Sports Med 2007; 37 (3): 213-224
0112-1642/07/0003-0213/$44.95/0

The Effects of Stretching on Strength Performance

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Abstract

Strength and flexibility are common components of exercise programmes; however, it is not clear how best to include both of these elements in a single training programme. It is common practice among athletes, coaches and recreational exercisers to perform a stretching routine before a strength training session. Stretching exercises are regularly recommended, even in many textbooks, with the claimed purpose of preventing injury and muscle soreness, or even enhancing performance. However, as highlighted in recent review articles, this recommendation lacks scientific evidence. Thus, the purpose of the present review is to determine the acute and chronic effects of stretching on strength performance, together with the underlying mechanisms. Although most studies have found acute decreases in strength following stretching, and that such decreases seem to be more prominent the longer the stretching protocol, the number of exercises and sets, and the duration of each set have, in general, exceeded the ranges normally recommended in the literature. Consequently, the duration of the stimuli were excessively long compared with common practice, thus making evident the need for further studies. In addition, when recommending flexibility exercises, one should consider other underlying issues, such as the safety of the participants, possible increases in injury risks and the unnecessary time expenditure. Many mechanisms underlying stretching exercises still demand investigation so that links between the observed effects, their causes and the consequences may be constructed.

Exercise programmes often include strength and flexibility training. Both components are considered fundamental for those who wish to attain a healthy physical fitness level.[1] However, the best way to include both components in a single training session is not yet clear.

It is common practice among athletes, coaches and recreational exercisers to perform a stretching routine before the main exercise session, such as strength training. In addition, stretching exercises have been recommended in many textbooks for the claimed purpose of preventing injury and muscle soreness, and even enhancing performance. Two randomized studies[2,3] investigating the effect of stretching before the main exercise session concluded that this did not decrease injury risks. Regarding the reduction of delayed onset muscular soreness (DOMS), only one study observed reduction in soreness;[4] however, this occurred 72 hours after maximum eccentric knee flexion. Results from this study should be interpreted with caution because, not only did it take a long time for the beneficial effects to be noticed, but the sample size was also very small (ten females). Recent reviews[5-9] have suggested that stretching exercises do not protect against injury, nor do they diminish DOMS or enhance performance.

Stretching routines appear to have a negative acute effect on the subsequent main activity, particularly when this is predominantly strength-dependent.[10-30] As stretching exercises are traditionally recommended before most physical activities, it is important to determine to what extent a stretching routine may influence performance of the main activity.

The present study had two purposes: (i) to review the acute and chronic effects of stretching on strength performance; and (ii) to review the underlying mechanisms associated with these adaptations.

Scientific articles were obtained from an extensive search on several databases, including MEDLINE (1966–2006), EMBASE (1974–2006), Cochrane Database of Systematic Reviews (1993–2006), Lilacs (1982–2006) and SciELO (1997–2006). References listed on recent reviews[5-9,31-34] on the topic were also retrieved. The computer search used the following keywords individually or combined: ‘flexibility’, ‘stretching’, ‘elasticity’, ‘range of movement’, ‘range of motion’, ‘training’, ‘injury’ and ‘warm-up’. These keywords were further combined with ‘resistance exercise’, ‘resistance training’, ‘strength training’ and/or ‘acute effects’ or ‘chronic effects’. Most studies retrieved were in English, although articles in Portuguese and Spanish were also considered in this search. All studies related to the acute effects of stretching on strength performance were considered, regardless of the methodological aspects; however, a critical assessment of the text was included when needed.

1. Acute Effects of Stretching on Strength Performance

1.1 Effects on Isotonic, Isometric and Isokinetic Strength Tests

Many authors have studied the acute effect of a stretching routine on strength performance, but the results are often controversial. Various studies, with total stimuli duration varying from 120 to 3600 seconds, found that stretching exercises preceding the main strength activity significantly decreased performance.[10-30] All of these studies used static stretching, except for one article that used ballistic exercises[15] and three that used proprioceptive neuromuscular facilitation (PNF) stretching.[21,24,25] Decreases in strength ranged from 4.5% to 28%, irrespective of the testing mode (i.e. isometric, isotonic or isokinetic). Most studies used lower body exercises, except for Evetovich et al.,[18] who investigated the biceps brachii. Tests were isotonic (one repetition maximum [RM]), isokinetic (peak torque) and isometric (peak torque and maximum voluntary contraction). In contrast to these results, other authors[35-40] did not observe any detrimental effects of stretching on strength. The total stimuli duration in these studies was shorter, ranging from 30 to 480 seconds. Bandeira et al.[41] did not observe decreases in strength performance of ballet dancers when using 15 seconds of static active stretching exercises, with a total of 90 seconds stretching. On the other hand, when using 60 seconds for each exercise (360 seconds total stimuli), performance of the hip flexors was decreased, but not that of the hip extensors (table I).

Most studies showed decreases in strength performance when preceded by stretching exercises. However, it should be noted that these studies used more than one stretching exercise for the same muscle group and/or the number of sets and the duration of stretching were greater than the ranges normally recommended in the literature and used in sporting activities. It has been recommended that four sets of stretching is performed for each muscle group,[42] with 10–30 seconds duration in each stretched position.[42-46] For individuals >65 years of age, a longer duration of 60 seconds should be used.[47] Therefore, it is possible that the total stretching duration may have been excessively long in the studies showing decreases in strength performance.

Data from our laboratory[21,25] showed 8.9% and 12.3% reductions in hip adductor isometric strength measured at 45°, and 10.4% and 10.9% at 30° following four 30-second sets of static or PNF (‘contract-relax’ technique) stretching, respectively. Decreases in strength after static stretching in knee flexion and extension were 9.9% and 2.3%, and decreases after PNF were 11.4% and 4.8%, respectively. These findings concur with the evidence that, even with a total stretching time following the literature recommendations and with only one exercise for each muscle group, a significant decrease in strength performance may still take place. Interestingly, the deleterious effect of stretching on strength performance seems to occur even with experienced stretchers, as evidenced by Nelson et al.[23] Recently,[29] it was shown that the duration of the stimuli (15 or 30 seconds) did not influence the degree of force loss following static stretching.

1.2 Effects on Jumping Performance

Several studies have investigated the acute effect of stretching exercises on vertical jump performance. Church et al.[48] reported a significant decrease in performance when this was preceded by PNF stretching, but not by static stretching. This confirms the findings of Power et al.[22] and Knudson et al.,[49] who investigated the effects of static stretching and also found no significant decreases in vertical jump performance. On the other hand, two studies did not find decreases in vertical jump performance in trained women either after PNF stretching[50] and following static or ballistic stretching.[51] Other studies found decreases in vertical jump performance after static stretching,[52-55] ranging from −4.5% to −7.3% and −3.2% to −4.4% with and without counter movement, respectively (table II).

Muscular strength is one of the most important factors in performing the vertical jump. If stretching has the acute effect of reducing performance in strength, it would be expected to reduce that of jumping as well. In practice, this information is highly important for sporting events in which strength and jumping performance are fundamental, since a decrease in performance may hinder the final result. It is possible that conflicting results could be explained by the different methods used for stretching or by the absence of information regarding reliability and precision of these methods. Therefore, it is clear that this subject deserves further investigation. In addition, studies investigating the chronic effect of stretching on jump performance are also required.

2. Chronic Effects of Stretching on Strength Performance

Very few studies have looked into the chronic effects of stretching on strength performance. Worrel et al.[56] used static and PNF ‘contract-relax’ methods to train the flexibility of the hamstrings; exercises were performed five times a week, for 3 consecutive weeks, totaling 15 sessions with 20 minutes per method, per session. Handel et al.[57]

Table I. Studies investigating the acute effect of stretching on strength performance

Reference (sample size)	Type of stretching	Duration of stretching	Muscles stretched	Muscles tested	Total duration (s)	Type of action	Results
Kokkonen et al.[10] M (n = 15); F (n = 15)	Static (passive) [assis./not assis.]	5 exercises 3 × 15s 15s rest	Hamstrings, hip adductors, plantar flexors, quadriceps	Hamstrings, quadriceps	450	Isot 1RM	↓ 7.3% flexion ↓ 8.1% extension
Muir et al.[35] M (n = 20)	Static (active)	1 exercise 4 × 30s 10s rest	Plantar flexors	Plantar flexors, dorsi flexors	120	Isok	No change in performance
Avela et al.[11] M (n = 20)	Static (passive)	1 exercise 1 × 60 min	Plantar flexors	Plantar flexors	3600	Isom	↓ 23.2% MVC
Fowles et al.[12] M (n = 6); F (n = 4)	Static (passive)	1 exercise 13 × 135s	Plantar flexors	Plantar flexors	1755	Isom	↓ 28% MVC
Nelson et al.[16] M (n = 10); F (n = 5)	Static (active and passive)	3 exercises 4 × 30s 20s rest	Quadriceps	Quadriceps	360	Isok	↓ 7.2% 60°/s PT ↓ 4.5% 90°/s PT
Nelson et al.[14] M (n = 25); F (n = 30)	Static (passive)	2 exercises 4 × 30s 20s rest	Quadriceps	Quadriceps	240	Isom	↓ 7% PT, at angle of 162°
Behm et al.[13] M (n = 12)	Static (passive)	4 exercises 5 × 45s 15s rest	Quadriceps	Quadriceps	900	Isom	↓ 12.2% MVC
Nelson and Kokkonen[15] M (n = 11); F (n = 11)	Ballistic	5 exercises	Hamstrings, thigh adductors, plantar flexors, quadriceps	Hamstrings, quadriceps	450	Isot 1RM	↓ 7.5% flexion ↓ 5.6% extension
Tricoli and Paulo[17] M (n = 11)	Static (active)	6 exercises 3 × 30s 30s rest	Quadriceps, hamstrings	Quadriceps, hamstrings	540	Isot 1RM	↓ 13.8% maximum strength
Garrison et al.[37] (n = 29)	Static	NA	Quadriceps	Quadriceps	480	Isok	No change in performance
Mello and Gomes[36] M (n = 5); F (n = 3)	Static (passive)	2 exercises 2 × 15, 30 and 60s 10s rest	Hamstrings, quadriceps	Hamstrings, quadriceps	30 60 120	Isok	No change in performance
Evetovich et al.[18] M (n = 10); F (n = 8)	Static (2 active; 1 passive)	3 exercises 4 × 30s 15s rest	Biceps brachii	Biceps brachii	360	Isok	↓ 30°/s PT ↓ 270°/s PT
Bandeira et al.[41] F (n = 10)	Static (active)	6 exercises 1 × 15s and 60s	Hip flexors, hip extensors	Hip flexors, hip extensors	90 or 360	Isok	↓ Flexors 60°/s

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Table I. Contd

Reference (sample size)	Type of stretching	Duration of stretching	Muscles stretched	Muscles tested	Total duration (s)	Type of action	Results
Avela et al.[19] M (n = 8)	Static (passive)	2 exercises 60 min 2 weeks between exercises	Plantar flexors	Plantar flexors	360	Isom	↓ 13.8% MVC (1st measure) ↓ 13.2% MVC (2nd measure)
Cramer et al.[20] F (n = 14)	Static (1 active; 3 passive)	4 exercises 4 × 30s 20s rest	Quadriceps	Quadriceps	480	Isok	↓ 3.3% 60°/s PT ↓ 2.6% 240°/s PT
Rubini et al.[21] M (n = 18)	Static PNF (passive)	1 exercise 4 × 30s or 4 × (3 × 10s)	Hip adductors	Hip adductors	120	Isom	45°: ↓ 8.9% and ↓ 12.3% 30°: ↓ 10.4% and ↓ 10.9% (static and PNF, respectively)
Cramer et al.[38] M (n = 15)	Static (1 active; 3 passive)	4 exercises	Quadriceps	Quadriceps	NA	Isok	No change in performance
Behm et al.[39] M (n = 16)	Static (passive)	3 exercises 3 × 45s 15s rest	Quadriceps hamstrings, plantar flexors	Quadriceps	405	Isom	No change in performance
Power et al.[22] M (n = 12)	Static	6 exercises 3 × 45s 15s rest	Quadriceps hamstrings, plantar flexors	Quadriceps, plantar flexors	810 (270 for each muscle group)	Isom	↓ 9.5% MVC quadriceps and no change in plantar flexors
Mello and Gomes[25] F (n = 17)	Static PNF (passive)	6 exercises 30s or (3 × 10s)	Quadriceps, hamstrings	Quadriceps, hamstrings	3600	Isok	↓ 9.9% and ↓ 2.3% ↓ 11.4% and ↓ 4.8% (static and PNF; flexion and extension, respectively)
Marek et al.[24] M (n = 9); F (n = 10)	Static PNF (passive)	4 exercises 5 × 30s 30s rest	Quadriceps	Quadriceps	120 (static) 120 (PNF)	Isok	↓ 2.8% (static and PNF)
Nelson et al.[23] M (n = 13); F (n = 18)	Static (passive) [assis./ not assis.]	5 exercises 3 × 15s 15s rest	Quadriceps, hamstrings	Quadriceps, hamstrings	1200	Isot 1RM	↓ 3.2% extension ↓ 5.5% flexion
Cramer et al.[26] M (n = 7); F (n = 14)	Static (passive)	4 exercises 4 × 30s 20s rest	Quadriceps (dominant)	Quadriceps (dominant/not dominant)	966	Isok	↓ 60°/s and 240°/s PT (dominant) ↓ 60°/s PT (not dominant)
Derek et al.[27] M (n = 15)	Static (passive)	1 exercise 5 × 120s	Plantar flexor	Plantar flexor	600	Isom	↓ 7% MVC
Behm et al.[28] (Pre) M (n = 9); F (n = 9)	Static (passive)	3 exercises 3 × 30s 30s rest	Quadriceps, hamstrings, plantar flexors	Quadriceps	270	Isom	↓ 6.5% MVC

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Table I. Contd

Reference (sample size)	Type of stretching	Duration of stretching	Muscles stretched	Muscles tested	Total duration (s)	Type of action	Results
Behm et al.[28] (Post) M (n = 12)	Static (passive)	3 exercises 3 × 30s 30s rest	Quadriceps, hamstrings, plantar flexors	Quadriceps	270	Isom	↓ 8.2% MVC
Brandenburg[29] M (n = 10); F (n = 6)	Static (assist./not assist.)	2 exercises 3 × 15s or 30s 30s rest	Hamstrings	Hamstrings	90 or 180	Isom Conc Exce	↓ 15s ↓ 30s NS difference between type of actions
Egan et al.[40] F (n = 11)	Static	4 exercises 4 × 30s 20s rest	Quadriceps	Quadriceps	480	Isok	NS 60°/s NS 300°/s 5 min after stretching
Yamaguchi et al.[30] M (n = 20)	Static (3 assist.; 3 not assist.)	6 exercises 4 × 30s 20s rest	Quadriceps	Quadriceps	720	Isom	↓ 5% MVC ↓ 30% MVC ↓ 60% MVC

assis. = assisted; **conc** = concentric; **exce** = excentric; **F** = females; **Isok** = isokinetic; **Isom** = isometric; **Isot** = isotonic; **M** = males; **MVC** = maximum voluntary contraction; **NA** = not available; **NS** = statistically not significant; **PNF** = proprioceptive neuromuscular facilitation; **Post** = after a 4-week training programme; **Pre** = before training programme; **PT** = peak torque; **RM** = repetition maximum; ↓ indicates decrease.

used the PNF 'contract-relax' method to train the knee extensor and flexor muscles; exercises were performed three times a week for 8 consecutive weeks, with a total of 86 minutes 40 seconds in each session. The study by Worrel et al.[56] showed no significant gains in flexibility, but 8.5% and 13.5% increases in eccentric peak torque measured at 60°/s and 120°/s, respectively, and 11.2% increase in concentric peak torque at 120°/s. Significant increases in flexibility (up to 6.3%), in knee flexor and extensor muscle eccentric peak torque (18.2% and 23.0%, respectively), knee flexor concentric peak torque (9.4%) and knee flexor isometric peak torque (11.3%) were found by Handel et al.[57]

Despite the need for more studies, the enhancement of strength following flexibility training may be attributed to hypertrophy of the stretched muscles. Muscle hypertrophy has been observed in animals that underwent stretching protocols lasting 24 hours per day, for 3–30 days.[58-60] Although these studies were conducted with animals, researchers used stretching methods and duration that differed greatly from those recommended for humans for gains in flexibility, thus limiting applicability of these results. In the case of humans, gains in strength seem to occur after 3 weeks of flexibility training, without any specific training for strength development.[56,57] Therefore, evidence suggests that, although stretching exercises may have a negative acute effect on strength, this may not be the case after chronic stretching.

3. Adaptation Mechanisms

3.1 Neurological Adaptations

Although evidence is still lacking, some authors have tried to explain the possible neural mechanisms underlying the acute effects of stretching exercises and their effects on muscle strength performance. The literature is rather inconclusive and some of the findings do not relate to one other.

Rosenbaum and Henning[61] observed a significant 5% decrease in isometric peak torque following 3 minutes of static stretching of the triceps surae, which was accompanied by an increase in muscular

Table II. Studies investigating the acute effect of stretching on jumping performance

Reference (sample size)	Method	Sets and exercises	Muscles stretched	Stimuli duration (s)	Test	Results
Church et al.[48] F (n = 40)	Static PNF	3 sets	Quadriceps, hamstrings	NA	VJ	↓ PNF NS static
Cornwell et al.[52] M (n = 10)	Static (passive)	1 set 3 exercises	Hip extensors, knee extensors	90	VJ	↓ 4.4% (VJ) ↓ 4.3% (VJCM)
Knudson et al.[49] M (n = 10); F (n = 10)	Static	3 sets 3 exercises	Quadriceps, hamstrings, plantar flexors	45	VJ	NS (VJ)
Cornwell et al.[53] M (n = 10)	Static (passive)	3 sets 2 exercises	Triceps surae	180	VJ	↓ 7.3% (VJCM) NS (VJ)
Serzedêlo Corrêa et al.[50] F (n = 10)	PNF (CR)	3 exercises	Quadriceps, hamstrings, calf, gluteus	240	VJ LJ	NS (VJ) ↑ 10.7% (LJ)
Young and Behm[54] M (n = 13); F (n = 3)	Static	4 exercises	Quadriceps, plantar flexors	120	VJ	↓ 3.2% (VJ)
Power et al.[22] M (n = 12)	Static	2 sets 3 exercises	Quadriceps, hamstrings, plantar flexors	270	VJ	NS (VJ)
Unick et al.[51] F (n = 16)	Static Ballistic	3 sets 4 exercises	Quadriceps, hamstrings, plantar flexors	180	VJ	NS (VJ) Statistic/Ballistic
Wallmann et al.[55] M (n = 8); F (n = 6)	Static (passive)	3 sets	Gastrocnemius	90	VJ	↓ 5.6% (VJ)

CR = contract/relax; **F** = females; **LJ** = long jump; **M** = males; **NA** = not available; **NS** = statistically not significant; **PNF** = proprioceptive neuromuscular facilitation; **VJ** = vertical jump; **VJCM** = vertical jump with counter movement; ↑ indicates increase; ↓ indicates decrease.

compliance. Muscle offers less resistance to passive stretching and increases its capability of distending when muscular compliance increases. This phenomenon is know as ‘stress relaxation’, which is a loss in tension occurring when the muscle is stretched with a constant length and which occurs irrespective of observed electromyographic alterations, as suggested by McHugh et al.[62] Thus, muscle compliance resulting from stretching is suggested as one of the mechanisms responsible for the decrease in muscular performance.

In another study, Fowles et al.[12] found that there was a decrease in motor unit activation and in electromyographic activity immediately following passive stretching of the plantar flexors. In addition, there was a 28% decrease in maximum voluntary contraction, which was still depressed by 9% 1 hour after stretching cessation.

In the study by Avela et al.,[11] maximum voluntary activation was decreased by 23.2% immediately following 1 hour of repeated passive stretching of the triceps surae. The authors observed a reduction in sensitivity to repeated stretches of the muscle spindles, reducing the activity of the large-diameter afferents and producing a smaller electromyographic amplitude.

In addition to these mechanisms, other neural systems may be involved, such as activation of nociceptors and inhibition generated by Golgi tendon organs, which contribute to a decrease in excitability of the α motoneuron.[13] An increased inhibitory drive of the α motoneuron pool generated by types III and IV joint receptors after stretching exercise was also suggested by Avela et al.[63]

Halbertsma and Göeken,[64] investigated the effects of 10 minutes of static stretching on subjects with shortened hamstring muscles. The authors concluded that the effect of such exercises would not be due to alterations in muscle elasticity, but to a greater tolerance to stretching. The same conclusions were reported by Magnusson et al.[65] in a study of static stretching of the hamstrings over 3 weeks and by Halbertsma et al.[66] after a 10-minute session of 30 seconds of static stretching of the hamstrings with rest intervals of 30 seconds.

Therefore, there seems to be a reduction in sensibility of the muscle, tendon, joint receptors and nociceptors, which are fundamental mechanisms for the protection of structures involved in motion. In addition to these alterations, there is a period where neuromotor responses are delayed immediately following stretching exercises. These acute neural alterations may be related to the observed decrease in strength and may predispose to or increase the risks of injury, although this requires further investigation.

3.2 Structural Adaptations

One of the hypotheses suggested for the reduction in strength performance following successive stretching is the alteration of viscoelastic properties of the muscle, which, in turn, may alter the length-tension relationship. However, there seems to be no consensus on the subject.

Toft et al.[67] investigated viscoelastic and plasticity properties of the plantar flexor muscles. They concluded that these muscles experienced no modification when measured 90 minutes after a passive stretching programme, nor at 24 hours after 3 weeks of training twice a day. On the other hand, Taylor et al.[42] observed a capacity to alter the length of the musculo-tendinous unit of rabbits following stretching, thus decreasing passive tension. Toft et al.[68] found 36% decreases in passive tension of the plantar flexors after 3 weeks of ‘contract-relax’ flexibility training, twice a day. Furthermore, these authors found no significant correlation between the initial flexibility level of the subjects and the effect of stretching on passive tension, which was equivalent for all levels.

In order to understand the viscoelastic alterations resulting from stretching, the same group of authors, in three different studies, used ultrasound to observe the medial gastrocnemius tendon and aponeurosis before and after stretching. Kubo et al.[69] concluded that 10 minutes of static stretching decreased the viscosity of the tendinous structures and increased their elasticity. In a chronic study,[70] the same group combined resistance exercises with static stretching; exercise were performed for 45 seconds with 15-second intervals, two sessions a day, 7 days a week for 8 weeks. In a third study,[71] the subjects performed static stretching in 20 consecutive days, with two sessions a day of five stretching exercises, lasting for 45 seconds, with 15 seconds of rest between exercises. The authors concluded from the latter two studies that training decreased the viscosity of the tendinous structures, but did not alter elasticity.

Still trying to understand muscle elasticity, Edman and Tsuchiya[72] concluded that during stretching exercises the most affected elastic structure was the titin, and that compliance properties of tendons and all the other elastic structures were less than for this protein. This concurs with other studies that have shown titin to be the main structure responsible for muscular elasticity.[73,74] Further investigating this question, Avela et al.[63] hypothesised that the increase in compliance caused by stretching would be responsible for the decrease in the response caused by muscle spindles and, subsequently, a lower activity of α motoneurons. Rubini and Gomes[75] provide a review of the role of titin in muscular elasticity.

Therefore, stretching exercises seem to acutely produce a decrease in viscosity of the tendinous structures, allowing muscle fibres to slide with less resistance to movement. At the same time, stretching exercises generate an increase in muscle compliance that may limit more crossbridge coupling, thus decreasing the capacity of the muscle to produce force.

Chronic studies with stimuli of longer duration may help to improve understanding of the structural adaptations and their effects on strength performance resulting from stretching exercises.

3.3 Cellular Adaptations

De Deyne,[76] in an attempt to explain the permanent increase in range of motion resulting from flexibility training, suggested a chronic adaptation through cellular mechanisms, such as new serial sarcomere addition. Myofibrilogenesis has been observed in animals[77-80] and occurs, basically, in the insertion of muscles exposed to casting, with the muscle immobilised in a stretched position for 24 hours a day, over several days. However, these models are very different from the methods normally used in flexibility programmes for humans.

Significant increases in protein synthesis were found in studies with mice[81] that were exposed to casting immobilization in a stretched position for 7 days. The author suggested that stretching was the stimulating factor for protein synthesis.

Whether the addition of new sarcomeres has a beneficial or detrimental effect on strength is still not known. This is a question that requires further investigation, despite the difficulty in conducting long-term studies. Studies that observed the occurrence of myofibrilogenesis in animals did not investigate the effects on strength, and the very few chronic studies that investigated the effects of stretching on strength did not investigate the occurrence of myofibrilogenesis.

3.4 Hormonal Adaptations

During the last two decades, several studies have been carried out with the aim of observing the hormonal changes due to stretching. Some studies were conducted with animals being immobilised in a stretched position for various days by casting. Goldspink et al.[58] observed that stretching increased insulin-like growth factor (IGF)-1 messenger RNA (mRNA) levels in mice. Yang et al.,[82] analysing possible hormonal alterations in rabbits, observed that stretching generated an IGF-1 isoform (IGF-1 Eb), corresponding to the human IGF-1 Ec isoform, which is related to muscular growth. In another study, Yang et al.[60] observed increases in IGF-1 mRNA levels, which correlated with increases in muscle mass in rabbits. IGF-1 Ec, also known as mechano growth factor (MGF), is an IGF splice variant that has autocrine and paracrine functions capable of stimulating protein synthesis and muscle hypertrophy.[83] Its secretion is stimulated in response to mechanical stimuli such as force generation and stretching, with stretching being the main mechanical stimulus.[83,84] MGF locally controls tissue repair, maintenance and remodeling.[83,85] The discovery of MGF finally linked the mechanical stimulus and genetic expression, demonstrating that cellular phenotypes are not determined only in the genome.[84,86] A particular function of MGF is to activate satellite muscle cells.[83,85] MGF generates a rapid increase in the number of ribosomal RNA, indicating that hypertrophy of the muscle fibers occur during translation.[84,86] These findings showed that stretching is capable of promoting increases in muscle strength or hypertrophy. Nevertheless, the experimental conditions of the studies discussed in section 3.4 are very different from the conditions normally recommended and applied to humans.

4. Conclusions

Flexibility and strength are fitness components that are fundamental in many sports modalities and even for common daily motor tasks. Training for flexibility and strength is widely recommended for those who wish to attain good fitness levels and a better quality of life. Many activities rely heavily on strength, but strength performance may be diminished by a preceding stretching routine; therefore, it is important to understand this phenomenon when prescribing physical exercise programmes. There appears to be substantial evidence suggesting a decrease in strength following stretching. Studies used different stretching techniques, duration and targeted different muscle groups, and were tested with isotonic, isometric or isokinetic devices. However, the number of exercises, duration of each exercise and number of sets (i.e. the total duration of stretching) was much longer than the ranges normally used in practice and what is recommended in the literature. This makes evident the need for further studies with designs that do not threaten their external validity. Training studies should also be conducted in order to assess whether the decreases in strength observed during the training session will have long-term consequences (i.e. suboptimal gains in strength when compared with training without prior stretching).

Furthermore, the safety of the participants should be taken into consideration in the recommendation of stretching exercises. When the possible effects of these exercises are analysed, it seems that many of the mechanisms responsible for maintaining the myo-osteo-articular integrity, such as muscle, tendon and joint receptors, are inhibited following stretching. Tolerance to pain also seems to be increased, allowing range of motion to be greater and closer to the maximal limit of the stretched structures, and consequently, closer to injury risk. The hypothesis that flexibility exercises preceding other physical activities may lead to greater injury risks should be considered and investigated in future studies.

Many mechanisms underlying stretching exercises still demand investigation so that links between the observed effects, their causes and consequences may be constructed.

Acknowledgements

We would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ), Ministry of Education, Brazil, for their financial support to Ercole C Rubini. The authors would also like to thank Dr Marta Inez Rodrigues Pereira for the preparation of the English version of the manuscript and Dr Ana Maria Miragaya for reviewing the English version. The authors have no conflicts of interest directly relevant to the content of this review.

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