to correct the biomechanical misalignment, such as dynamic valgus [27,28]. In general, the intervention programs were comprised of exercises that emphasized hip and lumbopelvic stabilization, correction of hip muscle imbalance, biomechanical control and sensory motor training. The results from these studies showed improved joint alignments, pain relief, increased range of motion, strength and motor control gains, in patients with knee injuries. There is an unjustified lack of scientific evidence on the effects of preventive programs that focus on correcting altered movement patterns in ballet dancers. The authors of the present study believe that if the altered movement is repeated, the sequence of compensations leading to microtrauma and macrotrauma progress, producing pain and, eventually, tissue abnormalities [29]. Thus, investigations into the effects of preventive programs on parameters related to movement competency are considered of great value for clinical practice in the dance world.

The fact that no differences in terms of foot arch stabilization were observed was expected because most of the participants had presented the highest scores (stable foot arch) during the phases in the MADAAMI assessment prior to the intervention program. However, we expected our intervention to ameliorate the pelvic stabilization capacity due to the inclusion of exercises focused on trunk stabilization, such as the *Frontal* and *Lateral Plank* (Table 1). The objective of these exercises was to challenge the body to activate what Piret and Beziers [16] refer to as the "rectus muscle system" to stabilize the trunk based on the antagonism between the spine flexor (rectus abdominis) and extensor (erectors spinae) muscles. For Piret and Beziers, this stabilizing tension can support any movement demanded of it, such as the torsions performed in the "cross-system dynamic" opposition action, especially by the abdominal oblique muscles [17]. This concept is very important for classical ballet because before spinning around themselves, using their lower limbs as a base, dancers need to stabilize their own trunk in static postures during the teaching-learning-training process [17].

One possible explanation for the lack of changes in the pelvic position is that the effect generated by the intervention was a false negative (Type II error) given that the final sample size was very small ( $n = 20$ ). Aiming to maintain high levels of quality regarding the execution of the intervention protocol, we decided to exclude all participants that presented poor adherence to intervention sessions from the study. The small sample size is considered a potential limitation of this study, as it reduces the power of our statistical test in determining real differences, given that our sample size calculation determined that 35 subjects achieved a calculated power of 0.80.

It is important to note that the participants could have obtained additional clinical benefits unevaluated in the assessment protocol, such as improvements to the proprioception system. Future studies could use an isokinetic dynamometer to assess the effect of a Motor Coordination principles-based intervention program on proprioception measurements, such as joint position sense [26] and assess the correlation of these effects with the improved alignments. Furthermore, it may be that the proposed MADAAMI protocol classification lacked sufficient sensitivity to detect very small differences in the pelvic position between pre- and post-intervention since the pertinent scoring system has only three differentiated scores, two of which are associated with, hypothetically, more stable positions. However, this hypothesis also requires further study.

Moreover, the absence of a control or sham group might also be considered a study limitation. To minimise this limitation, we used a control period, at least in part of the sample, during which no intervention was used

to evaluate the natural variance expected without intervention. Considering that during the control period the participants engaged in a systematic routine of ballet classes according the Bolshoi Theatre School, we decided to assume the observed effect on knee alignment was produced by the intervention protocol, rather than being due to mere coincidence.

As a practical application, the results of the present study demonstrate that when the main goal of the treatment is to promote knee alignment, a preventive intervention based on Motor Coordination principles seems to be effective. It is important to note that moderate knee alignment improvement was found during several phases of the *En dehors* (feet in self-selected and 180-degree position). Finally, our findings point to an improved knee alignment who does persist beyond supervised sessions, what can be considered an advantage of this approach because dancers can incorporate without difficulties the “life lessons” and the home-based exercises into their ballet classes routine [30].

## Conclusion

The intervention was effective to promote knee center alignment, which persisted after 24 weeks, beyond supervised sessions. No effects in the pelvic position or in the foot arch were observed.

## Financial Disclosure or Sources of Support

Not applicable.

## Authors' Contributions

This manuscript was written with equal authors' contributions.

## References

- Ekegren CL, Quested R, Brodrick A (2014) Injuries in pre-professional ballet dancers: Incidence, characteristics and consequences. *J Sci Med Sport* 17: 271-275.
- Hincapié CA, Morton EJ, Cassidy JD (2008) Musculoskeletal injuries and pain in dancers: A systematic review. *Arch Phys Med Rehabil* 89: 1819-1829.
- Yau RK, Golightly YM, Richardson DB, Runfola CD, Waller AE, et al. (2017) Potential predictors of injury among pre-professional ballet and contemporary dancers. *J Dance Med Sci* 21: 53-63.
- Shah S, Weiss DS, Burchette RJ (2012) Injuries in professional modern dancers: Incidence, risk factors, and management. *J Dance Med Sci* 16: 17-25.
- Leanderson C, Leanderson J, Wykman A, Strender LE, Johansson SE, et al. (2011) Musculoskeletal injuries in young ballet dancers. *Knee Surg Sports Traumatol Arthrosc* 19: 1531-1535.
- Caine D, Bergeron G, Goodwin BJ, Thomas J, Caine CG, et al. (2016) A survey of injuries affecting pre-professional ballet dancers. *J Dance Med Sci* 20: 115-126.
- Bowerman E, Whatman C, Harris N, Bradshaw E, Karin J (2014) Are maturation, growth and lower extremity alignment associated with overuse injury in elite adolescent ballet dancers? *Phys Ther Sport* 15: 234-241.
- Barnes MA, Krasnow D, Tupling SJ, Thomas M (2000) Knee rotation in classical dancers during the grand plié. *Medical Problems of Performing Artists* 15: 140-147.
- Hamilton D, Aronsen P, Loken JH, Berg IM, Skotheim R, et al. (2006) Dance training intensity at 11-14 years is associated with femoral torsion in classical ballet dancers. *Br J Sports Med* 40: 299-303.
- Louw Q, Grimmer K (2006) Biomechanical factors associated with the risk of knee injury when landing from a jump. *South African Journal of Sports Medicine* 18: 18-23.
- Coplan JA (2002) Ballet dancer's turnout and its relationship to self-reported injury. *J Orthop Sports Phys Ther* 32: 579-584.
- Kushner S, Saboe L, Reid D, Penrose T, Grace M (1990) Relationship of turnout to hip abduction in professional ballet dancers. *Am J Sports Med* 18: 286-291.
- Milan KR (1994) Injury in ballet: A review of relevant topics for the physical therapist. *J Orthop Sports Phys Ther* 19: 121-129.
- Solomon R, Solomon J, Minton SC (2005) Preventing dance injuries. (2<sup>nd</sup> edn), Human Kinetics, Champaign, USA.
- Sohl P, Bowling A (1990) Injuries to dancers. Prevalence, treatment, and prevention. *Sports Med* 9: 317-322.
- Piret S, Beziers MM (1971) La Coordination motrice: aspect mécanique de l'organisation psycho-motrice de l'homme, par S. Piret et MM Béziers. Masson et Cie.
- Gontijo KNS, Candotti CT, de Brito CIB, Vieira A (2018) The Motor Coordination reasoning in acting dancer's performance improvement and injury prevention. *Journal of Physical Fitness, Medicine & Treatment in Sports* 2: 1-9.
- Rosario JL (2017) Understanding muscular chains - a review for clinical application of chain stretching exercises aimed to correct posture.
- Gontijo KNS, Candotti CT, dos Santos Feijó G, Ribeiro LP, Loss JF (2017) Dynamic evaluation method of lower limbs joint alignment (MADAAMI) for dancers during the plié. *Rev Bras Ciênc Esporte* 39: 148-159.
- Gontijo KNS, Candotti CT, Dos Santos Feijó G, Ribeiro LP, Loss JF (2015) Kinematic evaluation of the classical ballet step “plié”. *J Dance Med Sci* 19: 70-76.
- Gontijo KNS, Candotti CT, do Amaral MA, Dos Santos GC, Williams V, et al. (2018) A new version of the MADAAMI method for assessing lower limb alignment during demi-plié, grand plié, and fondu. *J Dance Med Sci* 22: 123-131.
- Field A (2009) *Discovering statistics using SPSS*. (3<sup>rd</sup> edn), Sage Publications Ltd., London.
- Cohen J (1992) A power primer. *Psychol Bull* 112: 155-159.
- Sharma L, Pai YC, Holtkamp K, Rymer WZ (1997) Is knee joint proprioception worse in the arthritic knee versus the unaffected knee in unilateral knee osteoarthritis? *Arthritis Rheum* 40: 1518-1525.
- Chang AH, Lee SJ, Zhao H, Ren Y, Zhang LQ (2014) Impaired varus-valgus proprioception and neuromuscular stabilization in medial knee osteoarthritis. *J Biomech* 47: 360-366.
- Dieling S, van der Esch M, Janssen TWJ (2014) The effect of muscle fatigue on knee joint proprioception in ballet dancers and non-dancers. *Journal of Dance Medicine & Science* 18: 143-148.

27. Mascal CL, Landel R, Powers C (2003) Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. *J Orthop Sports Phys Ther* 33: 647-660.
28. Ferber R, Kendall KD, Farr L (2011) Changes in knee biomechanics after a hip-abduction strengthening protocol for runners with patellofemoral pain syndrome *J Athl Train* 46: 142-149.
29. dos Reis AC, Correa JCF, Bley AS, dos Anjos Rabelo ND, Fukuda TY, et al. (2015) Kinematic and kinetic analysis of the single-leg triple hop test in women with and without patellofemoral pain. *J Orthop Sports Phys Ther* 45: 799-807.
30. Yazbek PM, Ovanessian V, Martin RL, Fukuda TY (2011) Nonsurgical treatment of acetabular labrum tears: A case series. *J Orthop Sports Phys Ther* 41: 346-353.