The Relation Between Stretching Typology and Stretching Duration: The Effects on Range of Motion

Authors
Ewan Thomas[1, 2], Antonino Bianco[1, 2], Antonio Paoli[3], Antonio Palma[1, 2]

Affiliations
1 Sport and Exercise Research Unit, University of Palermo, Palermo, Italy
2 Regional Sport School of CONI Sicilia, CONI Sicilia, Italy
3 Department of Biomedical Sciences, University of Padova, Padova, Italy

Key words
flexibility, range of motion, stretch, long term, ballistic stretching, passive stretching, PNF, static stretching, active stretching

accepted 05.01.2018

Bibliography
DOI https://doi.org/10.1055/s-0044-101146

Int J Sports Med

ISSN 0172-4622

Correspondence
Dr. Ewan Thomas,
University of Palermo
Sport and Exercise Research Unit
Via Giovanni Pascoli, 6
Palermo, 90144
Italy
Tel.: +39/320/8899 934, Fax: +39/09123860894
ewan.thomas@unipa.it

ABSTRACT

Different stretching strategies and protocols are widely used to improve flexibility or maintain health, acting on the muscle tendon-unit, in order to improve the range of motion (ROM) of the joints. This review aims to evaluate the current body of literature in order to understand the relation between stretching typology and ROM, and secondly to evaluate if a relation exists between stretching volume (either as a single training session, weekly training and weekly frequency) and ROM, after long-term stretching. Twenty-three articles were considered eligible and included in the quantitative synthesis. All stretching typologies showed ROM improvements over a long-term period, however the static protocols showed significant gains ($p < 0.05$) when compared to the ballistic or PNF protocols. Time spent stretching per week seems fundamental to elicit range of movement improvements when stretches are applied for at least or more than 5 min, whereas the time spent stretching within a single session does not seem to have significant effects for ROM gains. Weekly frequency is positively associated to ROM. Evaluated data indicates that performing stretching at least 5 days a week for at least 5 min per week using static stretching may be beneficial to promote ROM improvements.

Introduction

Flexibility is a physical characteristic defined as the ability to voluntarily move a joint through its full range of motion (ROM)[10]. This characteristic depends on individual anatomical and physiological components such as the muscle-tendon unit, the states of ligaments, bones and cartilages that form the joint and the reflex stiffness that the neural spinal circuitry provides [16].

A reduction in flexibility or limited mobility can limit the achievements of goals in sporting and athletic environments or increase the incidence of injuries, especially musculotendinous strains [14] as well as limit independency of people with neurological impairments [20]. In addition, as a consequence of aging, muscles and connective tissues decay, resulting in a concomitant decrease of strength and flexibility that may limit individuals functional capacity [40]. A reduction in flexibility has also been progressively noted across decennial age groups ranging from 20 to 49 years of age [18], with an average 10 % decrease every 10 years. Such reduction may significantly affect the activities of daily living and reduce the quality of life in adults [40].

Therefore an optimal level of flexibility is a key component of health and should be promoted [10].

An effective strategy that may be adopted to increase ROM is muscle stretching. Such a strategy has shown to act on ROM at various levels, decreasing the visco-elastic properties of human tendons increasing the compliance in vivo at an anatomical level [25, 35], reducing the spinal reflex activity and modulating the presynaptic excitability of the Ia inhibitory pathways at a physiological level [16] and acting through a progressive modification of sensation as a result of an increased tolerance to a stretch [41].

In particular, acute bouts or short term stretching sessions up to three weeks seem to promote stretch tolerance, whereas long term stretching sessions over three weeks seem to act on the biomechanical and physiological properties of muscles, tendons and the nervous system [16, 25, 41].

It is also known that the term stretching generally refers to a technique adopted for muscle elongation and that this act can be carried out in different modalities with four main stretch parameters able to influence the increase or decrease of flexibility of a joint: intensity, duration, frequency that may be distinguished in frequency per session and frequency per week, and stretch position [1]. The most commonly used stretching techniques can be summarized as follows: static stretching (which can be divided into active or passive), ballistic (a form of static or dynamic stretching performed in a bouncing motion) and proprioceptive neuromuscular facilitation (PNF, a form of stretching that involves a stretching and a contraction of the muscle being targeted. The stretching phase is generally performed using passive techniques)[27]. These techniques have been widely investigated in relation to injury prevention, performance and ROM improvement [32]. However, the majority of studies are cross-sectional [20, 35] and thus, do not take into account long term adaptations, or are reviews that examine acute stretching adaptations [5].

Therefore, the main aim of this review will be to analyze studies that have carried out long term stretching interventions and understand if there are any relations, between stretching typology and stretching duration and frequency and how these affect ROM adaptations.

Materials and Methods

Literature search

The PRISMA guidelines for conducting a systematic review were adopted [33]. A literature search was performed using three online databases: MEDLINE, ScienceDirect and SPORTDiscuss, using a number of keywords: stretch, stretching, exercise and flexibility. These were identified through an initial snowballing sampling that started from the keywords: Stretching, adaptation and range of motion. The selected keywords were used combined: stretch AND exercise, stretch AND flexibility, stretching AND exercise, stretching AND flexibility. Bibliographies of relevant publications were also examined. Abstracts and unpublished material were not included. Only papers in English were reviewed. The PRISMA flow diagram (▶ **Fig. 1**) illustrates the process by which the manuscripts were selected.

Inclusion criteria

Studies examining the influence of stretching typology and stretching duration on ROM were included for review if they fulfilled the following selection criteria: 1) The studies were published between 1995 and 2015; 2) the studies were original articles, published in English and in peer review journals; 3) the studies had a minimum timeframe of intervention of 4 weeks; 4) the studies properly described a defined stretching technique; and 5) the studied had a ROM measure as outcome (Pre- and Post-intervention measures). Articles that evaluated acute ROM variations or articles that evaluated pathological cohorts or subjects with impaired flexibility were excluded from investigation. The exclusion of non-English manuscripts is a limitation of this review due to possible loss of useful information, however inappropriate language interpretation may lead to inclusion of irrelevant data. The article screening was carried out by two independent investigators, who eventually resolved disagreements about article inclusion by negotiation. All duplicates were removed. The study was conducted in line with the ethical international guidelines for sport and exercise science research [19].

Statistical analysis

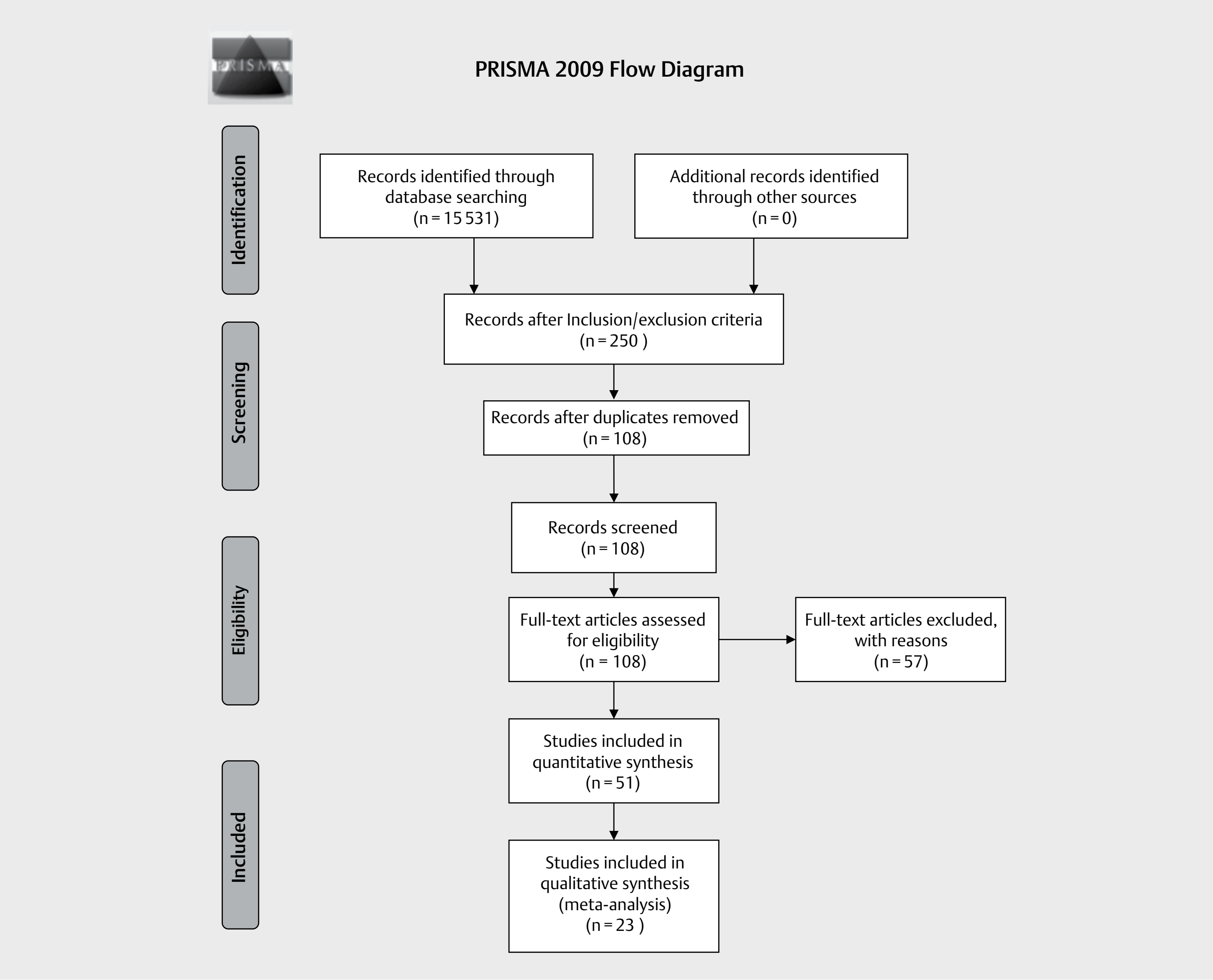
The manuscripts included in the qualitative synthesis were initially classified according to their stretching technique and for each one, the mean change of ROM variation between pre and post intervention was determined (if not already available, %Δ). Subsequently 95 % confidence intervals (CIs) for each stretching typology and effect sizes (ES) based on the population size, describing the magnitude of the effects, were determined on the identified articles. After the CIs were determined, the included studies in the quantitative synthesis were subsequently stratified by time of intervention: 1) Total time per week spent stretching (i. less than 5 min, ii. between 5 and 10 min, iii. more than 10 min), 2) total time per stretching session (i. less than 60 s, ii. between 60 and 120 s, iii. More than 120 s) and number of days per week spent stretching. Differences between ROM %Δ for stretching typologies and stretching durations were assessed through an unpaired t-test and through ANOVA when appropriate using STATISTICA 10.0 for windows (Statsoft inc., Tulsa, OK, USA). Significance level was set at $p < 0.05$ for all analyses.

Results

A total of 250 articles were identified through the literature search (▶ **Fig. 1**). One-hundred and forty-two articles were removed as duplicates. The first screening identified 108 articles as eligible. After the application of inclusion and exclusion criteria 57 articles were excluded and 51 articles were included in our qualitative synthesis. After the CIs were determined 23 articles were included in the quantitative synthesis for analysis (▶ **Table 1**).

Five articles analyzed active stretching [2, 3, 26, 38, 42], two studies analyzed ballistic stretching [23, 30], seven articles analyzed passive stretching [21, 24, 26, 31, 38, 39, 44], two articles analyzed PNF stretching [26, 29] and seven articles analyzed static stretching [4, 6–9, 34, 44] (▶ **Table 2**).

Nine studies, independently of stretching typology focused on hip extensibility, targeting the hamstring muscles with their stretch intervention. The ROM measures were assessed through the passive bilateral straight leg raise (PSRL). This consisted in having the participants in a supine position with both legs straight and the ankle of the tested leg at 90 ° of dorsiflexion [2–4, 8, 21, 26, 31, 38, 44]. From this position the investigators raised the tested leg until an end point. The end point was determined when the leg either opposed a firm resistance or when a palpable onset of pelvic



▶ **Fig. 1** PRISMA flow diagram illustrating the different phases of articles inclusion.

▶ **Table 1** Description of the retrieved studies for the qualitative synthesis divided by stretching type, mean variation, 95 % confidence interval (CI) and effect size (ES).

Stretch type	N ° of records	Mean ROM ± SD Variation	95 % CI	ES
Active	13	18.16 ± 4.82	13.34 - 22.98	0.91
Ballistic	4	11.68 ± 1.20	10.47 - 12.88	0.99
Passive	20	17.4 ± 4.87	12.53 - 22.27	0.86
PNF	10	15.27 ± 5.81	9.46- 21.08	0.88
Static	41	19.47 ± 5.79	13.68 - 25.26	0.75

rotation arose. The calculated ROM was the maximum angle formed between the leg and the body. Two studies measured hip extensibility through the sit and reach test [9, 22], that may be considered a common test for the evaluation of flexibility of the posterior chain. However this test has many limitations. Variations in limb and trunk length of the participants can make comparisons between individuals misleading. One study used photography [42] through the SiliconCOACH software to analyze ROM, and calculated the angle formed between the two malleoli of each leg with markers positioned on the hip and ankle. Two studies, measured the ROM variations of the hamstrings through the passive knee extension test. This test consisted of laying the participants in a supine position, with the contralateral leg firmly held, and the opposite hip moved at 90 ° of hip flexion [21, 39]. An inclinometer was positioned on the tibial crest at the distal end of the tibial tuberosity. The examiner passively extended the knee to the point the subject reported the stretch to be of discomfort [12].

Other analyzed studies had as main stretch target the ankle dorsiflexors. Four of these studies measured the ROM variations through an electronic goniometer fixed on the ankle joint [23, 24, 29, 30]. The measurements were taken positioning the participants standing upright in a neutral position, with the ankle joint at 90 °. The participants were then asked to step back one leg and bring the ankle joint at a maximum dorsiflexion keeping the heel on the ground. The knee of the tested leg (back leg) had to remain fully extended and the knee of the opposite leg flexed. Both feet had to stay parallel. The remaining three studies assessed ROM

▶ **Table 2** Summary of main characteristics of the retrieved studies for the quantitative synthesis.

Authors	Sample size (n)	Age (mean)	Typology	Interven-tion period (weeks)	Interven-tions per week (days)	Sets (n)	Duration (s)	Tot. Time per session (s)	Tot. Time per week (s)	ROM Pre (°)	ROM Post (°)	District	%Δ
Ayala et al. [1]	35	21	Active	12	3	12	15	180	540	87.9 ± 11.9	107.7 ± 12.2	Hip	22.5
Ayala et al. [2]	76	22	Active	12	3	6	30	180	540	90.1 ± 8.8	103.7 ± 12.5	Hamstrings	13.6
Bandy et al. [3]	18	20-24	Static	6	5	3	60	180	900	43.33 ± 8.31	32.83 ± 7.26	Hip	24.2
Bandy et al. [3]	19	20-24	Static	6	5	3	30	90	450	42.31 ± 10.13	32.26 ± 9.68	Hip	23.9
Bandy et al. [3]	18	20-24	Static	6	5	1	60	60	300	43.78 ± 6.91	33.33 ± 8.32	Hip	22.2
Blazevich et al. [4]	12	18.6	Static	4	5	4 × 2	30	120	1200	n/a	n/a	Ankle Dorsi flexors	19.9
Blazevich et al. [5]	11	18.7	Static	4	5	4 × 2	30	120	1200	40.6 ± 10.0	48.5 ± 10.9	Ankle Plantar flexors	19.5
Cipriani et al. [6]	14	18-46	Static	4	7	2	30	60	420	78.8 ± 14.3	97.7 ± 16.7	Hip	23.9
Cipriani et al. [6]	13	18-46	Static	4	3	2 × 2	30	60	360	78.5 ± 13.2	97.7 ± 11.0	Hip	24.5
Cipriani et al. [6]	13	18-46	Static	4	3	2	30	60	180	81.1 ± 12.6	94.7 ± 11.1	Hip	16.8
Coledam et al. [7]	58	8	Static	16	2	6	20	120	240	24.9 ± 5.0	29.1 ± 4.5	Hamstrings	16.7
Johnson et al. [9]	12	18-25	Passive	6	6	3	30	90	540	59.9 ± 6.5	72.2 ± 5.2	Hamstrings	20.5
Johnson et al. [9]	14	18-25	Passive	6	6	9	10	90	540	58.4 ± 7.0	71.6 ± 9.5	Hamstrings	22.6
Kokkonen et al. [10]	19	22-23	Static	10	3	3	15	45	135	n/a	n/a	Lower body	18.1
Konrad et al. [11]	24	23	Ballistic	6	5	4	30	120	600	33.8 ± 6.3	37.8 ± 7.2	Ankle Dorsi flexors	11.8
Konrad et al. [12]	25	23	Passive	6	5	4	30	120	600	30.9 ± 5.3	36.6 ± 6.1	Ankle Dorsi flexors	18.4
Lòpez-Bedoya et al. [14]	9	20-24	Active	9	2	4 × 2	12	48	192	120.8 ± 14.5	139.3 ± 13.2	Hip	15.4
Lòpez-Bedoya et al. [14]	11	20-24	Passive	9	2	10	10	100	200	118.6 ± 21.4	141.9 ± 17.2	Hip	19.5
Lòpez-Bedoya et al. [14]	9	20-24	PNF	9	2	10	10	100	200	115.5 ± 15.7	132.7 ± 15.8	Hip	14.3
Mahieu et al. [16]	21	22	Ballistic	6	7	5	20	80	560	28.7 ± 6.8	32.0 ± 7.3	Ankle Plantar Flexors	11.5
Mahieu et al. [15]	33	22	PNF	6	7	5	15	75	525	28.3 ± 1.2	34.2 ± 1.0	Ankle Plantar Flexors	20.8
Mahieu et al. [15]	33	22	PNF	6	7	5	15	75	525	36.2 ± 1.3	41.9 ± 1.0	Ankle Dorsi Flexors	15.7
Marshall et al. [17]	22	23	Passive	4	5	3	30	90	450	76.1 ± 15.9	92.0 ± 18.0	Hamstrings	20.9
Nakamura et al. [18]	9	21	Static	4	7	2	60	120	840	32.9 ± 2.8	n/a	Ankle Dorsi Flexors	20.4
Sainz de Baranda et al. [19]	28	21	Active	12	3	12	15	180	540	88.5	106.5	Hip	20.3
Sainz de Baranda et al. [19]	38	21	Active	12	3	6	30	180	540	89.2	102.8	Hip	15.2
Sainz de Baranda et al. [19]	33	21	Active	12	3	4	45	180	540	87.9	102.5	Hip	16.6
Sainz de Baranda et al. [19]	14	21	Passive	12	3	6	30	180	540	84.2	102.6	Hip	21.8
Sainz de Baranda et al. [19]	19	21	Passive	12	3	4	45	180	540	85.4	100.0	Hip	17.1
Shadmehr et al. [20]	30	20-25	Passive	4	3	3	10	30	90	147.9 ± 3.2	166.5 ± 3.4	Hamstrings	12.6
Wyon et al. [22]	14	14	Active	6	5	3	60	180	900	99.7 ± 25.6	120.2 ± 24.9	Lower body	20.5
Zakas et al. [23]	18	10	Passive	12	3	2	30	60	180	84.2 ± 3.7	96.2 ± 4.3	Hip	14.2
Zakas et al. [23]	19	13	Passive	12	3	2	30	60	180	82.2 ± 4.4	97.7 ± 4.8	Hip	18.9
Zakas et al. [23]	18	16	Passive	12	3	2	30	60	180	83.8 ± 3.5	95.1 ± 3.7	Hip	13.5

▸ **Table 3** Summary of studies stratified by stretching type.

Typology	Authors	Sets (n)	Duration (s)	Tot. Time per session (s)	Tot. Time per week (s)	%Δ
Active	Ayala et al. [1]	12	15	180	540	22.5
	Ayala et al. [2]	6	30	180	540	13.6
	Lòpez-Bedoya et al. [14]	4 × 2	12	48	192	15.4
	Sainz de Baranda et al.[19]	12	15	180	540	20.3
	Sainz de Baranda et al.[19]	6	30	180	540	15.2
	Sainz de Baranda et al.[19]	4	45	180	540	16.6
	Wyon et al. [22]	3	60	180	900	20.5
mean		6.7	27.8	146.7	490.9	17.7
Ballistic	Konrad et al. [11]	4	30	120	600	11.8
	Mahieu et al. [16]	5	20	80	560	11.5
mean		4.5	25	100	580	11.65
Passive	Johnson et al. [9]	3	30	90	540	20.5
	Johnson et al. [9]	9	10	90	540	22.6
	Konrad et al. [12]	4	30	120	600	18.4
	Lòpez-Bedoya et al. [14]	10	10	100	200	19.5
	Marshall et al. [17]	3	30	90	450	20.9
	Sainz de Baranda et al. [19]	6	30	180	540	21.8
	Sainz de Baranda et al. [19]	4	45	180	540	17.1
	Shadmehr et al. [20]	3	10	30	90	12.6
	Zakas et al. [23]	2	30	60	180	14.2
	Zakas et al. [23]	2	30	60	180	18.9
	Zakas et al. [23]	2	30	60	180	13.5
mean		4.36	25.9	96.3	367	18.2
PNF	Lòpez-Bedoya et al. [14]	10	10	100	200	14.3
	Mahieu et al. [15]	5	15	75	525	15.7
mean		6.6	13.3	83.3	416.6	15.0
Static	Bandy et al. [3]	3	60	180	900	24.2
	Bandy et al. [3]	3	30	90	450	23.9
	Bandy et al. [3]	1	60	60	300	22.2
	Blazevich et al. [5]	4 × 2	30	120	1200	19.5
	Blazevich et al. [4]	4 × 2	30	120	1200	19.9
	Cipriani et al. [6]	2	30	60	420	23.9
	Cipriani et al. [6]	2 × 2	30	60	360	24.5
	Cipriani et al. [6]	2	30	60	180	16.8
	Coledam et al. [7]	6	20	120	240	16.7
	Kokkonen et al. [10]	3	15	45	135	18.1
	Nakamura et al. [18]	2	60	120	840	20.4
mean		3.8	35.9	94.1	565	20.9

through an isokinetic dynamometer with the knee of the tested leg completely extended [6, 7, 34]. The foot was strapped to the dynamometer's ankle footplate and from here rotated towards dorsiflexion at a speed of 2 °/s [6, 7] and at 1 °/s [34] up to the maximal tolerable degree.

The limited number of retrieved records did not allow a direct comparison of ROM variations for each joint, therefore this review focused on the mean %Δ of ROM between each pre and post measure. However, all the included studies focused their attention on the lower limb and this may limit biases during analysis.

Effect of the typology of stretching on ROM

Static stretching can be further distinguished in active or passive. However, if during the analysis of the retrieved records this distinction was not specified, nor clear, the term "static" alone was maintained and a more generic category was created. During the analysis of static stretching a mean %Δ of 20.9 of ROM was obtained between pre and post interventions across the studies [4, 6–9, 22, 34]. This variation was 17.7 % across the static active stretching [2, 3, 22, 26, 38, 42] and 18.2 % across the static passive stretching [21, 24, 26, 31, 38, 39, 44]. No statistically significant difference was found across these groups amongst the mean %Δ of ROM.

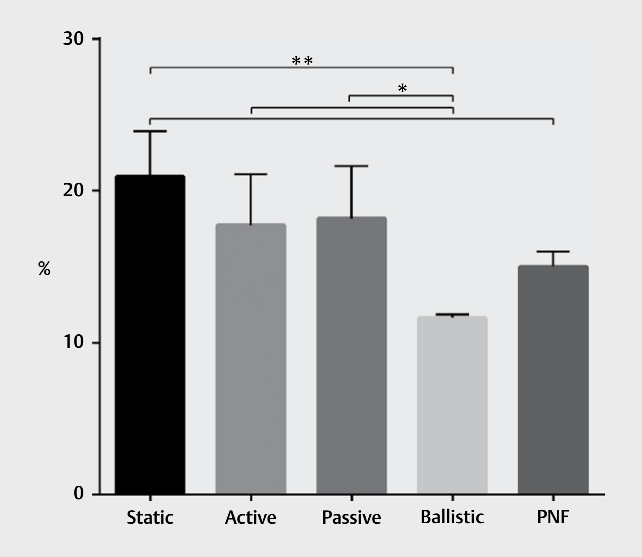
The %Δ of ROM regarding ballistic and PNF stretching was, 11.65 and 15.0, respectively [6–9, 23, 30, 34]. The analysis showed significant differences between all the static stretching groups and the ballistic stretching ($p < 0.01$, for static vs. ballistic stretching and $p < 0.05$ for active and passive vs. ballistic stretching) and differences between static stretching and PNF ($p < 0.05$), but no differences were shown between ballistic and PNF stretching or between the other static stretching groups and the PNF group. The relatively small sample size of the groups may not permit a broader application of the results to a wider population. Therefore these findings may be limited to the analyzed cohorts. The results are summarized in ▶ **Table 3** and ▶ **Fig. 2**.

Effect of time spent stretching

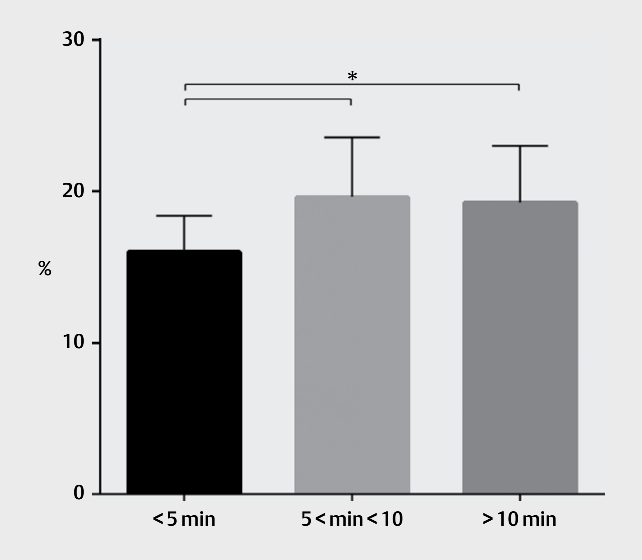
Further stratification was carried out using as the main discriminant training volume. The two training volumes taken into account were the total volume per week (the total time spent stretching every week, in seconds, e. g. 3 days a week for 3 sets of 30 s stretch = 30 * 3 * 3 = 270 s spent stretching each week, for each muscle) and the total volume per stretching session (the total time in seconds spent stretching in each training session, e. g. 3 sets of 30 s stretch = 30 * 3 = 90 spent stretching each training session, for each muscle). The total volume per week has been further divided in less than 5 min [8, 9, 22, 26, 39, 44], between 5 and 10 min [2–4, 8, 21, 29–31, 38], and more than 10 min [4, 6–8, 23, 24, 34, 42] having as mean stretching time 177.7 s (about 3 min), 497.1 s (about 8:30 min) and 891.4 s per week (about 15 min) respectively, regardless of stretching typology. The %Δ in ROM showed statistical significance between the “less than 5 min” group and the “between 5 and 10 min” group ($p < 0.05$) and also between the “less than 5 min” group and the “more than 10 min” group ($p < 0.05$). No difference was found between the “between 5 and 10 min” group and the “more than 10 min” group (▶ **Table 4** and ▶ **Fig. 3**).

The total volume per stretching session, was divided in less than 60 s [4, 8, 22, 26, 39, 44], between 60 and 120 s [4, 6, 7, 9, 21, 23, 24, 26, 29–31, 34] and more than 120 s[2–4, 38, 42] having as mean stretching time 54.3, 100.6 and 180 s per training session, respectively. The %Δ in ROM did not show any significant differences between any group despite the different training volumes per session. However an incremental trend is shown across groups according to stretching duration (18.1 % vs. 18.4 % vs. 19.1 %, respectively, ▶ **Table 5** and ▶ **Fig. 4**).

It is interesting to note that even though the volumes of the “volume per stretching session” significantly differ between each other, no significant differences are shown across groups, in contrast to the “total volume per week” that also display different volumes. This indicates that ROM gains over a period of at least 4 weeks, may be better promoted by increasing the time spent stretching per week. However, it is plausible that an increase in the time spent stretching in each session will lead to an increase in the time spent stretching each week. Further stratification relating stretching frequency and %Δ of ROM is shown in ▶ **Fig. 5**. Analysis of variance has shown no differences between any group except between 2 and 3 vs. 6 days spent stretching per week ($p < 0.05$). Indicating that more frequent stretching sessions per week promote a better gain in ROM.



▶ **Fig. 2** Stretching typology and percentage ROM variations. Statistical differences are shown between all the static and the ballistic typologies ($p < 0.01$) and between static and PNF stretching ($p < 0.05$).



▶ **Fig. 3** Time spent stretching per week and percentage ROM variations. Statistical differences are shown between the less than 5 min per week stretching group and both groups that stretch more than 5 min per week ($p < 0.05$). No difference is shown between the two groups that stretch more than 5 min per week.

Discussion

The main aim of this review was to understand the relation between stretching typology and stretching duration in long term stretching and how these parameters affect ROM. The findings suggest that an improvement in ROM is achieved independently from stretching typology. All stretching typologies exhibit increases in ROM after a period of at least 4 weeks although, relatively higher gains are shown with static stretching (20.9 % increase), compared

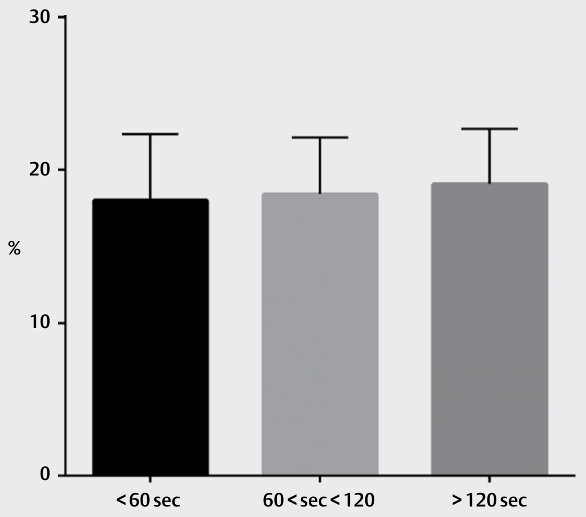
▶ **Table 4** Summary of studies stratified by time spent stretching per week.

Time	Tot. Time per week (s)	Authors	Typology	Sets (n)	Duration (s)	Tot. Time per session (s)	%Δ
Stretching < 5 min	90	Shadmehr et al. [20]	Passive	3	10	30	12.6
	135	Kokkonen et al. [10]	Static	3	15	45	18.1
	180	Cipriani et al. [6]	Static	2	30	60	16.8
	180	Zakas et al. [23]	Passive	2	30	60	14.2
	180	Zakas et al. [23]	Passive	2	30	60	18.9
	180	Zakas et al. [23]	Passive	2	30	60	13.5
	192	Lòpez-Bedoya et al. [14]	Active	4 × 2	12	48	15.4
	200	Lòpez-Bedoya et al. [14]	PNF	10	10	100	19.5
	200	Lòpez-Bedoya et al. [14]	Passive	10	10	100	14.3
	240	Coledam et al. [7]	Static	6	20	120	16.7
mean	177.7			4.0	19.7	68.3	16.0
5 min < stretching < 10 min	300	Bandy et al. [3]	Static	1	60	60	22.2
	360	Cipriani et al. [6]	Static	2 × 2	30	60	24.5
	420	Cipriani et al. [6]	Static	2	30	60	23.9
	450	Bandy et al. [3]	Static	3	30	90	23.9
	450	Marshall et al. [17]	Passive	3	30	90	20.9
	525	Mahieu et al. [15]	PNF	5	15	75	20.8
	525	Mahieu et al. [15]	PNF	5	15	75	15.7
	540	Ayala et al. [1]	Active	12	15	180	22.5
	540	Ayala et al. [2]	Avtive	6	30	180	13.6
	540	Sainz de Baranda et al. [19]	Passive	12	15	180	20.3
	540	Sainz de Baranda et al. [19]	Passive	6	30	180	15.2
	540	Sainz de Baranda et al. [19]	Passive	4	45	180	16.6
	540	Sainz de Baranda et al.[19]	Active	6	30	180	21.8
	540	Sainz de Baranda et al. [19]	Active	4	45	180	17.1
	540	Johnson et al. [9]	Passive	3	30	90	20.5
	540	Johnson et al. [9]	Passive	9	10	90	22.6
	560	Mahieu et al. [16]	Ballistic	5	20	80	11.5
mean	497.1			5.3	28.3	119.4	20.8
Stretching ≥ 10 min	600	Konrad et al. [11]	Ballistic	4	30	120	11.8
	600	Konrad et al. [12]	Passive	4	30	120	18.4
	840	Nakamura et al. [18]	Static	2	60	120	20.4
	900	Wyon et al. [22]	Active	3	60	180	20.5
	900	Bandy et al. [3]	Static	3	60	180	24.2
	1200	Blazevich et al. [5]	Static	4 × 2	30	120	19.5
	1200	Blazevich et al. [4]	Static	4 × 2	30	120	19.9
mean	891.4			4.57	42.85	137.4	19.2

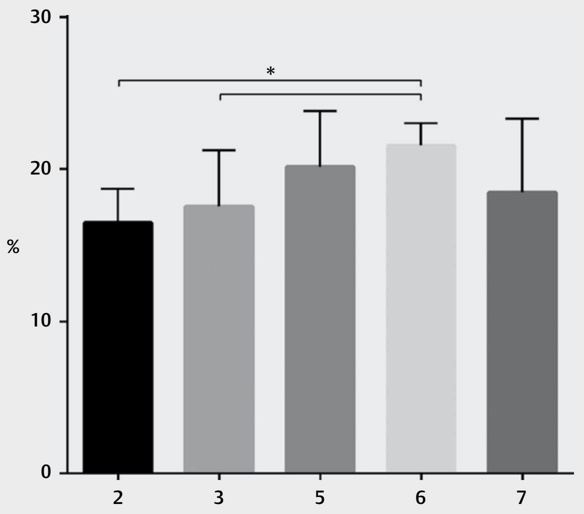
to ballistic (11.65 % increase) or PNF stretching (15 % increase). There also seems to be a timely relation with ROM improvements, being this mainly related to the total volume per week, with a minimum of 5 min per week needed to elicit a significant response and 5 days being the minimum weekly recommended frequency to achieve significant ROM improvements.

As suggested by Guissard and Duchateau[16], static stretching, being performed with slow movements, with low amplitude stretching maneuvers, and for a relatively long time, does not increase reflex activity of the stretched muscles, in contrast to ballistic stretching, but reduces its spinal excitability. The authors describe a reduction of both T and H reflexes (Tendon reflex and Hoffman reflex, both evoked and measured through Electromyography) during the stretch maneuver caused by a reduction of the muscle spindle sensitivity, that translates into a reduction of the tonic reflex activity. In addition, large amplitude stretching maneuvers seem to induce spinal postsynaptic inhibitory mechanisms, that result in a lower excitation of both the cortical and α-motor neurons during the stretch maneuver [17].

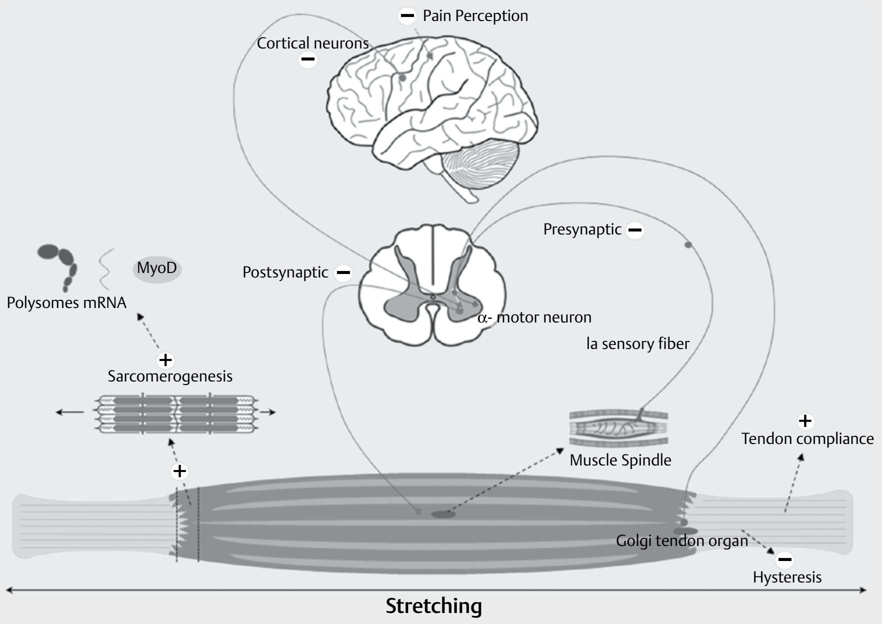
The higher gains obtained by static stretching may also be explained by a reduction in muscle stiffness with consequent increase of the compliance of the muscle already described in humans in vivo [25], promoting ROM gains through a combination of neural and mechanical adaptations.



▶ **Fig. 4** Time spent stretching per session and percentage ROM variations. No differences are shown across groups despite the different stretching volume during each stretching session.



▶ **Fig. 5** Weekly stretching frequency and percentage ROM variations. Statistical differences are shown between the 6 days per week frequency and all other groups ($p < 0.05$) except for the 5 and 7 days per week group. No differences are shown between the5 and 6 or 7 days per week groups.



▶ **Fig. 6** Schematic representation of the different adaptations induced by stretching. Stretch type, duration and frequency may contribute to a different extent to each single adaptation.

Over the past few years, PNF stretching has been preferred as a stretching technique over static or ballistic stretching, due to the ability to further inhibit the nervous system. A contraction before a static stretching allows a further increase in ROM compared to a static stretch without an initial contraction. However, the decrease of the spinal reflex excitability seems to last about 5 s and immediately returns to its initial excitability level at the end of the stretch [16]. This characteristic may suggest PNF stretching as a methodology to acutely improve ROM [5].

▶ **Table 5** Summary of studies stratified by time spent stretching per session.

Time	Tot. Time per week (s)	Authors	Typology	Sets (n)	Duration (s)	Tot. Time per session (s)	%Δ
Stretching ≤ 60 sec	90	Shadmehr et al. [20]	Passive	3	10	30	12.6
	135	Kokkonen et al. [10]	Static	3	15	45	18.1
	192	Lòpez-Bedoya et al. [14]	Active	4 × 2	12	48	15.4
	420	Cipriani et al. [6]	Static	2	30	60	23.9
	360	Cipriani et al. [6]	Static	2 × 2	30	60	24.5
	180	Cipriani et al. [6]	Static	2	30	60	16.8
	300	Bandy et al. [3]	Static	1	60	60	22.2
	180	Zakas et al. [23]	Passive	2	30	60	14.2
	180	Zakas et al. [23]	Passive	2	30	60	18.9
	180	Zakas et al. [23]	Passive	2	30	60	13.5
mean	221.7			1.7	27.7	54.3	18.1
60 sec < Stretching ≤ 120 sec	525	Mahieu et al. [15]	PNF	5	15	75	20.8
	525	Mahieu et al. [15]	PNF	5	15	75	15.7
	560	Mahieu et al. [16]	Ballistic	5	20	80	11.5
	450	Marshall et al. [17]	Passive	3	30	90	20.9
	540	Johnson et al. [9]	Passive	3	30	90	20.5
	540	Johnson et al. [9]	Passive	9	10	90	22.6
	450	Bandy et al. [3]	Static	3	30	90	23.9
	200	Lòpez-Bedoya et al. [14]	PNF	10	10	100	19.5
	200	Lòpez-Bedoya et al. [14]	Passive	10	10	100	14.3
	240	Coledam et al. [7]	Static	6	20	120	16.7
	600	Konrad et al. [11]	Ballistic	4	30	120	11.8
	600	Konrad et al. [12]	Passive	4	30	120	18.4
	840	Nakamura et al. [18]	Static	2	60	120	20.4
	1200	Blazevich et al. [5]	Static	4 × 2	30	120	19.5
	1200	Blazevich et al. [4]	Static	4 × 2	30	120	19.9
mean	578			4.6	24.6	100.6	18.4
Stretching > 120 sec	540	Ayala et al. [1]	Active	12	15	180	22.5
	540	Ayala et al. [2]	Avtive	6	30	180	13.6
	900	Bandy et al. [3]	Static	3	60	180	24.2
	540	Sainz de Baranda et al. [19]	Passive	12	15	180	20.3
	540	Sainz de Baranda et al. [19]	Passive	6	30	180	15.2
	540	Sainz de Baranda et al. [19]	Passive	4	45	180	16.6
	540	Sainz de Baranda et al.[19]	Active	6	30	180	21.8
	540	Sainz de Baranda et al.[19]	Active	4	45	180	17.1
	900	Wyon et al. [22]	Active	3	60	180	20.5
mean	620			6.2	36.6	180	19.1

Only one study directly compared static stretching and PNF stretching after an intervention period [26]. The authors applied two stretching protocols for 9 weeks, twice a week, in order to improve hamstring flexibility. The results of this study showed that both active and passive ROMs, measured through the active bilateral straight leg raise (AROM) and through the passive bilateral straight leg raise (PSLRT) tests were greater after the static protocol rather than the PNF one (8.2 vs. 3.1 % improvement during active ROM for AROM and 19.5 vs. 14.3 % improvement during passive ROM for PSLRT). Other studies that did not meet our inclusion criteria [11, 43] also directly compared static stretching with PNF stretching, finding higher gains with static stretching [11] or no differences between the two methodologies [43]. Although, it is difficult to rank stretching protocols based on their effectiveness in increasing muscle flexibility, because all the analyzed typologies showed increases in ROM.

There also seems to be a relation between time and ROM variations, especially regarding time spent stretching each week. Various studies have also related time and ROM improvements. A study by Feland et al. [13] compared three stretching protocols of different durations (60 s, 30 s and 15 s). The participants stretched their hamstrings, according to their time duration, for four sets five days a week; this resulted in 1200 (20 min), 600 (10 min) and 300 (5 min), respectively each week. Results found that, over a period of four weeks, the group with the highest gains in ROM was the one that underwent the longest intervention. Similar findings are also shown in the studies of Cipriani et. al[8]. A review by Weppler and Magnusson[41] that summarizes the main factors that contribute to muscle extensibility, describes a relation between time and muscle extensibility caused by the viscoelastic properties of the muscle. The decline of resistance to a stretch is termed viscoelastic stress relaxation and gradually increases while the stretch is applied. However, in human muscles this property is transient. Therefore, the authors reject the hypothesis of mechanical adaptation as the main contributor to muscle extensibility and suggest that, over a period of time between 3 and 8 weeks, the main contributor to muscle extensibility is a modification in the subjects' sensation. This may also explain the higher gains in ROM achieved by the group that stretched with a higher weekly frequency.

Other underling mechanisms responsible for ROM increases would be that during stretching the deformation of the extracellular matrix links with cellular integrins and transmembrane receptors creating a cell-extracellular matrix link that induces sarcomerogenesis in the muscle cell [1, 45]. A passive stretch over the physiological length of the muscle promotes eccentric growth of the muscle inducing a serial deposition of sarcomere units that are added at the muscle fiber ends [45]. The mechanism by which this process is promoted has been described in limbs immobilized in a stretch position and just after 4-6 days an increase of mRNA and polysomes was noted in addition to an overexpression of Myo-D regulatory factors, a mechanism which is associated with the stretching stimulus[15]. An increase in sarcomere deposition has also been described in relation to eccentric training with flexibility increases similar to those obtained by static stretching [36]. This increased sarcomere deposition which resulted in an increase in muscle length, occurred within just 10 days after the start of the eccentric training. The creation of new sarcomers would lead to increased muscle extensibility with less tension required to stretch a muscle at a particular length [41]. However, this process has been described not only in relation to duration and frequency but also to stretch intensity and position [1]. Of the included studies only ten took into account stretching intensity. However, none of them agree on a uniform procedure to control stretch intensity. Wyon et al. [42] used a stretch intensity ranging between 30–40 % of maximal tolerable stretch, Ayala et al. and Blezevich et al. described stretching intensity as the maximal tolerable [3, 6, 7], Cipriani and Johnson as to a point of discomfort or slight discomfort[8, 21], Lopez-Bedoya et al. [26] at a point of maximal irritation before pain, Nakamura[34] to the point the participants were willing to tolerate and Zakas et al. [44] until an end point was achieved determined when the participants felt a strain in the muscle without feeling pain. All the described procedures base the intensity according to each participant personal perception, that may vary depending on physiological and psychological transient conditions[37]. Shadmher et al. [39] was the only author that controlled stretch intensity based on the mechanical properties of the muscle where an end point was set at the primary resistance point.

Stretching possesses a variety of different parameters, including intensity, position, frequency (daily or weekly) and typology (Ballistic, PNF and Static that may also be divided in active or passive). The combination of these parameters is shown to act on anatomical and physiological properties at different levels. Modification of the viscoelastic properties of the muscle, modification of subjects sensation, sarcomerogenesis and decreased motorneuron excitability are the main components affected by stretching parameters which act on ROM. A schematic representation is presented in ▶ **Fig. 6**.

The studies included in the present review ranged between 4 and 16 weeks, and for such it is difficult to state if the increased ROM shown between the pre and post measures of each one is due to real changes in muscle extensibility or apparent muscle extensibility [28]. Since the majority of studies based their intensity on subjects personal perception or discomfort, the increased ROM shown may be caused by increased tolerance to the stretch rather than a real change in muscle extensibility [27, 28]. On the basis of such evidence it is difficult to state to which extent stretch intensity participates in the increase or decrease in ROM.

The main limit of this study is the limited number of retrieved records that analyzed stretching variations over a long term period; the results may vary across different cohorts. It is however important to note that the age range of the participants in the retrieved records lies between 18 and 46 years of age.

Stretching is an effective strategy for increasing range of motion regardless of stretching typology. However, static stretching shows slightly higher gains in ROM during a period of time between 4 and 16 weeks. There is also a time dependency in ROM gains, with this being mainly related to the total time spent stretching per week rather than the time spent stretching per session. A minimum time of 5 min each week and for each stretched muscle, seems to be more beneficial for ROM gains. In addition, stretching to a higher weekly frequency, at least 5 times per week, has shown further gains compared to lower frequencies. However, all analyzed groups showed increases in ROM and for such it is difficult to rank stretching protocols based on their effectiveness in increasing muscle flexibility.

Conflict of Interest

The authors declare no conflict of interest.

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