European Journal of Human Movement, 2015: **34**, 96-108

# STATIC-STRETCHING VS. CONTRACT-RELAX - PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING: STUDY THE EFFECT ON MUSCLE RESPONSE USING TENSIOMYOGRAPHY

Juan Manuel García-Manso [1]; Jesús López-Bedoya [2];
Darío Rodríguez-Matoso [1]; Leopoldo Ariza [3];
David Rodríguez-Ruiz [1]; Mercedes Vernetta [2]

1. Laboratory analysis and planning of the sports training. Department of Physical Education. University of Las Palmas de Gran Canaria.
2. Faculty of Physical Activity and Sport. Department of Physical Education and Sports. University of Granada.
3. Faculty of Education Sciences. Department of Artistic and Physical Education. University of Cordoba.

## ABSTRACT

This study used tensiomyography to examine the changes observed in the response of the biceps femoris muscle of the dominant leg of ten young female gymnasts (Mean age ± *SD*: 13.2 ± 1.8 years, height: 153.9 ± 6.0 cm, body mass: 42.0 ± 5.3 kg) after performing two different stretching protocols: *contract-relax* (*CR*) and *static-stretching* (*SS*). Results revealed change of muscle response immediately after warm-up: increased velocity of deformation ($V_{3mm}$), stiffness, holding time (*Ts*) and reduced relaxation time (*Tr*). The changes were most evident in the first three minutes after applying the two stretching protocols, being more evident in *CR* than in *SS*. The results suggests that athletes who include stretching in their warm-up will find the post warm-up mechanical response less impaired after the first three minutes and more so when using the techniques based on working with static-stretching, compared to techniques based in contract-relax.

**Key Words**: flexibility training, muscular response, tensiomyography

## RESUMEN

Este estudio utiliza tensiomiografía para examinar los cambios observados en la respuesta del músculo biceps femoral, de la pierna dominante, en diez jóvenes gimnastas femeninas (edad: 13,2 ± 1,8 años, altura: 153,9 ± 6,0 cm, masa corporal: 42,0 ± 5,3 kg), cuando realizan dos protocolos diferentes de estiramiento muscular: contract-relax (*CR*) y static-streching (*SS)*. Los resultados revelan cambios de la respuesta muscular inmediatamente después del calentamiento (incremento de la velocidad de deformación ($V_{3mm}$), stiffness y tiempo de sostén (*Ts*) y disminución del tiempo de relajación (*Tr*). Estas alteraciones son especialmente relevantes en los tres primeros minutos posteriores a la aplicación de los protocolos de estiramiento, siendo más evidentes en *CR* que en *SS*. Los resultados sugieren que los atletas que incluyen estiramientos en su calentamiento encontrarán la respuesta mecánica menos afectada una vez transcurridos los primeros tres minutos tras la finalización del calentamiento, y más aún cuando se utilizan técnicas basadas en el trabajo con Estiramiento-estático, en comparación con las técnicas basadas en la Contracción-Relajación.

**Palabras clave:** entrenamiento flexibilidad, respuesta muscular, tensiomiografia

---

*Correspondence:*
Leopoldo Ariza-Vargas
Faculty of Education Sciences. Department of Artistic and Physical Education. University of Cordoba. Avda. San Alberto Magno s/n, 14004, Córdoba (Spain).
eo1arval@uco.es

*Submitted: 29*/04/2014
*Accepted:* 25/02/2015

## INTRODUCTION

Of all physical abilities, flexibility has attracted least interest among the scientific community. This may be caused by its lack of a sound scientific foundation. It is a relevant part of many athletes' warm-up routines (Dadebo, White & George, 2004), but its application has not always been backed up by solid research to support the supposed benefits of its use from a scientific perspective.

Although the chronic response to a flexibility training protocol is well known and understood, there are some doubts about the acute effect that stretching has on muscular structures. There is absolute consensus that flexibility work brings with it a subsequent increase in joint range (ROM) (Robles, 2010; Rubini, Costa & Gomes, 2007), but there are doubts about the potential positive effect it may have on other physical abilities. In that regard, in recent years there have been numerous studies that propose the negative effects of stretching on maximal voluntary force (Rubini, Pereira & Gomes, 2005; Rubini et al., 2007), isokinetic strength (Agopyan, Tekin, Unal, Kurtel & Ersoz, 2013; Power, Behm, Cahill & Young, 2004), jumping ability (La Torre et al., 2010; Robles, 2010; Tsolakis & Bogdanis, 2012), anaerobic capacity (Cè, Margonato, Casasco & Veicsteinas, 2008), aerobic endurance (Wilson et al., 2010) or speed (Cè et al., 2008; Kistler, Walsh, Horn & Cox, 2010).

These works are in contradiction with the popular view and with other studies that state that isokinetic strength (Nelson & Kokkonen, 2001), jumping ability (Cè et al., 2008; Dalrymple, Davis, Dwyer & Mori, 2010; Murphy, Nagle, Robertson & MCrory, 2010), throwing (Haag, Wright, Gillette & Greany, 2010; McMillian, Moore, Hatler & Taylor, 2006) or speed (Wong et al., 2011) are not prejudiced (they may even improve slightly) after performing stretching exercises. The different types of flexibility work and variety of existing protocols used are the source of such discrepant results.

There is little documentation regarding the acute effect of stretching on muscle response (timing and magnitude of muscle response). Therefore, the purpose of this research was to evaluate the changes observed in the femoral biceps muscle response of the dominant leg after applying two different muscle stretching protocols: contract-relax (CR) and static-stretching (SS).

## METHOD

### *Participants*

Ten women (mean age [± SD]: 13.2 ± 1.8 years, height: 153.9 ± 6.0 cm, body mass: 42.0 ± 5.3 kg, body mass index: 17.7 ± 1.8 $kg.m^{-2}$; body fat: 5.1 ± 1.4 kg) were recruited from federated gymnasts (rythmic gymnasts). They all had a high competitive level and 6.02 ± 6.58 years of competitive experience. Participants and their parents were informed of the nature and objectives of the study and gave their signed written consent, following the criteria proposed in the Ethical Principles for Medical Research Involving Humans (Helsinki Declaration of the World Medical Association).

### *Procedure*

Before the working session, there was 10 minute-warm up running on the treadmill at a speed of 8 km·h$^{-1}$. The stretching exercise was done with "straight leg rise" over the entire range of motion in the static position of forced stretching and during isometric contractions of the stretched hamstrings. The free leg was anchored correctly in the horizontal position the athlete was supported on the bench. At all times, we sought to ensure that the preconditions for evaluation were identical for all participants in the sample (rest, training, etc.).

The stretching exercises followed two different protocols (Contract-Relax and Static- Stretching) separated by 90 minutes. The first protocol (CR) consisted of a series of 15 repetitions of 10 seconds of maximum forced stretching with 5 seconds relaxation between each stretch (Total: 150 s). The second protocol (SS) consisted of a series of 10 repetitions of 5 seconds contraction, followed by 10 seconds of maximum forced stretching and 2 seconds of relaxation (Total: 150 s).

### *Evaluation Criteria*

We evaluated the response of the biceps femoris muscle by Tensiomyography (TMG), before warm-up (Rest), after warm-up (Post Warm-up) and after each protocol (Post Exercise, 3 [Rest 3 '] and 5 [Rest 5 '] minutes thereafter).

### *Materials*

TMG measured the muscle response by a pressure sensor placed over the muscle belly of the muscle selected, ensuring that it was placed perpendicular to the muscle belly and in the position of the segment to be evaluated according to the manufacturer's recommendations. A bipolar electric current (110 mA) of one millisecond in duration was applied to cause the contraction, through two electrodes placed on the proximal and distal extremes of the muscle, not affecting the insertion tendons and with a pause between stimuli to avoid the phenomenon of post-tetanic activation (Simunic, 2003).

The following parameters were determined for all measurements for each muscle and participant: maximum radial deformation or displacement of the muscle belly (Dm), speed of response at 3 mm deformation ($V_{3mm}$), length of time for which the contraction was maintained (Ts) and relaxation time (Tr).

The reproducibility of the method and validity of the experimental protocol used (TMG) have been evaluated in different studies and considered to be a highly accurate tool (Simunic, 2003).

### *Statistical analysis*

After testing for normality (Shapiro-Wilk) we carried out a comparison of means for samples tested in both conditions (pre and post). We used an ANOVA for repeated measures, opting for the univariate analysis using the Greenhouse-Geisser correction rate of Epsilon (post hoc Bonferroni) for parametric data and Friedman Repeated Measures analysis (Wilcoxon paired-samples tests with Bonferroni adjusted significance levels) for nonparametric data (significance level of $p < 0.05$). The calculation of effect size (ES) was performed using the statistic Cohen's d. The statistical package used was SPSS-v18 (SPSS Inc., Chicago, IL, EE.UU.).

## RESULTS

Different changes were detected (see table 1) in the muscular response, due to the effect of the warm-up (slow running) and stretching (CR and SS) of the hamstring muscles of the leg evaluated.

The changes produced after the warm-up exhibited the same behaviour in both assessed protocols. In both cases there was an increase of the average range of the values of $V_{3mm}$, between pre and post-warm-ups ($p = .02$, $d = 0.15$ and $p = .01$, $d = 0.50$, in CR and SS, respectively). The alterations produced in the values of each of the variables studied, after the warm-up, did not generate statistically significant differences between CR and SS, ensuring the same starting position prior to the implementation of the two stretching protocols.

Table 1

Changes (mean and standard deviation) in muscle response ($V_{3mm}$, Dm, Ts and Tr) due to the effect of warm-up (post warm-up) and after applying two different muscle stretching protocols: contract-relax and static-stretching.

| **Protocol** | **Measure** | $V_{3mm}$ | ***Dm*** | ***Ts*** | ***Tr*** |
|---|---|---|---|---|---|
| Contract-Relax | Rest | 40.53 ± 9.21 | 8.87 ± 2.46 | 157.36 ± 25.86 | 74.36 ± 22.55 |
| | Post Warm-up | 41.78 ± 8.17 | 8.61 ± 2.45 | 147.58 ± 27.61 | 76.47 ± 27.00 |
| | Post Exercise | 38.82 ± 10.74* | 8.79 ± 2.44 | 134.25 ± 19.03 | 56.48 ± 20.71* |
| | Rest 3’ | 38.88 ± 8.61* | 8.26 ± 2.23 | 124.33 ± 21.23 | 45.80 ± 15.89* |
| | Rest 5’ | 38.60 ± 8.77* | 8.46 ± 2.49 | 148.10 ± 40.31 | 69.75 ± 36.88 |
| Static-Stretching | Rest | 38.75 ± 7.61 | 9.26 ± 2.02 | 147.25 ± 22.89 | 64.73 ± 26.47 |
| | Post Warm-up | 42.26 ± 7.07 | 8.68 ± 2.04 | 137.06 ± 18.93 | 66.86 ± 20.73 |
| | Post Exercise | 39.72 ± 9.00 | 8.69 ± 2.58 | 132.62 ± 20.48 | 59.31 ± 15.68 |
| | Rest 3’ | 40.34 ± 6.88 | 8.17 ± 2.40 | 128.77 ± 16.73 | 45.61 ± 13.22 |
| | Rest 5’ | 40.37 ± 6.92* | 9.01 ± 2.42 | 138.29 ± 26.84 | 61.21 ± 22.59 |

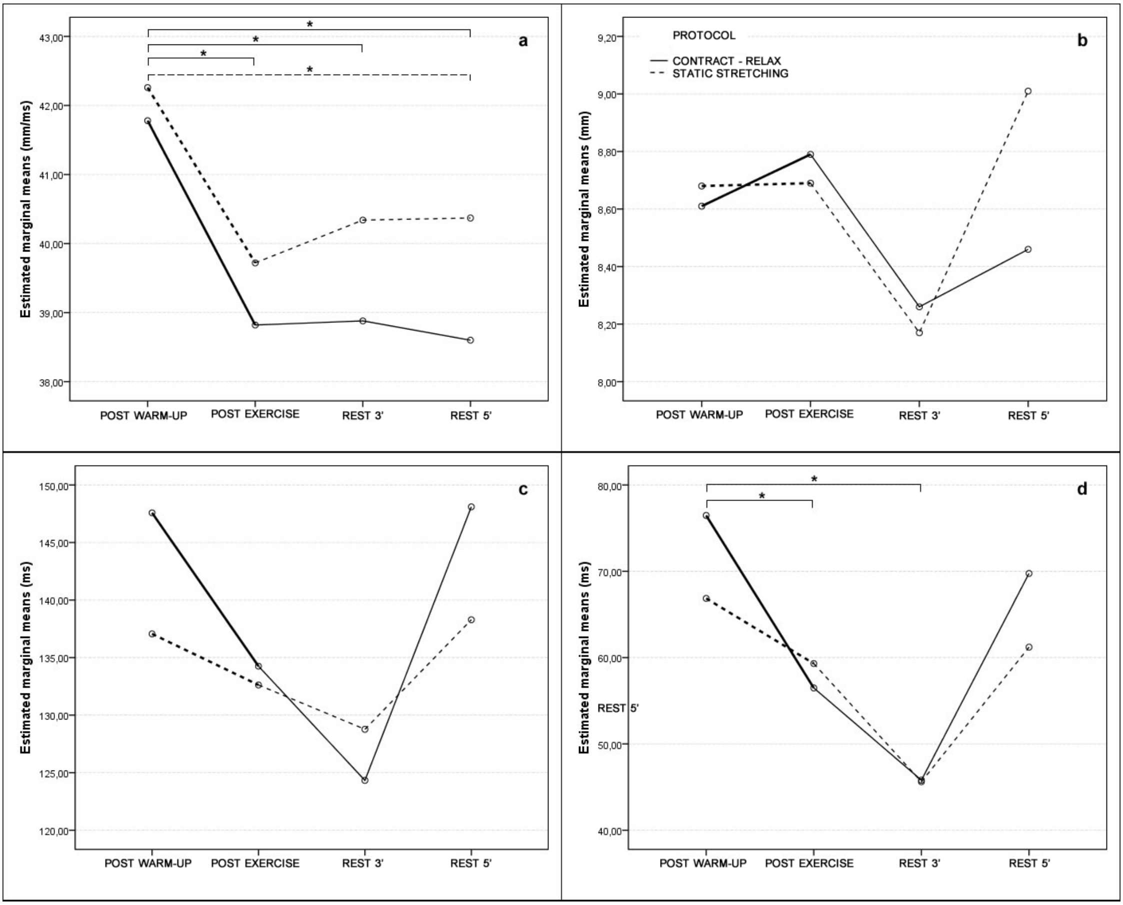
*Note. * represents the values showing statistically significant differences to the Post Warm-up values. p < .05.*

*Analysis of the changes produced after the application of CR and SS*

The changes produced by the work of stretching were more relevant when the stretch was accompanied by an intense isometric contraction (CR). The application of this protocol produced decreases in values of $V_{3mm}$ between Post Warm-up – Post-exercise ($p = .049$, $d = 0.28$), Post Warm-up – Rest 3' ($p = .03$, $d = 0.35$), and Post Warm-up – Rest 5' ($p = .01$, $d = 0.36$), as well as the values of Tr ($F(3, 10) = 5.234$, $p = .01$) in the pairs of Post warm-up – Post-execise ($p = .04$, $d = 0.97$) and Post Warn-up – Rest 3' ($p = .02$, $d = 1.93$).

On the other hand, the application of protocol SS only gave relevant or significant decreases in the values of the average range of $V_{3mm}$ between the Post Warm-up – Rest 5' situation ($p = .03$, $d = 0.25$).

It can be seen how the evolution of the changes following the application of the two protocols and the recovery phase presents the same behaviour in both protocols (see Figure 1).



** = p < .05*

FIGURE 1: Evolution of the changes in muscle response (a: $V_{3mm}$; b: Dm; c: Ts; d: Tr) due to the effect of applying two different muscle stretching protocols: contract-relax and static-stretching.

## DISCUSSION

The results revealed the change of muscle function immediately after warm-up. This variation is manifested in an increase in the velocity of deformation and muscle stiffness accompanied by an increase of holding time and a decrease in relaxation time. These changes reflect neuromuscular and structural alterations that may be the main cause of the loss of mechanical efficiency and performance capability that is usually observed in muscles after intense stretching.

The two protocols used in the study (CR and SS) also show, similar responses in the four evaluated parameters (Dm, $V_{3mm}$, Ts and Tr) during recovery. In all cases, especially in the initial three minutes of recovery, there is a reduction of their values. These changes are different in magnitude for $V_{3mm}$ and Tr in the two protocols analysed.

These changes in muscle response tend to be reversed in the minutes following recovery except in the case of the velocity in the radial deformation of the muscle. $V_{3mm}$ values decrease after stretching, especially in SS, and these lower values are maintained during the five minutes after finishing the protocol.

Two mechanisms appear to be involved in these changes of muscle response: a reduced neuromuscular activation (Avela, Finni, Liikavainio, Niemela & Komi, 2004; Fowles, Sale & MacDougall, 2000), and changes in the mechanical properties of muscle-tendon unit (MTU) (Fowles et al., 2000; Kay & Blazevich, 2008; Nelson & Kokkonen, 2001).

In the first protocol analysed (contract-relax), isometric muscle contraction tends to cause major tensions in actomyosin bridges, as well as elongating myotendinous unions, tendons and aponeurosis. Consequently, everything seems to indicate that these changes reduce the stiffness of the MTU and the elastic capacity of muscle.

This alteration seems to affect tendon, myotendinous unions, the cytoskeleton of the sarcomere and intramuscular connective tissue. All these structures contribute to passive tension, modification of which could lead to a change in overall stiffness of the MTU. We must also take into account that the joints between fibers and connective tissue that surrounds them, suffer considerable tension when the muscle is elongated and tries to contract. The transmission of force from the contractile component inparallel to the connective tissue is carried out through the costameres, integrins that demarcate the sarcomeres and conjunctive covers of the muscle, which are the structures responsible for connective tissue drag when the contractile component is deformed. The tension at this point is greater when the muscle is stretched rather than when it is contracted.

During isometric contraction, the deformation of the connective tissue that occurs with the muscle in forced elongation undoubtedly modifies the viscoelastic behaviour of muscle and alters muscle stiffness. The stiffness originates from the state of the contractile and noncontractile structures of the muscle and may be considered time dependent (Murphy et al., 2010). The degree of influence of each component will vary depending on whether there is passive or active stretching of the muscle and, therefore, the deformation of non-contractile components and the level of activation (voluntary or reflex) of the contractile components.

These alterations may become manifest during the subsequent passive stretching by a reduction in passive stiffness enabling greater elongation of the elastic components in series and parallel (Kubo, Kanehisa, Kawakami &

Fukunaga, 2001) and, quite possibly altering the muscle response during recovery. We should also note that in the CR protocol, the sustained action of contraction and forced extension results in a continuous and gradual deformation (creep) of the elastic components while maintaining the deforming external load and causes a reorientation of the supporting connective tissue to more-ordered arrays (Avela et al., 2004). This may be related to changes in subsequent behaviour of the elastic component in series and parallel (viscoelastic), especially when the stretching is forced and prolonged in time (Kay & Blazevich, 2008).

The muscular compliance represents the inverse of the stiffness. More compliant connective tissue may reduce the sensitivity of muscle spindles (Avela, Kyrolainen & Komi, 1999), possibly reducing the speed of muscle activation just as occurs with CR.

However, in our sample, after carrying out the CR protocol the values of Dm increase slightly, with no statistically significant differences, for a few seconds after completing the work, to then decline and remain low during the subsequent 5 ' analyzed. Also, and prominently, the values of $V_{3mm}$ then drop ($p < 0.05$), and remained low until 5' ($p < 0.05$). In addition, we noted that the initial decline (Post Exercise and Rest 3' ) of Ts (ns) and Tr (Post Exercise: $p = 0.04$; Rest 3': $p = 0.023$) reversed this tendency in the following minutes of recovery to return to initial values.

The obvious changes detected in Ts and Tr may be linked to a possible state of muscle potentiation that facilitates a rapid decline in calcium concentrations within the cytoplasm and its uptake by the sarcoplasmic reticulum. The extent of phosphorylation of regulatory myosin light chain depends on the enzyme dephosphatase of myosin light chains. In any case, in our participants the values of Ts and Tr returned to resting levels at 5' recovery. It should be kept in mind that the participants are young women who practice rhythmic gymnastics intensively and, consequently, work systematically at flexibility in all training sessions. Therefore, they are characterized by high articulation mobility and with considerable muscle stretching capacity. Athletes who present a different muscular profile may possibly show a different result to that described in these gymnasts.

Although it is true that with CR they achieve better ROM favored by alteration of neuromuscular mechanisms (reflex inhibition and autogenous reflex activation), is also true that they bring with them a pre-synaptic mechanism characterized by autogenous inhibition of α-motoneurons induced by the activation of Golgi bodies via Ib afferent fibres (Guissard & Duchateau, 2006). Moreover, peripheral inhibition of the α-motoneuron pool from stimulation of mechanoreceptors and nociceptors (group III and IV) cannot be totally disregarded (Avela et al., 1999; Fowles et al., 2000). However, Fowles et al. (2000) propose that Golgi tendon discharge rarely persists during maintained stretch and the inhibitory effects are transitory (Power et al., 2004).

With the second protocol (static-stretching), in each repetition the participant was asked to try to achieve maximum ROM during the passive stretching of hamstring muscles while staying as relaxed as possible during each repetition (controlled stretching and maximum stretch position). This strategy is intended to gain the maximum deformation of the contractile component by trying to minimize as far as possible any reflex response, particularly by activation of muscle spindles. Consequently, a priori, no significant tension should appear in the muscle-tendon junctions of the hamstring muscles or tendons. In the case of passive stretching the muscle should be almost or fully relaxed, and for that reason everything seems to indicate that the muscle stiffness will be associated with the deformation of the connective tissue in parallel (muscle fasciae). This connective tissue, particularly the perimysium, is considered to be a major extracellular contributor to passive stiffness (Morse, Degens, Seynnes, Maganaris & Jones, 2008).

With relaxed passive stretching (SS), non- statistically significant changes were detected, with Dm values slightly higher than those described in CR. However, at the 5 ' recovery Dm values exceeded those that participants had had post warm-up and approached the resting values. Unlike with CR, the values of $V_{3mm}$ recovered almost completely 5 ' after stretching had finished. Something similar happened with the values of Ts and Tr, where the values decreased at the end of stretching and 3- minute recovery to return to baseline at the end of recovery.

Morse et al. (2008) propose that, with this type of work, connective tissue elements within the muscle change their elastic properties when subject to repeated stretches. It is possible that when the total stretching duration is excessively long, performance decreases (Rubini et al., 2007). However, other authors such as Brandenburg (2006) propose that the duration of the stretching (15 or 30 seconds) does not influence the degree of performance loss.

The revisions made by De Deyne (2001), note that during passive muscle deformation, similar to those made in this protocol (SS), most of the stiffness (60%) is due to resistance offered by the fasciae on being deformed and the rest (40%) corresponds to the deformation of non-contractile components of muscle structure (sarcolemma, glycoproteins, membrane proteins and cytoskeleton [talin, vinculin, titin, desmin, dystrophin, α-actin, β-spectrin, etc.]). In light of our data, it appears that it's these initial alterations of elastic tissue in parallel that prevent changes in the values of Dm during the first moments of recovery.

However, in any flexibility work certain reflex muscle activations that may be activated during the stretch, or as a result thereof, should also be taken into account as they alter the state of the muscle (strenthening or fatigueing it) depending on the magnitude of the stretching (intensity, duration and number). Some studies even suggest that loss of muscle performance following stretching is due more to neurological than mechanical factors (Behm, Button & Burt, 2001).

This type of work causes the stretch reflex, H-reflex and M-wave not to be activated during stretching and in the minutes thereafter (or stretched slightly). The reduced reflex activation of motoneurons in SS appears to be driven by two mechanisms: presynaptic mechanisms identified with the autogenous depression of the 1a afferent fibres, and the postsynaptic mechanisms represented by autogenous inhibition induced by the Golgi corpuscles via Ib afferent fibres (Avela et al., 1999; Guissard & Duchateau, 2006). In people with limited flexibility something different occurs, as after stretching, muscle stiffness increases significantly due to the activation of muscle spindles.

Avela et al. (2004) find that maximal H-reflex amplitude decreased immediately after a stretching protocol similar to SS. This reduction was not associated with any changes in the maximal M-wave, indicating that there was no failure in neuromuscular transmission. Therefore, the changes in the maximal H-reflex resulted in a reduced maximal H-to-M ratio, suggesting impaired excitation of the α-motoneuron pool. Avela et al. (1999) suggested that the decrease of the motoneuron pool resulted from a reduction in excitatory drive from the Ia afferents onto the a-motoneurons motivating a possible decreased resting discharge of the muscle spindles via increased compliance of the MTU. Nevertheless, reduced reflex assistance (H-reflex) as a result of stretching serves to reduce muscle contraction, especially during stretching and recovery immediately thereafter.

According to this behaviour, the ability of muscular response will be altered immediately after stretching and recovery returning to yield decreased to baseline. In this line, Chaouachi et al. (2010) propose that trained individuals who wish to implement static stretching should include an adequate warm-up and dynamic sport-specific activities with at least 5 or more minutes of recovery before their sport activity. This proposal coincides with the behaviour observed among the gymnasts who made up our sample. Possibly, these recovery times should be greater among participants with less flexibility.

## CONCLUSIONS

In light of the data observed in the participants, it may be thought that stretching used during a warm-up (CR or SS) can cause an acute decrease in the velocity of muscular deformation that can affect the mechanical response during the first minutes of recovery. These changes are particularly relevant in the first three minutes after stretching, when Dm, Ts, and especially, Tr are also altered. These data could explain the drop in performance capacity in different studies showing acute response to stretching. These changes are most evident in the contract-relax protocol rather than in static-stretching.

## PRACTICAL APPLICATIONS

The results of this study suggest that athletes who include stretching in their warm-up will find the post warm-up mechanical response less impaired after the first three minutes and more so when using the techniques based on working with static-stretching (SS), compared to techniques based in contract-relax (CR).

## REFERENCES

Agopyan, A., Tekin, D., Unal, M., Kurtel, G., & Ersoz, A. (2013). Acute effects of static stretching on isokinetic thigh strength on modern dancers. J Sports Med Phys Fit, 53(5), 538-550.

Avela, J., Finni, T., Liikavainio, T., Niemela, E., & Komi, P. V. (2004). Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. J Appl Physiol, 96(6), 2325-2332.

Avela, J., Kyrolainen, H., & Komi, P. V. (1999). Altered reflex sensitivity after repeated and prolonged passive muscle stretching. J Appl Phys, 86(4), 1283-1291.

Behm, D. G., Button, D. C., & Burt, J. C. (2001). Factors affecting force loss with prolonged stretching. Can J Appl Physiol, 26(3), 261-272.

Brandenburg, J. P. (2006). Duration of stretch does not influence the degree of force loss following static stretching. J Sports Med Phys Fit, 46(4), 526-534.

Cè, E., Margonato, V., Casasco, M., & Veicsteinas, A. (2008). Effects of stretching on maximal anaerobic power: the roles of active and passive warm-ups. J Strength Cond Res, 22(3), 794-800. doi: 10.1519/JSC.0b013e31816a4353

Chaouachi, A., Castagna, C., Chtara, M., Brughelli, M., Turki, O., Galy, O., Chamari, K., & Behm, D. G. (2010). Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals. J Strength Cond Res, 24(8), 2001-2011. doi: 10.1519/JSC.0b013e3181aeb181

Dadebo, B., White, J. & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. Br J Sports Med, 38(4), 388-394.

Dalrymple, K. J., Davis, S. E., Dwyer, G. B., & Mori, G. L. (2010). Effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. J Strength Cond Res, 24(1), 149-155. doi: 10.1519/JSC.0b013e3181b29614

De Deyne, P. G. (2001). Application of passive stretch and its implications for muscle fibers. Phys Ther, 81(2), 819-827.

Fowles, J. R., Sale, D. G., & MacDougall, J. D. (2000). Reduced strength after passive stretch of the human plantar flexors. J Appl Physiol, 89(3), 1179-1188.

Guissard, N., & Duchateau, J. (2006). Neural aspects of muscle stretching. Exerc Sport Sci Rev, 34(4), 154-158.

Haag, S. J., Wright, G. A., Gillette, C. M., & Greany, J. F. (2010). Effects of acute static stretching of the throwing shoulder on pitching performance of National Collegiate Athletic Association Division III baseball players. J Strength Cond Res, 24(2), 452-457. doi: 10.1519/JSC.0b013e3181c06d9c

Kay, A. D., & Blazevich, A. J. (2008). Reductions in active plantar flexor moment are significantly correlated with static stretch duration. Eur J Sport Sci, 8(1), 41-46. doi: 10.1080/17461390701855505

Kistler, B. M., Walsh, M. S., Horn, T. S., & Cox, R. H. (2010). The acute effects of static stretching on the sprint performance of collegiate men in the 60- and 100-m dash after a dynamic warm-up. J Strength Cond Res, 24(9), 2280-2284. doi: 10.1519/JSC.0b013e3181e58dd7

Kubo, K., Kanehisa, H., Kawakami, Y., & Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. J Appl Phys, 90(2), 520-527.

La Torre, A., Castagna, C., Gervasoni, E., Cè, E., Rampichini, S., Ferrarin, M., & Merati, G. (2010). Acute effects of static stretching on squat jump performance at different knee starting angles. J Strength Cond Res, 24(3), 687-694. doi: 10.1519/JSC.0b013e3181c7b443

McMillian, D. J., Moore, J. H., Hatler, B. S., & Taylor, D. C. (2006). Dynamics vs. static-stretching warm up: the effect on power and agility performance. J Strength Cond Res, 20(3), 492-499.

Morse, C. I., Degens, H., Seynnes, O. R., Maganaris, C. N., & Jones, D. A. (2008). The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. J Physiol, 586(1), 97-106.

Murphy, J. C., Nagle, E., Robertson, R. J., & MCrory, J. L. (2010). Effect of single set dynamic and static stretching exercise on jump height in college age recreational athletes. Int J Exerc Sci, 3(4), 214-224.

Nelson, A. G. & Kokkonen, J (2001). Acute ballistic muscle stretching inhibits maximal strength performance. Res Q Exerc Sport, 72(4), 415-419.

Power, K., Behm, D., Cahill, F., & Young, W. (2004). An acute bout of static stretching: effects on force and jumping performance. Med Sci Sports Exerc, 36(8), 1389-1396.

Robles, A. (2010). Efecto agudo y a largo plazo de la técnica active isolated stretching sobre el rango de movimiento y la fuerza [master's thesis]. Spain: University of Granada.

Rubini, E. C., Costa, A. L., & Gomes, P. S. (2007). The effects of stretching on strength performance. Sports Med, 37(3):213-224.

Rubini, E. C., Pereira, M. I., & Gomes, P. S. (2005). Acute effect of static and PNF stretching on hip adductor isometric strength. Med Sci Sports Exerc, 37(5), S183-184.

Simunic, B. (2003). Model of longitudinal contractions and transverse deformations in skeletal muscles [master's thesis]. Slovenia: University of Ljubljana.

Tsolakis, C. & Bogdanis, G. C. (2012). Acute effects of two different warm-up protocols on flexibility and lower limb explosive performance in male and female high level athletes. J Sports Sci Med, 11(4), 669-675

Wilson, J. M., Hornbuckle, L. M., Kim, J. S., Ugrinowitsch, C., Lee, S.R., Zourdos, M.C., Sommer, B., & Panton, L.B. (2010). Effects of static stretching on energy cost and running endurance performance. J Strength Cond Res, 24(9), 2274-2279. doi: 10.1519/JSC.0b013e3181b22ad6

Wong, P. L., Lau, P. W., Mao, D. W., Wu, Y.Y., Behm, D.G., & Wisløff, U. (2011). Three days of static stretching within a warm-up does not affect repeated-sprint ability in youth soccer players. J Strength Cond Res, 25(3), 838-845. doi: 10.1519/JSC.0b013e3181cc2266