High-impact routines to ameliorate trunk and lower limbs flexibility in women

Abstract

Several types of routines and methods have been experimented to gain neuro/muscular advantages, in terms of overall range of motion, in athletes and fitness enthusiasts. The aim of the present study was to evaluate the impact of different routines on trunk- and lower limbs flexibility in a sample of young women. In a randomized-crossover fashion, eleven subjects underwent to: hamstrings stretching [S]; hamstrings stretching plus whole-body vibration [S + WBV]; partial-body cryotherapy [Cryo]; rest [Control]. Standing hamstrings stretch performance and sit-and-reach amplitude resulted to be improved with [S + WBV] compared to all other protocols ($p < 0.05$). [Cryo] ameliorated the active knee extension performance with respect to all other interventions ($p < 0.05$). These flexibility improvements were obtained without a loss in the trunk position sense proprioception. These results represent the first evidence that a single session of either vibration or cryotherapy can ameliorate ~~favourably impact on~~ flexibility without losing the trunk position sense ~~compromising~~ proprioception in young women.

Keywords: cryotherapy, whole-body vibration, standing hamstrings stretch

Abbreviations: AKET, active knee extension test; ES, effect size; ICC, intraclass correlation coefficient; PBC, partial body cryotherapy, ROIs, regions of interest; ROM, range of motion; S, stretching; SHS, standing hamstrings stretch; SD, standard deviation, TRE, trunk repositioning errors, WBC, whole-body cryotherapy; WBV, whole-body vibration

Introduction

A litany of studies has been repeatedly debating on different methods of stretching to gain advantages in range of motion (ROM) and therefore in flexibility. However, it is still controversial the extent by which a particular stretching routine might be effective in relation to a specific sport rather than in the general population. For instance, it has been previously shown that static stretching may be counterproductive immediately before performing a strength/power sports discipline [1–3]. ~~In fact, P~~Prolonged static stretching can impair maximal muscle performance [4], however these negative effects, owing to the decrease of the muscle-tendon unit stiffness, are transient [5] and affect muscle performance only marginally [6]. Other works have reported that either static or dynamic stretching can increase flexibility by the same magnitude of change [7–10]. In the vast majority of these studies, the stretching-induced effects were observed with the targeted muscles, in isolation, rather than in comparison with contralateral muscles, i.e. as global effects [11]. The effects of whole-body vibration (WBV) have been extensively investigated [12–15], either as an adjunct to static stretching with the potential to enhance retention of flexibility gains [16], or alone, to improve hamstring flexibility [17]. Short-term WBV interventions have obtained improvements in flexibility and in other health-related physical fitness indicators such as endurance, balance, and muscle strength, in physically active adults and elderly [17, 18]. In essence, WBV transmits mechanical oscillations of a given frequency, through a contact with the base of the platform, to the human body. Prior works [15, 19–21] have explained how the mechanical stimulus could generate effects on the neuromuscular system. Issurin et al. [19] proposed that WBV would facilitate flexibility by means of potential mechanisms such as: increase in pain threshold,

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elevation of blood flow and induced-relaxation of the stretched muscle. Sands et al. [20] underlined that carrying out a stretching exercise during vibration could result in Golgi tendon organs activation, inducing an autogenic inhibition of the vibrated muscle.

Moreover, acute whole-body cryotherapy has been successfully used to reduce neural activation therefore affecting ROM and increasing sit-and-reach amplitude in men and women [22]. Even when locally applied, cryotherapy has been shown to decrease nerve conduction velocity along with an analgesic effect [23]. Basically, cryostimulation consists in a short exposure to very cold air (from -130 to -170 °C) either in on-purpose designed cryo-chamber (Whole-Body Cryotherapy, WBC) or cryo-cabin (Partial-Body Cryotherapy, PBC) or vaporizers (local cryotherapy) [24]. Bleakely and Costello reported favourable effects of cryotherapy on ROM [25], however cohesive results are lacking and therefore more research protocols are warranted. The hypothesised mechanism is that cryostimulation inhibits spinal excitability [23], hence decreases neural activity, allowing more elongation of the muscle at a given load [22].

A variety of routines have been sought by athletes, fitness enthusiasts and general population to earn specific advantages in muscular performance, in terms of ROM and/or flexibility, or simply in order to meet prevention programs against osteo-arthro-muscular injuries, which represent the major cause of sick leave and back pain [26–28].

In this context, the aim of this study was to explore the effects of different interventions, including stretching, WBV and PBC on trunk/lower limbs flexibility, while also taking into account for trunk proprioception in young women. The hypothesis was that a single session of either or some of these interventions would improve the indicators of flexibility.

Materials & Methods

Research design

Based on the *a priori* sample-sized determination (software package, G * Power 3.1.9.2), with a statistical power of 0.8, a probability level of 0.05, an effect size *f* of 0.38 (which corresponds to a $\eta^2 = 0.13$), eleven young adult women were enrolled for this study. The present investigation was designed as a randomized-crossover trial. Using a restricted blocks randomization (computer-generated sequence), the 11 participants were randomly subjected to: 1) hamstrings stretching [S] in upright position; 2) S in conjunction with whole-body vibration [S + WBV]; 3) PBC [Cryo]; 4) rest [Control]. All 11 participants completed the 4 experimental trials, for which there were two within-group independent variables, one with four conditions (intervention) and the other with two conditions (time: pre- and post-interventions). To evaluate the flexibility responses to the interventions, three dependent variables were examined: the ROM measured during the standing hamstring stretch (SHS) test, sit-and-reach amplitude, and active knee extension test (AKET). In addition, another dependent variable was registered as the absolute difference during the trunk repositioning test: trunk repositioning error (TRE, Fig. 1). All the dependent variables were measured prior and following each experimental condition (Fig. 1).

All subjects were examined by a qualified physician to exclude severe hypertension, chronic low back pain, history of cardiovascular diseases, cold hypersensitivity (Raynaud's syndrome) and history of previous fractures of bone lesions prior to performing ~~any contraindication to PBC and to WBV~~the study. To minimize the effects of circadian variation, measurements were consistently carried out at the same hour of the day (from 08:30 to 10:30). Subjects were also instructed to refrain from consuming alcohol, caffeine, theine, hot drinks nor undertaking any stretching, weight-training, or arduous physical activity in the day before and during testing days. In addition, subjects were also instructed not to take medications or supplements during the study. All measurements were completed by the principal investigator and recorded onto a separate data collection sheet. To avoid potential bias, the investigator did not review the participants' measurements from the previous days on which they completed the other interventions until the~~y complete~~ end of the study. Rater was experienced with measurement protocol and the utilization of the digital inclinometer and the Flex-Tester box.

[Figure 1 near here]

Ethics statement

The study protocol, including each aspect of the design, was approved by the academic ethical board in accordance with the Declaration of Helsinki. All subjects were given verbal and written information on the study and gave their written informed consent to participate. The experimental protocol meets the ethical standards of the journal [29].

Procedures

A diagram of the overall study-design is offered in Fig. 1.

On the day of the experiment, each participant arrived at the laboratory 30 min before the session so to acclimate to the room temperature (22 ± 0.5 °C). They had to wear loose fitted clothing such as a T-shirt and shorts, to prevent any restrictions in range of movement [30]. After acclimatisation, a measurement training session was held to standardize measurement protocol. Before each session movements were practiced three times to diminish stretching and learning biases [31]. Hamstring and lower limb muscle length tests were performed in the same order at each testing session for each participant.

Tests

Before placement of the digital inclinometer (Fabrication Enterprises Inc., White

Plains, NY, USA), the anatomical reference points were marked with a skin marker. Reference points were on the mid-point of the anterior tibial crest, which was determined by applying tape to measure the participant's tibia length from the medial malleolus to the medial joint line of the knee [32] and at the level of the T4 spinous process [33].

Standing Hamstrings Stretch (SHS) test [34–36] To assess the maximum trunk and lower limb flexibility. During the SHS test, the baseline digital inclinometer ~~(Fabrication Enterprises, White Plains, NY, USA)~~ was used to measure the trunk flexion. The manufacturer reports an accuracy of ± 0.5 degrees [37]. The participants were asked to stand upright in a comfortable position and to flex slowly the trunk in the sagittal plane without bending the knees, and hold this position for 3 s. After returning to the neutral upright position, they were asked to ~~duplicate the previously attained position~~perform once again the maximal anterior trunk flexion and held the position for 3 s. The mean of the two scores was used to assess the value of the SHS test. ~~The reliability of the standing hamstring stretch test was excellent (α = 0.990).~~

Sit-and-reach test [38] Using a Flex-Tester box (Cranlea, Birmingham, UK), participants were barefoot with legs fully extended and instructed to lean forward as far as possible with the end position held for at least 2 s. The task was repeated two times. The better of the two trials from each time point was taken for further statistical analysis [22]. ~~The reliability of the sit-and-reach tests was excellent (α = 0.990).~~

Active Knee Extension Test (AKET) [30] Participants were positioned supine on a plinth so that the leg not being tested was flat on the plinth with the knee extended. A strap was placed over the mid-thigh of this leg to eliminate any elevation of the limb. An additional strap was positioned over the front of the participant's pelvis and around the plinth to maintain the pelvis in a neutral position during hamstring measurements. An iron apparatus was then placed on the plinth in line with the participant's anterior superior iliac spine of the pelvis. The participant was asked to flex the hip of the tested leg so that their thigh was touching the iron apparatus. The participant was then asked, "straighten your leg at the knee as far as you can while maintaining your thigh touching the iron apparatus" and held the end position for at least 2 s. The digital inclinometer determined the angle of knee extension giving an indication of hamstring muscle length [30]. Two measurements were taken for each leg and the mean of the two scores was used to assess the value of the AKET. ~~The reliability of the AKET testing was excellent ($\alpha = 0.976$ for the left leg; $\alpha = 0.987$ for the right leg).~~

Trunk repositioning To assess the trunk position sense, as indicated by trunk reposition errors (TRE), a digital inclinometer was held at the level of the T4 spinous process. Participants, with eyes closed, flexed the trunk in the sagittal plane until the position the rater wanted the individual to be and hold this position for 3 s and to remember this position (position 1). After returning to the neutral upright position, they were asked to duplicate the previously attained position. Participants indicated verbally when they felt they had reached the angle and held their position for a count of 3 s (position 2). The absolute difference in degrees between position 1 and 2 was defined as the TRE [33]. Participants generated three scores and the mean of the scores represents the TRE score. ~~The reliability of the trunk repositioning testing was excellent ($\alpha = 0.976$).~~

<u>Interventions</u>

The four above mentioned tests were performed before and immediately after each condition: 1) [S]; 2) [S + WBV]; 3) [Cryo]; 4) [Control];

1) Subjects performing [S] were asked to stand upright in a comfortable position and to flex the trunk in the sagittal plane and hold this position for 30 s. After returning to the neutral upright position, they were asked to recover for 30 s and to repeat this

procedure for three times [39]: the total duration (SHS repetitions plus recovery) was 150 s.

2) Similarly to [S], subjects performing [S + WBV] had to stand upright in a comfortable position and to flex the trunk in the sagittal plane and hold this position for 30 s over a vibration platform (Power Plate pro5; Power Plate International Ltd, London, United Kingdom) set with a moderate (40Hz) frequency and a low (2-4 mm) amplitude. After returning to the neutral upright position, they were asked to recover for 30 s and to repeat this procedure for three times [39]: the total duration (SHS repetitions and recovery) was 150 s. The 30 s duration of each set over the vibration platform can provide adequate safety for participants who engage in WBV training for the first time [40].

3) During the PBC [Cryo], subjects completed a partial-body cryotherapy session of 150 s in a cryo-cabin (Space Cabin, Criomed, Ltd, Kherson, Ukraine). PBC session allowed to expose participants to very low temperatures (from -130 to -170 °C, as reported by the manufacturer). During the session subjects wore swimwear, a pair of gloves, woollen socks and wooden clogs to prevent the occurrence of frostbite. The head was not cryo-exposed. Participants were instructed to turn around continuously in the cabin for the entire time of the session [41].

4) Under control condition [Control], subjects rested in sitting position for a period of 150 s between the two bouts of tests, upright against the back of a chair with feet flat on the floor, in a room where the temperature was stabilized (22 ± 0.5 °C).

Skin temperatures of the ventral and dorsal regions of of interest (ROIs) were assessed by means of a ThermoVision SC640 thermal imaging camera (Flir Systems, Danderyd, Sweden) in accordance with the standard protocol of infrared imaging in medicine [42,43]. Thermal images were taken prior to each testing protocol. The camera, with the emissivity set in the range of 0.97 to 0.98, was connected to a personal computer with appropriate software (Thermacam Researcher Pro 2.10, version 5.13.18031.2002, Flir systems 2015, Danderyd, Sweden). The camera was mounted on a tripod and positioned in a way to focus on the hamstrings area. The distance between the camera and the ROIs was kept constant at 1m. A mean temperature was calculated by averaging the skin temperature recorded for the ROIs.

Statistical analysis

The normality of the data distribution was assessed by Shapiro-Wilk test.

The test-retest reliability of the sit-and-reach test, AKET, SHS test, trunk repositioning test were measured using an intraclass correlation coefficient (ICC, Cronbach-α) and interpreted as follows: $\alpha \geq 0.9$ = excellent; $0.9 > \alpha \geq 0.8$ = good; $0.8. > \alpha \geq 0.7$ = acceptable; $0.7 > \alpha \geq 0.6$ = questionable; $0.6 > \alpha \geq 0.5$ = poor [44].

All data were presented as mean ± standard deviation (SD). The flexibility performances and trunk repositioning pre- and post-intervention, and the relative thermographic measurements were analyzed with a mixed (time x intervention) repeated measures analysis of variance (ANOVA). Post hoc pair-wise comparisons were conducted utilizing Tukey's or Bonferroni's test when main or interaction effects were demonstrated. The sphericity assumption was examined using Mauchly's test. Eta squared (η^2) effect sizes (ES) were determined and interpreted using the following criteria: 0.01 = small; 0.06 = medium; 0.14 = large [45]. For all analyses, a p value less than 0.05 was considered statistically significant.

Analyses were carried out with the Statistical Package SPSS version 25 for Mac (IBM Corp., Armonk, NY, USA), GraphPad Prism 5 (San Diego, CA, USA), and Excel version 16.32 for Mac (Microsoft, Redmond, WA, USA).

Results

All demographic and anthropometric characteristics of the participants are offered in Table 1. All women resulted to be normal weight, fit, and healthy, as assessed on physical examination.

[Table 1 near here]

Flexibility variables and proprioception

Standing Hamstring Stretch (SHS) test Results, expressed as change from baseline, revealed a main interaction (F = 3.575, pP = 0.0254, η^2 = 0.153) among the interventions with a significant improvement in ROM after [S + WBV] with respect to [Control] (Tukey's post-hoc, pP < 0.05; mean difference: -2.909, 95% CI: -5.599 to -0.2188) (Fig. 2A). The reliability of the standing hamstring stretch test was excellent (α = 0.990).

Sit-and-reach ANOVA showed a significant interaction among the interventions as to the sit-and-reach amplitude of the women tested (F = 3.688, pP = 0.0226, η^2 = 0.243). In line with the SHS results, the participants' sit-and-reach amplitude benefitted from [S + WBV] as compared to [Control] (Tukey's post-hoc, pP < 0.05; mean difference: -2.136, 95% CI: -4.067 to -0.2058) (Fig. 2B). The reliability of the sit-and-reach test was excellent (α = 0.990).

Active Knee Extension Test (AKET) Outcomes, still expressed as change from baseline, revealed a main effect among the interventions (F = 4.694, pP = 0.0084, η^2 = 0.168), with a significant improvement in ROM after PBC [Cryo] with respect to [Control] (Tukey's post-hoc, pP < 0.05; mean difference: 3.434, 95% CI: 0.4880 to 6.380) (Fig. 2C). The reliability of the AKET testing was excellent (α = 0.976 for the left leg; α = 0.987 for the right leg).

Trunk Repositioning Error As to absolute difference during the repositioning test, a main effect was not found (Fig. 2D). The reliability of the trunk repositioning testing was excellent ($\alpha = 0.976$).

Overall performance data, emerging from the four routine protocols, are also reported as pre- and post- intervention values in Table 2.

[Figure 2 near here]

[Table 2 near here]

Thermal responses

Ventral skin temperature analysed by means of thermal images confirmed an effective decrease procured by cryotherapy (Fig. 3). A significant interaction “time x treatment” was documented (F = 715.6, pP < 0.0001, $\eta^2 = 0.906$). In detail, ventral temperature of both lower limbs was significantly affected by PBC (F = 146.2, pP < 0.0001, $\eta^2 = 0.916$) and time (F = 845, pP < 0.0001, $\eta^2 = 0.793$). As expected, post-hoc comparisons revealed that temperature was significantly lower after PBC (13.7 ± 1.9 °C, Bonferroni’s, p P< 0.0001, Fig. 3) with respect to all other post-intervention temperatures, which remained ~ 29-30 °C (Fig. 3).

[Figure 3 near here]

Discussion

In this study we investigated the impact of different routines to ameliorate trunk-, lower limbs flexibility while considering trunk proprioception in a sample of young women.

The present data showed that women gained a greater effect in SHS test and sit-and-reach amplitude with [S + WBV] as compared to all other protocols. PBC allowed to achieve a major benefit in the AKET with respect to the other routines. Overall, these flexibility improvements were obtained without a loss in the trunk position sense proprioception.

A broad literature entails a multitude of strategies and stretching protocols to obtain specific advantages in flexibility [9, 10, 46, 47]. Nevertheless, only a few studies have included cryo-exposures protocols to assess possible gains in ROM and proprioception acuity [48, 49]. Proprioception can be defined as the awareness of the position of a joint or of a particular body district in space. Although proprioception encompasses several components, including kinesthesia, balance, reflexive joint stability, somatosensation, a number of evidence-based indications suggest that the somatosensory system is affected when very low temperature is applied to the muscles [48]. Increases in flexibility could be due a reduced neural activation during cryo-exposure [22]. Cryo-induced pain limitation may represent another potential mechanism responsible for these flexibility improvements. Similarly, increases in pain thresholds have been reported in research articles studying flexibility by means of whole-body vibration [19, 20].

Consistently with other studies focusing on the combination of stretching with vibration [15,16], the present results confirmed the efficacy of WBV in augmenting flexibility, acutely. ~~Differently from cryotherapy, i~~It has been suggested that vibration might procure increases in flexibility by enhancing the stretch reflex loop, through the activation of the primary endings of the muscle spindles, which influences agonist muscle contraction, whilst antagonists are simultaneously inhibited [50]. Furthermore, vibration may also enhance flexibility by activating the Ia inhibitory interneurons of the antagonist muscle, thus decreasing the braking force around a joint [51]. It has also been hypothesized that the inhibition of the antagonist muscle, induced by vibration, is mediated by supraspinal neuronal circuitry [52]. Finally, the vibratory stimulus of the Ia neural drive and proprioceptive loop may also replicate a warm-up effect by increasing pain threshold, blood flow and muscle elasticity~~augmenting muscle temperature and elasticity resulting from elevated blood flow~~ [19, 20]. However, these mechanisms remain putative and associated to prolonged interventions and longer vibration applications than the subjects experienced in the present study.

At the superficial level, skin temperature decreased significantly only after cryostimulation as expected.

The results of this research provided the first and unique evidence that a single session of either PBC or WBV can significantly and positively impact on flexibility without compromising the proprioception capacity. This is of practical value for coaches and trainers aiming to find routines to ameliorate trunk and lower limbs flexibility of female athletes in sports disciplines where a high level of proprioception, in addition to the flexibility, is required. That might be the case, for example, for ice skaters, divers and gymnasts.

As a limitation, the present research was restricted to female subjects therefore generalizations cannot be inferred and applied to a large spectrum of the population. This latter problem is exacerbated by the small sample size. Promising data stemming from previous works [22], along with a prevalent practice of gymnastics and skating among females [53], justified a local mono-gender investigation. Beyond enrolling different gender, further insights could be gathered by recruiting different athletes and diverse sport practitioners. In addition, longitudinal studies may examine adaptive effects originating from chronic modalities of training.

As a strength point, the experimental design in which all the tests were performed, in all interventions, in the same subjects, enhanced the signal-to-noise ratio associated to this study, permitting to achieve a clear-cut significance.

In light of the emerged findings, it is now sound that coaches can schedule PBC and WBV sessions before a training session or a competition, such as in skating, diving, and gymnastics, whereby adequate levels of both flexibility and proprioception are required.

Declaration of interest

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions M.D.N., C.F. performed the studies. R.C. analyzed the data. M.D.N., R.C. wrote the manuscript. M.D.N., C.F., P.R., A.L.T., R.C. contributed to the discussion and reviewed the manuscript. M.D.N. designed the studies. M.D.N., R.C. supervised the studies. All authors edited the manuscript. R.C. is the guarantor of this work and, as such, had full access to all the data in the studies and takes responsibility for the integrity of the data and the accuracy of data analysis.

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Captions

Table 1. Demographic and anthropometric characteristics of the women studied.

Table 2. Summary results of the participants performing different routine protocols (mean ± SD)

Figure 1. Flow-chart of the study.

AKET, active knee extension test; Cryo, partial-body cryotherapy; S, stretching; SHS, standing hamstrings stretch; SD, standard deviation, TRE, trunk repositioning errors; WBV, whole-body vibration.

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Figure 2. Flexibility outcomes and proprioception

Graphical representation of the absolute difference in the three flexibility tests (A, B, C) and trunk position sense (D) compared to the baseline measurements. Whiskers box-plot: the hinges of the plot extend from the 25th to 75th percentiles. The whiskers go down to the smallest value and up to the largest one.

AKET, active knee extension test; Cryo, partial-body cryotherapy; S, stretching; SHS, standing hamstrings stretch; SD, standard deviation, TRE, trunk repositioning errors; WBV, whole-body vibration.

* $p < 0.05$

Figure 3. Thermal responses

Cryo, partial-body cryotherapy; S, stretching; WBV, whole-body vibration.

*** $p < 0.0001$