Habilitation

based on a collection of scientific studies

The acute and long-term impact of various exercises on the muscle-tendon unit properties and sports performance

submitted by

Andreas Konrad

submitted at the

University of Graz

December 2020

Summary

Frequent exercise with the right dose has a positive impact on both cardiovascular function and mental wellbeing (Vina et al., 2012). Besides this, the other major goal of athletes is to increase their performance through different types of exercise. For example, it has been reported that exercises/interventions such as resistance training (Schoenfeld et al., 2017) and stretching training (Meideros and Lima, 2017) can have a positive impact on the performance of an athlete. However, as of the date of this habilitation, there are still a lot of open research questions about the effects of various exercises (e.g. stretching, foam rolling, flossing, massage, jumping) on functional parameters (e.g. range of motion, strength) and the possible structural mechanism behind the changes in the muscle-tendon function (e.g. changes in muscle stiffness). Therefore, the purpose of this habilitation is to investigate unexplored acute, prolonged, and long-term exercises/stimuli (e.g. stretching, foam rolling, flossing, jumping) and their relationship with and impact on muscle-tendon properties and/or muscle performance.

This habilitation is based on several scientific studies related to training and movement sciences, and is divided into five main chapters. However, synergies exist between the chapters, and in most cases, the topic of one chapter is linked to the previous chapter.

First of all, the main chapters of this habilitation and the included studies are briefly introduced in the following, before being described in more detail.

Chapter I deals with the acute effects of different stretching techniques (see the *Fehler! Verweisquelle konnte nicht gefunden werden.* on page **Fehler! Textmarke nicht definiert.** of ***Study 8***) and intensities (see ***Study 7***) on the muscle and tendon tissue properties. Moreover, a review article about the acute effects of stretching on running performance and running economy (see ***Study 11***) is also presented in Chapter I. Based on the findings of Chapter I, the goal of Chapter II is to investigate the time course of the effects of a single static stretching

exercise with different stretching durations on the muscle and tendon tissue properties (see ***Studies 3, 4, and 5***). Moreover, the effects of static stretching interventions over 5 weeks on the passive properties (e.g. muscle stiffness; see ***Study 13***) and active properties (e.g., muscle thickness; see ***Study 14***) of the muscles are presented in Chapter III. Chapter IV presents further advanced techniques, such as flossing (see ***Study 1***), massage (see ***Study 2***), and foam rolling (see ***Studies 9 and 12***), which can have acute impacts on various muscle parameters. At the end of this habilitation, Chapter 5 considers the muscle-tendon unit properties of soccer players (see ***Study 6***) and how the muscle-tendon unit relates to jump performance (see ***Study 10***).

In the following, to provide a clearer picture of the topic of this habilitation and the connections between the studies and the chapters, the five chapters are introduced in more detail. After this introduction, all of the studies included in this habilitation are presented (as they originally appeared in the journals) in the associated chapters.

Chapter I: The acute effects of various stretching techniques and intensities on the muscle-tendon unit properties and sports performance

Many athletes use stretching exercises as a warm-up routine (Mc Hugh & Cosgrave, 2010). The most common techniques are static, ballistic, and proprioceptive neuromuscular stretching (PNF) (Magnusson et al., 1996). When this project was first planned, there was some limited evidence about the effects of single stretching exercises on various elastic muscle-tendon unit properties (e.g. muscle stiffness and tendon stiffness) following static stretching (Kay and Blazevich, 2009, Kay et al., 2015; Kubo et al., 2001; Kato et al., 2010) and particularly other stretching techniques (e.g., PNF: Kay et al., 2015). However, at this time, no study had investigated and compared the effects of a single stretching exercise with the three main techniques (static, ballistic, PNF) on various mechanical and morphological parameters of the muscle-tendon unit (muscle stiffness, tendon stiffness, fascicle length, pennation angle). Thus, the main purpose of the first study presented in Chapter I ***(Study 8)***[1] was to investigate the effects of the three main stretching techniques on various muscle and tendon tissue properties of the gastrocnemius medialis. Moreover, the secondary aim was to compare the different effects of the three stretching techniques.

The idea for the second study in Chapter I ***(Study 7)***[2] came about during the interpretation of the results of ***Study 8***. In ***Study 8***, we found smaller increases (although significant) in range of motion (static: +1.4° ballistic: +1.5° PNF: +1.1°) compared to other studies of static stretching (+4.6° Morse et al. 2008; +9° Kato et al., 2010; +2.6° Kay et al., 2015) and PNF stretching (+5.3° Kay et al., 2015). Furthermore, we found that the prolonged stretching durations in some (Morse et al., 2008; Kato et al., 2010) but not all (Kay et al., 2015) of these aforementioned studies was a possible explanation for the smaller increases in range of motion, due to the different stretching intensities used. While in ***Study 8***, a constant-angle stretching approach (stretching always with the same angle throughout the whole stretching protocol) was used, the other studies used a more intense stretching approach, where the participants adapted the joint angle when the perception of stretch decreased (constant torque: Morse et al. 2008; Kato et al., 2010; adapted joint angle following every bout: Kay et al., 2015). Indeed, Cabido et al. (2014) reported a greater increase in range of motion and greater reductions in overall joint (muscle-tendon) stiffness in the more intense approach (constant torque) compared to the approach used in ***Study 8*** (constant angle). However, at this time, no study had compared the effects of the two static stretching intensities (constant torque vs. constant angle) at a structural level (e.g. muscle stiffness or tendon stiffness). Thus, the purpose of ***Study 7*** was to investigate and compare the

[1] Konrad, A., Stafilidis, S., & Tilp, M. (2017). Effects of acute static, ballistic, and PNF stretching exercise on the muscle and tendon tissue properties. Scandinavian Journal of Medicine & Science in Sports, 27(10), 1070–1080.
[2] Konrad, A., Budini, F., & Tilp, M. (2017). Acute effects of constant torque and constant angle stretching on the muscle and tendon tissue properties. European Journal of Applied Physiology, 117(8), 1649–1656.

acute effects of two stretching intensities (constant torque vs. constant angle) on both the functional (e.g. range of motion, maximum voluntary torque) and structural (muscle stiffness, tendon stiffness) parameters of the gastrocnemius medialis.

Stretching exercises in terms of a warm-up are also frequently used by endurance athletes (Bishop, 2003). However, if stretching, in general, can be useful for endurance athletes (Magnusson et al., 1996), the diversity of the duration (Behm et al., 2016) and the approach used to stretch all the involved muscles before exercise (Allison et al., 2008) are subjects of some controversy in the literature. Thus, I wrote a grant proposal for the Erwin Schrödinger Fellowship with the title "Targeted muscle stretching to improve running economy", which was finally granted in May 2020 (J 4484; Principal Investigator: Andreas Konrad) and will likely start in March 2021. On the one hand, this research grant will allow me to fulfill the study plan, and on the other hand, it will allow me to go abroad (TU Munich) for one year and gather some new insights at another research institution. In brief, this proposal is about the effect of targeted stretching of various muscles that likely need to be more compliant for a running task (e.g. stretching of the quadriceps muscles; Arampatzis et al., 2006) on various parameters such as running economy and biomechanical parameters in running. In the course of writing this grant application, the literature about stretching and its impact on running economy and running performance was screened. Consequently, in collaboration with colleagues from Graz and also Japan, I submitted a systematic review of this topic (***Study 11***)[3]. The purpose of this systematic review was to summarize the existing literature about the effects of a single stretching exercise on running performance and running economy.

[3] Konrad, A., Močnik, R., Nakamura M., Sudi, K., & Tilp, M. The impact of a single stretching exercise on running performance and running economy. A systematic review. Frontiers in Physiology (status: under review).

Chapter II: The acute time course of muscle-tendon unit function and structure following different durations of static stretching

The published studies described in this chapter (***Studies 3, 4, and 5***) were part of a project coordinated by the Austrian Science Fund (Project P 27665; Principal Investigator: Markus Tilp).

Depending on the stretch duration and intensity, it is known that a single stretching exercise can lead to an increase in range of motion (Morse et al., 2008; Kato et al., 2010), associated with either changes in stretch tolerance (Magnusson et al., 1996) and/or a decrease in the stiffness of the muscular (Kay et al., 2015) or tendinous component (Kato et al., 2010) immediately following the stretching exercise (see also ***Chapter I, Studies 7 and 8***). Moreover, it has been reported that static stretching durations for ≥60 s will likely cause an impairment in strength tasks immediately following the stretching exercise (Behm et al., 2016). However, when this project started, there was a gap in the literature about what happens in the minutes following the stretching exercises, with parameters such as strength, range of motion, and the associated changes in soft tissue (e.g. muscle stiffness or tendon stiffness). This is of specific interest for sports practice, since the time between stretching during the warm-up and the start of a competition often exceeds several minutes. Therefore, the purpose of Chapter II was to investigate the time course of the changes in the various muscle and tendon mechanical properties (e.g. muscle and tendon stiffness) and the functional responses (e.g. range of motion) of the gastrocnemius medialis and Achilles tendon following 1 min (***Study 3***)[4], 3 min (***Study 4***)[5], and 5 min (***Study 5***)[6] of static stretching.

<u>Chapter III: The effects of a high-volume 5-week static stretching intervention on the muscle-tendon structure and function of the calf muscles</u>

Although the topic of my dissertation was to investigate the effects of a 6-week stretching intervention with static (Konrad & Tilp, 2014a), ballistic (Konrad & Tilp, 2014b), and PNF (Konrad et al., 2015) techniques on the muscle-tendon unit function (e.g. range of motion, maximum voluntary contraction torque) and structure (e.g. muscle stiffness, tendon stiffness), there are still gaps in the literature with regard to stretching interventions and the impact on the muscle-tendon unit function and structure (Freitas et al., 2018). The conclusion of the stretching intervention review and meta-analysis of Freitas et al. (2018) was that up to eight weeks of frequent stretching might not be enough stimulus to induce changes in the muscle and tendon tissue properties, which might explain the changes in range of motion. Thus, an adapted perception of stretch and pain was reported as being the main mechanism responsible for the changes in range of motion following several weeks of frequent stretching by Freitas et al. (2018). However, the included studies in Freitas et al. (2018) which investigated muscle stiffness or tendon stiffness had stretch durations of 360 s to 3150 s per week. In fact, the majority of the studies considered less than 1000 s of stretching time per week. Thus, a further

[4] Konrad, A., & Tilp, M. (2020) The acute time course of muscle and tendon tissue changes following one minute of static stretching. Current Issues in Sport Science (CISS), 5:63–78.
[5] Konrad, A., & Tilp, M. (2020). The time course of muscle-tendon unit function and structure following three minutes of static stretching. Journal of Sports Science and Medicine, 19(1), 52–58.
[6] Konrad, A., Reiner, M. M., Thaller, S., & Tilp, M. (2019). The time course of muscle-tendon properties and function responses of a five-minute static stretching exercise. European Journal of Sport Science, 19(9), 1195-1203.

possible explanation for the lack of changes in the muscular or tendinous extensibility in the meta-analysis of Freitas et al. (2018) could have been the short weekly stretching duration. Therefore, the purpose of the first study in Chapter III (***Study 13***)[7] was to investigate the effects of a 5-week static stretching intervention of the plantar flexors with a high-volume stretching duration (3600 s/week) on dorsiflexion range of motion, passive torque at maximum dorsiflexion range of motion, and muscle stiffness. A further goal was to investigate the effects of an additional 5-week detraining (by simply stopping the stretching training) on the aforementioned parameters.

While there is some evidence that repeated static stretching over three to six weeks does not alter muscle performance (Kubo et al., 2002; Konrad et al., 2014a; Medeiros and Lima, 2017), recent studies that included 10 weeks of stretching reported increased dynamic muscle performance (i.e. counter movement jump height) (Kokkonen et al., 2007; Hunter and Marshall, 2002; Medeiros and Lima, 2017). In their review, Medeiros and Lima (2017) concluded that habitual stretching (regardless of the technique used) might have a positive impact on dynamic muscle performance. Kokkonen et al. (2007) speculated that their positive results were due to changes in the muscle and tendon structure, which were not analyzed in their study. In addition, early animal studies reported muscle hypertrophy following massive stretching durations in animals (Goldberg et al., 1975). Therefore, there was a need to analyze the muscle-tendon structure to understand the mechano-morphological mechanism behind the changes in muscle performance following a high-volume stretching intervention in human participants. Thus, the purpose of the second study of Chapter III (***Study 14***)[8] was to investigate the effects of a 5-week static stretching intervention of the plantar flexors with a high-volume stretching duration

[7]Nakamura, M., Yahata, K., Sato, S., Kiyono, R., Riku, Y., Fukaya, T., Nunes, J. P., & Konrad, A. The chronic and detraining effects of static stretching programs on passive properties of the medial gastrocnemius. Scandinavian Journal of Medicine & Science in Sports (status: under review).

[8] Yahata, K., Konrad, A., Sato, S., Kiyono, R., Riku, Y., Fukaya, T., Nunes, J. P., & Nakamura, M. Effect of a high-volume static stretching program on plantar flexor muscle strength and architecture. European Journal of Applied Physiology (status: under review).

(3600 s/week) on plantar flexor strength and architecture (muscle thickness, pennation angle, fascicle length).

Chapter IV: The acute effects of several myofascial techniques on the muscle-tendon unit properties and sports performance

This chapter is mainly based on an ongoing (until 2022) project funded by the Austrian Science Fund (FWF) (P 32078-B; Principal Investigator: Andreas Konrad) and is divided into three techniques: foam rolling, flossing, and percussive therapy with a massage gun.

a. Foam rolling

In addition to myofascial release techniques applied by a therapist (e.g. the therapist gives a gentle stretch to the restricted fascia), self-myofascial release techniques have gained popularity in the last few years (Kalichman and David, 2017). The most common technique and indeed the most explored self-myofascial release technique is foam rolling (Wilke et al. 2020). Wilke et al. (2020) showed in their systematic review and meta-analysis that foam rolling is able to induce acute changes in range of motion, and the magnitude of the effect is comparable to that of single stretching exercises. Moreover, Wilke et al. (2020) concluded that foam rolling with an additional vibration stimulus can lead to an enhanced effect on range of motion. However, due the small amount of studies, this can only be seen as speculation at present (Wilke et al., 2020).

Although several studies about foam rolling and its effect on the range of motion of a joint have been conducted in recent years, to date, the mechanism for the increase in range of motion remains unclear. Since Wilke et al. (2020) reported a similar magnitude of increase in range of motion following an acute bout of foam rolling to that following stretching, it can be assumed that a similar mechanism to that seen in stretching, such as an adapted perception of pain (Magnussson et al., 1996) and/or a decrease in the muscular (e.g. Kay et al., 2015 or see ***Studies 7 and 8 in Chapter I***) or tendinous stiffness (e.g. Kato et al., 2010), is the mechanism for the increase in range of motion. Therefore, the purpose of the first study in Chapter IV (***Study 9***)[9] was to investigate the acute and prolonged (following 30 min) effects of a single foam rolling exercise of the calf muscles of different durations (30 s, 90 s, and 300 s) on range of motion, passive torque at maximum range of motion, muscle stiffness with shear elastic modulus, and maximum voluntary contraction torque of the plantar flexors.

Since vibration foam rolling has gained in popularity in the last five years, and no study, prior to this date, had compared the effects of non-vibration foam rolling with the effects of vibration foam rolling on functional parameters (e.g. range of motion, maximum voluntary contraction torque) and possible changes in the muscle structure (muscle stiffness), especially the quadriceps muscle, ***Study 12*** was conducted. Therefore, the purpose of the second study in Chapter IV (***Study 12***)[10] was to investigate and compare the effects of a single foam rolling exercise of 3 min with and without vibration stimulus on range of motion, passive resistive torque (at a standardized angle), maximum voluntary contraction torque, and muscle stiffness, assessed with shear wave elastography of the leg extensor muscles.

b. Flossing

A further myofascial technique is flossing with a floss band. A floss band is a latex rubber band that is wrapped around a target tissue (muscle or joint) with a certain amount of compression

[9] Nakamura, M., Onuma, R., Kiyono, R., Yasaka, K., Sato, S., Yahata, K., Fukaya, T., & Konrad, A. (2021) The acute and prolonged effects of different durations of foam rolling on range of motion, muscle stiffness, and muscle strength. Journal of Sports Science and Medicine. Accepted.

[10] Reiner, M. M., Glashüttner, C., Bernsteiner, D., Tilp, M., Guilhem, G., Morales-Artacho, A., & Konrad, A. A comparison of foam rolling and vibration foam rolling on the quadriceps muscle function and mechanical properties. European Journal of Applied Physiology (status: under review).

and for a certain amount of time (Driller and Overmayer, 2017). It is believed that the compression release (when removing the floss band) reduces myofascial restrictions and results in better joint and muscle function (Starrett and Cordoza, 2015). In the last five years, a handful of studies have investigated the functional effects of flossing of joints, and most of these studies reported an increase in range of motion (e.g., Driller and Overmayer, 2017; Vogrin et al., 2020) and beneficial effects on strength and springiness (Driller and Overmayer, 2017, Mills et al., 2020). However, prior to the date of this study, no study had investigated the possible neuromuscular or mechanical mechanisms behind these changes. Moreover, since all of the previous studies focused on wrapping the floss band around a joint, no study had investigated the effects of flossing the soft tissue only. Therefore, the purpose of the fourth study in Chapter IV (***Study 1***)[11] was to investigate the effects of flossing of the thigh on muscle function (range of motion, maximum voluntary contraction, jump performance) and to investigate potential mechanical (passive torque at standardized joint angles) and neuromuscular mechanisms (electromyography) which might explain the possible changes in muscle function.

c. Percussive therapy with a massage gun

In the last few years, hand-held percussive treatment devices from manufactures such as Theragun or Hyperice have gained popularity in the athlete and therapist community. Due to the vibrations of up to 53 Hz that such devices can produce, it is possible to perform a self-massage, or the therapist can add other stimuli to their portfolio. The world wide web is full of tutorials and explanations as to why these devices are able to release tissue restrictions, and hence have a beneficial effect on muscle function. For example, one tutorial and explanation of

[11] Konrad, A., Bernsteiner, D., Budini, F., Reiner, M. M., Glashüttner, C., Berger, C., & Tilp, M. (2020). Tissue flossing of the thigh increases isometric strength acutely but has no effects on flexibility or jump height. European Journal of Sports Science. Accepted.

the possible mechanism was provided by Kelly Starrett, author of the bestselling book *Becoming a Supple Leopard* (Starrett and Cordoza, 2015). However, as of the date when this study was conceived, no peer-reviewed publication had tested the effects of such a device on muscle function. Since conventional massage is able to increase the range of motion (Davis et al., 2020), and vibration therapy can increase strength (Lee et al., 2018), a hand-held percussive treatment device likely combines these effects. Therefore, the purpose of the fifth study in Chapter IV (***Study 2***)[12] was to investigate the effects of a 5-min massage of the plantar flexors with a Hypervolt device on ankle range of motion and plantar flexor maximum voluntary contraction torque.

Chapter V: Muscle-tendon unit characteristics of soccer players, in relation to jump performance

Due to the specific training regimes, different kinds of sports have different impacts on the muscle and tendon unit characteristics. For example, Arampatzis et al. (2007) reported higher tendon stiffness and higher maximum voluntary contraction torque in sprinters compared to endurance athletes. However, not only the type of sport can result in differences in the muscle-tendon unit properties, but also the position within the sport (e.g. playing position in team sports). However, for soccer, Faria et al. (2013) reported no difference between defenders, midfielders, wingers, and forwards in strength and muscle-tendon (joint) stiffness. However, they did not include goalkeepers and did not investigate the muscle architecture (e.g. muscle thickness, fascicle length) in their study. Therefore, the purpose of the first study in Chapter V

[12] Konrad, A., Glashüttner, C., Reiner, M. M., Bernsteiner, D., & Tilp, M. (2020). The Acute Effects of a Percussive Massage Treatment with a Hypervolt Device on Plantar Flexor Muscles' Range of Motion and Performance. Journal of Sports Science and Medicine, 19(4), 690–694.

(***Study 6***)[13] was to compare the muscle and tendon unit characteristics of the gastrocnemius muscle in soccer goalkeepers and midfielders, and also in less-active controls. The parameters were range of motion, passive resistive torque at maximum range of motion, maximum voluntary torque, muscle-tendon (joint) stiffness, muscle stiffness, tendon stiffness, muscle thickness, fascicle length, and pennation angle.

Although we could not find a difference between goalkeepers and midfielders in ***Study 6*** (since it was a pilot study, this was likely due to the small sample size), specific muscle-tendon unit adaptations between different types of sports have been reported in several cross-sectional studies (e.g. Arampatzis et al., 2007). Stiffer tendons in sprinters compared to endurance athletes, as reported in Arampatzis et al. (2007), likely results in a higher jump height (Bojsen-Møller et al., 2005). Although there was evidence that higher ankle joint (muscle-tendon) stiffness resulted in shorter ground contact time during jumping (Arampatzis et al., 2001), the role of the Achilles tendon stiffness with regard to ground contact time during drop jumps had not previously been investigated. Therefore, the purpose of the second study in Chapter V (***Study 10***)[14] was to relate Achilles tendon stiffness and ground contact time during drop jumps. Moreover, a further goal was to relate Achilles tendon stiffness to squat jump and counter movement jump performance.

---

[13] Konrad, A., & Tilp, M. (2018). Muscle and tendon tissue properties of competitive soccer goalkeepers and midfielders. German Journal of Exercise and Sport Research, 48(2), 245–251.
[14] Abdelsattar, M., Konrad, A., & Tilp, M. (2018). Relationship between Achilles Tendon Stiffness and Ground Contact Time during Drop Jumps. Journal of Sports Science & medicine, 17(2), 223–228.

References

Allison, S. J., Bailey, D. M., & Folland, J. P. (2008). Prolonged static stretching does not influence running economy despite changes in neuromuscular function. Journal of sports sciences, 26(14), 1489–1495.

Arampatzis, A., Schade, F., Walsh, M., & Brüggemann, G. P. (2001). Influence of leg stiffness and its effect on myodynamic jumping performance. Journal of Electromyography and Kinesiology, 11(5), 355–364.

Arampatzis, A., De Monte, G., Karamanidis, K., Morey-Klapsing, G., Stafilidis, S., & Brüggemann, G. P. (2006). Influence of the muscle-tendon unit's mechanical and morphological properties on running economy. Journal of Experimental Biology, 209(17), 3345–3357.

Arampatzis, A., Karamanidis, K., Morey-Klapsing, G., De Monte, G., & Stafilidis, S. (2007). Mechanical properties of the triceps surae tendon and aponeurosis in relation to intensity of sport activity. Journal of Biomechanics, 40(9), 1946–1952.

Bishop, D. (2003). Warm-up II: Performance changes following active warm up on exercise performance. Sports Medicine, 33(1), 483–498.

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. Applied Physiology, Nutrition, and Metabolism, 41(1), 1-11.

Bojsen-Møller, J., Magnusson, S. P., Rasmussen, L. R., Kjaer, M., & Aagaard, P. (2005). Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. Journal of Applied Physiology, 99(3), 986–994.

Cabido, C. E., Bergamini, J. C., Andrade, A. G., Lima, F. V., Menzel, H. J., & Chagas, M. H. (2014). Acute effect of constant torque and angle stretching on range of motion, muscle passive properties, and stretch discomfort perception. The Journal of Strength and Conditioning Research, 28(4), 1050–1057.

Davis, H. L., Alabed, S., & Chico, T. J. A. (2020). Effect of sports massage on performance and recovery: a systematic review and meta-analysis. BMJ Open Sport & Exercise Medicine, 6(1), e000614.

Driller, M. W., & Overmayer, R. G. (2017). The effects of tissue flossing on ankle range of motion and jump performance. Physical Therapy in Sport, 25, 20–24.

Faria, A., Gabriel, R., Abrantes, J., Wood, P., & Moreira, H. (2013). Mechanical properties of the triceps surae: Differences between football and non-football players. Journal of Sports Sciences, 31(14), 1559–1567.

Freitas, S. R., Mendes, B., Le Sant, G., Andrade, R. J., Nordez, A., & Milanovic, Z. (2018). Can chronic stretching change the muscle-tendon mechanical properties? A review. Scandinavian Journal of Medicine & Science in Sports, 28(3), 794–806.

Goldberg, A. L., Etlinger, J. D., Goldspink, D. F., & Jablecki, C. (1975). Mechanism of work-induced hypertrophy of skeletal muscle. Medicine and Science in Sports, 7(3), 185–198.

Hunter, J. P., & Marshall, R. N. (2002). Effects of power and flexibility training on vertical jump technique. Medicine & Science in Sports & Exercise, 34(3), 478–486.

Kalichman, L., & David, C. B. (2017). Effect of self-myofascial release on myofascial pain, muscle flexibility, and strength: a narrative review. Journal of Bodywork and Movement Therapies, 21(2), 446–451.

Kato, E., Kanehisa, H., Fukunaga, T., & Kawakami, Y. (2010). Changes in ankle joint stiffness due to stretching: The role of tendon elongation of the gastrocnemius muscle. European Journal of Sport Science, 10(2), 111–119.

Kay, A. D., & Blazevich, A. J. (2009). Moderate-duration static stretch reduces active and passive plantar flexor moment but not Achilles tendon stiffness or active muscle length. Journal of Applied Physiology, 106(4), 1249–1256.

Kay, A. D., Husbands-Beasley, J., & Blazevich, A. J. (2015). Effects of contract–relax, static stretching, and isometric contractions on muscle–tendon mechanics. Medicine & Science in Sports & Exercise, 47(10), 2181–2190.

Kokkonen, J., Nelson, A. G., Eldredge, C., & Winchester, J. B. (2007). Chronic static stretching improves exercise performance. Medicine & Science in Sports & Exercise, 39(10), 1825–1831.

Konrad, A., & Tilp, M. (2014a). Increased range of motion after static stretching is not due to changes in muscle and tendon structures. Clinical Biomechanics, 29(6), 636–642.

Konrad, A., & Tilp, M. (2014b). Effects of ballistic stretching training on the properties of human muscle and tendon structures. Journal of Applied Physiology, 117(1), 29–35.

Konrad, A., Gad, M., & Tilp, M. (2015). Effect of PNF stretching training on the properties of human muscle and tendon structures. Scandinavian Journal of Medicine & Science in Sports, 25(3), 346–355.

Kubo, K., Kanehisa, H., Kawakami, Y., & Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. Journal of Applied Physiology, 90(2), 520–527.

Kubo, K., Kanehisa, H., & Fukunaga, T. (2002). Effect of stretching training on the viscoelastic properties of human tendon structures in vivo. Journal of Applied Physiology, 92(2), 595–601.

Lee, C. L., Chu, I. H., Lyu, B. J., Chang, W. D., & Chang, N. J. (2018). Comparison of vibration rolling, nonvibration rolling, and static stretching as a warm-up exercise on flexibility, joint proprioception, muscle strength, and balance in young adults. Journal of Sports Sciences, 36(22), 2575–2582.

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Dyhre-Poulsen, P., McHugh, M. P., & Kjaer, M. (1996). Mechanical and physiological responses to stretching with and without preisometric contraction in human skeletal muscle. Archives of Physical Medicine and Rehabilitation, 77(4), 373–378.

McHugh, M. P., & Cosgrave, C. H. (2010). To stretch or not to stretch: the role of stretching in injury prevention and performance. Scandinavian Journal of Medicine & Science in Sports, 20(2), 169–181.

Medeiros, D. M., & Lima, C. S. (2017). Influence of chronic stretching on muscle performance: Systematic review. Human Movement Science, 54, 220–229.

Mills, B., Mayo, B., Tavares, F., & Driller, M. (2020). The effect of tissue flossing on ankle range of motion, jump, and sprint performance in elite rugby union athletes. Journal of Sport Rehabilitation, 29(3), 282–286.

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

Schoenfeld, B. J., Grgic, J., Ogborn, D., & Krieger, J. W. (2017). Strength and hypertrophy adaptations between low-vs. high-load resistance training: a systematic review and meta-analysis. The Journal of Strength and Conditioning Research, 31(12), 3508–3523.

Starrett, K., & Cordoza, G. (2015). Becoming a Supple Leopard 2nd Edition: The Ultimate Guide to Resolving Pain, Preventing Injury, and Optimizing Athletic Performance. Victory Belt Publishing.

Vina, J., Sanchis-Gomar, F., Martinez-Bello, V., & Gomez-Cabrera, M. C. (2012). Exercise acts as a drug; the pharmacological benefits of exercise. British Journal of Pharmacology, 167(1), 1–12.

Vogrin, M., Novak, F., Licen, T., Greiner, N., Mikl, S., & Kalc, M. (2020). Acute Effects of Tissue Flossing on Ankle Range of Motion and Tensiomyography Parameters. Journal of Sport Rehabilitation, 1(aop), 1–7.

Wilke, J., Mueller, A. L., Giesche, F., Power, G., Ahmedi, H., & Behm, D. G. (2020). Acute effects of foam rolling on range of motion in healthy adults: a systematic review with multilevel meta-analysis. Sports Medicine, 50(2), 387–402.