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ORIGINAL ARTICLE

Different stretching methods do not affect maximal force and neuromuscular response in young soccer players

Les différentes méthodes d'étirement n'affectent pas la force maximale et la réponse neuromusculaire chez les jeunes joueurs de football

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KEYWORDS
Team sports;
Physical performance;
Range of motion;
Muscle strength

Summary
Objectives. — The aim of the present study was to compare the acute effects of different stretching methods on maximal force and neuromuscular responses in young soccer players.
Equipment and methods. — Twelve players (17.7 ± 0.9 years) were randomly subjected to active, ballistic, passive, and proprioceptive neuromuscular facilitation stretching methods, in addition to a control condition. Before and after 3 sets comprising 30 s stretching intervention, the range of motion, peak force, superimposed twitch, potentiated twitch, percentage of voluntary activation, and root mean square of the electromyography signal normalized by the maximal wave were assessed.

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Results. — The stretching modalities effectively improved the range of motion (1.71 to 2.46 cm; $P < 0.05$). On the other hand, no independent (i.e., test time, condition) and interactive (i.e., test time and condition) effects were found on maximal force and neuromuscular parameters.
Conclusion. — Active, ballistic, passive and proprioceptive neuromuscular facilitation stretching did not negatively affect the subsequent maximal force and muscle activation, but enhanced soccer players' range of motion. The results suggest that physical trainers and athletes could use these stretching modalities to improve flexibility without subsequent adverse effects on maximal force.

MOTS CLÉS
Sport collectif ;
Performance physique ;
Amplitude de mouvement ;
Force musculaire

Résumé
Objectifs. — Le but de cette étude était de comparer les effets aigus de différentes méthodes d'étirement sur la force maximale et la réponse neuromusculaire chez les jeunes joueurs de football.
Matériels et méthodes. — Douze joueurs (17,7 ± 0,9 ans) ont été soumis au hasard à des étirements actifs, balistiques, passifs, et à la facilitation neuromusculaire proprioceptive, au-delà d'une condition de contrôle. Avant et après l'intervention de trois séries comprenant trente secondes d'allongement d'intervention, on a évalué l'amplitude de mouvement, la force maximale, la contraction superposée, la contraction potentialisée, le pourcentage d'activation volontaire, et la racine carrée moyenne du signal électromyographique normalisé par l'onde maximale.
Résultats. — Les modalités d'étirement ont effectivement amélioré l'amplitude du mouvement articulaire (1,71 à 2,46cm ; $p < 0,05$). D'autre part, aucun effet indépendant (moment, condition) et interactif (moment et condition) sur la force maximale et les paramètres neuromusculaires n'a été trouvé.
Conclusion. — Les étirements actifs, balistiques, passifs et la facilitation neuromusculaire proprioceptive n'ont pas affecté négativement la force maximale et l'activation musculaire, mais ils ont augmenté l'amplitude de mouvement des joueurs de football. Les résultats suggèrent que les entraîneurs et les athlètes peuvent utiliser ces modalités d'étirement pour améliorer la flexibilité sans entraîner d'effets néfastes ultérieurs sur la force maximale.

1. Introduction

In soccer, stretching exercises are commonly used in warm-up activities during training sessions and competitions. Among the methods used are active, passive, ballistic, and proprioceptive neuromuscular facilitation (PNF) stretching [1]. However, previous studies have shown that acute stretching sessions can temporarily reduce muscle force production capacity [2—11]. In soccer, the decisive game actions are of high intensity and short duration with highly associated maximal force [12]. Therefore, it is critical to understand whether a particular stretching method has a detrimental effect on muscle force. Likewise, understanding the neuromuscular mechanisms involved is fundamental to developing strategies to avoid adverse effects.

Performance reductions in maximal force are often observed after stretching sessions, including active [4,9,13,14], passive [2,3,5—8,10,11,15—17], and PNF stretching methods [11,18]. On the other hand, the ballistic method does not seem to compromise performance for this capacity [15,18]. When the methods were confronted in the same study, similar reductions in maximal force were found comparing the passive and PNF stretching methods [11], with maximal force decrease for passive stretching and unchanged maximal force for ballistic stretching [15]. Other studies showed unchanged maximal force for ballistic and passive and reductions for PNF stretching [18]. These studies show contrasting responses, and suggest that the effects may differ depending on the stretching method used.

The force loss, termed ''stretching induced force deficit'', has been attributed to changes in neural/central factors, peripheral/mechanical or the combination of both [6,7,18—22]. In this sense, the twitch interpolation technique is frequently used for investigating the physiological mechanisms associated with stretching induced force deficit. Previous studies using this technique reported reductions in peak force (Fpeak) [2,7], percentage of voluntary activation (VA) [2,6,7], and the root mean square of the electromyographic signal normalized by the maximal amplitude (RMS/M-wave) [6,7]. In addition, increased associations were found between the drop percentage of Fpeak and drop percentage for both variables, VA and RMS/M-wave [7]. These data demonstrate that reductions in force after stretching exercises are associated with a decreased muscle activation capacity mediated by neural factors.

However, contradictory responses were observed as reduced maximal force is not followed by reduced muscle activation [3,5,8,11], or no change at all in both maximal force and muscle activation [23,24]. In addition, most studies involving analysis of neural factors employed only passive stretching [2,6,7], while others identified differ-

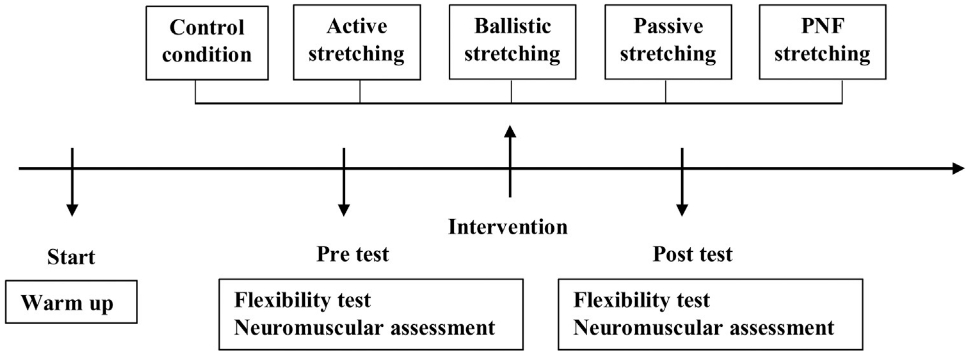

Figure 1 Experimental design. PNF: proprioceptive neuromuscular facilitation stretching condition.

ences between the stretching methods, but investigated only peripheral factors or did not look at the neural mechanisms involved [15,18]. Thus, it is reasonable to investigate whether these differences may be associated with neural factors mechanisms. In addition, our group's previous study demonstrated that the active and ballistic methods did not negatively affect vertical jump and sprint, while passive and PNF stretching decreased vertical jump performance [25]. These results indicated that the stretching methods induced different responses, probably related to neuromuscular mechanisms. To investigate these differences, the present study will demonstrate neuromuscular responses induced by different stretching methods on the maximal force using the interpolated twitch technique. In addition, to clarify the possible ''stretching-induced force deficit'', we also tested the effects of stretching stimuli on the maximal force test.

Therefore, the purpose of the present study was to compare the acute effects of active, ballistic, passive, and PNF stretching methods on maximal force performance and the neuromuscular mechanisms involved in young soccer players. Our hypothesis is that the active and ballistic stretching methods do not change, while the passive and PNF reduce the maximal force performance, associated with different contributions of neuromuscular mechanisms.

2. Methods

2.1. Participants

The sample of the present study was calculated based on the study of Haddad et al. [26]. This study observed an effect size on the difference between the groups of 0.94 [27]. Adopting 0.05 as alpha parameters, power (1 - β) of 0.80 and the effect size observed in the aforementioned study using the means of dependent groups, we calculated that at least 11 sample units were necessary. The calculations were performed in the statistical software G*Power, version 3.1.9.4 (Universität Düsseldorf, Düsseldorf, Germany).

Twelve soccer players participated in the study (mean ± SD: age 17.7 ± 0.9 years; height 1.8 ± 0.1 m; body mass 67.4 ± 4.8 kg). They were from the U-20 team category playing in the third division of the Chinese national league. The inclusion criteria were men between 16 and 20 years old and at least one year of experience in strength training. The exclusion criteria were current neuromuscular injuries. The current study was approved by the Research Ethics Committee of the School of Physical Education and Sport of Ribeirão Preto (protocol no. 1.050.789), and carried out following the rules set out in the Declaration of Helsinki.

2.2. Experimental design

A randomized crossover design was used to investigate the acute effects of five experimental conditions- active, ballistic, passive and PNF stretching, and control- on maximal force and neuromuscular responses. The experimental protocol was carried out over five days, with a minimum interval of 48 hours between each day. The evaluations always took place at the same time (8:00–11:00 am), and the mean daily temperatures were between 29–31 °C (climatic record of the Meteorological Research Institute, IPMet, Brazil).

The participants started the protocol with a general warm-up consisting of 5 min running at 9 $km \cdot h^{-1}$ on a treadmill, and an initial test of flexibility. Then neuromuscular assessments were performed, starting with the determination of the electrostimulation threshold point, followed by the interpolated twitch technique. After that, each participant performed one of the five experimental conditions (active, ballistic, passive and PNF stretching, and control) in random order - the randomization process was conducted through a draw on the assessment day. For the stretching conditions, a 15-min session was performed, while the participants sat during the same period in the control condition. Finally, an additional flexibility test was performed, followed by neuromuscular evaluations using the interpolated twitch technique (Fig. 1).

2.3. Flexibility test

The sit and reach test was used to evaluate the range of motion (ROM) [28]. Participants started the test in a sitting position, trunk upright, knees extended, and the soles of the feet resting on the evaluation box, and with hands over the measuring tape (Sanny®, BW2005, São Paulo – Brazil). For the test execution, three preparatory oscillatory movements were performed, followed by a fourth movement where the participant had to slide his hands along the tape, seeking the point of most possible horizontal reach, and maintaining the position for at least two seconds. Three trials were performed, and only the best result was considered for statistical purposes.

2.4. Neuromuscular assessment

2.4.1. Electrostimulation and threshold determination

Participants were seated and positioned in a specific chair customized for the analysis, with the hips and knees flexed at 90° [29], and firmly attached to the seat by crossed belts around the chest, waist, and lower thigh. The participant's dominant member was attached to the equipment on the ankle, using a velcro strap, attached to a metal rod coupled to a load cell (MK Controle®, CSR 200, São Paulo - Brazil). The maximal response threshold to electrostimulation was determined by applying consecutive incremental electrical stimuli (increments of 5—10 mA) to the femoral nerve towards the relaxed muscle. The increments reached the participant's voluntary limit, up to the intensity where no increase in the torque produced by the muscle was observed [6]. The electrical stimuli were applied with a single pulse, short duration (1 ms), and high voltage (400 V), through an electrostimulation prototype (Insight®, Ribeirão Preto - Brazil), with conductive rubber electrodes (7 × 5 cm) positioned on the femoral triangle (cathode) and gluteal fold (anode) [29]. The specific sites were located in the most sensitive area through a transcutaneous neuromuscular stimulator (Ibramed, São Paulo - Brazil).

2.4.2. Interpolated twitch technique

Neuromuscular evaluation sessions started with specific warm-up exercises, consisting of two sets of three submaximal isometric knee extensions with a 3 s duration and 10/30 s resting intervals between repetitions and sets, respectively. During the evaluation protocol, three maximal voluntary isometric contractions of 5 s duration and 1 min rest were performed to obtain peak force values (Fpeak) [30]. The participants were instructed to apply force ''as hard as possible''. Next, the interpolated twitch technique was applied. For this, three extra maximal voluntary isometric contractions were performed, using the same configuration, 5 s duration, and 1 min rest between sets. However, after the initial 3 s, supramaximal electrical stimuli (20% above the electrostimulation threshold) [6] under a maximal voluntary isometric contraction - superimposed twitch (ST). After 2 s, new electrical stimuli were applied to the relaxed muscle - potentiated twitch (PT) [6]. The electrical stimuli were applied in the femoral nerve with a single pulse, short duration (1 ms), and high voltage (400 V). During the evaluation of the interpolated twitch, the collected variables were ST and PT amplitude, voluntary activation percentage (VA) referring to the force signal, the root mean square (RMS), and the maximal amplitude of the electromyography signal (M-wave).

2.4.3. Force data collection and analysis

The force measures were collected by a load cell (MK Controle®, CSR-200, São Paulo - Brazil), connected to an analog/digital signal acquisition board (National Instruments®, NI-USB 6009, Texas - United States). The signal was acquired with a sample rate of 1,000 Hz and smoothed in a fourth-order Butterworth filter and 15 Hz cutoff frequency. The variables Fpeak, ST, PT, and VA were obtained. The Fpeak was obtained in a 100 ms window at the force plateau. ST and PT were determined as the peak-to-peak amplitude signal at the moment of electrical stimulation under conditions of superimposition to a maximal voluntary isometric contraction and with the muscle relaxed, respectively. The equation (1) proposed by Allen et al. [31] was used to determine the VA and, when necessary, it was corrected by equation (2) adapted by Strojnik and Komi [32] when the stimulus was not given in the window corresponding to the force peak:

$$\text{VA}(\%) = \left[1 - \left(\frac{\text{ST}}{\text{PT}}\right)\right] \times 100 \quad (1)$$

$$\text{VA}(\%) = \left\{1 - \left[\frac{\text{ST} \times \left(\frac{\text{force level at stimulation}}{\text{Fpeak}}\right)}{\text{PT}}\right]\right\} \times 100 \quad (2)$$

2.4.4. Muscle activity data collection and analysis

The muscle activity was monitored using an electromyograph, Bagnoli-2 EMG System (Delsys®, Boston - United States). The skin was previously shaved with fine sandpaper and sanitized with alcohol 70% at the electrode fixation site (Ag-AgCl, 20 mm). The disposition of the electrode followed the guidelines of Hermens et al. [33], and the muscle monitored was the vastus lateralis. The electromyography acquisition signal was performed at 2,000 Hz with a gain of 1,000 times, using EMGworks software (Delsys®). Next, the signal was processed in a bandpass filter, with a cut-off frequency of 20—500 Hz. Muscle activity was expressed as the RMS of electromyography signal and normalized to the M-wave. The RMS was obtained at a 1,000 ms cut-off window during the force plateau, and the M-wave was determined as the peak-to-peak amplitude of the evoked signal during the PT. For all force and electromyography variables, only data from the trial with the highest Fpeak value was used for statistical purposes.

2.5. Stretching session

The stretching session was based on the ''sitting toe touch'', ''lateral quadriceps stretch'', ''supine knee flex'', and ''step stretch'' exercises [More details in Oliveira et al. [25]]. These exercises were for the hamstring, femoral quadriceps, gluteus maximus, and sural triceps muscle groups, respectively.

For the stretching session, 3 sets were performed, following the protocol proposed by Barroso et al. [34]. During the active method, the participants performed stretching in an active form, without external assistance, and maintained the stretched position for 30 s. The same protocol was used for the passive stretching, but performed in a passive form by a licensed physiotherapist. For the ballistic method, the participants performed oscillatory stretching movements, at a rate of 1:1 s per cycle, for 1 min. A metronome controlled the frequency of movement. For the PNF stretching, the hold-relax technique was used, consisting of 5 s of passive stretching, followed by 5 s of submaximal isometric contraction [∼ 65% of the maximal [35], determined by subjectively] of the stretched muscle, followed by group muscle relaxation, and another 20 s of passive stretching applied by a licensed physiotherapist.

The total volume of stretching was equalized between the methods, with three stretching sets of 30 s, a 30 s interval between sets, and one exercise per muscle group, totaling 90 s stretching per muscle group and 15 min total session time. Stretching intensity was pre-established as the maximal point of discomfort, level 100 on a 0—150 a.u. scale of effort perception, developed and validated for stretching exercises [36].

2.6. Statistical analysis

Normality was assessed using the Shapiro-Wilk test. Data were reported as mean and standard deviation. For all variables, the relative changes in relation to the pre test were calculated. To verify the effect of time (pre and post test) and condition (control, active, ballistic, passive and PNF) factors on range of motion, force and electromyography parameters, mixed-model ANOVA was used. Sidak's post hoc test was used to locate differences when significance was found. In addition, the effect size was calculated for pre and post test using Cohen's d, interpreted as trivial (< 0.20), small (0.20-0.50), moderate (0.51-0.80), and large (> 0.80) magnitude of changes [27]. The significance level adopted was $P < 0.05$. All statistical analyses were performed using Statistical Package for Social Science for Windows - SPSS, version 20.

3. Results

There was no experimental condition ($P > 0.998$) effect on ROM during the sit and reach test. However, a significant effect of time and interaction ($P < 0.05$) was found. Post-hoc analysis revealed a significant increase in ROM after active ($\Delta = 1.71 \pm 0.89$ cm; d = 0.28; ($P < 0.001$), ballistic ($\Delta = 1.83 \pm 1.21$ cm; d = 0.34; ($P < 0.001$), passive ($\Delta = 2.21 \pm 1.68$ cm; d = 0.39; ($P < 0.001$), and PNF ($\Delta = 2.46 \pm 1.23$ cm; d = 0.42; $P < 0.001$) experimental conditions. There was no significant change for control condition ($\Delta = 0.33 \pm 0.54$ cm; d = 0.07; ($P = 0.865$) (Fig. 2 and Table 1). For force and electromyography data monitored during a maximal isometric voluntary contraction, there was no effect of experimental condition, time or interaction on Fpeak, TS, TP, VA and RMS/M-wave variables.

4. Discussion

No evidence of acute stretching methods was found on maximal force and neuromuscular response after 3 sets of 30 s stretching. Our findings are interesting and demonstrate that stretching sessions of low to moderate volume may not affect maximal force and muscular activation for young soccer players. Although similar responses have already been reported for the passive method [24], the present study is novel as it extends these findings to active, ballistic and PNF stretching methods as well. These results, together with flexibility test, demonstrate that increasing the range of motion using any stretching method, does not change the maximal force and muscular activation.

Interestingly, except for the ballistic method [15,18], previous studies demonstrated Fpeak reduction after stretching sessions involving active [4,9,13,14], passive [2,3,5—8,10,15—17] and PNF [11,18] methods. For the passive stretching method, in addition to a decrease in force, reductions in VA [2,7] and RMS normalized by amplitude M-wave [6,7] have been observed. The RMS normalized by amplitude M-wave, enables the electromiography analysis to be free of peripheral factors influence during measurements [19]. Trajano et al. [7] reported high associations between the percentage of force loss after passive stretching and percentage drop for both VA (r = 0.93) and RMS/M-wave (r = 0.88). Together, these data demonstrate an acute reduction in muscle activation after stretching sessions, pointing to critical contribution of neural factors to force decline. Here we did not observe evidence of a decrease in voluntary force (Fpeak) or even significant alterations in the other evoked parameters of force (TS, TP, VA) and electromyography (RMS/M-wave) results from twitch interpolation data. Therefore, our data suggest that force and muscle activation seem preserved after stretching sessions.

However, significant methodological differences between the cited studies and the present study could explain the results. The main difference observed is related to the total stretching volume (i.e., volume accumulated by muscle group). While we used only 1.5 min of stretching volume in the present study, most previous studies apply volumes greater than 3 min [2—11]. There is a body of evidence demonstrating force decrease after high (> 3 min; 3.8 to 29.3 min) total stretching volumes [2—11] and mixed responses showing reductions [8,13—18] or no alterations [15,18,23,24,37,38] after moderate to low (≤ 3 min; 0.7 to 3 min) total stretching volume. Therefore, in the current study, only 3 sets of 30 s were used, and the total stretching volume (1.5 min) was probably insufficient to generate neural alterations that could affect maximal force capacity. These responses are interesting, since the force decrease found by most studies using high volumes [2—11] were not found here using moderate to low volume stretching.

In addition, it is known that the ''stretching induced force deficit'' is a transitory phenomenon, returning to baseline values after 10—15 min [6,39], 60 min [2], or even 24 hours [26] after stretching. In the present study, the order of the stretching exercises was fixed, where the hamstring muscles were stretched first, followed by the quadriceps, gluteus maximus, and sural triceps. Therefore, the quadriceps muscle group was always the second stretched muscle. Knowing that the quadriceps is the primary muscle group recruited during knee extension, the time interval between stretching the quadriceps and the neuromuscular evaluation (~ 10 min) was sufficient to dissipate the stretching effect. Indeed, a previous study showed that not only a passive interval but the inclusion of a specific warm-up involving actions of the sport modality, could reverse the harmful effect of stretching [40]. Therefore, a last explanatory hypothesis is that the inclusion of a specific warm-up, performed prior to the neuromuscular assessment, may have reversed the effect of reducing maximal force caused by stretching exercises.

Finally, the present study has limitations. The first is related to the sample size. Although the present study was based on a sample size from a previous study [26], the

Table 1 Description values for all parameters.

		Control	Active	Ballistic	Passive	PNF	ANOVAmixed-model	*P*-value
ROM (cm)	Δ change	0.33 ± 0.54	1.71 ± 0.89	1.83 ± 1.21	2.21 ± 1.68	2.46 ± 1.23	Interaction	< 0.001
	Cohen's-d	0.07 (trivial)	0.28 (small)	0.34 (small)	0.39 (small)	0.42 (small)	Time	< 0.001
							Condition	0.998
Fpeak (*n*)	Δ change	14.73 ± 108.18	−5.58 ± 63.04	13.34 ± 80.36	27.25 ± 78.22	−0.59 ± 77.91	Interaction	0.876
	Cohen's-d	0.08 (trivial)	0.03 (trivial)	0.06 (trivial)	0.14 (trivial)	0.01 (trivial)	Time	0.362
							Condition	0.976
ST (*n*)	Δ change	−4.72 ± 10.17	2.08 ± 13.29	−7.31 ± 21.54	2.59 ± 17.05	0.66 ± 14.89	Interaction	0.450
	Cohen's-d	0.27 (small)	0.13 (trivial)	0.37 (small)	0.15 (trivial)	0.03 (trivial)	Time	0.515
							Condition	0.816
PT (*n*)	Δ change	0.53 ± 23.37	8.01 ± 23.64	−4.75 ± 24.11	4.14 ± 21.97	−7.75 ± 21.08	Interaction	0.441
	Cohen's-d	0.01 (trivial)	0.28 (small)	0.08 (trivial)	0.17 (trivial)	0.22 (small)	Time	0.933
							Condition	0.483
VA (%)	Δ change	4.91 ± 6.20	−2.66 ± 7.35	−0.82 ± 8.46	−0.80 ± 7.66	−0.70 ± 6.41	Interaction	0.127
	Cohen's-d	0.69 (moderate)	0.46 (small)	0.14 (trivial)	0.09 (trivial)	0.08 (trivial)	Time	0.986
							Condition	0.917
RMS/M-wave	Δ change	−0.01 ± 0.13	−0.04 ± 0.20	0.01 ± 0.14	−0.02 ± 0.14	0.01 ± 0.14	Interaction	0.926
	Cohen's-d	0.19 (trivial)	0.23 (small)	0.15 (trivial)	0.18 (trivial)	0.01 (trivial)	Time	0.591
							Condition	0.128

ROM: range of motion; Fpeak: peak force; ST: superimposed twitch; PT: potentiated twitch; VA: percentage of voluntary activation; RMS/Mwave: root mean square normalized to the maximal M-wave amplitude; PNF proprioceptive neuromuscular facilitation stretching condition.

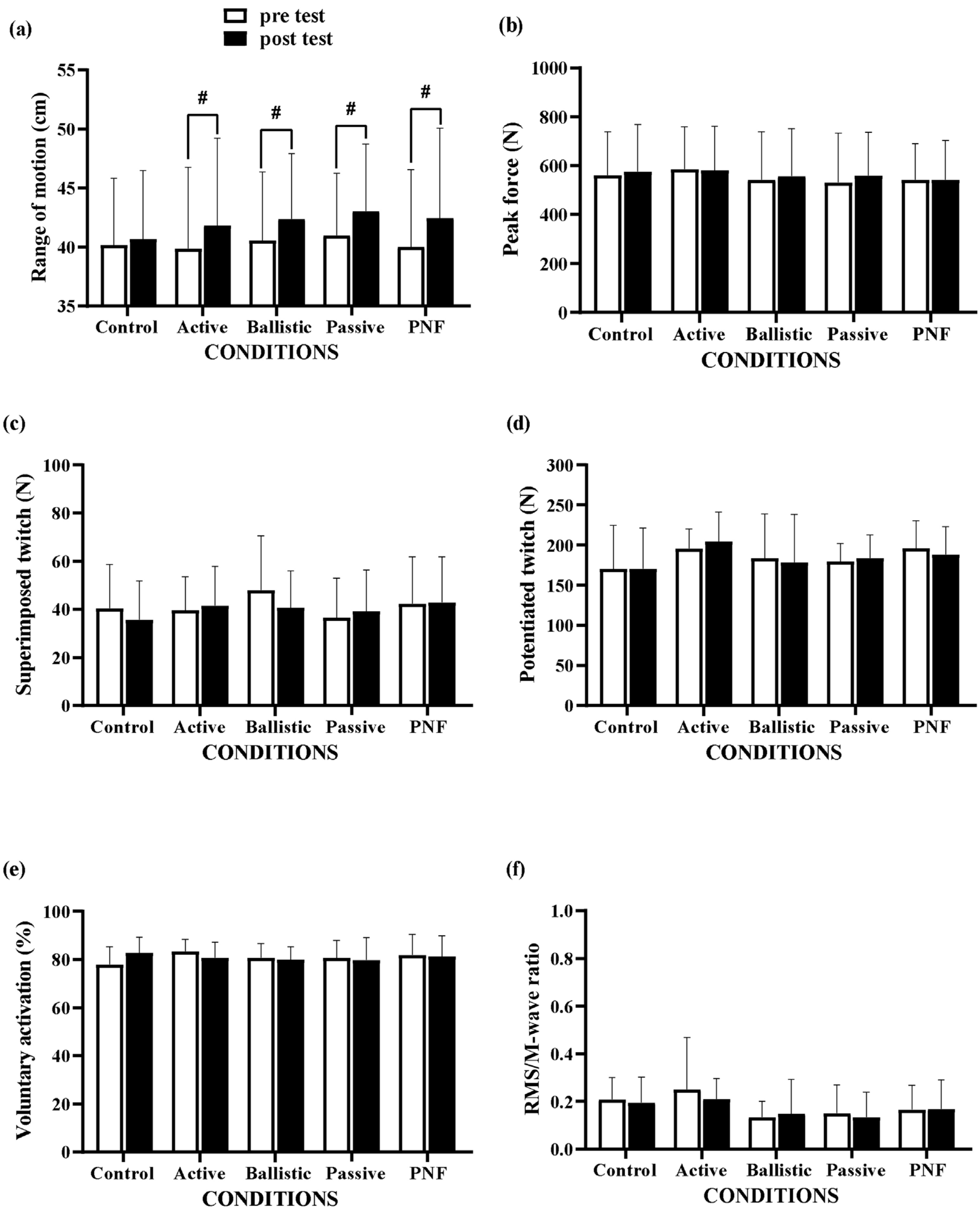

Figure 2 Acute effects of different stretching methods, or a control condition, on the range of motion, force, and electromyographic parameters. RMS/Mwave root mean square normalized to the maximal M-wave amplitude; PNF proprioceptive neuromuscular facilitation stretching condition; # Significant differences between pre and post test ($p < 0.05$).

sample size could have been larger. Another limitation is related to the experimental design. Although the repeated measures design here reduce inter-subject variability, we cannot rule out a possible carryover effect from one treatment to another. However, care involving the randomization of conditions, and a minimum interval of 48 hours between measurements were followed, reducing interference.

5. Conclusions

The stretching methods used in this study, including active, ballistic, passive and PNF stretching, did not negatively affect subsequent maximal force and/or muscle activation, but enhanced soccer players' range of motion. Our results suggest that physical trainers and athletes could use these stretching modalities to improve flexibility without subsequent adverse effects on maximal force. However, it is critical to note that our findings were studied under specific and standardized conditions of stretching volume and intensity for soccer players. Therefore, extrapolations to other conditions and populations should be viewed with caution.

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Disclaimer

The opinions, hypotheses, conclusions, or recommendations expressed in this material are the responsibility of the authors and do not necessarily reflect the views of FAPESP or CAPES.

Disclosure of interest

The authors declare that they have no competing interest.

Ethics Committee

This current study was approved by the Research Ethics Committee School of Physical Education and Sport of Ribeirão Preto (protocol no. 1.050.789) and carried out following the rules set out in the Declaration of Helsinki.

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