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Neuromuscular Warm-Up is Associated with Fewer Overuse Injuries in Ballet Dancers Compared to Traditional Ballet-Specific Warm-Up

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Abstract

Neuromuscular warm-up exercises (NMWU) have been shown to prevent injuries. In dance, research on warming-up is scarce. We investigated warm-up habits among ballet dancers and the effects of NMWU and traditional ballet-specific warm-up (TBSWU) on injuries. Using a cross-sectional survey among ballet dancers over the age of 18 years, we recorded acute and overuse injuries sustained in the previous 2 years. Warm-up behavior was assessed through 28 items. Dancers were grouped into NMWU or TBSWU: NMWU was based on neuromuscular warm-up programs in sports science and included exercises improving strength, power, proprioception, sensorimotor control, or cardiovascular stimulus; and TBSWU consisted of stretching, dance-technical exercises, marking steps and running-through-choreographies, or stretching with tools. Separate linear regression analyses adjusted for confounding factors were performed for acute and overuse injuries. A total of 192 dancers (26.7 ± 7.82 years, 159 females, 132 professionals) reported 203 acute and 469 overuse injuries. In total, 47.4% of dancers always warmed up (mean duration 20.7 ± 13.2 minutes) based on stretching (63%), technical-exercises (58.9%), strength-training (54.7%), and the barre (53.6%); and 9.4% never warmed up. A total of 31 dancers (16.15%) were classified as TBSWU, 16 dancers (8.3%) for NMWU, and 145 dancers did combined exercises. Those in the NMWU group were associated with fewer overuse injuries compared to those in the TBSWU group (β = -2.34; 95%CI -3.54 to -1.14). No association was found with acute injuries. As in other athletes, NMWU might be protective against overuse injuries in dancers. Large-scale prospective cohort studies are needed to gain more insight into NMWU as a possible component of injury prevention in ballet.

Key Points

- Neuromuscular warm-up should be considered as essential means of injury prevention in ballet dancers as it has shown to be in other athletes.
- The majority of ballet dancers' injuries are overuse in nature against which neuromuscular warm-up has shown to be specifically protective.
- Traditional ballet-specific warm-up routines such as stretching or the barre have shown to be associated with injuries.

Introduction

Injuries in classical ballet, especially overuse injuries, have a multifactorial etiology.[1-6] All involved, including dancers, dance companies, theaters, and insurance companies, sustain losses through the high numbers of injuries and dancers' temporary absences from work. This can include costs such as those from insurance claims, Workers Compensation, treatment, rehabilitation, re-casting, and re-rehearsing, among others.[7,8] In addition to the physical complaints, pain, and high stress resulting from their injuries, the affected dancers even risk termination of their careers.

An important injury prevention measure could be an appropriate warm-up. In sports science, neuromuscular (NM) sport-specific warm-up has been shown to prevent injuries.[10-14] This warm-up targets the athlete's proprioceptive[9] and sensorimotor abilities, strength, and power without engaging in technical drills. Neuromuscular warm-up specifically enhances the joint position sense (proprioception)

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and balance as well as anticipatory and compensatory reflexes relevant for protection of joints in dynamic stability.[15-23] Injury risk[24,25] is reduced, especially to the lower limbs,[26] which is the most affected anatomical location in dancers.[5]

There is little consensus in dance, specifically in ballet, as to which activities can be categorized as warm-up.[27] Traditional approaches are based on stretching routines[28] commonly followed by skill drills. Sports science has shown that stretching as a warm-up has no injury preventive effects.[29-32] Prolonged stretching is even discussed as a limiting factor for performance, especially for jump height, through a decrease in power production and muscle activation.[33,34] However, it remains unclear which warm-up routines are commonly used in ballet, and studies investigating the association between warm-up procedures and injury risk in ballet dancers are lacking.

Hence, the aim of this study was twofold: 1. to clarify the warm-up habits and behaviors of ballet dancers and 2. to compare the effects of neuromuscular warm-up exercises (NMWU) and traditional ballet-specific warm-up (TBSWU) on injuries.

Methods

Study Design

A cross-sectional cohort study was performed using an online survey. The METC-LDD (Medical-Ethic Committee Leiden, Den Haag, Delft) waived ethics approval as it did not fall under the purview of the WMO (Wet medisch-wetenschappelijk onderzoek met mensen), the Medical Research Involving Human Subjects Act. Prior informed consent of the participants was obtained electronically.[35]

Participants

Inclusion and Exclusion Criteria

Professional, pre-professional, and amateur ballet dancers over 18 years of age who had a regular classical ballet training experience of at least 3 years were eligible to participate. Surveys received with less than 75% of questions answered were excluded.

Recruitment Method

The link to the survey was presented via social media (Facebook, Instagram). A total of 188 ballet ensembles and 51 dance organizations from around the world were informed via email and through contact forms on their websites. The survey was accompanied by a short explanation in which the dancers were asked to further distribute and share the information through their personal contacts, within theaters, ensembles, dance panels, blogs, and other contact options. The survey was executed anonymously; no identifying data was collected.

Assessments

Population

The following baseline demographics were assessed: sex, nationality, age at initiating ballet, and workload of the previous 2 years. As recommended in dance science literature,[36] workload was assessed weekly as dancer exposure, which equals a dance event independent of the duration of the event (i.e., participation in a class, rehearsal, or performance). Furthermore, workload was recorded per athlete exposure hour. Level of expertise (professional or amateur) was derived from the reported athlete exposure hours: professional dancers were defined as dancers with 16 or more exposure hours per week, whereas amateurs had a maximum of 15 hours of dancing per week.[37,38]

Injuries

Primary outcome measures were the number of acute and overuse musculoskeletal injuries. Overuse injuries were defined as physical complaints, which "could not be linked to a clearly identifiable event"[39] (such as an accident), sustained within the previous 2 years[40] and from dance related activities (i.e., performance, rehearsal, or technique class). Self-reported overuse injuries were recorded through 17 possible injury locations, including 16 body parts and one injury location not listed on the survey but provided as a free-text item.

Acute injuries were defined as injuries in which the "onset could be linked to a specific injury event"[39] in the course of dance-related activities (i.e., performance, rehearsal, or technique class) within the previous 2 years. Comparable to the assessment of overuse injuries, 17 items (16 body parts and one additional free-text item) assessed acute injuries.

Warm-Up Behavior

Warm-up habits and behaviors in ballet dancers within the previous 2 years were assessed through a total of 28 items specifically composed for the purpose of this study (Table 1). Six questions were answered via Likert scale ranging from 1 to 5 (never = 1 to always = 5), two multiple response questions contained six and 15 items, respectively, and one question served to assess duration in minutes based on free-text input.

Creation of Survey Questions and Analysis of Warm-Up Programs

Available NMWU programs for injury prevention in sports science were analyzed through extensive literature research. The questions in the survey (Table 1) and the grouping of the dancers for the evaluation of the two warm-up protocols (i.e., NMWU and TBSWU) were derived from that analysis. Thus, we developed a novel and previously not validated questionnaire that was based on previous warm-up programs and practical experience of experts.

Neuromuscular Warm-Up

Three different injury-preventive neuromuscular warm-up programs served as models for the current study: the FIFA 11+,[11,13,41-45] the HarmoKnee,[46,47] and the Prevent Injuries and Enhance Performance Program (PEP).[14,48,49] Those three programs share a common structure, duration, and content and are commonly used in multiple athletic populations.[11,13,41,43,45] These programs are based on a variety of exercises grouped into exercise sets that target the overall aspects: 1. general warm-up through jogging or running for 5 to 10 minutes, and specific warm-up through 2. strength and core stabilization, 3. sensorimotor and proprioceptive abilities in statics and dynamics, and 4. cardiovascular stimulus based on longer duration of exercises supported by non-stop designs.

Table 1 Survey Questions that Assessed Warm-Up

Please, think of the previous two years when you answer the following questions
In the previous 2 years I have been warming up prior to class/training. ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always
In the previous 2 years I have been warming up prior to class/training for ___ minutes.
When I don't warm up, this is because ❑ I don't need to ❑ I use the barre as warm-up ❑ There is no room, space, or time available for me in my schedules ❑ I feel better without ❑ I am stretching ❑ My BMTPT doesn't like it when I do
I am structuring my warm-up into different blocks (general warm-up and specific warm-up) ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always
I am generally warming up by stretching. ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always
I am generally warming up by running, jogging, bouncing, or swinging for around 5 minutes. ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always
I am/was specifically warming up by doing ❑ Balance exercises on wobbly surfaces ❑ Balance exercises with eyes closed ❑ Stretching with weights, Therabands, Deuserbands, foot stretchers, and other ❑ Intense static stretching (staying in stretch positions for several minutes) ❑ Dynamic stretching (moving through stretching positions without stops) ❑ Marking steps ❑ Dancing through choreographies ❑ A barre ❑ Selected technical exercises (i.e., tendus, jetés, ronds…and other) ❑ Strength training (e.g., plank, side planks, airplane, push-ups, sit-ups, and other) ❑ Strength training using a Theraband for resistance ❑ A barre exercise with a nonstop design (= no breaks between exercises) ❑ Slow motion alignment training (e.g., training of dynamic leg axes, and other) ❑ Mentally going through steps ❑ Waiting for class/rehearsal to begin, doing nothing much
Does your BMTPT insist that you execute the warm-up you described above? ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always
I am feeling cold and "not ready" when I start dancing. ❑ never ❑ seldom ❑ sometimes ❑ very often ❑ always

BMTPT = ballet-master, teacher, pedagogue, or trainer/coach.

The survey questions for our purposes were composed with the aim to translate the NMWU protocols from sports science into practical dance settings. This resulted in seven exercise sets assessing the four overall aspects of NMWU. They were adapted to fit into dance settings by two of the authors of this study who are internationally acknowledged experts in the field of dance medicine and dance pedagogy and designing and conducting training for dancers (JEK, JHS).

Traditional Ballet-Specific Warm-Up

Since, to our knowledge, there is no documentation of warm-up habits in ballet dancers available, the design for the assessment of TBSWU was derived from practical experience of the experts and included practical descriptions from ballet teachers, ballet masters, and professional dancers in the preparatory phase of the study. The goal was to use a similar framework as was used for the NMWU assessment to support the purpose of this study (i.e., the comparison between the groups). This led to a final number of eight exercise sets assessing overall aspects of traditional ballet dancers' warm-up procedures: 1. general warm-up through stretching, 2. marking steps or dancing through choreographies and combinations, 3. dance technical exercises, and 4. various methods of stretching with and without tools.

Table 2 General Demographics

	All dancers (n = 192)
Sex	
Female	159 (82.6%)
Male	33 (17.4%)
Age at participation (years)	26.7 ± 7.82
Ballet experience (years)	14.5 ± 7.00
Age at ballet initiation (years)	8.1 ± 5.84
Athlete exposure (workload in hours/week)	26.8 ± 15.30
missings	4
Dancer exposure (workload in events/week)	12.3 ± 9.60
missings	5
Level of expertise	
Professionals	132 (68.8%)
(Athlete exposure/week)	35.6 ± 8.20
Amateurs	56 (29.2%)
(Athlete exposure/week)	6.1 ± 3.92
Acute injuries total	1.1 ± 1.15
Overuse injuries total	2.4 ± 1.86

Values are given as the mean ± SD or n (%) of the population; dancer exposure = per event independent of the duration of the event (i.e., not necessarily 60 minutes); athlete exposure = per 60 minutes; acute injuries: sudden onset caused by high-intensity forces (i.e., accidents resulting in sprains, strains, contusions, fractures etc.); overuse injuries: result from repetitive micro-trauma of submaximal mechanical loading, also called "chronic injuries."

Grouping of the Dancers Into the TBSWU and NMWU Groups

Our two groups were stratified based on data analysis. Dancers who performed more than one exercise set from both the TBSWU and NMWU were excluded from the analyses. Additionally, cutoff points were introduced to match the number of exercise sets to the warm-up programs cited in the sports science literature.[11,13,14,41-48] Those programs were based on multiple exercises grouped into exercise sets, rather than one or a few isolated exercises. Based on these studies, we only placed dancers into one of the warm-up groups when they included at least half of the exercise sets into their warm-up routines. Because the NMWU protocol consisted of seven exercises, a cutoff point of four was used. To be assigned to the TBSWU group, dancers had to perform at least five of the eight exercises (the cut-off point was five).

Statistical Analysis

IBM SPSS Statistics software version 25 (IBM, Armonk, New York, USA) was used for statistical analysis. Data was screened for errors using descriptive statistics, explorative plots, and multicollinearity statistics. Differences in baseline demographics of the TBSWU and NMWU were tested using the Mann-Whitney U-test for continuous variables and Fisher's exact (chi-squared) tests for categorical variables. In addition, with the same statistical tests, the TBSWU and NMWU groups were compared to the other dancers. Multivariate linear regression models were used to examine whether warm-up procedures were associated with injury risk. The dependent variables were number of acute injuries and number of overuse injuries per person. For both dependent variables, two models were conducted: Model 1 included the dichotomous variable "warm-up procedure" (i.e., NMWU versus TBSWU). Model 2 included warm-up procedure and adjusted for the confounders age, sex, and level of expertise (i.e., amateur, pre-professional, and professional dancers).

Results

Warm-Up Behavior

Population

A total of 192 ballet dancers (females: 159, 82.6%) with a mean age of 26.7 ± 7.8 years completed the questionnaire and were included in the analyses. Table 2 displays the general

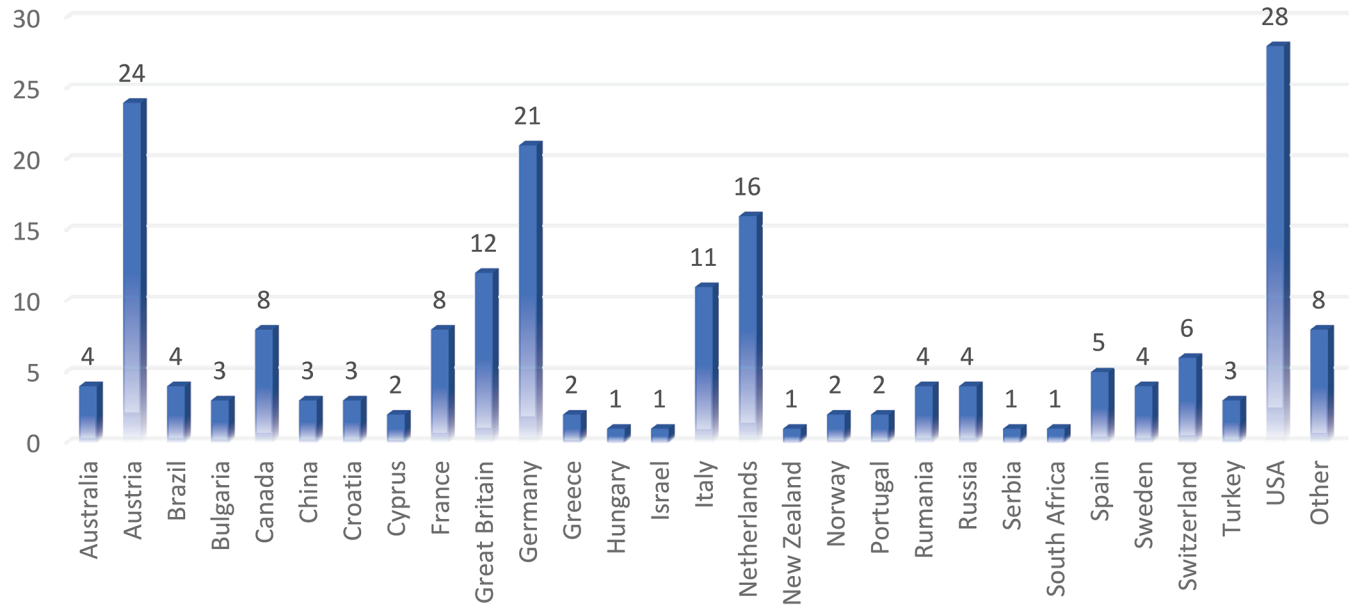

Figure 1 Nationalities of the population.

Table 3 Details on Warm-Up Habits in Ballet Dancers

Warm-up assessment	All dancers (n = 192)
Warm-up in the previous two years before training	
Never	4 (2.1)
Seldom	21 (10.9)
Sometimes	24 (12.5)
Very often	52 (27.1)
Always	91 (47.4)
Duration of warm-up (minutes, mean ± SD)	20.7 ± 13.2
When the dancer did not execute a warm-up it was because…	
…did not need to	33 (17.2)
…the barre was the warm-up	89 (46.4)
…there was no room or space or time available in the schedules	110 (57.3)
…she felt better without warm-up	7 (3.6)
…stretching was the warm-up	35 (18.2)
…the teacher or master did not like it when they warm-up	8 (4.2)
Did the teacher or master insist on a described warm-up	
Never	133 (69.3)
Seldom	17 (8.9)
Sometimes	13 (6.8)
Very often	11 (5.7)
Always	18 (9.4)
Warm-up was structured into two blocks (general and specific warm-up)	
Never	61 (31.8)
Seldom	37 (19.3)
Sometimes	43 (22.4)
Very often	33 (17.2)
Always	18 (9.4)
General warm-up: stretching	
Never	28 (14.6)
Seldom	34 (17.7)
Sometimes	57 (29.7)
Very often	41 (21.4)
Always	32 (16.7)
General warm-up: jogging, bouncing, swinging, or other for approximately 5 minutes	
Never	60 (31.3)
Seldom	55 (28.6)
Sometimes	40 (20.8)
Very often	27 (14.1)
Always	10 (5.2)
Specific warm-up:	
Dynamic stretching (moving through stretching positions without stops)	121 (63.0)
Selected technical exercises (e.g., tendus, jétés, ronds, and other)	113 (58.9)
Strength training (e.g., planks, air-plane, push-ups, and other)	105 (54.7)
The barre	103 (53.6)
Strength training using a Theraband for resistance	69 (35.9)
Stretching with weights, Therabands, Deuserbands, foot stretchers, and other	64 (33.3)
Intense static stretching (staying in stretch positions for minutes)	53 (27.6)
Marking steps	45 (23.4)
Slow motion alignment training (e.g., training of dynamic leg axes and other)	36 (18.8)
Balance exercises on wobbly surfaces	34 (17.7)
Balance exercises with eyes closed	26 (13.5)
Dancing through choreographies	23 (12.0)
A barre exercise with a non-stop design (i.e., no breaks between exercises)	15 (7.8)
Mental warm-up (e.g., mentally going through steps)	44 (22.9)
Waiting for class/rehearsal, doing nothing	18 (9.4)
The dancer felt cold and not ready when the class/rehearsal started	
Never	34 (17.7)
Seldom	62 (32.3)
Sometimes	51 (26.6)
Very often	30 (15.6)
Always	15 (7.8)

Values provided are n (%) of the study population or mean and standard deviation.

demographics. Dancers represented 28 nations (Figure 1), and most dancers were professional dancers (70%). A total of 203 acute injuries and 469 overuse injuries were recorded. Of the 192 dancers, 119 had at least one acute injury, 164 dancers had at least one overuse injury, and 110 dancers had at least one acute and one overuse injury.

Warm-Up Procedures

A total of 47.4% of the dancers always warmed up within the previous 2 years with a mean duration of 20.7 ± 13.2 minutes. Table 3 displays the details on warm-up habits in our population. A small percentage of dancers always (7.8%) or very often (15.6%) felt cold and not ready when they started dancing. When asked for reasons as to why they did not execute a warm-up, 57.3% of the dancers affected reported that there was no time in their schedules to warm up. Additionally, 69.3% of ballet teachers and masters never insisted that their dancers warm-up and 4.2% of teachers and masters did not want their dancers to warm-up.

A total of 63.0% used dynamical stretching, 58.9% selected ballet technique exercises, 54.7% used strength training, and 53.6% used the traditional barre as warm-up. A total of 16.7% always used stretching as general warm-up, while 5.2% used swinging, running, or bouncing to generally increase body core temperature. Only 9.4% structured their warm-up into general and specific warm-up exercises, while 31.8% never did.

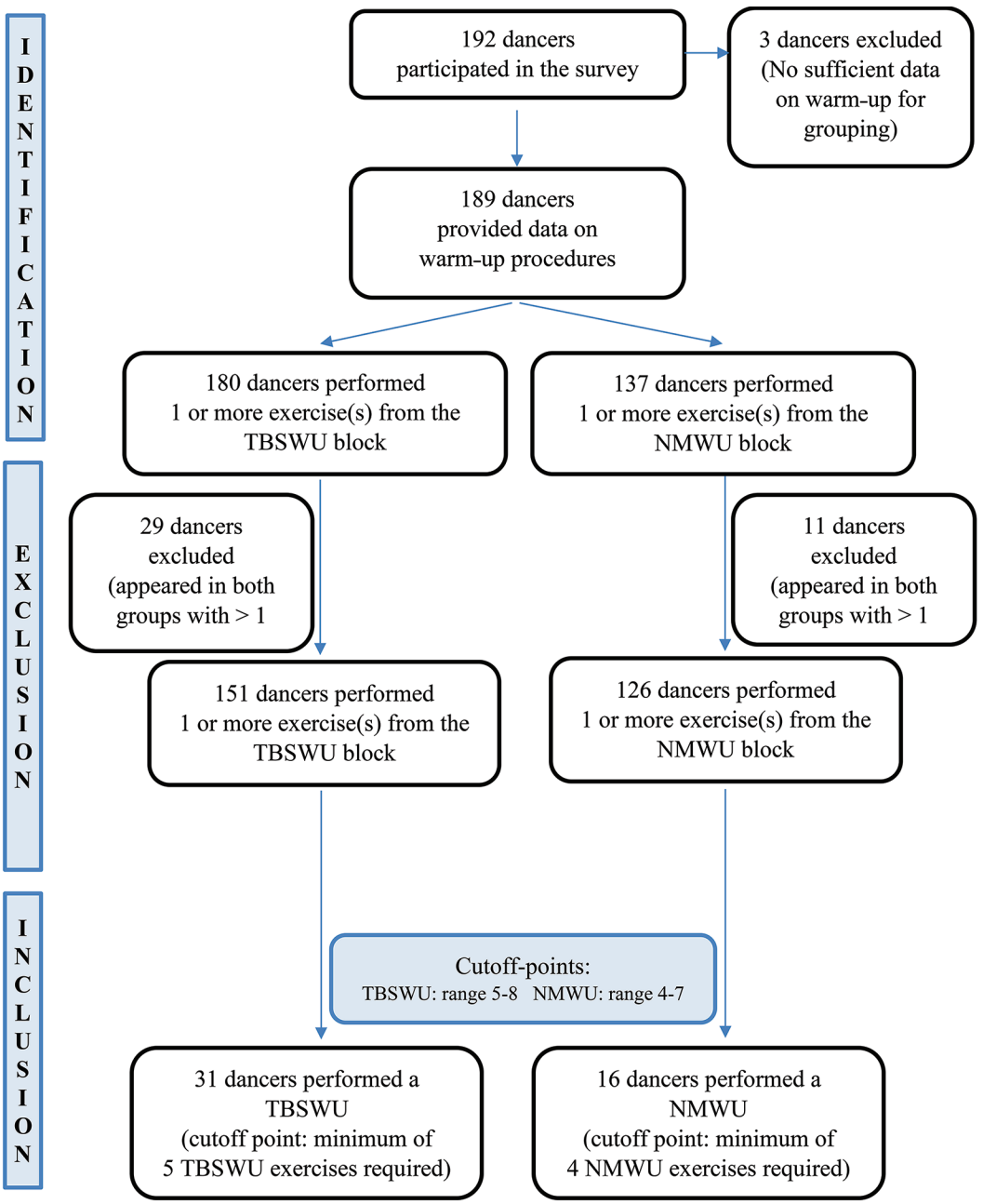

Figure 2 Identification and grouping of dancers according to warm-up procedures (traditional ballet specific warm-up: TBSWU; neuromuscular warm-up: NMWU).

Table 4 Demographics of the Traditional Ballet-Specific Warm-Up Group (TBSWU) and Neuromuscular Warm-Up Group (NMWU)

	TBSWU (n = 31)	NMWU (n = 16)	P-value
Sex			0.21
Females	28 (90.3%)	12 (75.0%)	
Males	3 (9.7%)	4 (25.0%)	
Age (years)	21.6 ± 3.6	28.1 ± 5.9	0.00
Experience (years)	12.7 ± 3.6	15.3 ± 5.1	0.08
Age at Initiation (years)	6.1 ± 2.1	8.7 ± 5.3	0.04
Athlete exposure (hours/week)	32.5 ± 9.6	33.4 ± 12.8	0.95
Missings	1	0	
Dancer exposure (events/week)	18.5 ± 6.3	14.0 ± 8.2	0.07
Missings	0	1	
Professionals	28 (93.3)	14 (87.5)	0.60
Amateurs	2 (6.7)	2 (12.5)	
Acute injuries	1.3 ± 0.7	1.1 ± 1.6	0.07
Overuse injuries	3.3 ± 1.8	1.3 ± 1.1	0.00

Values provided are mean ± SD or n (%) of the groups.

Table 5 Details on Habits and Comparison of Warm-Up Procedures in Ballet Dancers Who Were Assigned to Traditional Ballet-Specific (TBS) or Neuromuscular (NM) Warm-Up (WU)

	TBSWU group (n = 31)	NMWU group (n = 16)
Duration of warm-up (minutes)	18.39 ± 8.7	29.4 ± 14.3
Traditional Ballet-Specific Warm-Up		
General warm-up (1 exercise set):		
Always generally warming up by stretching	16 (51.6)	NA
Very often generally warming up by stretching	10 (32.3)	NA
Specific warm-up (7 exercise sets):		
Marking steps	18 (58.1)	NA
Dancing through choreographies/exercises	11 (35.5)	NA
The barre	27 (87.1)	NA
Selected technical exercises (e.g., tendus, jétés, ronds, and other)	28 (90.3)	5 (31.3)
Dynamic stretching (moving through stretching positions without stops)	25 (80.6)	4 (25.0)
Intense static stretching (staying in stretch positions for minutes)	19 (61.3)	NA
Stretching with weights, Therabands, Deuserbands, foot stretchers, and other	23 (74.2)	1 (6.3)
Neuromuscular Warm-Up		
General warm-up (1 exercise set):		
Always generally warming up by jogging, bouncing, swinging for 5 min.	NA	3 (18.8)
Very often generally warming up by jogging, bouncing, swinging for 5 min.	NA	10 (62.5)
Specific warm-up (6 exercise sets):		
Balance exercises on wobbly surfaces	NA	13 (81.3)
Balance exercises with eyes closed	NA	12 (75.0)
Slow motion alignment training (e.g., training of dynamic leg axes)	2 (6.5%)	10 (62.5)
Strength training (e.g., planks, airplane, push-ups, and other)	5 (16.1%)	16 (100.0)
Strength training using a Theraband for resistance	5 (16.1%)	13 (81.3)
A cardio barre with a nonstop design (no breaks between easy exercises)	NA	5 (31.3)

Values provided are n (%) of the groups or mean ± SD, NA: Not applicable.

Table 6 Associations Between Traditional Ballet-Specific or Neuromuscular Warm-Up and Acute or Overuse Injuries (Reference category: TBSWU is coded with 0, NMWU is coded with 1)

Parameters acute injuries	*B*	95% CI for *β* Lower	Upper	Parameters overuse injuries	*β*	95% CI for *β* Lower	Upper
Model 1: unadjusted Warm-up	-0.23	-0.92	0.46	Model 1: unadjusted Warm-up	-2.01	-3.00	-1.02
Model 2: adjusted Warm-up	-0.09	-0.96	0.78	Model 2: adjusted Warm-up	-2.34	-3.54	-1.14

Model 1: unadjusted model. Model 2: adjusted for age, sex, and level of expertise (i.e., pre-profesional, professional, or amateur dancer).

Association Between Warm-Up Procedures and Injuries

Population

Figure 2 shows the grouping of dancers into the two warm-up programs. Table 4 presents the demographics of the two warm-up groups, TBSWU and NMWU. There were 31 dancers (16.2%) assigned to the TBSWU group with a mean number of 5.71 ± 1.15 exercise sets per dancer. There were 16 dancers (8.3%) assigned to the NMWU group and used a mean of 5.1 ± 1.6 exercise sets per dancer. Table 5 shows the comparison of warm-up habits and exercises between the two groups: 83.9% of dancers in the TBSWU group always (51.6%) and very often (32.3%) generally warmed up by stretching compared to the NMWU group with 0.0%. In the NMWU group, 81.5% of dancers generally raised their body core temperature through jogging, swinging, or bouncing (18.8% always and 62.5% very often) compared to 0.0% in the TBSWU group. The NMWU group had a high focus on proprioceptive and sensorimotor control exercises: 81.3% performed balances on wobbly surfaces (0.0% in TBSWU), 75.0% trained balance exercises with eyes closed (0.0% in TBSWU), and 62.5% worked on slow motion alignment training (6.5% in the TBSWU group). Duration of warm-up also differed between the groups, with TBSWU reporting a mean warm-up duration of 18.39 ± 8.7 minutes, compared to 29.4 ± 14.3 minutes in the NMWU group.

Warm-Up and Injuries

Table 6 shows the results of the different linear regression models. The NMWU group was negatively associated with overuse injuries per participant. On average, in the NMWU group we found two fewer overuse injuries per participant compared to the TBSWU group (β -2.34, 95% CI: -3.54 to -1.14; r^2 36.1). No effects were noted for acute injuries (β -0.09, 95% CI: -0.96 to 0.78; r^2 0.59).

Discussion

The aim of this study was to clarify the warm-up habits of ballet dancers and to compare the effects of NMWU and TBSWU on injuries. In total, 192 dancers from 28 nations reported 203 acute and 469 overuse injuries. Results regarding warm-up behavior show dancers mainly engaged in stretching and technical dance exercises as a warm-up. Furthermore, warm-ups hardly ever followed injury preventive recommendations from sports science. However, half of our population did include strength training into their routines. The NMWU group was associated with fewer overuse injuries compared to those in the TBSWU group. No association was found between warm-up protocols and acute injuries.

There is little consensus in ballet on the design and execution of warm-up routines. Warm-up routines as well as their association with ballet injuries have not yet been studied. In sports science, the injury preventive effects of NMWU in individual and team sports of all sexes, ages, and levels of expertise has been demonstrated.[10,11,13,14,42-44,46,48,50] In dance, only a few studies are dedicated to the topic.[51,52] While classical ballet dancers are not always directly comparable to other athletes, many of the risk factors associated with dance injuries were tackled through NMWU in sports: insufficient dynamic joint stability, lower limb alignment and lumbopelvic control, as well as strength or general fitness deficits.[53-55]

In spite of the existing research stressing the importance of general warm-up, only 9.4% of our study population always structured their warm-up into two blocks (i.e., general followed by specific warm-up), whereas 31.8% never did. As our findings show, traditional ballet-specific ways of warming-up focus on stretching and mainly anaerobic, repetitive technical drills previously associated with overuse injuries.[56,57] In contrast, our NMWU group showed a focus on general warm-up, resembling examples from sports science, where a graduated increase in exercise intensity from 50% up to 90% of HRmax[17] is essential to increase performance[58] while avoiding injury risk from stretching on a cold body.[28] Moreover, NMWU protocols provide a different focus than the main technical training of the athlete, supplementing strength, power, and sensorimotor training, which are vital to prevent overuse injuries to the lower limbs.[11,26,41,44]

The duration of the NMWU routines in sports medicine we referred to was 20 to 30 minutes.[11-14,41-49] Our NMWU group reported a mean duration of 29.4 ± 14.3 minutes, while our TBSWU group showed a shorter mean time spent on their warm-up (18.39 ± 8.7 minutes). The question may arise whether duration matters more than content of warm-up. However, when only those NMWU and TBSWU dancers who warmed up for more than 20 minutes as well as those who warmed up specifically for 20 to 30 minutes were selected for linear regression, results did not differ from the regression presented in Table 6. Although the number of dancers was small in this testing of duration (n = 24 and n = 15, respectively), the results indicate that the content of the warm-up (i.e., the neuromuscular exercises) matters, not the duration.

Table 7 Baseline Comparison of Dancers Excluded (EX) from Assessment of the Association Between Warm-Up (WU) and Injuries and Those Who Performed One of Our Warm-Up Procedures [i.e., Traditional Ballet-Specific (TBS) or Neuromuscular (NM) Warm-Up]

	All EX n = 145	All WU n = 47	P-value
Females Males	119 (82.1) 26 (17.9)	40 (85.1) 7 (14.9)	0.82
Age (years)	27.6 ± 8.3	23.8 ± 5.4	0.00
Ballet experience (years)	14.8 ± 7.6	13.6 ± 4.3	0.48
Ballet initiation (age, years)	8.5 ± 6.3	7.0 ± 3.7	0.29
Athlete exposure (workload in hours/week)	142 24.8 ± 16.1	46 32.8 ± 10.7	0.01
Dancer exposure (workload in events/week)	141 10.8 ± 9.8	46 17.0 ± 7.2	0.00
Professionals Amateurs	90 (63.4) 52 (36.6)	42 (91.3) 4 (8.7)	0.00
Acute injuries total	1.0 ± 1.2	1.2 ± 1.1	0.11
Overuse injuries total	2.4 ± 1.9	2.6 ± 1.9	0.47

Values presented as n (%) or mean ± SD.

While injury risk through stretching is particularly high and underestimated in dancers,[59-62] our findings show many dancers use stretching as a warm-up. However, a focus on stretching as warm-up failed to prevent injuries.[29-32,63,64] Regular static stretching does increase long-term flexibility,[65,66] which is essential for classical ballet. However, stretching exceeding 30 to 60 seconds has shown to result in compression reducing blood supply for muscles, connective tissue, and nerves.[67] That, combined with a lack of stabilizing strength, might result in the often-reported reduced sensorimotor control[68] and decreased performance in athletes[33,34,69-72] as well as dancers.[73]

Reports in the literature indicate that there is a significant inverse correlation between the athletes' and coaches' knowledge, their compliance to injury prevention programs, and injury rates.[12,16,42] Our findings show that many dancers already engage in selected neuromuscular exercises. However, 69.3% of ballet teachers or ballet masters do not insist on their dancers' warming-up, and 4.2% of dancers reported their ballet teachers or ballet masters do not want them to warm-up. Moreover, when dancers could not execute a warm-up, the main reason reported (57.3%) was a lack time available, indicating missing support from teachers, masters, and administrations. Research points out the importance of knowledge and education in coaches, resulting in higher compliance of coaches and athletes for the implementation of injury preventive measures, such as warming-up.[16,74]

Comparing our warm-up groups (Table 7), we could see a discrepancy between reported athlete exposure hours (i.e., 60 minutes) and dancer exposure (i.e., the duration of an event is unknown).[75] Our warm-up groups are comparable with regard to athlete exposure hours as their weekly workload. However, the TBSWU group showed higher means of dancer exposure events than the NMWU group. Ramifications are important because, although athlete exposure hours are comparable, dancer exposure events must have been shorter in duration but higher in frequency. Thus, dancers might not have enough time or do not engage in sufficient warm-up before training or after any break of greater than 15 minutes.[17] Hence, our findings stress the importance of NMWU in injury prevention revealed by this discrepancy.

Strengths and Limitations

This is the first study investigating ballet dancers' warm-up routines in order to provide an essential overview on their preparatory habits. By comparing warm-up routines, this study suggests a preventive relationship between NMWU and overuse injuries. A strength of the study is that an international survey was conducted and the questionnaire was distributed over many dance ensembles and dance organizations. However, some limitations should be addressed. A non-validated questionnaire was used, and the retrospective design based on self-report might have introduced recall bias. Moreover, as always with a survey, the group that filled out the questionnaire might not be representative for the whole dance population. Another limitation is the small group size of especially the NMWU group. The warm-up groups showed differences in age, initiation-age, and dancer exposure, as discussed above, reducing their comparability. We attempted to correct these differences through confounder adjustment, although residual confounding cannot be ruled out. In older dancers, age and years of dancing could have led to more injuries based on more time available for their development or to fewer due to the dancers being more experienced. Being more mature, and therefore perhaps more knowledgeable,[76] the NMWU dancers may have already determined how essential NMWU is and identified it as a booster for performance and health, as suggested in previous literature.[77]

Being the first to study warm-up habits in ballet dancers as well as an association between warm-up programs and injuries, this study succeeded to show that (neuromuscular) warm-up is worth being investigated as a possible means of injury prevention in dancers.

Conclusion

Our study provides an overview on the warm-up routines ballet dancers use prior to training, rehearsal, and performance. When comparing traditional ballet-specific warm-up habits with neuromuscular approaches, we found that NMWU was negatively associated and TBSWU positively associated with injuries. In order to reduce the burden and risk of overuse injuries, dancers might consider introducing NMWU prior to activity. Prospective, longitudinal studies of warm-up routines as a means of injury prevention in ballet dancers are warranted.

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