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Published in:
International Journal of Exercise Science

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Citation for pulished version (APA):
Warneke, K., Wirth, K., Keiner, M., & Schiemann, S. (2023). Improvements in Flexibility depend on Stretching Duration. *International Journal of Exercise Science*, *16*(4), 83-94.
https://digitalcommons.wku.edu/ijes/vol16/iss4/4

International Journal of EXERCISE SCIENCE

Original Research

Improvements in Flexibility Depend on Stretching Duration

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ABSTRACT

International Journal of Exercise Science 16(4): 83-94, 2023. To improve flexibility, stretching is most commonly used and in training interventions duration-dependent effects are hypothesized. However, there are strong limitations in used stretching protocols in most studies, particularly regarding documentation of intensity and performed procedure. Thus, aim of this study was to compare different stretching durations on flexibility in the plantar flexors and to exclude potential biases. Eighty subjects were divided into four groups performing daily stretching training of 10min (IG10), 30min (IG30) and 1h (IG60) and one control group (CG). Flexibility was measured in bended and extended knee joint. Stretching was performed with a calf muscle stretching orthosis to ensure long-lasting stretching training. Data were analysed with a two-way ANOVA for repeated measures on two variables. Two-way ANOVA showed significant effects for time (η^2 = 0.557-0.72, p < 0.001) and significant interaction effects for time x group (η^2 = 0.39-0.47, p < 0.001). Flexibility in the knee to wall stretch improved with 9.89-14.46% d = 0.97-1.49 and 6.07-16.39% with d = 0.38-1.27 when measured via the goniometer of the orthosis. All stretching times led to significant increases in flexibility in both tests. While there were no significant differences measured via the knee to wall stretch between the groups, the range of motion measurement via the goniometer of the orthosis showed significantly higher improvements in flexibility depending on stretching duration with the highest increase in both tests with 60 minutes of stretch per day.

KEY WORDS: Long-lasting stretching, range of motion, plantar flexors, stretching device

INTRODUCTION

In literature there is evidence that improved muscle flexibility (extensibility of the muscle) is associated with higher joint mobility, which is the ability to cover higher ranges of motion (ROM), better performance and reduced injuries (42). Gymnasts and dancers are known for having great flexibility (1, 26, 38), while in team sports, athletes are usually characterised by poor mobility (8, 9, 11), especially in the calf muscles and hamstrings (32). Consequently, it seems beneficial to enhance flexibility as a measure to improve performance and decrease the risk of injury. Thomas et al. (39) showed that higher gains in flexibility are related to higher weekly stretching volume, especially by performing long stretching durations with high frequency and would therefore result in higher ROM. Apostolopoulos et al. (3) demonstrated that stretching intensity is of particular importance regarding physiological adaptations. Therefore, a dose-response relationship is hypothesized. There are several studies showing effects of long-term stretching interventions on flexibility (12, 23, 24). While there are increases in flexibility in the plantar flexors of 18.8% (d = 1.90) performing a 60 sec stretching on three days per week (15), Simpson et al. (37) pointed out significant increases in ROM of 14.94 % (d = 2.05) by performing stretches for the plantar flexors of three minutes on five days per week for five weeks. Besides, investigation performing long-lasting stretching training for one hour per session showed significant increases of 13.2% (d = 1.49) in the knee to wall test (41). In general, maximum heterogeneity in study protocols can be observed, e.g. through the use of different types of equipment to induce stretching stimulus (stretching board (27, 31, 33, 43) leg press (37), stretching device (40, 41), or without equipment (5). Furthermore, different training conditions regarding training frequency, stretching duration and therefore weekly volume were used, ranging from 4x30 sec on three days per week (25, 29) to one hour per day on seven days per week (41). Based on this, comparability of results from different studies is limited considering discrepancies in stretching duration or weekly stretching volume. Furthermore, there was no quantification of stretching intensity in any study. To improve comprehension of stretching training and its effects on flexibility, the aim of this study was to compare different stretching durations from ten min to 60 min per day and to investigate the role of stretching duration on improvements in flexibility. Therefore, participants stretched their plantar flexors on seven days per week for six weeks. It is hypothesized that stretch training induces significant improvements in ROM depending on training duration.

METHODS

Participants

Eighty active subjects (m = 45, f = 35, age: 26.4 ± 4.6 years, height: 176.3 ± 8.1 cm and weight: 74.3 ± 5.5 kg) were recruited from sports study programs and local sports clubs. The training level of participants was evaluated by self-reported time spent with training. Participants were classified as active athletes with moderately trained flexibility when they performed two or more training sessions per week in a gym or a team sport continuously for the previous six months. However, participants were excluded if they perform stretch training in their training routines like additional separated stretching sessions or Yoga training or if they reported injuries within the last six months leading to immobilization of one limb. Furthermore, participants had to declare no increased risk of thrombosis to be included to the investigation. Included subjects were randomly divided into three stretching groups and one control group and instructed not to start any further flexibility training while participating in this study. Characteristics of subjects are shown in Table 1.

All participants were informed about the experimental risks and provided written informed consent to participate in the present study. Furthermore, approval for this study was obtained from the institutional review board (Carl von Ossietzky Universität Oldenburg, No.121-2021). The study was performed with human participants in accordance with the Helsinki Declaration and in accordance with ethical policies (28).

Table 1. Characteristics of participants for overall sample size and divided into IG10, IG30, IG60 and CG

Group	*N*	Age (in years)	Height (in cm)	Weight (in kg)
total	80 (f = 35, m = 45)	26.4 ± 4.6	176.3 ± 8.1	74.3 ± 5.5
IG10	20 (f = 9, m = 11)	25.5 ± 5.5	177.2 ± 6.4	76.9 ± 4.1
IG30	20(f = 10, m = 10)	26.7 ± 2.5	175.2 ± 8.4	77.7 ± 7.0
IG60	20 (f = 8, m = 12)	24.9 ± 2.9	174.6 ± 4.9	73.9 ± 4.2
CG	20 (f = 8, m = 12)	26.1 ± 3.3	176.6 ± 3.7	74.7 ± 2.3

IG10 = intervention group 10 with a stretching with a daily stretching duration of 10 minutes, IG30 = intervention group 30 with a stretching with a daily stretching duration of 30 minutes, IG60 = intervention group 60 with a stretching with a daily stretching duration of 60 minutes, CG = control group

Protocol

Since Arampatzis et al. (4) and Signorile et al. (34) described different involvements of the gastrocnemius and soleus in muscle performance depending on the knee angle, there were two testing procedures performed to investigate the ROM in the upper ankle with bended and extended knee joint. ROM with bended knee joint was assessed via the goniometer on the orthosis (ORTH) and ROM with extended knee joint was assessed by using the knee to wall stretch (KtW) as a commonly performed flexibility test for the plantar flexors (7, 35, 41). Participants were instructed to perform the testing procedure without wearing shoes.

The KtW was used to examine flexibility in dorsiflexion in the upper ankle joint by trying to maximize the distance of the foot from the wall and pushing the knee forward to the wall until the heel lifts off. Afterwards, the distance between the foremost point of the toes and the wall was measured. To improve objectivity and reliability, a sliding device was used. The participants were instructed to place the foot on the marker while stabilizing the body with their hands inside a doorframe (Fig. 1) as they pushed the board of the sliding device forward until the heel of the standing leg lifted off. To check this, the investigator pulled on a sheet of paper which was placed under the subject's heel. The test procedure was stopped when the sheet could be removed. The reached value was read off in cm from the attached measuring tape (see Fig. 2). The KtW measurement can be seen as a screening tool for ankle flexibility with a bended knee. Three valid trials were performed per leg, and the maximal value was used for evaluation. Reliability in ROM assessment with comparable methods can be classified as high with ICC > 0.97 (36). Moreover, due to a ICC of 0.987-0.992 and a CV of 0.94-1.74% this procedure can be assumed to be reliable (41).

Figure 1. Sliding device for the knee to wall test to evaluate flexibility in the ankle joint with bended knee joint.

As a second test to determine the effects of the stretching training on ROM, ORTH was used. While sitting on a chair, participants had to place their foot on an object of same height as the hip. From the starting position (neutral 0 position), the investigator pushed the foot carefully into maximal dorsiflexion. The angle, which was reached by pressing the foot of the participant in the maximally dorsiflexed position determined as either the participant's maximal tolerable pain or the inability to further increase the angle, in the upper ankle joint was measured via the goniometer on the orthosis. Each big indentation of the goniometer corresponds to an increase of 5°, and each little indentation corresponds to an increase of 2.5°. While performing a stretch with extended knee joint, the achieved angle was read off. This procedure was also performed in previous studies with high reliability (ICC = 0.990-0.997) (41).

Figure 2. Orthosis for stretching the calf muscles with included goniometer to determine the range of motion in the ankle joint with extended knee joint.

The intervention groups were instructed to perform a daily stretching training of the calf muscles lasting ten min (IG10), 30 min (IG30) and one hour (IG60) each session for six weeks, respectively. To realize described long-lasting stretching training, a calf muscle stretching orthosis was provided (see Fig.2). Subjects were instructed to wear the orthosis without shoes with extended knee joint and the stretch intensity was controlled by a goniometer which was also used to determine the angle representing the starting value during the pre-test. To achieve high intensity and muscle tension during the stretching training, subjects were asked to reach a maximally dorsiflexed position with an individual stretching pain by using the VAS at 8 on a scale one to ten, which is commonly used in stretching research (14, 27). To achieve a constant, high stretching tension, the participants were instructed to aim for a stretching pain of 8 on the VAS throughout the study. Therefore, the angle of the orthosis was progressively increased when stretching pain was perceived as being below 8. The stretching was performed seven days a week in a standardized body posture: the subjects were instructed to sit with their backs as straight as possible against the backrest of a chair and place their feet on a support plate at the same height as their chair. All subjects in the intervention groups borrowed one orthosis for the duration of the intervention and had to complete a stretching diary in which the daily stretching duration as well as the set angle were written down to record stretching duration and to provide a homogenous stretching stimulus as well as the possibility to document progression in ROM. If subjects were not able to perform their stretching routine on more than five days within the intervention period or were not able to perform stretching on three consecutive days, the values of these participants were excluded.

Statistical Analysis

The analysis was performed with SPSS (Version 28.0., IBM Corp., USA). Reliability was evaluated by calculating ICC and CV between the best and the second-best value in the KtW and ORTH, providing intra-session reliability. Descriptive data are provided with mean (M) ± standard deviation (SD). Normal distribution was checked via Shapiro Wilk test, whereas the Levene test showed homogeneity in variance. One-way ANOVA was used to rule out significant differences between groups of the pre-test values. A mixed model ANOVA using two factors was performed for the collected parameters. The Scheffé test was used as post-hoc for mean differences. Effect sizes were presented as Eta squares (η^2) and categorized as: small effect $\eta^2 < 0.06$, medium effect $\eta^2 = 0.06$-0.14, large effect $\eta^2 > 0.14$ as well as Cohen's *d*. (10). Effect sizes with Cohen's *d* were categorized as: small effects $d < 0.5$, medium effect $d = 0.5$-0.8, large effect $d > 0.8$. Post-hoc Power (1-β) was calculated via G-Power (Version 3.1, Düsseldorf, Germany).

RESULTS

High intra-session reliability for KtW with ICC = 0.942 and a CV of 1.01% and for ORTH with ICC = 0.991 and CV of 0.83% were calculated. A one-way ANOVA for pre-test values shows no significant differences between groups with $F(79,3) = 0.22$, $p = 0.881$. Descriptive statistics as well as evaluation of two-way ANOVA are provided in Table 2.

Table 2. Descriptive statistics and results of two-way ANOVA for both flexibility tests

Parameter	Pre-test (M ± SD) in *N*	Post-test (M ± SD) in *N*	Pre- post Differences in %	Time effect	Time x group
IG10KtW	11.71 ± 3.33	12.88 ± 3.44	+10.02	$p < 0.001$ $F(77.3) = 196.58$ $\eta^2 = 0.72$	$p < 0.001$ $F(77.3) = 22.5$ $\eta^2 = 0.47$
IG30KtW	12.39 ± 3.8	13.61 ± 4.0	+9.89		
IG60KtW	11.96 ± 2.37	13.69 ± 2.19	+14.46		
CGKtW	12.29 ± 1.81	12.36 ± 1.9	+0.57		
IG10ORTH	8.65 ± 2.02	9.18 ± 1.9	+6.07	$p < 0.001$ $F(77.3) = 96.7$ $\eta^2 = 0.557$	$p < 0.001$ $F(77.3) = 16.55$ $\eta^2 = 0.392$
IG30ORTH	8.23 ± 1.75	8.93 ± 1.48	+8.51		
IG60ORTH	9.00 ± 1.5	10.48 ± 1.33	+16.39		
CGORTH	8.74 ± 1.55	8.83 ± 1.69	+1.12		

IG10 = intervention group 10 with a stretching with a daily stretching duration of 10 minutes, IG30 = intervention group 30 with a stretching with a daily stretching duration of 30 minutes, IG60 = intervention group 60 with a stretching with a daily stretching duration of 60 minutes, CG = control group, KtW = Range of motion measurement via knee to wall test, ORTH = Range of Motion measurement via the goniometer of the orthosis

Figure 3 and Figure 4 illustrate the progression in flexibility from pre- to post-test in all four groups.

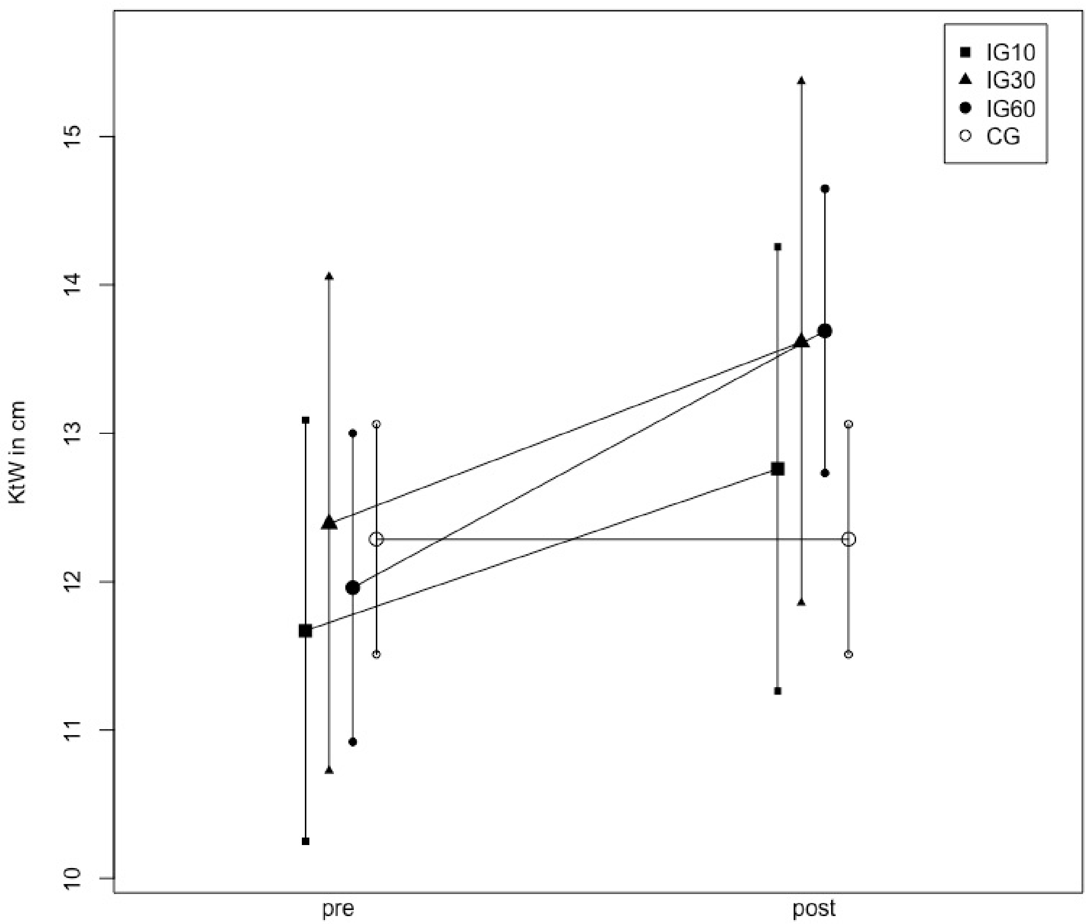

Figure 3. Comparison of progressions measured via the knee to wall stretch between all groups, IG10 = intervention group 10 with a stretching with a daily stretching duration of 10 minutes, IG30 = intervention group 30 with a stretching with a daily stretching duration of 30 minutes, IG60 = intervention group 60 with a stretching with a daily stretching duration of 60 minutes, CG = control group

For results of KtW (see Fig. 3), a mixed model ANOVA demonstrated high effects for the time-dependent effect ($\eta^2 = 0.7$, $p < 0.001$) and for the time x group interaction ($\eta^2 = 0.46$, $p < 0.001$).

The Scheffé test determined no significant difference for the mean differences between pre- and post-test values between IG10, and IG30 ($p = 0.996$) as well as between IG10 and IG60 ($p = 0.09$) and between IG30 and IG60 ($p = 0.14$). Whereas there were significant differences between CG and IG10 with $d = 0.97$, $p < 0.001$, CG and IG30 with $d = 1.03$, $p < 0.001$ as well as IG60 and CG $d = 1.49$, $p < 0.001$.

Post-hoc analysis of G-Power calculated $1-\beta = 100\%$ with $\eta^2 = 0.33$ for the within effects and $1-\beta = 93.1\%$ with $\eta^2 = 0.46$ for the interaction for $\alpha = 0.05$ for 4 groups and two measuring time points.

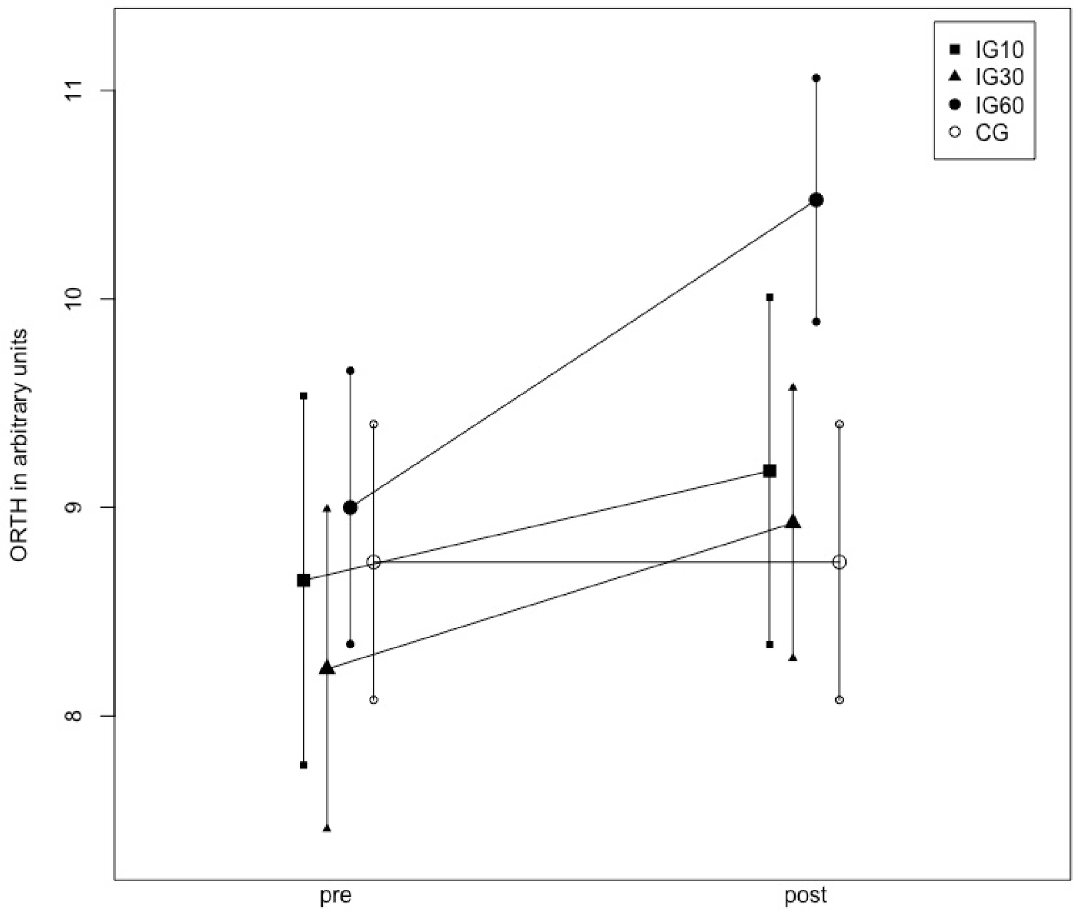

Figure 4. Comparison of progressions measured via the goniometer of the Orthosis between all groups, IG10 = intervention group 10 with a stretching with a daily stretching duration of 10 minutes, IG30 = intervention group 30 with a stretching with a daily stretching duration of 30 minutes, IG60 = intervention group 60 with a stretching with a daily stretching duration of 60 minutes, CG = control group

For results of ORTH (see Fig. 4), a mixed model ANOVA demonstrated high effects for the time-dependent effect ($\eta^2 = 0.56$, $p < 0.001$) and for the time x group interaction ($\eta^2 = 0.39$, $p < 0.001$).

The Scheffé test determined no significant difference for the mean differences between pre- and post-test values between IG10 and IG30 (p = 0.86, d = 0.16) as well as between IG10 and CG (p = 0.21, d = 0.38). However, there were significant differences between IG60 and IG10 (p < 0.001, d = 0.88), IG60 and IG30 (p = 0.004, d = 0.71) as well as IG60 and CG (p < 0.001, d = 1.27) and between IG2 and CG (p = 0.03, d = 0.55).

Post-hoc analysis of G-Power calculated 1-β = 100% with $\eta^2 = 0.33$ for the within effects and 1-β = 93.1% with $\eta^2 = 0.46$ for the interaction for α = 0.05 for 4 groups and two measuring time points for KtW.

Summary of results: All three stretching durations led to significant increases in ROM in both testing routines. The results show that stretching duration of 60 minutes per day increased flexibility to a higher magnitude than 30 minutes (p = 0.004) and ten minutes (p < 0.001) when measuring via ORTH, but not via KtW.

DISCUSSION

The aim of this study was to investigate if there is a duration- and volume-dependent effect of stretching training for several weeks regarding the improvements in flexibility. Results of the present study compared different stretching durations from ten min to one hour per day and showed significant improvements in flexibility in all three intervention groups with d = 0.97-1.49, p < 0.001 via KtW and d = 0.38-1.27, p < 0.001 via ORTH compared to the control group. However, results showed no significant differences between the intervention groups (p = 0.09-0.99) in the KtW, but significant differences when ROM was measured via ORTH (p = 0.001-0.03, d = 0.16-1.27).

As mentioned before, there is maximum heterogeneity in study designs when comparing the procedure of different studies examining effects of stretching training on flexibility. Therefore, comparability of results of the present study with other investigations seems to be limited since there are differences in study designs, e. g. regarding the way in which the stretching stimulus was generated as well as weekly stretching volume. In this study, the training volume of IG30 and IG60 was significantly higher compared to other studies (19, 25, 29, 33). Mizuno (25) performed stretching intervention on three days per week with 4x30 sec of stretching gaining 12.7% (d = 1.0) in flexibility, Kokkonen et al. (19), showed significant increases of 18.1% (d = 1.15) performing stretching for 3x15 sec per session on three days per week for 12 weeks. Compared to the results of this study showing increases of 10.02% with stretching durations of ten and 30 min per day, listed results of studies using short-time stretching interventions seem to be comparatively high (19, 25, 29, 31). It seems that different factors influence results of stretching training, e.g. training status, stretching frequency and intensity (3, 13). Only one investigation with a comparable study design investigated the influence of a one-hour daily static stretching training which was performed by this research group leading to comparable results of 13.2% (d = 1.49) in the KtW.

While increases in ROM measured via KtW showed no significant differences depending on stretching time, improvements in flexibility measured via the goniometer at the orthosis showed time dependent increases in ROM. While there were no significant differences between stretching time of ten and 30 minutes, there were significant differences to other groups when performing one hour stretching per day. Higher increases in ROM measured via ORTH may be attributed to the identical execution to the stretch training of the intervention. Since an influence of the knee angle of used muscles in the lower extremity can be assumed (4, 34) and the KtW (partially) examines the dorsiflexion with bended knee joint, results show that there is high specificity in effects of stretching training on ROM. It can be noticed that while there is a significant influence of time on flexibility when ROM is measured via ORTH, no clear influence can be seen when measuring the KtW. Between different knee joints influencing the results, influence of hysteresis effects (21) possibly play a major role when longer stretching duration are used (6, 20). It could be hypothesized that stretching stimulus decreases when intensity is not readjusted. Consequently, further studies could possibly investigate the influence of constant torque stretching and compare different stretching durations. Furthermore, poor flexibility values in many sports (8, 9, 11) could possibly be attributed to the intensity being too low or inadequate volume of the training stimuli.

There are several hypotheses explaining increased ROM following stretching training. While some authors hypothesize an increased tolerance of stretching tension via reduced pain threshold instead of structural adaptations (13), other authors demonstrated changes in stiffness, viscosity and elasticity of the muscle-tendon unit. Furthermore, animal models show evidence of structural adaptations by a serial accumulation of sarcomeres (2). From the authors' point of view, there is no conflict with the hypothesis of a reduced pain threshold in a given angle if a serial accumulation in humans can be hypothesized. Based on the hypothesis that pain is present by reaching higher degrees of stretching in sarcomeres, a serial accumulation of sarcomeres would lead to an occurrence of pain in a higher joint angle. Consequently, an increased number of serial sarcomeres would lead to a later occurrence in pain. However, although neither in this study nor in other listed studies a serial sarcomere accumulation could be investigated, it should not be excluded as an explanation.

Limitations: We used a stretching orthosis to induce long-lasting stretching stimuli. Since in other studies comparatively low stretching durations showed higher increases in ROM, investigations using comparable study design are requested to replicate comparable high results from other studies (25, 29) and examine the influence of higher stretching durations by using the same stretching procedure as it was used in listed studies. As a common tool to quantify stretching intensity, VAS was used in this study (14, 18, 27). However, subjective perception may influence comparability between subjects (22). To improve the quality of intensity documentation, a torque measurement should be included to stretching interventions in further studies. Examining flexibility in the plantar flexors by performing the knee to wall stretch, depending on flexibility, knee joint must be bended to a higher extent by increasing flexibility. Since Arampatzis et al.(4) showed that depending on the knee joint angle different parts of the plantar flexors are used, it can be hypothesized that there are also differences in used muscles when reaching higher values in the KtW.

Practical Application: In many sports, there are athletes with poor flexibility values leading to many problems, e.g. reduced performance or a higher risk of injury (16, 30, 42). The results of this study show that daily stretching durations between ten minutes and 60 minutes induce significant improvements in ROM. However, there are stretching routines performed in other studies with much lower stretching durations producing comparable results. Since doubling daily stretching time (30 min to one hour) in present study does not lead to doubling the effects of stretching training, further studies should investigate the optimal stretching duration to achieve flexibility gains which seems to be lower than ten minutes to achieve higher economy of training, even if a dose-response relationship by comparing percentage increases can be assumed (9.89%-14.46%). Based on this, further studies should enhance the intervention period to at least eight to twelve weeks or longer to consider that effects of morphological adaptation may occur more recently. Consequently, increases in ROM are influenced by many other factors than the stretching duration, e.g., stretching intensity, training status and the way the stretch is induced. Even if one questions the practical application of seven hours of stretch per week, stretching durations used in this study can be understood as an extreme situation provided by 60 minutes stretch per day. This, in turn, can be seen as an appropriate way to investigate general principles of a training method (17). Consequently, this study provides valuable information on the dose-response relationship and demonstrates that regarding adaptations in flexibility, the more time spent in a stretched position, the higher the assumed adaptations will be.

ACKNOWLEDGEMENTS

We thank all participants for performing the stretching interventions. Further, we thank PD Dr. Martin Hillebrecht for providing software and equipment. Additionally, we thank Carina Mählmeyer for assistance with data collection.

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