Revista Brasileira de Ciências do Esporte
ISSN: 0101-3289
rbceonline@gmail.com
Colégio Brasileiro de Ciências do Esporte
Brasil

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Revista Brasileira de Ciências do Esporte, vol. 39, núm. 2, abril-junio, 2017, pp. 148-159
Colégio Brasileiro de Ciências do Esporte
Curitiba, Brasil

Revista Brasileira de
CIÊNCIAS DO ESPORTE
www.rbceonline.org.br

ORIGINAL ARTICLE

Dynamic evaluation method of lower limbs joint alignment (MADAAMI) for dancers during the *plié*

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Received 13 May 2013; accepted 13 January 2014
Available online 5 March 2016

KEYWORDS
Validation;
Evaluation;
Dance;
Physiotherapy

Abstract In classical *ballet*, the joint misalignments during the *plié* can generate various injuries. To evaluate potential misalignments during the *plié* the aim of this study was to present a method for dynamic evaluation of lower limb alignment articulation (called MADAAMI). MADAAMI was validated by 12 experts, and for the evaluation of its reproducibility and for agreement with 3D kinematics, 20 dancers were assessed using a video recording of their *plié*. For statistical analysis we used the Kappa coefficient (k) ($p < 0.05$) and percentage agreement (C). We conclude that MADAAMI had satisfactory reproducibility and intra-rater agreement with 3D kinematics ($k > 0.40$ and $C > 80\%$), and it is a suitable and valid method for use by the same examiner.

PALAVRAS-CHAVE
Validação;
Avaliação;
Dança;
Fisioterapia

Método de avaliação dinâmica do alinhamento articular dos membros inferiores (MADAAMI) de bailarinos durante o *plié*

Resumo No *ballet* clássico, os desalinhamentos articulares durante o passo *plié* podem gerar várias lesões. Para avaliar esses possíveis desalinhamentos durante a sua execução, o objetivo deste estudo foi apresentar um Método de Avaliação Dinâmica do Alinhamento Articular dos Membros Inferiores (chamado MADAAMI). O MADAAMI foi validado por 12 especialistas e, para

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http://dx.doi.org/10.1016/j.rbce.2016.02.016

a avaliação da sua reprodutibilidade e da sua concordância com a análise cinemática 3D, 20 dançarinos foram avaliados através de uma gravação de vídeo em que executavam o plié. Para a análise estatística foi usado o coeficiente Kappa (k) (p<0,05) e o percentual de concordância (C). Concluímos que o MADAAMI teve reprodutibilidade intra-avaliador e concordância com a análise cinemática 3D satisfatórias (k>0,40 e C>80%) e se caracterizou como um método adequado e válido para uso por um único examinador.

PALABRAS CLAVE
Validación;
Evaluación;
Danza;
Fisioterapia

Método de evaluación dinámica del alineamiento articular de las extremidades inferiores (MADAAMI) de bailarines durante el *plié*

Resumen En *ballet* clásico, los desajustes articulares durante el *plié* pueden generar diversas lesiones. Para evaluar esos posibles desajustes durante el *plié*, el objetivo de este trabajo fue presentar un método para la evaluación dinámica de la alineación de las extremidades inferiores (conocido como MADAAMI). MADAAMI fue validado por 12 expertos y para la evaluación de su reproducibilidad y de su concordancia con la cinemática en 3D se evaluó a 20 bailarines mediante grabaciones de vídeo durante el *plié*. Para el análisis estadístico se utilizó el coeficiente de kappa (k) (p <0,05) y el acuerdo de porcentaje (C). Se concluyó que MADAAMI cuenta con reproducibilidad intraevaluador, que la concordancia con la cinemática en 3D fue satisfactoria (k > 0,40 y C > 80%), y que es un método adecuado y válido para su uso por el mismo examinador.

Introduction

This study was conducted to evaluate changes in movement patterns, which is a recurrent concern of professionals and researchers in the field of Physical Education and Sport (Gomes et al., 2009). In recent years, checking lists (CL) has been introduced as an alternative, practical and scientific method, to measure change in motor performance over time (Gomes et al., 2009; Meira, 2003). With the use of these lists sports coaches and physical education teachers, can for example, deduce if a pattern of movement in a particular sport is evolving or not, because they allow for the comparison of motor performance at different times (Gomes et al., 2009). Such lists also assist in maintaining or changing the method of ''teaching–learning–training'' (Collet et al., 2011).

In the literature there are references to the use of traditional CL in sports, such as judo (Gomes et al., 2009) and volleyball (Meira, 2003; Collet et al., 2011). Nevertheless, in dance, more specifically, in classical *ballet*, there are no studies that link CL as a method to evaluate the technical performance of dancers. In addition, there are no studies that show any validated tool that enables the quantification of quality of execution of basic *ballet* moves during lessons. Thus, it is speculated that the method of CL can also be used in the environment of classical dance, helping dance teachers and other health professionals such as physiotherapists, clinicians and fitness trainers and others who deal directly with this audience, identify possible incorrect movements performed during basic technical moves worked in *ballet* classes. Furthermore, this methodology applied to the training of classical dance, would enable the detection of levels of proficiency, the inference in the evolution of a proficiency level to another and the prescription of the most appropriate action for each level of proficiency of classical *ballet*.

Whereas the *plié*[1] – one of the most important moves of the methodology of classical dance, inherent in all dance movements – from the simplest to the most complex (Vaganova, 1945) – when executed correctly and repeated numerous times during a class or choreography, can lead to problems with the spine, knees, feet and ankles (Gantz, 1989), and also considering the lack of research to assist technically the process of teaching–learning–training in classical *ballet*, this study aimed to: (1) present the dynamic evaluation method of lower limbs joint alignment (MADAAMI, from Portuguese: Método de Avaliação Dinâmica do Alinhamento Articular dos Membros Inferiores) for dancers during the *plié*, (2) perform content validation of the proposed instrument, (3) verify reproducibility inter and intra-rater and (4) identify the correlation between the results of MADAAMI (qualitative method) with those obtained by kinematic evaluation (quantitative method) during the *plié*. Hence, the MADAAMI constitutes as a multidisciplinary instrument because, apart from use by teachers and professionals who follow the evolution of the dancers, it may also

[1] The execution of the *plié* requires simultaneous flexion of joints: hips, knees and ankles, associated with *en dehors* (outward rotation of hip joints), maintaining the vertical alignment between the knee joint with the second toe ipsilateral, pelvic stabilization neutral position and support of the midfoot during all three phases of the move: knees straight, *demi plié* and *grand plié* (Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996; Vaganova, 1945; Achcar, 1998).

Figure 1 Image from the video camera used in MADAAMI illustrating a dancer performing the *plié* during data acquisition.

be used by physiotherapists and clinicians as an evaluation tool to monitor the rehabilitation process of musculoskeletal injuries caused by misalignment joint (Hincapié et al., 2008; Barnes et al., 2000; Kadel, 2006; Nilsson et al., 2001).

Materials and methods

Description of MADAAMI

The dynamic evaluation method of lower limbs joint alignment (MADAAMI) consists of a filming (Fig. 1) of the lower limbs during the *plié* and a score sheet (Appendix 1). The filming was done with a video camera placed 1.75 m from the line against the heel of each dancer, and on a tripod to 47 cm from the floor. This position aligned with the second toe of the right foot at the starting position of the sequence of movements (first position of the feet from classical *ballet* technique). A metal tape-measure was placed on the floor at this finger, aligning it with the center of the tripod, which helped with the centralization of the camera (Fig. 1). The aim of the score sheet is to evaluate four technical criteria that guide the execution of the *plié* (Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996): (1) maintaining pelvic stability, (2) neutral position of the pelvis along the move, (3) maintenance of external rotation of the hip joints (*en dehors*), assessed by alignment of the knee joint with ipsilateral second toe, and (4) maintaining the support of the longitudinal arch of the foot during the move.

Thus, to evaluate these four technical criteria, the score sheet shows the scoring *plié* didactically divided into three phases (with knees extended; during *demi plié*[2]; and during the *grand plié*[3]), which were further subdivided into four stages of motion: static, during the descent; end of the movement, and during the ascent (Fig. 2). The execution of the *plié* used in the assessment protocol consists of MADAAMI dancer performing was: two *demi pliés* and two *grand pliés* with the feet in first and second position.[4] For this implementation, only the left leg is moved to change a standing classical position of the foot, thus keeping the right foot fixed to the ground.

The ratings and their scores initially provided by MAADAMI are ''excellent'', equivalent to 4 points; ''good'', equivalent to 3 points; ''regular'', equivalent to 2 points; ''insufficient'', equivalent to 1 point; pelvis positioning ''retroverted'' or ''anteverted'', equivalent to 1 point each, and lastly, in positioning the pelvis ''neutral'', corresponding to 4 points.

Content validation

Twelve professional experts in dance and kinesiology, who has experience in teaching and learning classical *ballet* for at least 10 years, were asked to evaluate the content of MADAAMI. These evaluators received for their consideration, a video demonstration of a dancer performing a sequence of the *plié*, the score sheet and a glossary supplement containing the instructions for use of MADAAMI. Was asked the evaluators to: (1) fill out the MADAAMI score sheet from their observation of the video, and (2) answer a questionnaire that consisted of seven questions, each having as objective response options: ''very suitable'', ''suitable'' or ''unsuitable''. The questions were related to the ease of visualization of the stability and alignment of the dancer in the video, as well as on the understanding of the score sheet and glossary supplement. Beyond these questions, the evaluators were able to add suggestions and propose modifications to the instrument in a descriptive way.

Based on the answers, suggestions and modifications of the 12 evaluators, changes were made in both the MADAAMI score sheet, as well as in the glossary supplement. To complete the process of content validation, the evaluators were asked to rate the new score sheet and the new glossary, from the observation of the same video. Therefore, the evaluators had to complete a second questionnaire, with response options: ''very suitable'', ''suitable'' and ''unsuitable'', about the changes made.

Inter and intra-rater reproducibility

Twenty dancers from three *ballet* schools in Porto Alegre-RS-Brazil were selected intentionally. Inclusion criteria were: female, practice *ballet* regularly with a frequency of at least twice a week during the data acquisition period, have at least 5 years of uninterrupted practice of classical *ballet*

[2] *Demi plié* (''semi flexion'') is a flexion of the knees without lifting the heels off the ground to, approximately, half of the total range of knee flexion (Vaganova, 1945; Howse and Hancock, 1992; Fitt, 1996).

[3] *Grand plié* (''large flexions'') is a maximum flexion of knees accompanied by heel rising off the ground to its maximum range of flexion in all positions of the feet, except in the second position (Vaganova, 1945; Howse and Hancock, 1992; Fitt, 1996).

[4] Both the first and the second positions of the feet is characterized by the search of alignment of the medial edges of both feet forming a maximum angle of 180° between them and with the only difference between both the distance between the heels – the first one, both are lean and in the second, they keep a distance equivalent to approximately the size of the dancer foot (Achcar, 1998; Vaganova, 1945; Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996).

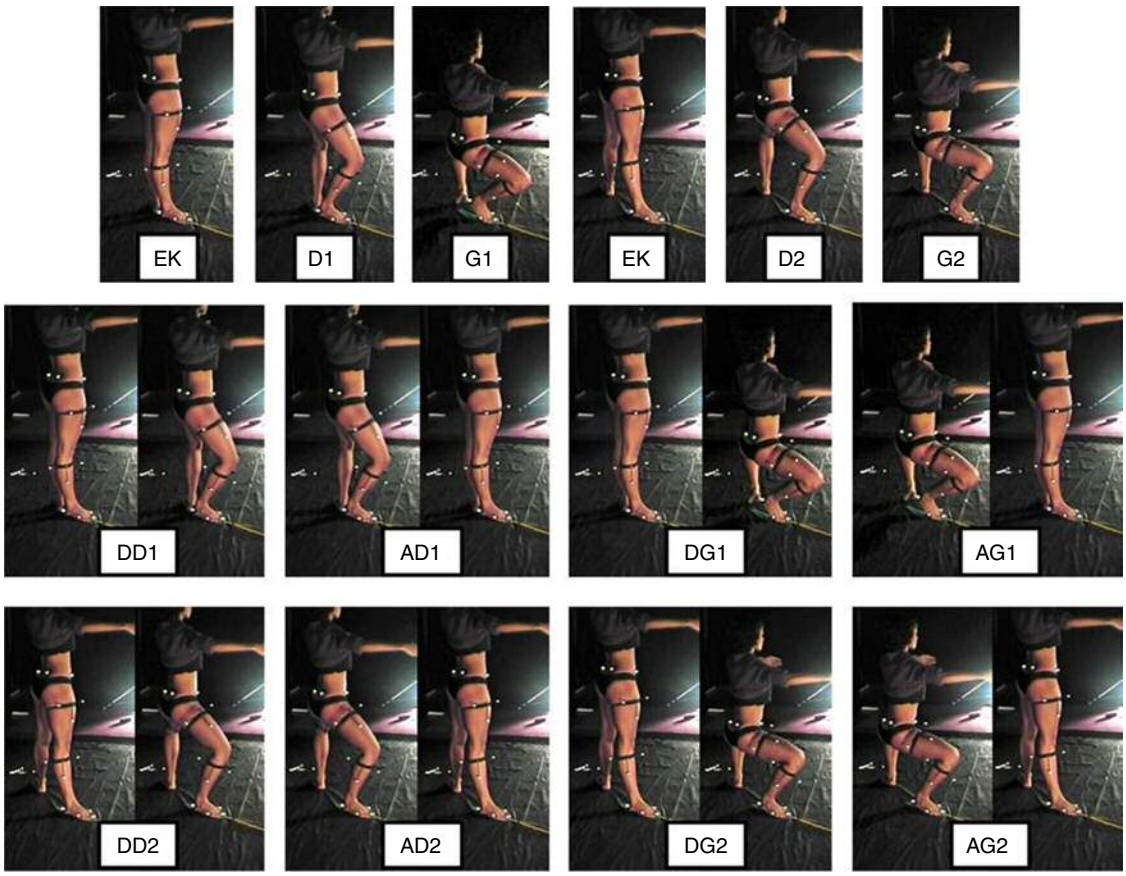

Figure 2 Sequence of the step plié didactically divided into three phases: with knees extended (EK); during demi plié (D1 and D2); and during the grand plié (G1 and G2); and the four stages of motion: static (both EK); during the descent (DD1, DD2, DG1 and DG2); end of the movement (D1, G1, D2 and G2); and during the ascent (AD1, AD2, AG1 and AG2).

and not showing any kind of injury during collection. The Ethics Committee of the Federal University of Rio Grande do Sul (UFRGS) approved this study (number 46019).

At this stage, three researchers (called Res1, Res2 and Res3), which were physiotherapists and practitioners of classical *ballet* for over 10 years without interruption, were invited to analyze the collected 20 videos. The three researchers individually evaluated the videos on one day, without any contact between them and their responses were compared to each other to verify inter-rater reproducibility of MADAAMI. Seven days later, they reassessed all videos for verification, then the intra-rater reproducibility of the instrument, allowed for comparison of their responses before and after this period (Thomas and Nelson, 2002).

Concordance between MADAAMI and 3D kinematic evaluation

For the reliability analysis, the same 20 dancers were also subjected to a 3D kinematic evaluation, consisting of a system with four digital video cameras (JVC GR-DVL 9800) with a sampling frequency of 50 Hz (50 frames per second). Each camera was connected to a microcomputer, and connected to each other through a wireless network (Araújo, 2002). Furthermore, these four cameras simultaneously recording and synchronized with the camera, which was used by MAADAMI (Sony DSC H50), allowing the subsequent comparison of the results of both evaluation methods.

Specific anatomic points on the body of the dancers were identified by 22 reflective ball shaped markers (15–20 mm in diameter), attached with double-sided tape. The protocol for the placement of reflective markers, adapted from Wu et al. (2005), was conducted by a team of four experienced and trained evaluators. The anatomical points of interest were chosen in order to evaluate only the right lower limb (Fig. 1), and among them the right femoral trochanter, the right posterior superior iliac spines and right anterior superior (PSIS and ASIS), the left anterior superior iliac spine, the pubic symphysis, the right anterior tibial tuberosity, the rights femoral condyles (medial and lateral), the second toe of the right foot, the right navicular bone, the medial region of the 1st metatarsophalangeal joint and calcaneus bone at right, the human rights malleolus (medial and lateral) and the lateral region of the 5th metatarsophalangeal joint and calcaneus bone at right. Two technical markers (one for the thigh and one for the tibia) were used in order to ensure the kinematic tracking points during movement, moved beneath the skin, such as the femoral condyles.

The software Dvideow – Digital Video for Biomechanics for Windows 32-bit (Figueroa et al., 2003) was used for scanning and reconstruction of 3D cinematic footage of dancers performing the *plié*. The data position obtained by the spatial reconstruction have been used in programming routines

developed using MATLAB®, which provide stability values of the middle foot stability and pelvic positioning and alignment of the ipsilateral knee and foot in accordance with the following technical criteria guide the implementation of the *plié*:

Criterion 1 – ''Midfoot stability'': we analyzed the variation of the height of the marker positioned on the right navicular bone to the ground. To sort the stabilization of the midfoot used the following parameters: (1) ''optimal stabilization'' – decrease in height of the navicular bone, a part of moving to another, less than 0.7 cm, (2) ''stable'' – down 0.7–1.3 cm, and (3) ''unstable'' – fall more than 1.3 cm (Sabino et al., 2012).
Criteria 2 and 3 – ''Positioning and pelvic stability'': from the line drawn by joining PSIS and ASIS, we analyzed the angle and angular variation of this line to the horizontal. To sort the positioning of the pelvis (criterion 2) we used the following parameters: (1) ''neutral'' – pelvic angles between 12° and 15°, (2) ''retroversion'' – pelvic angles below 12°, (3) ''anteversion'' – pelvic angles greater than 15°. To ensure pelvic stability (criterion 3) we used the following parameters: (1) ''pelvic instable'' – angular variation exceeding 3° from one part of the movement to the next part, and (2) ''pelvis stable'' – variation angle of at most 3° from one part of the movement to another (Achcar, 1998; Vaganova, 1945; Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996; Kapandji, 2000; Tribastone, 2001).
Criterion 4 – ''Alignment between knee and ipsilateral foot'': (i) we drew a straight line connecting the marker placed on the second toe of the right foot with the center point equidistant from the markers placed on the medial and lateral regions of the right calcaneus (representing the straight line of reference in this foot); (ii) was calculated by the center point of the knee by obtaining the location of the markers placed equidistant from the medial and lateral femoral condyles (representing the knee center); and (iii) was performed the projection of the knee center on the ground so that, from this projection, throughout the execution of the move we calculated the distance between this point and the projected reference straight leg (assuming that when the distance is equal to zero, we have a perfect alignment between both). To sort the alignment between knee and foot ipsilateral we considered the following parameters: (1) knee ''aligned'' – metric variation from −1 to 1 cm distance between the projection of the center of the knee on the ground and the reference line of the ipsilateral foot; (2) ''medial misalignment'' – metric variation less than −1 cm; and (3) ''lateral misalignment'' – metric variation exceeding 1 cm (Achcar, 1998; Vaganova, 1945; Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996).
The results derived from quantitative analysis (3D kinematic) were compared with the results obtained in the qualitative analysis (MADAAMI) from a single researcher drawn between the three participating ones in the previous step.

Statistical treatment

Data were analyzed using software SPSS 18.0, adopting the statistical significance level of $p < 0.05$. For the content analysis, objective responses (''very suitable'', ''suitable'' and ''unsuitable'') from the 12 invited evaluators were coded and subjected to descriptive statistics, through the frequency table. To evaluate the MADAAMI inter and intra-rater reproducibility and to evaluate the concordance of MADAAMI with kinematic evaluation ratings MADAAMI score sheet (''excellent'', ''good'', ''regular'' or ''insufficient'') were grouped into only two distinct groups: (1) ''correct'', corresponding to the classification ''excellent'', and (2) ''incorrect'', corresponding to the three other classifications. Similarly, the four criteria used in quantitative analysis were grouped into two distinct groups: (1) ''correct'', corresponding only to the best classification, and (2) ''incorrect'', corresponding to the other classifications. Thus, to evaluate the reliability of the MADAAMI with 3D kinematic evaluation, we used the percentage of agreement (*C*) and the extent of Cohen's Kappa (*k*). Kappa values were classified as ''weak'' ($k \leq 0.2$), ''reasonable'' (*k* 0.21–0.4), ''moderate'' (*k* 0.41–0.6), ''substantial'' (*k* 0.61–0.8) and ''almost perfect'' ($k \geq 0.81$) (Sim and Wright, 2005). In the present study all Kappa values greater than 0.4 were classified as ''satisfactory''.

The final MADAAMI followed the classification criteria adapted from Grant and Davis (1997), Rubio et al. (2003) and Noll (2012): (1) ''Accepted'' Criteria, if all values of Kappa for inter and intra-rater reproducibility and the correlation between MADAAMI ratings and 3D kinematic evaluation are greater than 0.4, and all percentages of agreement are greater than 80%, (2) ''Accepted with Exceptions'' Criteria (under the same conditions described, it can only be used by the same examiner), and (3) ''Rejected'' Criteria for the other values that do not fit in the two previous classifications.

Results

The content validation, performed by 12 evaluators, initially presented results that indicated the need of improvements in the instrument (Fig. 3 – 1st questionnaire), which, after implementation, presented all the responses classified as ''very suitable'' (Fig. 3 – 2nd questionnaire). Given the favorable outcome of the applicability and relevance of the evaluative components, the MADAAMI submitted content validity.

Twenty dancers with age of 26.6 ± 8.3 years, 18.2 ± 7.7 years who practice *ballet* with a weekly frequency of 3.7 ± 1.7 classes were evaluated to reproducibility tests. In general, the intra-rater reproducibility results showed that the higher inter-rater for both the values of *C* and *k* (Tables 1–3). Of all the MADAAMI criteria, only the ''knee aligned'' in the first and second position of feet in all stages of motion and the ''midfoot stable'' only in the first position of feet in move ''static phase with knees extended'' before the *demi plié*, were rated as ''Accepted'', can be used independently of the assessor. All other MADAAMI criteria, including the previous two were ''Accepted with Exceptions'' after checking of the greats and satisfactory results of intra-rater reproducibility, demonstrating that the instrument is valid to be used by the same evaluator.

The results concerning the validation of agreement criterion 1 (''Midfoot stability'') demonstrate that MADAAMI was

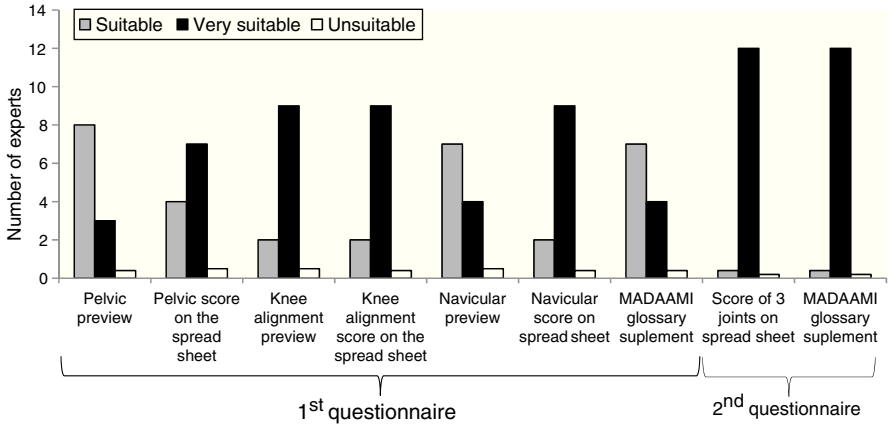

Figure 3 Frequency of the answer from the 12 evaluators, referring to both the 1st as the 2nd questionnaire for validation of content MAADAMI. Caption: 1st questionnaire: contains seven questions about the easy visualization of technical criteria in the video and about the understanding of the score sheet and the MADAAMI glossary. 2nd Questionnaire: contains two final questions that assess whether the modifications suggested by evaluators for the score sheet and glossary are appropriate.

rated as ''Accepted Instrument with Exceptions'' to evaluate the stabilization of the midfoot during all steps of the *plié* (Table 4).

The results concerning the validation of agreement of criterion 2 (''Pelvic positioning'') demonstrate that MADAAMI was classified as ''Rejected Instrument'' to review this technical criterion, called the score sheet as ''Description of pelvis position'' in all parts of the move, both before and after the ''descent'' and ''ascent'' and in the end of *demi pliés* and *grand plies* (Table 5).

Regarding the validation of agreement of the criterion 3 (''Pelvic stability''), the results show that the MADAAMI was rated as ''Accepted Instrument with Exceptions'' to evaluate dynamically pelvic stability at all phase sin which there is movement the lower limbs, or in steps ''descent'' and ''ascent'' of the *plié* (Table 6).

The results concerning the validation of agreement of the criterion 4 (''Alignment between knee and foot ipsilateral'') presented in Table 7, show that MADAAMI was classified as ''Accept instrument'' to assess this alignment in all phases

Table 1 Values of Kappa coefficient (k) and concordance (C) for intra-rater reproducibility (average of results from the three researchers: Res1 × Res1; Res2 × Res2; Res3 × Res3), and inter-rater reproducibility (average of the results of each two researchers: Res1 × Res2; Res1 × Res3; Res2 × Res3) of the evaluative MADAAMI criteria regarding alignment and pelvic stability.

Variables			Intra-rater reproducibility		Inter-rater reproducibility	
Evaluation criteria	Phases of the move	Movement Step	Average (k)	Average (C)	Average (k)	Average (C)
1st feet position						
Aligned pelvis	With knees extended	Static	0.75	88%	0.29	63%
Stable pelvis		Descent	0.57	82%	0.23	60%
Aligned pelvis	During *demi plié*	End of the move	0.65	86%	0.45	73%
Stable pelvis		Ascent	0.66	85%	0.11	53%
Aligned pelvis	With knees extended	Static	0.67	85%	0.36	67%
Stable pelvis		Descent	0.61	83%	0.27	63%
Aligned pelvis	During *grand plié*	End of the move	0.92	97%	0.17	57%
Stable pelvis		Ascent	0.57	82%	0.27	63%
Aligned pelvis	With knees extended	Static	0.79	90%	0.36	67%
2nd feet position						
Aligned pelvis	With knees extended	Static	0.82	92%	0.37	68%
Stable pelvis		Descent	0.63	85%	0.33	65%
Aligned pelvis	During *demi plié*	End of the move	0.71	88%	0.33	70%
Stable pelvis		Ascent	0.73	90%	0.19	55%
Aligned pelvis	With knees extended	Static	0.83	92%	0.41	70%
Stable pelvis		Descent	0.96	98%	0.04	57%
Aligned pelvis	During *grand plié*	End of the move	0.92	97%	0.16	60%
Stable pelvis		Ascent	0.96	98%	0.09	57%
Aligned pelvis	With knees extended	Static	0.75	88%	0.27	63%

All Kappa values were significant ($p < 0.05$).

Table 2 Values of Kappa coefficient (*k*) and concordance (*C*) for intra-rater reproducibility (average of results from the three researchers: Res1 × Res1; Res2 × Res2; Res3 × Res3), and inter-rater reproducibility (average of the results of each two researchers: Res1 × Res2; Res1 × Res3; Res2 × Res3) of the evaluative MADAAMI criteria regarding alignment between knee and foot to midfoot stability.

Variables			Intra-rater reproducibility		Inter-rater reproducibility	
Evaluation criteria	Phases of the move	Movement Step	Average (*k*)	Average (*C*)	Average (*k*)	Average (*C*)
Knee aligned with foot (1st feet position)	With knees extended	Static	1.00	100%	1.00	100%
		Descent	1.00	100%	1.00	100%
	During *demi plié*	End of the move	1.00	100%	0.48	90%
		Ascent	1.00	100%	1.00	100%
	With knees extended	Static	1.00	100%	1.00	100%
		Descent	1.00	100%	0.82	97%
	During *grand plié*	End of the move	0.80	95%	0.49	81%
		Ascent	1.00	100%	1.00	100%
	With knees extended	Static	1.00	100%	0.76	97%
Knee aligned with foot (2nd feet position)	With knees extended	Static	1.00	100%	1.00	100%
		Descent	1.00	100%	0.58	93%
	During *demi plié*	End of the move	0.89	97%	0.65	87%
		Ascent	1.00	100%	0.76	97%
	With knees extended	Static	1.00	100%	1.00	100%
		Descent	1.00	100%	0.58	93%
	During *grand plié*	End of the move	0.50	81%	0.46	83%
		Ascent	1.00	100%	0.58	93%
	With knees extended	Static	1.00	100%	1.00	100%
Stable midfoot (1st feet position)	With knees extended	Static	1.00	100%	0.88	98%
		Descent	0.59	85%	0.21	57%
	During *demi plié*	End of the move	0.61	85%	0.14	53%
		Ascent	0.49	83%	0.21	60%
	With knees extended	Static	0.52	88%	0.07	73%
		Descent	0.78	90%	0.30	63%
	During *grand plié*	End of the move	0.76	90%	0.19	57%
		Ascent	0.47	80%	0.33	63%
	With knees extended	Static	0.88	98%	0.02	77%
Stable midfoot (2nd feet position)	With knees extended	Static	1.00	100%	0.34	83%
		Descent	0.68	90%	0.10	55%
	During *demi plié*	End of the move	0.66	90%	0.08	63%
		Ascent	0.61	87%	0.27	67%
	With knees extended	Static	0.75	95%	0.05	83%
		Descent	0.86	95%	0.17	57%
	During *grand plié*	End of the move	0.79	92%	0.39	70%
		Ascent	0.90	97%	0.24	60%
	With knees extended	Static	0.77	95%	0.37	87%

All Kappa values were significant ($p < 0.05$).

of the *plié*, except the static steps of the move in which the knees were extended and now taking into account the results obtained satisfactory reproducibility for both intra and inter-rater.

Given these results, the score sheet initially proposed (Appendix 1) to validate the MAADAMI needed to be reformulated in order to display only the variables that had concordance between the two methods of assessment and verification of satisfactory results in there reproducibility of their technical criteria. Thus, in Fig. 4, we present the final version of the MAADAMI score sheet indicated to be used by the same examiner in the clinical, artistic or scientific way.

Discussion

The aim of this study was to present the results of all the validation processes associated with the dynamic evaluation method of lower limbs joint alignment (MADAAMI) of dancers during the execution of the *plié*. We showed that the instrument is valid to evaluate all technical criteria that guide the successful execution of the *plié*, except for criterion 3, ''Pelvic positioning''.

Nevertheless, considering the absence in the literature of other instruments with characteristics similar to that of MADAAMI and considering also the technical

Table 3 Values of Kappa coefficient (k) and concordance (C) for intra-rater reproducibility (average of results from the three researchers: Res1 × Res1; Res2 × Res2; Res3 × Res3), and inter-rater reproducibility (average of the results of each two researchers: Res1 × Res2; Res1 × Res3; Res2 × Res3) of the evaluative MADAAMI criteria regarding ''Description of Pelvis Position''.

Variables			Intra-rater reproducibility		Inter-rater reproducibility	
Evaluation criteria	Phases of the move	Movement Step	Average (k)	Average (C)	Average (k)	Average (C)
Description of pelvis position (1st feet position)	With knees extended	Static	0.78	90%	0.35	67%
		Descent	0.67	87%	0.34	68%
	During *demi plié*	End of the move	0.66	85%	0.38	70%
		Ascent	0.70	88%	0.25	65%
	With knees extended	Static	0.74	88%	0.36	67%
		Descent	0.67	88%	0.32	68%
	During *grand plié*	End of the move	0.64	83%	0.20	60%
		Ascent	0.67	88%	0.31	68%
	With knees extended	Static	0.82	92%	0.45	72%
Description of pelvis position (2nd feet position)	With knees extended	Static	0.78	90%	0.28	63%
		Descent	0.84	93%	0.25	63%
	During *demi plié*	End of the move	0.66	87%	0.33	70%
		Ascent	0.62	87%	0.24	67%
	With knees extended	Static	0.83	92%	0.41	70%
		Descent	0.96	98%	0.33	70%
	During *grand plié*	End of the move	0.96	98%	0.16	60%
		Ascent	0.96	98%	0.43	73%
	With knees extended	Static	0.79	90%	0.28	63%

All Kappa values were significant ($p < 0.05$).

importance of the *plié* in classical dance (Vaganova, 1945; Gantz, 1989; Howse and Hancock, 1992), it is clearly a necessary tool that would also serve as the basis for the development of other studies that can expand on alternatives assessment for this move. According to the literature, the *plié*, if repeated incorrectly countless times, can result in several injuries of the lower limbs (Gantz, 1989; Bordier, 1975; Guimarães and Simas, 2001), and this justifies the aim of this study, which was to develop a tool capable of evaluating the *plié* methodologically. The MADAAMI is characterized as an instrument that can directly assist both dance teachers, in the development of their teaching–learning–training in *ballet* classrooms, as well as other professionals involved in the well-being of dancers, including physiotherapists, physical educators and physicians. We understand the MADAAMI as an important

Table 4 Results regarding to the validation agreement of the criterion 1 (''Midfoot stability'') showing the percentage of agreement (C), the values of the Kappa coefficient (k) and its significance level (p) for all steps of the *plié* ($n = 20$).

Evaluation criteria	Phases of the move	Movement step	Validation of agreement		
			k	p	C
Midfoot stability (1st feet position)	With knees extended	Static	0.64	0.002	95%
		Descent	0.45	0.015	90%
	During *demi plié*	End of the move	0.14	0.209	65%
		Ascent	0.31	0.144	85%
	With knees extended	Static	0.64	0.002	95%
	With knees extended	Static	0.45	0.015	90%
Midfoot stability (2nd feet position)	With knees extended	Static	1.00	0.001	90%
		Descent	0.64	0.002	95%
	During *demi plié*	End of the move	0.45	0.015	90%
		Ascent	0.64	0.002	95%
	With knees extended	Static	0.64	0.002	95%
		Descent	0.44	0.047	90%
	During *grand plié*	End of the move	0.64	0.002	95%
		Ascent	0.46	0.002	90%
	With knees extended	Static	0.45	0.015	90%

Table 5 Results regarding to the validation agreement of the criterion 2 (''Pelvic positioning''), showing the percentage of agreement (*C*), the values of the Kappa coefficient (*k*) and its significance level (*p*) for all steps of the *plié* (*n* = 18).

Evaluation criteria	Phases of the move	Movement step	Validation of agreement		
			k	*p*	*C*
Description of pelvis position (1st feet position)	With knees extended	Static	0.22	0.949	61%
	During *demi plié*	End of the move	0.50	0.019	78%
	With knees extended	Static	0.22	0.343	61%
	During *grand plié*	End of the move	0.30	0.060	72%
	With knees extended	Static	0.34	0.138	67%
Description of pelvis position (2nd feet position)	With knees extended	Static	0.24	0.280	61%
	During *demi plié*	End of the move	0.04	0.822	61%
	With knees extended	Static	0.34	0.138	67%
	During *grand plié*	End of the move	0.15	0.436	67%
	With knees extended	Static	0.34	0.138	67%

Table 6 Results regarding to the validation agreement of the criterion 3 (''Pelvic stability''), showing the percentage of agreement (*C*), the values of the Kappa coefficient (*k*) and its significance level (*p*) for all steps of the *plié* (*n* = 18).

Evaluation criteria	Phases of the move	Movement step	Validation of agreement		
			k	*p*	*C*
Pelvic stability (1st feet position)	During *demi plié*	Descent	0.60	0.005	89%
		Ascent	0.60	0.009	83%
	During *grand plié*	Descent	0.60	0.005	89%
		Ascent	0.72	0.001	89%
Pelvic stability (2nd feet position)	During *demi plié*	Descent	0.87	0.001	94%
		Ascent	0.82	0.001	94%
	During *grand plié*	Descent	1.00	0.001	100%
		Ascent	1.00	0.001	100%

interdisciplinary instrument, able to be used in both rehabilitation and prevention of injuries associated with incorrect performance of *plié* (Hincapié et al., 2008; Barnes et al., 2000; Kadel, 2006; Nilsson et al., 2001). Therefore, the MADAAMI can be used by several health professionals and dance teachers which are interested in analyzing the motion of *plié* and its negative effect on the body when poorly executed.

Table 7 Results regarding to the validation agreement of the criterion 4 (''Alignment between knee and foot ipsilateral''), showing the percentage of agreement (*C*), the values of the Kappa coefficient (*k*) and its significance level (*p*) for all steps of the *plié* (*n* = 13).

Evaluation criteria	Phases of the move	Movement step	Validation of agreement		
			k	*p*	*C*
Knee aligned with foot (1st feet position)	During *demi plié*	Descent	0.62	0.010	92%
		End of the move	1.00	0.001	100%
		Ascent	0.62	0.010	92%
	During *grand plié*	Descent	1.00	0.001	100%
		End of the move	1.00	0.001	100%
		Ascent	1.00	0.001	100%
Knee aligned with foot (2nd feet position)	During *demi plié*	Descent	0.62	0.010	92%
		End of the move	0.43	0.050	85%
		Ascent	0.62	0.010	92%
	During *grand plié*	Descent	1.00	0.001	100%
		End of the move	0.56	0.040	85%
		Ascent	1.00	0.001	100%

Position of the foot	*Phases of plié*	Steps	Criteria	Evaluation
1st Position (evaluate the right foot)	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	During *demi plié*	Descent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		End of the move	Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		Ascent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	During *grand plié*	Descent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
		End of the move	Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
		Ascent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
2nd Position (evaluate the right foot)	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	During *demi plié*	Descent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		End of the move	Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		Ascent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
	With Knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )
	During *grand plié*	Descent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		End of the move	Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
		Ascent	Pelvic stability	E ( ) G ( ) R ( ) I ( )
			Knee aligned with foot	E ( ) G ( ) R ( ) I ( )
			Midfoot stability	E ( ) G ( ) R ( ) I ( )
	With knees extended	Static	Midfoot stability	E ( ) G ( ) R ( ) I ( )

Figure 4 MADAAMI score sheet in its final version after validation procedures of agreement and evaluation of intra and inter-rater reproducibility. Caption: E, excellent; G, good; R, regular; I, insufficient.

It should be noted that in the present study, it was occasionally not possible to compare MADAAMI and 3D kinematic evaluation, with regards to the assessment of criterion 1 (''Midfoot stability'') in steps of ''descent'', ''ascent'' and ''end of the move'' motion phase ''During *grand plié*'' in the first position of the feet (Table 3). We know that, technically, during these steps of the *plié* there is loss of contact between the heels and the ground (Vaganova, 1945). So, given the fact that there were no references in the literature to numerical techniques that represents an instability of the midfoot when it is not in contact with the ground, it was not possible for us to define the kinematic parameters that would be able to verify this.

Furthermore, it is important to highlight that MADAAMI have been classified as a ''Rejected Instrument'' to assess the criterion ''Pelvic Positioning'' static at all phases, both before and after the ''descent'' and ''ascent'' at the end of *demi pliés* and *grand pliés* (Table 5). It is speculated that the non-compliance of the data obtained by both methods underlies the difficulties that the human eye has to evaluate the positioning of the pelvis accurately, with respect to the classification of this position angles. This is because the pelvic angle variation is very low, only 3° (Kapandji, 2000; Tribastone, 2001) which without the aid of specific technology, prevents the human eye, even if trained, to check the angles corresponding to the pelvis ratings ''neutral'', ''retroversion'' or ''anteversion''. Thus, based on predefined criteria in this study, MADAAMI is suitable for evaluating alignment of the pelvic positioning only in the dynamic steps of the *plié*. Therefore, it is suitable for evaluating pelvic stability only.

Regarding the results of the validity of the agreement criterion 4 (''Alignment between knee and foot ipsilateral'') for all phases of the *plié:* there was no validation of all the

steps in which the knees were extended (Table 7). This is likely due to a limitation in the methodology of this study: positions that allow reference in mathematical routines to identify internal and or external rotation of the femur relative to the external rotation of the tibia, were not collected. In contrast, the human eye was able to identify the position of the patella in relation to the second toe ipsilateral when the knees remained extended.

It is believed that assessment of the four technical criteria that guide the successful execution of *plié* in classical *ballet* (Vaganova, 1945; Howse and Hancock, 1992; Clippinger, 2007; Fitt, 1996) enables dance teachers to track and assess whether their students are following these criteria or performing compensatory movements predictive of musculoskeletal injuries during the teaching–learning–training process. Whereas the implementation of these compensatory movements such as misalignment between the knees and the feet, holding insufficient external rotation of hip (*en dehors*) accompanied by compensatory tibial external torsion, foot pronation and eversion to reach 180° maximum *en dehors*, appears in parallel with an increase in injuries in joints and regions that comprise the lower limbs (Wohlfahrt and Bullock, 1982; Gantz, 1989; Bordier, 1975; Kushner et al., 1990; Hincapié et al., 2008; Barnes et al., 2000; Kadel, 2006; Nilsson et al., 2001). This highlights the importance of a simple method, easy to use, valid, reproducible and able to assess methodically and specifically each and every step of the move advocated by the technique of classical *ballet*.

Golomer and Féry (2001) claim that injuries caused by the practice of classical *ballet* are related to the technical guidance given during the teaching–learning–training process, which must rely, indispensably, to fix the compensations described above. The authors stated further that the practice of this type of dance, even if based on physical and biomechanical scientifically correct foundations, if not well targeted and executed, can become a cause of inconvenience to the good implementation, performance and even the health of practitioners. It is of great importance to monitor, evaluate and to continually reassess the way in which the *plié* is implemented, regardless of the technical level of the dancers, because the best way to prevent changes and injuries is to maintain ''pure technique'' with the necessary intelligence that allows it to adapt to anatomical and physiological peculiarities of each dancer (not the reverse) (Pozo Municio, 1993).

We therefore conclude that the MADAAMI, which constitutes a checklist to the dance area, is a new assessment tool that allows for the identification and monitoring of individualized technical execution of the *plié*, being suitable for use by the same examiner. Some of the practical applications of MADAAMI include its use in the detection of levels of proficiency of classical *ballet* by dance teachers, and as an evaluation instrument for diagnostic of joint misalignments and monitor the rehabilitation process of musculoskeletal injuries by healthcare professionals. Thus, we believe that the MADAAMI is an interdisciplinary tool with easy and direct language, which besides being used in teaching–learning–training process can also be used in primary care and rehabilitation of dancers.

Funding

This study was funded by CAPES (graduate student stipend mode).

Conflicts of interest

The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.rbce.2016.02.016.

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