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CURRENT OPINION

Perception-Based Methods and Beyond: A Current Opinion on How to Assess Static Stretching Intensity

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Abstract

Muscle stretching is widely used in clinical, athletic, and otherwise healthy populations, yet a consensual definition of stretch intensity—a key component of stretch load—does not exist. This is important because the effects of stretch intensity on range of motion and strength are controversial but suggested to affect clinical practice and scientific research. Most commonly, stretch intensity is defined in relation to an individual's perceived level of discomfort or pain; however, these definitions are problematic for several reasons, including that consensual and objective quantifiable definitions of 'pain' and 'discomfort' do not exist, perceptions vary widely (and may not be sensed in some populations), and their ordinal (interval) nature is problematic from a statistical (research) point of view. The maximal range of motion or stretch distance may instead be useful; however, it can be difficult to define the 'start of stretch' and tissue stress varies non-linearly with range of motion or distance, meaning tissue load (stress) varies markedly with small changes in joint angle or distance near the stretch limit but varies less when stretches are performed further from it. Alternatively, setting joint angles or stretch distances as a percentage of the peak passive torque or resistive force can circumvent these issues, removing the need to define the 'start of stretch' and ensuring that intensity changes largely reflect changes in tissue load; however, torque/force measurement can sometimes be difficult or impossible to assess. A concerted research effort is thus required to produce an accepted definition of stretch intensity, and then to clarify how this can be quantified in scientific and practical settings.

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Key Points

Stretching is often implemented as part of warm-up routines but also used longer term to improve muscle function and structure. However, quantification of stretching intensity in the literature is highly heterogeneous and far from consensual.

Stretch intensity is often quantified via pain perception but this approach must be questioned as results are not interval scaled and depend on subjective experiences of individuals.

A more objective approach, including passive peak torque and/or muscle stiffness evaluations, may be necessary to allow scientifically sound conclusions to be drawn about the stretched structures.

Real-world applications may require alternative definitions of stretching intensity (e.g., based on percentage of maximum range of motion).

1 Introduction

Exercise is widely recommended for health promotion [1, 2] but its effects critically depend on several loading variables (e.g., intensity, duration, volume, weekly frequency) [2–5]. While acknowledging their relevance and non-linear interactions in the definition of exercise *load*, the focus of this Current Opinion is on *intensity*. Different exercise intensities may produce distinct adaptations [6–8]. For example, in resistance training (RT), intensity is commonly defined in relation to a 1-repetition maximum (1-RM) test (e.g., 30% 1-RM, 85% 1-RM [9–11]) or maximum voluntary isometric contraction force (MVC), and greater strength gains are thought to be obtained through training at higher intensities [12], although there is some debate about this [13]. While 1-RM and MVC testing are common, other means to assess intensity in RT have been proposed (e.g., multiple RM [14, 15], minimum velocity threshold [9]).

For stretching, a very popular exercise modality [16, 17], intensity assessments are not so straightforward [18], and the clinical role of intensity is debatable [6, 18–20]. Stretching (in its various forms and flavors) is widely used for many stated purposes, with a range from acute post-exercise recovery [21] to long-term improvements in range of motion (ROM) [19], among several others. Despite its wide appeal and vast body of research (e.g., over 300 peer-reviewed empirical papers on competitive athletes alone [22]), the topic of defining and assessing stretching intensity is contentious. Stretch duration is commonly reported in seconds or minutes [23, 24], stretch volume in number of sets and repetitions or seconds (if a single set of static stretching is implemented) [25–27], and stretch frequency in the number of daily and/or weekly sessions [28, 29]. Conversely, reporting of stretch intensity is highly heterogeneous. This may partly explain why the role of stretching intensity in acute and chronic outcomes has yielded mixed results in the literature [19, 20, 30–32].

A recent large-scale scoping review [22] highlighted problems with the reporting of stretching intensity in research, including: (i) lack of any description; (ii) inter-study variation in outcome denoting the endpoint (e.g., pain[1] vs discomfort); and (iii) inter-study variation in threshold for the endpoint (e.g., to point of initial discomfort, maximal discomfort, beyond the point of discomfort). A meta-analysis indicated that long-term structural adaptations to static stretching (e.g., increased fascicle length, muscle thickness) depend on stretching intensity when the assessment is performed via perceived rating of pain or discomfort [6]. However, while one systematic review showed that higher intensity static stretching training (defined as above the points of discomfort or pain) generated larger ROM gains [7], two other meta-analyses reported no significant differences in ROM with either high- or low-intensity stretching following an acute bout [20] or chronic stretch training [19]. Nonetheless, the question should be asked: can perceived pain or discomfort be considered the most accurate indicators of static stretching intensity? Pain and discomfort may only appear at greater magnitudes of stretching intensity (indeed, pain may not be experienced at all) and neither may be useful when the desired range falls well below the endpoint. Furthermore, some stretches are anatomically constrained, thereby precluding the onset of pain or discomfort (e.g., elbow extension ends upon bone-to-bone contact).

Objectively assessing the effectiveness of exercise training interventions with aims to optimize health, injury prevention, and rehabilitation [34, 35], and/or athletic performance [36, 37], relies on standardized the reporting of interventions [38–40] that enable an accurate contextualization of the findings and provide a solid basis for study replication [41, 42]. As load parameters, including intensity, influence specific adaptations to a training program [2], it is essential to understand dose–response relationships to properly prescribe an exercise intervention for targeted practical applications [3]. While in other interventions, such as strength and endurance training, intensities play a crucial

[1] Pain and nociception are different constructs, but are often (and misguidedly) conflated [33]. An exploration of this issue would stray far from the scope of this article, and therefore we use the term "pain" as commonly used in the stretching literature [6, 22].

role for physiological adaptations and are therefore clearly defined and applied in practice. Given the popularity of stretching as a training method [16, 17] without objective intensity prescriptions, it is timely to critically appraise how to define and assess stretching intensity [22]. Our goal is to review current methods for assessing static stretching intensity, including potential advantages and disadvantages, and to propose potential alternatives for further exploration. The aim is to raise awareness regarding the relevance and complexity of this topic, helping researchers to engage in a much needed discussion, while at the same time helping practitioners to assess available options and ponder their advantages and disadvantages.

The application of stretching intensity into exercise prescription is a distinct area of inquiry that would depend on specific training objectives (e.g., acute vs chronic adaptation, maximum ROM gains vs tissue stiffness reduction vs physical and mental relaxation). This aspect will not be addressed in this article.

2 Perception-Based Methods for Assessing Stretching Intensity

Stretching intensity assessment is an acute problem, i.e., the aim is to quantify the intensity of a specific stretch, at a specific moment. Therefore, stretching intensity can be understood as *a mechanism-agnostic procedure*, in parallel with tests such as 1-RM and VO_2max. How those data are used to prescribe specific exercise intensities is another problem and requires knowledge of the mechanisms driving the desired adaptations [4, 5]. Within this framework, reviews have shown that perception-based measurements (e.g., pain, discomfort) of static stretching intensity are common [22], and are especially predominant for static stretching protocols [6]. Even when included studies assess pre- and post-intervention ROM, the prescription is not usually based on the desired degrees of ROM or percentage of maximal ROM but on subjective perceptions of pain, discomfort, or other constructs [6, 22].

2.1 Are Perception-Based Methods Truly Assessing Stretching Intensity?

In one meta-analysis [6], 18 of 19 studies using static stretching adopted perception-based assessments of stretching intensity. This highlights a fundamental and evident issue: although ROM tests quantify degrees or distances, participants are instructed to perform stretching at specific subjective intensities with no reference to such degrees or distances. This contrasts with RT, where a common practice in research is to prescribe intensity based on a percentage of a maximal lifted load or force produced (e.g., 1-RM, MVC).

A second problem is that the correlation between perception-based methods (e.g., visual analog scales commonly used to assess perceived pain [43]) and objective assessments is less than ideal and may be especially fragile for lower intensity loads, as was shown for RT [44]. For static stretching, intensity as measured through dynamometry was not significantly correlated with subjective pain perception assessed through a visual analog scale [45]. Another study used PNF (proprioceptive neuromuscular facilitation) stretching (which is admittedly distinct from static stretching) and determined intensity as a percentage of MVC [46]. The authors found a significant correlation between *post*-stretch pain (but not *during* stretching) and stretching intensity, but no correlation between perceived pain and ROM gains.

Pain perception varies considerably between individuals and may depend on several factors including pain history of the participants, previous experiences, and sex [47, 48]. Because exercise modulates pain perception [49, 50], it becomes relevant to consider whether a study was performed with previously untrained or trained participants. Attention, expectations, and reappraisal modulate pain perception [51], which may explain why the specific wording that is provided to participants before stretching influences the maximal ROM [52]. An experienced team of researchers observed that participants reached their maximal ROM (defined by perceived pain) earlier when visually monitoring the stretched joint. Consequently, they performed studies in which participants stretched with their eyes closed to eliminate visual feedback of the stretch amplitude [53, 54].

Pain perception also varies greatly as the body position, or position of non-stretched joints, varies. For example, pain may be strongly felt in the popliteal region (behind the knee) as the ankle is dorsiflexed to stretch the calf muscles when the hip joint is flexed but may be minimal or absent when the hip joint is extended during the stretch. This is at least partly due to the stretching of the tibial nerve during dorsiflexion when the hip is flexed, which is absent when the hip is extended [55, 56], and significantly reduces maximal ankle dorsiflexion ROM [57, 58]. Some researchers therefore perform calf muscle stretches (moving the ankle into dorsiflexion) with subjects at least partly reclined to minimize this pain [54, 59]. In such cases, pain perception itself would be of minimal use as an intensity marker.

As previously alluded to, some stretches may not even allow the participants to reach discomfort or pain. Elbow extension, for example, will be naturally bound by bone-on-bone contact and, depending on normal inter-individual variability, it may not allow everybody to reach discomfort or pain when performing a stretching of the region. For biarticular muscles, stretching amplitude might be increased by altering the position of other joints (e.g., shoulder extension to increase biceps brachii excursion). These arguments converge to suggest that perceived pain or discomfort may not provide an accurate measure of stretching intensity. Moreover, stretch tolerance responses may differ between men and women [60], and may even explain part of the differences in lower hamstring extensibility [61]. Therefore, using perception-based measures for prescribing stretching intensity may be population specific. So, while the constructs discussed in this section could be accepted as reasonably accurate proxies of stretching intensity, there are additional issues to consider.

2.2 Inconsistency of Outcomes, Thresholds, and Terminology

Pain and discomfort tend to be used somewhat interchangeably in stretching research and their data might be pooled as a measure of stretching intensity [6], but they are not synonymous and will likely be interpreted differently by the participants [62, 63]. This affects inter-study comparability and the replication of results as some studies refer to the term "pain" [53, 64, 65], while others use the term "discomfort" [66, 67]. Moreover some studies use both interchangeably (e.g., "without discomfort or pain"), as recently underlined in two reviews [6, 22]. Some studies use alternative terms that are not synonyms of pain or discomfort, including "tolerable" or "feeling of stretch" [6, 22]. To compound the problem, even when two studies refer to the same outcome or terminology (e.g., pain), they do not necessarily use the same threshold (e.g., "without feeling pain" vs "onset of pain"), or the same terminology for what may be assumed as a comparable threshold (e.g., "without feeling pain" vs "preceding pain threshold") [6, 22].

Regardless of exceptions whereby pain perception is compromised (e.g., congenital nociceptor deficiency [33], neuropathic pain [68]), a purported adaptation to stretching is increased stretch tolerance [69–72], even in the absence of measurable changes in muscle passive stiffness [73] or ROM [71]. The diffuse noxious inhibitory control theory of pain suggests that global reductions in pain sensitivity are modulated by the release of endorphins and enkephalins, which would alter pain perception with each repetition or set of stretching [20, 69]. This suggests that an identical stretch amplitude may be perceived differently depending on individual factors. Therefore, using pain, discomfort, or other similar outcomes likely does not provide an easily comparable measure of stretching intensity. Consistent with this, Lim and Park [45] found no rank correlation between perceived pain during stretching and the passive resistive torque produced.

2.3 The Stretching Intensity Scale

The Stretching Intensity Scale [74] is an alternative perception-based method that assesses the perceived magnitude of stretching intensity. Participants are tested to experience maximal intensity stretching (i.e., maximal ROM) and then learn to report their perceived stretching intensity in relation to that threshold, with a range from none to supramaximal (the technical reason for including supramaximal intensity is addressed in Sect. 3.1). Despite being a subjective method, its specific language (i.e., directly related to the perception of stretching intensity) and its strong correlations with objective measures (e.g., ROM, passive torque) [74] provide a practical and potentially robust tool to consider in regular training applications. However, we are not aware of subsequent studies that could either support or question the validity and reliability of the Stretching Intensity Scale.

2.4 Statistical Concerns When Analyzing Perception-Based Methods

The above methods use ordinal scales, where the intervals between the actual distances between points are neither equal nor empirically determined [75]. In practice, using the arbitrary example of an ordinal scale that ranges from 0 to 10, the difference between 5 and 6 will likely be of a different magnitude than the difference between 9 and 10. Numbers in an ordinal scale only provide a measure of order, not of interval [76], and research should avoid treating these data as if they represented a continuous set of values [75, 77–80]. This problem affects research on stretching intensity, including within meta-analyses [6, 19]. At a minimum, ordinal data should first be rescaled to an interval scale [80], and for pain scales it has been suggested that 95% confidence intervals should be used instead of the p value for interpreting the results [81]. The common practice of analyzing these scales through means and standard deviations assumes that the intervals between numbers are proportional (i.e., they require interval scales), which is untrue and may falsely suggest a proportional course of stretching pain and stretching intensity, which may not hold up to scrutiny [45].

Another problem arises when meta-analyses combine data from different studies to produce statements about the effects of stretching intensity [6]. Pooling data from studies using different outcomes (e.g., pain vs discomfort), inconsistent thresholds, and heterogeneous terminology for similar outcomes and thresholds poses a significant risk of providing misleading conclusions in meta-analyses. Unclear definitions of pain and discomfort, different definitions across studies, and complex relationships between subjective assessments and objective stretching effects contribute to substantial clinical heterogeneity between studies and preclude meta-analytical treatment [82, 83]. Meta-analyses that pool heterogeneous data are likely providing biased and invalid conclusions.

3 Alternatives for Assessing Static Stretching Intensity

Perception-based methods to determine static stretching intensity are easy to apply in most settings, requiring little-to-no time and financial or human resource investment, but present important limitations that were previously discussed. Researchers and practitioners might find inspiration in the RT literature to implement objective methods to assess maximal intensity.[2]

3.1 Percentage of Maximal Active ROM

Static stretching intensity can be determined based on maximal ROM [89]. To parallel common RT assessments, this would be the maximal *active* ROM, or *self*-ROM, without external aids. Participants would be asked to reach maximum ROM, i.e., where they cannot actively reach further. This maximal ROM would be assessed using goniometry (e.g., degree of hip flexion) or, in some cases, excursion distance (e.g., sit-and-reach), and would represent 100% intensity. Stretching intensity ranges would then be determined in relation to maximal active ROM [74].[3] Importantly, the specific verbal instructions provided to achieve maximal ROM in terms of intensity (minimum, point, maximum) and sensation (tolerance, discomfort, pain) may change the maximal ROM and should be carefully considered and standardized [52].

Assessments should be joint and position specific, although we currently lack solid evidence to understand how position may change stretching intensity [18]. For example, the sit-and-reach and the stand-and-reach (also known as toe touch) tests are similar movements and involve the same joints; however, differences in body position and the resulting effects of gravity lead to relevant differences between the two, indicating that testing protocols should be specific. Moreover, the toe-touch test may be influenced by the sense of balance [90], which is unlikely to affect the sit-and-reach test.

Nonetheless, accurately measuring ROM requires (in most scenarios) an outside observer and this may not be practical (or feasible). Furthermore, torque or force during stretch varies non-linearly with ROM or distance, so the tissue load (stress) will vary markedly with only small changes in the joint angle or distance near to the maximum but vary less when stretches are performed further from it; i.e., changes in tissue stress or sensory load (pain, discomfort, pressure) may be minimal when moving from about 20 to 70% of maximum ROM or distance, but become substantial when advancing from 70 to 90% or from 90 to 100%. Finally, the 'start of stretch' can be hard to define, so subsequent calculations of percent ROM or distance may be difficult. Regardless, because the Stretching Intensity Scale presents large correlations with ROM [74], it may prove to be a useful proxy for a more objective measure.

3.2 Maximal Tolerable Torque of the First Stretching Repetition

Research has also assessed and prescribed static stretching intensity as the angle (or distance) achieved at a given percentage of the peak passive torque during maximal stretch [8, 53, 54, 91–93], e.g., the ankle angle at which 90% of peak passive torque was reached [94]. Passive torque is determined at prescribed joint angles and passive resistive torque increases near the end ROM. As maximal ROM varies between individuals, and joint anatomical properties might influence maximal ROM, it is possible to move to the angle at which a given percentage of maximal passive torque occurs to achieve a similar stretch intensity. The passive torque decreases within a stretching session owing to relaxation effects [95] or holding the stretch for a short period of time [96], consistent with non-linear increases observed in ROM in successive repetitions (hysteresis) [97]. The end-ROM intensity could become more objective after completion of an appropriate task-specific warm-up. When stretch intensity is high and passive torque (or resistive force) decreases via the stress relaxation response, the joint angle or stretch distance can be increased to maintain the target passive torque level, allowing for real-time changes to maintain intensity as biomechanical and physiological adaptations occur, for example, as in 'constant torque' stretching [96, 98–100].

3.3 Muscle Stiffness

Stiffness refers to the amount of force or stress opposing tissue deformation, and muscle stiffness plays a pivotal role in determining maximal ROM [101], although it may vary depending on the joint and specific movement [102]. Conversely, tendon stiffness appears to have little influence on ROM [53, 103], although its effects on perceived stretch, discomfort, or pain should be explored in future research. Strong linear relationships have been demonstrated between muscle stiffness and the passive muscle

[2] Assessments may vary depending on ambient temperature, time of day, and other fluctuating factors, which is why standardization of test conditions is so important [2, 84, 85]. Likewise, a familiarization period is necessary, or otherwise changes may result exclusively from learning the test instead of reflecting "true" outcomes [86–88]. Periodic assessments are required to update the reference values.

[3] Acute stretch tolerance may improve ROM in subsequent repetitions, and it is therefore possible to talk of "supramaximal ROM" [74]. Two options are available: (i) assess a single repetition and consider the possibility of supramaximal percentages; or (ii) assess multiple repetitions and consider the best attempt to reflect "true" maximal intensity, whereby supramaximal percentages would only be applicable to assisted stretches.

force during the passive stretch [104–107]. Therefore, muscle stiffness could provide an objective approach to determine stretching intensity, as stiffness would increase with increasing muscle length. Stiffness may vary depending on joint position (e.g., neutral vs flexed) [108, 109]. However, muscle tissues are not the sole determinants of ROM, and indeed their relative importance in limiting ROM may decrease with age [110].

Given the complexities in the set-up to assess stiffness, this method may not be feasible for ongoing applications typical of "real-world" training settings, although it may be useful for scientific research. As for passive torque, stiffness assessments are meaningful only if associated with maximal ROM. In cases where other structures (e.g., nerve, bone, joint capsule) greatly influence ROM (e.g., for some joints or movements), stiffness may become a less useful parameter (e.g., as previously mentioned in the study by Reiner et al. [102]). In addition, because the muscle force–length relationship generally mirrors the joint torque–angle relationship, peak passive torque might be a convenient proxy for the muscle stiffness assessment. Figure 1 synthesizes the methods discussed in this Current Opinion.

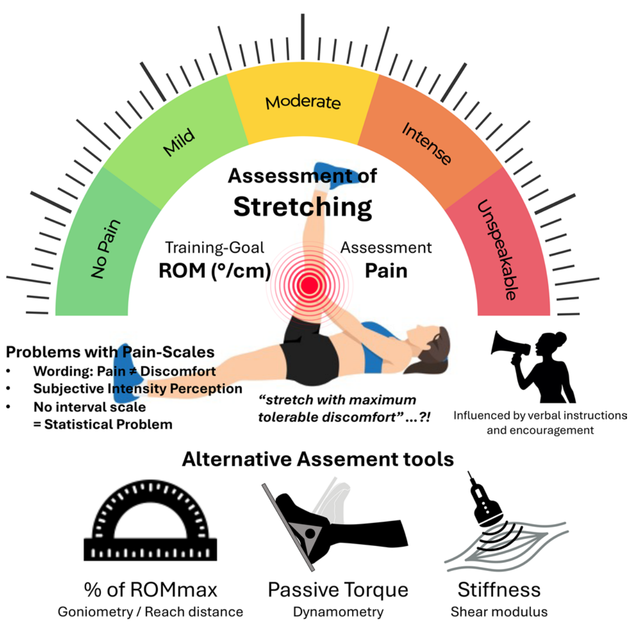

Fig. 1 Different methods to determine stretch intensity. *ROM* range of motion, *ROMmax* maximal ROM

4 Conclusions

Stretch intensity is an important load control parameter influencing stretching outcomes but lacks a consensual definition. Current conclusions and recommendations regarding the implementation of different intensities lack validity because of unclear definitions of stretching intensity and the absence of standardized assessment procedures. Moreover, the wide variation in assessment methods renders inter-study comparisons difficult. The use of perception-based scales, while practical, has several limitations that curb its scientific validity. Although it is theoretically sound to use parameters such as passive torque or force or muscle stiffness, these approaches remain unvalidated and future studies are needed before investing further in testing approaches with higher practical or clinical relevance. For researchers, we call for further discussion on the topic; for practitioners, we suggest the adoption of practical measures to assess stretching intensity while avoiding definitive statements on the topic.

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