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Research article

Effects of a Home-Based Stretching Program on Bench Press Maximum Strength and Shoulder Flexibility

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Abstract

Recent research showed significant stretch-mediated maximum strength increases when performing stretching between 5 to 120 minutes per day with the calf muscle. However, since the practical applicability of these long stretching durations was questioned and studies exploring the transferability to the upper body are scarce, the aim of this study was to investigate the possibility of using a home-based stretching program to induce significant increases in maximum strength and flexibility. Therefore, 31 recreationally active participants (intervention group: 18, control group: 13) stretched the pectoralis major for 15min/day for eight weeks, incorporating three different stretching exercises. The maximum strength was tested isometrically and dynamically in the bench press (one-repetition maximum: 1RM) as well as shoulder range of motion (ROM) performing bilateral shoulder rotation with a scaled bar. Using a two-way analysis of variance (ANOVA) with repeated measures, the results showed high magnitude Time effects (η^2 = 0.388 - 0.582, $p < 0.001$) and Group*Time interaction (η^2 = 0.281 - 0.53, $p < 0.001$ - 0.002), with increases of 7.4 ± 5.6% in 1RM and of 9.8 ± 5.0% in ROM test in the intervention group. In the isometric testing, there was a high-magnitude Time effect (η^2 = 0.271, $p = 0.003$), however, the Group*Time interaction failed to reach significance (p = 0.75). The results are in line with previous results that showed stretch-mediated maximum strength increases in the lower extremity. Future research should address the underlying physiological mechanisms such as muscle hypertrophy, contraction conditions as well as pointing out the relevance of intensity, training frequency and stretching duration.

Key words: Range of motion, maximum voluntary isometric contractions, 1 RM, static stretching, pectoralis major.

Introduction

Maximum strength is stated as a basic ability in sports performance (Wirth et al., 2016). Using resistance training to improve lower (Sander et al., 2013; Wirth et al., 2016) and upper extremity maximum strength is of high importance for jumping and sprinting performance (Styles et al., 2016; Suchomel et al., 2016) as well as throwing performance (Hermassi et al., 2015), respectively. Enhanced strength has been associated with improved athletic performance in numerous sports, such as handball (Hermassi et al., 2015), basketball (Warneke et al., 2022a), soccer (Lohmann et al., 2022), wrestling (McGuigan et al., 2006), boxing (Dunn et al., 2022), and swimming (Wirth et al., 2022). In addition, increased muscle strength contributes to injury prevention and rehabilitation (Østerås et al., 2015; Sommervold and Østerås, 2017).

Frequently, upper body strength is measured and trained with the bench press (Lum et al., 2022; Young et al., 2015). Bench press training typically necessitates equipment such as barbells, weight plates and a bench. However, in phases of limited accessibility to equipment (e.g., pandemic lockdowns) or limited mobility (e.g., injuries), developing alternatives to common resistance training exercises to improve strength capabilities seems beneficial. Therefore, performing bodyweight training could be seen as an alternative, especially in health-related sports (Musick and Childs Cymet, 2006). Unfortunately, untrained individuals may not be able to adequately move their own bodyweight (e.g., full push-ups).

Interestingly, high volume stretch training has been shown to provide sufficient muscle stimulation to induce maximum strength increases in humans (Arntz et al., 2023), mostly measured in the plantar flexors (Nelson et al., 2012; Warneke et al., 2023a; Yahata et al., 2021) and in the pectoralis major (Reiner et al., 2023).

Nevertheless, performing stretching with devices for about one hour per day limits the practical applicability (Schoenfeld et al., 2022). Furthermore, most of the available literature tested strength under isometric conditions in practically uncommon testing conditions (isolated movements) (Reiner et al., 2023; Warneke et al., 2023a). Since there are limitations when transferring results from isometric and isolated testing conditions to dynamic complex movements, with this study we aimed to investigate the effectivity of a home-based stretching program on pectoralis isometric and dynamic muscle strength and range of motion (ROM), to potentially enable the participants to stretch independent of location and time of the day. Based on prior publications (Arntz et al. 2023, Reiner et al., 2023), it was hypothesized that an increase in bench press strength and shoulder ROM would be observed in response to incorporating three different stretching exercises for 15min/day for eight weeks.

Methods

Participants

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A priori sample size calculation was performed for the parameter of maximum isometric strength was performed using G-Power (Version 3.1) for F-tests with an assumed high effect size of f = 0.35 level for α - error of 0.5 (Warneke et al. 2022d) and estimated power of 1 - β error set at 80% using two groups with two measurement points estimated a total sample size of at least 20 participants. Thirty-one (31) recreationally active participants were allocated into an IG (n = 18, m: 13, f: 5, age:25.17 ± 3.81 years, 183.06 ± 7.24cm, 80.61 ± 13.4kg) and Control (n = 13, m: 8, f: 5, 25.38 ± 3.38 years, 179.77 ± 8.65cm, 76.08 ± 12.23kg). Participants were recruited from the university sports program and physical education classes, therefore, performing team or individual sports such as gymnastics or swimming at least twice per week regularly or fitness or resistance training in a gym for at least two days per week for the last six months. Group allocation was based on their willingness to participate, since numerous participants did not want to be included to the intervention group. Participants were excluded if they reported shoulder and/or chest pain, an injury of the upper limb within the last six months, if they did not participate in group fitness programs or university sports classes or changed their training routines (starting a new routine or stopping their previous training). The study was conducted under consideration of the Declaration of Helsinki and the study design was approved by the local ethical review board (Drs.EK/2022/064-01).

Experimental design

To answer the research question, athletically active participants were allocated to an intervention group (IG) and a control group (Control). Stretching was performed 3x5 minutes per day for eight weeks using three different exercises to stretch the pectoral musculature. Using a pre-post-test design, the effects on maximum strength using dynamic and isometric testing conditions were assessed. Since it is well known that stretch training leads to improved flexibility (Medeiros et al., 2016) flexibility adaptations in the shoulder were examined to check the effectiveness of the stretching intervention. Prior to testing, a familiarization session was performed to counteract habituation effects.

Maximum strength testing

Maximum strength was tested under dynamic conditions, testing the one repetition maximum (1RM), and under isometric conditions using a Smith machine. Before testing, a 5- minute ergometer cycling at 1 kilopond and 2x5 push-ups were performed to ensure a general warm up.

One repetition maximum (1RM) testing

The bench press 1RM was tested using the full ROM. Therefore, the participant was instructed to adopt a supine position on a training bench and the bar had to be lowered until the bar rested on the chest for one second. After reacting to an acoustic signal, the participant was instructed to push the weight as fast as possible to a fully extended elbow position. The weight was increased using 2.5kg steps until the participant failed to perform the repetition. Between each attempt, a rest of two minutes was ensured. To minimize the attempts to reach the maximum weight in the testing, the familiarization session was used to set a baseline value for the pre-test. Amarante do Nascimento et al. (2013) pointed out high reliability of 1RM strength testing in the bench press with intraclass coefficient correlations (ICC) up to 0.99.

Maximum isometric testing

Maximum isometric strength was tested with an elbow angle of 90°. The participant was positioned in a supine position on a training bench. The bar was fixed in the Smith machine to present an insurmountable resistance. Afterwards, the participant was instructed to perform a maximum voluntary contraction for three seconds. Trials were performed until no increase in the maximum strength value was observed, however, a minimum of three trials was performed. With an ICC of 0.89 - 0.97 a high reliability of isometric bench press testing can be assumed (Young et al., 2014).

Flexibility

Shoulder ROM was tested using a straight wooden bar with a scale measuring the distance between the hands. The participant was instructed to hold the bar with extended elbows in front of the body and flex the shoulders as far as possible to move the bar over and behind the head and back respectively (see Figure 1). To the best of our knowledge, no reliability values for this test could be found in literature, therefore ICC and CV were calculated in this study for the intra-day reliability (see Results section).

Figure 1. Shoulder range of motion ROM testing with the straight wooden bar with the scale to measure the distance between the hands

Stretching intervention

Participants were instructed to perform an eight-week home-based stretching program, using a gymnastic band with a resistance equal to 13.6 - 27.2 kg. Stretching was applied for 15 minutes by including three different exercises, each performed for five minutes. The three stretching variations are presented in Figures 2 a-c and were used to primarily stretch the pectoralis muscles. Participants were instructed to rest 30 seconds between the exercises. The order was chronologically determined as shown in Figure 2. The participants were instructed to perform the stretch training by using a 6 - 7 on a stretching visual analogue scale, as previously performed by Warneke et al. (2022c; 2022d) and were instructed to document the training in a stretching diary.

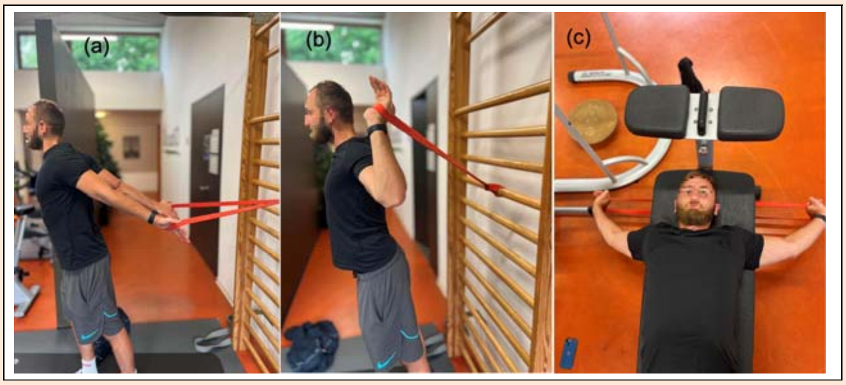

Figure 2. Three stretching exercises (a-c) included in the intervention. In figure (a) the participant was instructed to stretch the pectoralis muscle with straight arms pointing to the back with the elastic band as a resistance. The second stretch was performed with 90° elbow and shoulder angle, forearms pointing upwards, with the elastic band pulling from the back (shoulder external rotation) (b). The stretching exercise illustrated in (c) was performed in a supine position performing a fly movement with the arms, while the elastic band provides a resistance by holding in both hands with straight arms and shoulders externally rotated towards the ground.

Table 1. Descriptive statistics and results of two-way ANOVA for both flexibility tests.

Parameter	Pretest (M±SD)	Posttest (M±SD)	Pre-Post % Differences	Time effect	Time x group
IG 1RM (kg)	75.25 ± 33.62	79.69 ± 34.0	+7.4 ± 5.6	$p < 0.001$ $F_{29,1} = 18.414$ $\eta^2 = 0.388$	$p = 0.002$ $F_{29,2} = 11.314$ $\eta^2 = 0.281$
Control 1RM (kg)	68.65 ± 25.76	69.19 ± 26.11	+0.7 ± 2.5		
IGISO (N)	649.99 ± 337.07	685.53 ± 325.11	+12.1 ± 22.3	$p = 0.003$ $F_{29,1} = 10.801$ $\eta^2 = 0.271$	$p = 0.754$ $F_{29,2} = 0.1$ $\eta^2 = 0.003$
Control ISO (N)	600.50 ± 251.37	643.61 ± 241.67	+9.3 ± 15.0		
IGROM (cm)	54.61 ± 9.05	49.28 ± 8.7	-9.8 ± 5.0	$p < 0.001$ $F_{29,1} = 40.318$ $\eta^2 = 0.582$	$p < 0.001$ $F_{29,2} = 32.001$ $\eta^2 = 0.53$
CGROM (cm)	50.00 ± 5.34	49.69 ± 5.7	-0.7 ± 2.5		

IG = intervention group, CG = control group, 1RM = one repetition maximum, ISO = isometric maximum strength, ROM = range of motion, kg = kilogram, N = Newton, cm = centimeter, M = mean, SD = standard deviation

Statistical analysis

The analysis was performed with SPSS 28 (IBM, Armonk, New York, USA). Data is provided as mean (M) ± standard deviation (SD) for the pre-post values. The normal distribution of data was checked via Shapiro Wilk test. Reliability was determined using ICC, coefficient of variability and 95% confidence interval (CI) for aforementioned tests. Moreover, Levene's test for homogeneity in variance was performed. A t-test for independent values was used to rule out significant differences between IG and Control in pre-test values. A 2 x 2 two-way ANOVA (2 conditions x 2 times) with repeated measures was performed for data analyses of the pre-post comparisons for each parameter separately. Effect sizes are 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 $\eta^2 > 0.14$ (Cohen, 1988). Additionally, effect sizes for in-between group mean differences from pre- to posttest were calculated. Considering the sample size differences between the IG and the Control, Hedges g was therefore calculated and categorized as: small effects $g < 0.5$, medium effect $g = 0.5 - 0.8$, large effect $g > 0.8$. The level of significance was set to $p < 0.05$.

Results

As instructed, participants stated that they performed their stretching exercises daily. Data were normally distributed ($p = 0.112 - 0.659$). No significant differences between the pre-test values between the IG and Control was detected with $p = 0.094 - 0.66$. For the isometric strength testing and ROM testing, there were high inter-day ICCs with 0.996 - 0.999, CV = 0.06 ± 0.09 - 2.43 ± 3.1% and high intra-day ICCs of 0.997 - 0.998 and CV = 0.01 ± 0.03% - 1.8 ± 1.7%. No intra-day reliability was obtained for the bench press 1RM since this was tested only once in the pre-test condition. However, the inter-day reliability also revealed high reliability with ICC = 0.987 and CV = 3.26 ± 3.9%.

The results illustrated in Table 1 show significant, high magnitude strength and shoulder ROM increases with a Time effect in the 1RM and the ROM testing with $p < 0.001$, $\eta^2 = 0.388$ and $p < 0.001$, $\eta^2 = 0.582$, respectively. Furthermore, both parameters showed a high magnitude, significant Group * Time interaction effect with $p = 0.002$, $\eta^2 = 0.281$ and $p < 0.001$, $\eta^2 = 0.53$, respectively. In the maximum isometric strength testing, a significant, high magnitude Time effect was found ($p = 0.003$, $\eta^2 = 0.271$), however, the Time * Group interaction effect did not reach the level of significance ($p = 0.754$). The results are graphically illustrated in Figure 3, Figure 4 and Figure 5.

The illustrations of the individual mean differences plot the difference between pre- and posttest of each parameter and therefore, the consistency of the effect can be reviewed. For 1RM, only one participant showed a decrease in performance from pre- to posttest while for the maximal isometric strength measuring, no consistent effect can be figured out. In ROM, all participants of the IG showed significant flexibility improvements. Hedges g for mean differences of the 1RM testing showed a high magnitude effect of g = 1.22, a trivial effect in isometric testing of g = 0.11 and a high magnitude effect of g = 4.67 in ROM testing.

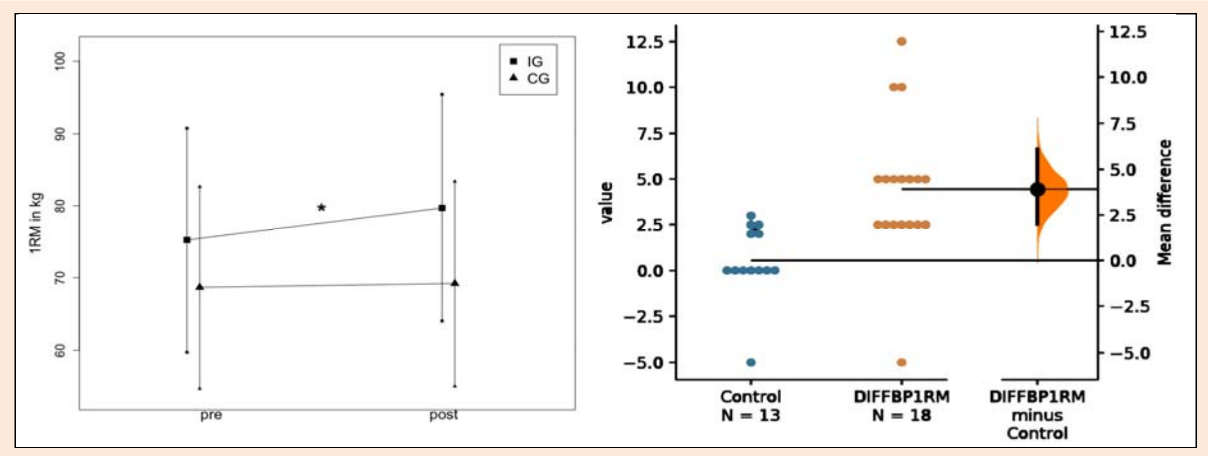

Figure 3. 1RM (kg) progression from pre- to post-test and the individual mean differences. * = significant change with p <0.05, 1RM = one repetition maximum, IG = intervention group, CG = control group, DIFFBPIso = Difference from pre- to post-test in the bench press one repetition strength test.

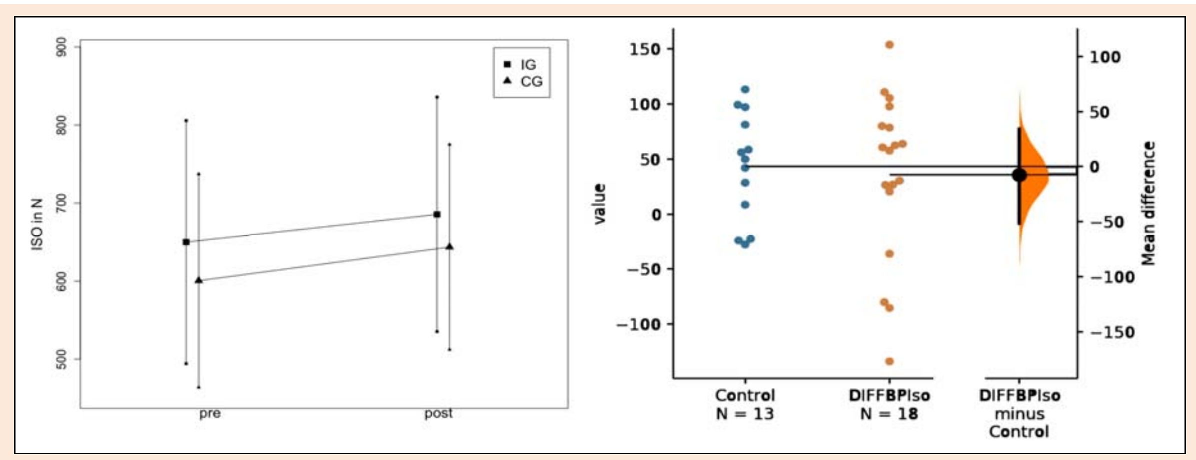

Figure 4. Maximum isometric strength (N) progression from pre- to post-test and the individual mean differences. ISO = isometric maximum strength test, IG = intervention group, CG = control group, DIFFBPIso = Difference from pre- to post-test in the maximum isometric bench press strength

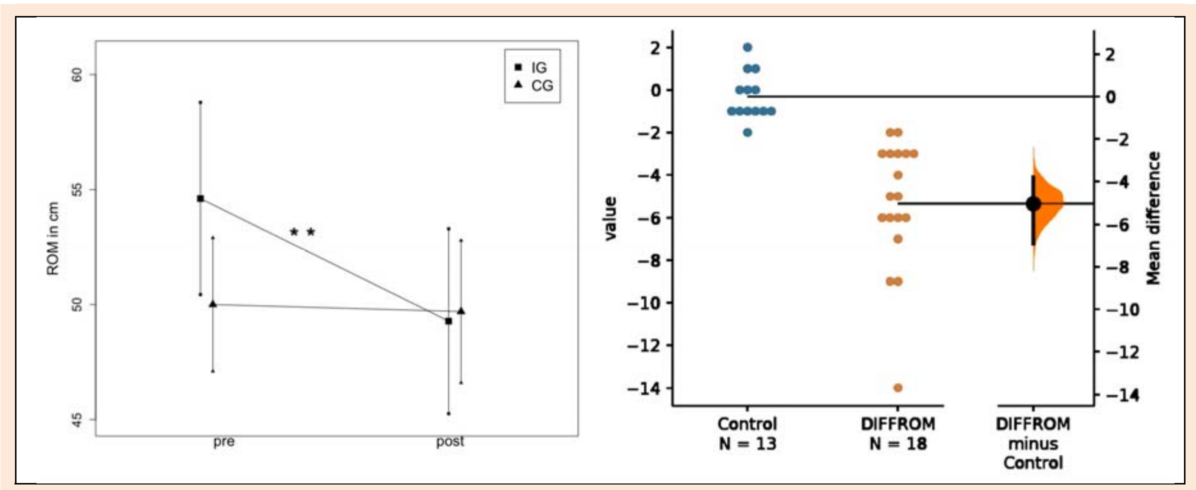

Figure 5. ROM (cm) progression from pre- to post-test and the individual mean differences. ** = significant change with p<0.001, ROM = Range of motion, IG = intervention group, CG = control group, DIFFROM = Difference from pre- to post-test in the shoulder girdle flexibility.

The illustrations of the individual mean differences plot the difference between pre- and posttest of each parameter and therefore, the consistency of the effect can be reviewed. For 1RM, only one participant showed a decrease in performance from pre- to posttest while for the maximal isometric strength measuring, no consistent effect can be figured out. In ROM, all participants of the IG showed significant flexibility improvements. Hedges g for mean differences of the 1RM testing showed a high magnitude effect of g = 1.22, a trivial effect in isometric testing of g = 0.11 and a high magnitude effect of g = 4.67 in ROM testing.

Discussion

With significant increases in maximum (dynamic) bench press 1RM strength (7.4%) and shoulder ROM (9.8%), our results are (partially) in line with recently published research, showing significant stretch-induced maximum strength increases. Previously, plantar flexor muscles maximal dynamic strength demonstrated stretch-induced increases of up to 29% with intervention periods of up to 10 weeks (Nelson et al., 2012; Warneke et al., 2022d). Previously, Reiner et al. (2023) performed a seven-week stretch training program, using three sessions per week performing three exercises with a stretching durations of five minutes per exercise, hence, the stretching volume was very similar to our study. However, they measured maximal voluntary isometric strength only, showing strength increases of up to 15%. Even though we measured a maximum isometric strength improvement of about 12%, the control group also significantly increased their isometric maximum strength 9.3%, leading to a lack of Time*Group interaction. Assuming not all people may be accustomed to isometric training and testing conditions (Drake et al., 2018; Warneke et al., 2023d), it can be hypothesized that habituation effects induced increases in the control group. Although we attempted to check potential learning effects by previously performing habituation/familiarization sessions showing high inter-day reliability, our results underline the limited value of isometric testing devices, since unfamiliar testing condition, muscle length- and joint angle specificity as well as exercise dependent conditions must be considered, leading to partially conflicting results (Drake et al., 2018; Warneke et al., 2023d). Discrepancies between isometric and dynamic testing conditions can be reviewed in Wirth (2007), investigating the effects of a dynamic resistance training program on isometric and dynamic maximum strength. With dynamic testing, five out of six testing conditions revealed a significant strength increase, while with isometric testing, they reported a significant training-induced performance enhancement in just one test, highlighting the relevance of specific testing conditions. Therefore, the lack of interaction effect in our study under isometric testing conditions is even more surprising, as the intervention was static stretching and not a dynamic training condition, which thus would have anticipated a higher effect in isometric testing conditions. Furthermore, the wide dispersion of the individual mean differences, (Figure 5) show an inconsistency in adaptations with a mean increase of 12.1% ± 22.3%, which could possibly be attributed to an inability to produce a consistent force output, because of unfamiliar testing conditions. In line with this theory, the dynamic results show higher consistency with only one participant showing a decrease in maximum strength.

Still, the question arises about the underlying mechanisms of stretch-mediated strength increases. While flexibility increases are mainly attributed to neuromuscular changes, such as enhanced pain or stretch threshold (Freitas et al., 2018) and/or muscle tendon unit stiffness changes (Takeuchi et al., 2023), the physiology of stretch-mediated strength increases remains still speculative. On the one hand, it is well known that muscle hypertrophy contributes to enhanced maximal strength (Goldspink and Harridge, 2003). Even though stretching has shown the potential to induce hypertrophy when using one to two hours of stretching, other experimental studies performing stretching for up to 20 minutes per session (Wohlann et al., 2023) nor systematic review (Nunes et al., 2020; Panidi et al., 2023) were able to point out significant muscle hypertrophy. Additionally, in the present study, we did not perform muscle volume measurements.

Since previous studies pointed out contralateral strength increases (Nelson et al., 2012; Panidi et al., 2021; Warneke et al., 2022b; 2022d) the involvement of neuronal training adaptation in response to stretching seems evident. While Holly et al. (1980) and Barnett et al. (1980) investigated the effects of stretching on EMG activity in animals showing no significantly enhanced neuronal activity, no studies were detected testing neuromuscular activity while performing stretching in humans. Furthermore, changes in reflex responses, changed activation patterns due to familiarization to stretching pain in higher muscle lengths or changes in neuromuscular activity due to changes in contraction properties (changes in fascicle angle/length, (Panidi et al., 2023)) could also be hypothesized. The commonly reported increase in stretch/pain threshold with ROM increases may also apply to strength gains, as individuals may be able to sustain greater discomfort when lifting/contracting and thus push harder (higher intensity contractions) with the suppression of pain. While there are some promising explanatory approaches when interpreting stretch-mediated strength increases (Warneke, et al., 2023b), there is still a lack of investigations exploring the underlying physiology. Therefore, the underlying mechanisms remain unclear to this point.

Furthermore, it is well known from previous research, that (static) stretching performed for a duration of several weeks commonly induces flexibility increases (Konrad et al. 2023). Accordingly, the stretch training showed significant increases in shoulder ROM. While not investigated in the present study, the literature suggests possible morphological and neurological mechanisms for the chronic stretch training-induced improvements in ROM. Five to six weeks of stretch training has been found to decrease muscle and tendon stiffness (Behm et al. 2016), although not in all studies (Freitas et al., 2018; Kubo et al., 2002; Mahieu et al., 2007), reduce tendon viscoelastic properties (Kubo et al., 2002), and muscle passive resistive torque (Mahieu et al., 2007). Neuronal or psychophysiological adaptations such as changes in stretch tolerance by increasing the pain threshold (Freitas et al., 2018; Konrad and Tilp, 2014) is a ubiquitously proposed underlying mechanism. With the vast extent of research focusing on ROM adaptations in response to stretching, this study did not focus on the underlying mechanisms of stretch training-induced increases in flexibility.

Limitations

First, sex-distribution was not balanced. Since Warneke et al. (2022c) described sex-related differences in stretch-mediated adaptations the results could be therefore influenced significantly. Furthermore, in the final data analysis, the sample size in IG and Control were not completely balanced. The results of the study are limited by providing only phenomenological results without evaluating underlying physiological parameters such as hypertrophy, passive stiffness, pain threshold or changes in the neuromuscular activation. Since literature regarding stretch-mediated strength increases is scarce, potential long-term issues regarding overstretching the shoulder joint were not reported in this study, however, they might occur by increasing the intensity and/or stretching duration. Therefore, potential risks should be considered carefully in further studies, especially if participants are not familiar with using the full ROM in the shoulder joint.

Conclusion

Significant, large magnitude increases in maximum (dynamic) bench press 1RM strength (7.4%) and shoulder ROM (9.8%) were documented following static stretching of the pectoralis major for 15min/day for eight weeks, incorporating three different stretching exercises. Since Schoenfeld et al. (2022) questioned the practical applications of using one hour of daily stretching to induce hypertrophy and previous studies pointed out the demand for further studies with the transferability to other muscle groups (Warneke et al., 2022b; 2022d), a home-based training program was developed to improve the application of improving maximum strength via stretching. To clarify, the authors do not recommend the replacement of strength training to increase muscle mass or maximum strength, especially considering the comparably prolonged time to induce comparable results via stretching (Warneke et al., 2023c). Nevertheless, the results point out a possible alternative to those individuals, who are not willing to, do not have access to strength training equipment or are less trained and therefore not able to perform bodyweight training. Furthermore, it is important to emphasize that these strength adaptations occurred with an unsupervised, at home program. Whether stretch training could induce enough tension to improve maximum strength significantly in various populations (e.g., previously trained or athletes) should be investigated in further studies, especially since Li et al. (2022) showed that stretching only improved performance in low performance level individuals.

Outlook

Research in the future should investigate the underlying mechanisms of stretch-induced stretching increases, including neuromuscular adaptations by performing EMG-measurements as well as structural changes of the muscle, tendon and muscle-tendon-complex. As Schoenfeld et al. (2022) suggested the inclusion of interest stretch to enhance hypertrophy adaptations, the combination of long-duration stretching interventions with the potential of inducing muscle hypertrophy and commonly used exercise interventions such as resistance training should be investigated in further studies.

Acknowledgements

There is no conflict of interest. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

References

Amarante do Nascimento, M., Borges Januário, R. S., Gerage, A. M., Mayhew, J. L., Cheche Pina, F. L. and Cyrino, E. S. (2013) Familiarization and Reliability of One Repetition Maximum Strength Testing in Older Women. *Journal of Strength and Conditioning Research* **27(6)**, 1636-1642. https://doi.org/10.1519/JSC.0b013e3182717318

Arntz, F., Markov, A., Behm, D. G., Behrens, M., Negra, Y., Nakamura, M., Moran, J. and Chaabene, H. (2023) Chronic Effects of Static Stretching Exercises on Muscle Strength and Power in Healthy Individuals Across the Lifespan: A Systematic Review with Multi-level Meta-analysis. *Sports Med*icine **53(3)**, 723-745. https://doi.org/10.1007/s40279-022-01806-9

Barnett, J. G., Holly, R. G. and Ashmore, C. R. (1980) Stretch-induced growth in chicken wing muscles: biochemical and morphological characterization. *American Journal of Physiology* **239**, 39-46. https://doi.org/10.1152/ajpcell.1980.239.1.C39

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. https://doi.org/10.1139/apnm-2015-0235

Cohen, J. (1988) Statistical Power Analysis for Behavioral Sciences (2nd ed.).

Drake, D., Kennedy, R. and E. (2018). Familiarization, Validity and Smallest Detectable Difference of the Isometric Squat Test in Evaluating Maximal Strength. *Journal of Sports Science* **36(18)**, 2087-2095. https://doi.org/10.1080/02640414.2018.1436857

Dunn, E. C., Humberstone, C. E., Franchini, E., Iredale, K. F. and Blazevich, A. J. (2022) Relationships Between Punch Impact Force and Upper- and Lower-Body Muscular Strength and Power in Highly Trained Amateur Boxers. *Journal of Strength and Conditioning Research* **36(4)**, 1019-1025. https://doi.org/10.1519/JSC.0000000000003585

Freitas, S. R., Mendes, B., Le Sant, G., Andrade, R. J., Nordez, A. and Milanovic, Z. (2018) Can chronic stretching change the muscle-tendon mechanical properties? A Review. *Scandinavian Journal of Medicine Science and Sports* **28(3)**, 294-306. https://doi.org/10.1111/sms.12957

Goldspink, G. and Harridge, S. (2003) Cellular and Molecular Aspects of Adaptation in Skeletal Muscle. In P. V. Komi (Ed.), Strength and Power in Sport (2nd ed., Vol. 3, pp. 231-251). https://doi.org/10.1002/9780470757215.ch12

Hermassi, S., van den Tillaar, R., Khlifa, R., Chelly, M. S. and Chamari, K. (2015) Comparison of In-Season-Specific Resistance vs. A Regular Throwing Training Program on Throwing Velocity, Anthropometry, and Power Performance in Elite Handball Players. *Journal of Strength and Conditioning Research* **29(8)**, 2105-2114. https://doi.org/10.1519/JSC.0000000000000855

Holly, R. G., Barnett, J. G., Ashmore, C. R., Taylor, R. G. and Molti, P. A. (1980) Stretch-induced growth in chicken wing muscles: a new model of stretch hypertrophy. *American Journal of Physiology* **238**, 62-71. https://doi.org/10.1152/ajpcell.1980.238.1.C62

Konrad, A. and Tilp, M. (2014) Increased range of motion after static stretching is not due to changes in muscle and tendon structures. *Clinical Biomechanics* **29(6)**, 636-642. https://doi.org/10.1016/j.clinbiomech.2014.04.013

Konrad, A. Alizadeh, S., Daneshjoo, A., Anvar, S.H., Graham, A., Zahiri, A. Goudini, R., Edwards, C., Scharf, C., Behm, D.G. (2023) Chronic effects of stretching on range of motion with consideration of potential moderating variables: A systematic review with meta-analysis. *Journal of Sport and Health Science* **8,** S2095-2546(23)00057-1. https://doi.org/10.1016/j.jshs.2023.06.002

Kubo, K., Kanehisa, H. and Fukunaga, T. (2002) Effects of resistance and stretching training programmes on the viscoelastic properties of human tendon structures in vivo. *Journal of Physiology* **538(1)**, 219-226. https://doi.org/10.1113/jphysiol.2001.012703

Li, S., Wang, L., Xiong, J. and Xiao, D. (2022) Gender-Specific Effects of 8-Week Multi-Modal Strength and Flexibility Training on Hamstring Flexibility and Strength. *International Journal of Environmental Research and Public Health* **19(22)**. https://doi.org/10.3390/ijerph192215256

Lohmann, L. H., Warneke, K., Schiemann, S. and Faber, I. R. (2022) High-Load Squat Training Improves Sprinting Performance in Junior Elite-Level Soccer Players: A Critically Appraised Topic. *International Journal of Athletic Therapy and Train*ing **27(1)**, 1-6. https://doi.org/10.1123/ijatt.2021-0066

Lum, D., Soh, S. K., Teo, C. J. H., Wong, O. Q. H. and Lee, M. J. C. (2022) Effects of Performing Isometric Bench Press Training at Single Versus Multiple Joint Positions on Strength and Power Performance. *International Journal of Sports Physiology and Performance* **17(7)**, 1061-1069. https://doi.org/10.1123/ijspp.2021-0461

Mahieu, N. N., McNair, P., De Muynck, M., Stevens, V., Blanckaert, I., Smits, N. and Witvrouw, E. (2007) Effect of Static and Ballistic Stretching on the Muscle-Tendon Tissue Properties. *Medicine & Science in Sports & Exercise* **39(3)**, 494-501. https://doi.org/10.1249/01.mss.0000247004.40212.f7

McGuigan, M. R., Winchester, J. B. and Erickson, T. (2006) The Importance of Isometric Maximum Strength in College Wrestlers. *Journal of Sports Science and Med*icine **5**, 108-113. https://pubmed.ncbi.nlm.nih.gov/24357982/

Medeiros, D. M., Cini, A., Sbruzzi, G. and Lima, C. S. (2016) Influence of static stretching on hamstring flexibility in healthy young adults: systematic review and meta-analysis. *Physiothrapy Therapeutics Theory and Pract*ice **32(6)**, 438-445. https://doi.org/10.1080/09593985.2016.1204401

Musick, T. and Childs Cymet, T. (2006) Childhood obesity Normal variant or serious illness? *Comprehensive Therapy* **32(3)**, 147-149. https://doi.org/10.1007/s12019-006-0004-7

Nelson, A. G., Kokkonen, J., Winchester, J. B., Kalani, W., Peterson, K., Kenly, M. S. and Arnall, D. A. (2012) A 10-Week Stretching program Increases Strength in the Contralateral Muscle. *Journal of Strength and Conditioning Res*earch **26(3)**, 832-836. https://doi.org/10.1519/JSC.0b013e3182281b41

Nunes, J. P., Schoenfeld, B. J., Nakamura, M., Ribeiro, A. S., Cunha, P. M. and Cyrino, E. S. (2020) Does stretch training induce muscle hypertrophy in humans? A review of the literature. *Clinical Physiology and Functional Imaging* **40**, 148-156. https://doi.org/10.1111/cpf.12622

Østerås, H., Sommervold, M. and Skjølberg, S. (2015) Effects of a strength-training program for shoulder complaint prevention in female team handball athletes. A pilot study. *Journal of Sports Medicine and Physical Fitness* **55(8)**, 761-767.

Panidi, I., Bogdanis, G. C., Terzis, G., Donti, A., Konrad, A., Gaspari, V. and Donti, O. (2021) Muscle Architectural and Functional Adaptations Following 12-Weeks of Stretching in Adolescent Female Athletes. *Frontiers of Physiol*ogy **12**. https://doi.org/10.3389/fphys.2021.701338

Panidi, I., Donti, O., Konrad, A., Petros, C. D., Terzis, G., Mouratidis, A., Gaspari, V., Donti, A. and Bogdanis, G. C. (2023) Muscle architecture adaptations to static stretching training: a systematic review with meta-analysis. *Sports Medicine Open* **9(1)**, 47. https://doi.org/10.1186/s40798-023-00591-7.

Reiner, M., Gabriel, A., Sommer, D., Bernsteiner, D., Tilp, M. and Konrad, A. (2023) Effects of a High-Volume 7-Week Pectoralis Muscle Stretching Training on Muscle Function and Muscle Stiffness. *Sports Medicine - Open* **9(1)**, 40. https://doi.org/10.1186/s40798-023-00582-8

Sander, A., Keiner, M., Wirth, K. and Schmidtbleicher, D. (2013) Influence of a 2-year strength training programme on power performance in elite youth soccer players. *European Journal of Sport Sci*ence **13(5)**, 445-451. https://doi.org/10.1080/17461391.2012.742572

Schoenfeld, B. J., Wackerhage, H. and De Souza, E. (2022). Inter-set stretch: A potential time-efficient strategy for enhancing skeletal muscle adaptations. *Frontiers in Sports and Active Living* **4**. https://doi.org/10.3389/fspor.2022.1035190

Sommervold, M. and Østerås, H. (2017).What is the effect of a shoulder-strengthening program to prevent shoulder pain among junior female team handball players? *Open Access Journal of Sports Medicine* **8**, 61-70. https://doi.org/10.2147/OAJSM.S127854

Styles, W. J., Matthews, M. J. and Comfort, P. (2016) Effects of Strength Training on Squat and Sprint Performance in Soccer Players. *Journal of Strength & Conditioning Research* ***30*(6),** 1534-1539. https://doi.org/10.1519/JSC.0000000000001243

Suchomel, T. J., Nimphius, S. and Stone, M. H. (2016). The Importance of Muscular Strength in Athletic Performance. *Sports Medicine* **46**, 1419-1449. https://doi.org/10.1007/s40279-016-0486-0

Takeuchi, K., Nakamura, M., Konrad, A. and Mizuno, T. (2023) Long-term static stretching can decrease muscle stiffness: A systematic review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports* **33(8)**, 1294-1306. https://doi.org/10.1111/sms.14402

Warneke, K., Hillebrecht, M., Wirth, K., Schiemann, S. and Keiner, M. (2022a) Correlation between Isometric Maximum Strength and One Repetition Maximum in the Calf Muscle in Extended and Bended Knee Joint. *International Journal of Applied Sports Science* **34(1)**, 61-71. https://doi.org/10.24985/ijass.2022.34.1.61

Warneke, K., Keiner, M., Hillebrecht, M. and Schiemann, S. (2022b) Influence of One Hour versus Two Hours of Daily Static Stretching for Six Weeks Using a Calf-Muscle-Stretching Orthosis on Maximal Strength. *International Journal of Environmental Research and Public Health* **19(18)**, 11621. https://doi.org/10.3390/ijerph191811621.

Warneke, K., Zech, A., Wagner, C. M., Konrad, A., Nakamura, M., Keiner, M., Schoenfeld, B. J. and Behm, D. G. (2022c) Sex differences in stretch-induced hypertrophy, maximal strength and flexibility gains. *Frontiers of Physiol*ogy **13**,1078301.

Warneke, K., Brinkmann, A., Hillebrecht, M. and Schiemann, S. (2022d) Influence of Long-Lasting Static Stretching on Maximal Strength, Muscle Thickness and Flexibility. *Frontiers of Physiol*ogy **13**. https://doi.org/10.3389/fphys.2022.878955

Warneke, K., Keiner, M., Wohlann, T., Lohmann, L. H., Schmitt, T., Hillebrecht, M., Brinkmann, A., Hein, A., Wirth, K. and Schiemann, S. (2023a) Influence of Long-Lasting Static Stretching Interventions on Functional and Morphological Parameters in the Plantar Flexors: A Randomized Controlled Trial. *Journal of Strength and Conditioning Research*, *accepted*. https://doi.org/10.1519/JSC.0000000000004513

Warneke, K., Lohmann, L. H., Lima, C. D., Hollander, K., Konrad, A., Zech, A., Nakamura, M., Wirth, K., Keiner, M. and Behm, D. G. (2023b) Physiology of stretch-mediated hypertrophy and strength increases: a narrative review. *Sports Medicine*, *accepted*. https://doi.org/10.1007/s40279-023-01898-x

Warneke, K., Wirth, K., Keiner, M., Lohmann, L. H., Hillebrecht, M., Brinkmann, A., Wohlann, T. and Schiemann, S. (2023c) Comparison of the effects of long-lasting static stretching and hypertrophy training on maximal strength, muscle thickness and flexibility in the plantar flexors. *European Journal of Applied Physio*logy **123(8)**, 1773-1787. https://doi.org/10.1007/s00421-023-05184-6

Warneke, K., Wagner, C.-M., Keiner, M., Hillebrecht, M., Schiemann, S., Behm, D. G., Wallot, S. and Wirth, K. (2023d) Maximal strength measurement: A critical evaluation of common methods-a narrative review. *Frontiers of Sports and Active Living* **5**. https://doi.org/10.3389/fspor.2023.1105201

Wirth, K. (2007) *Training Frequency in hypertrophy training (Vol. 1).* Sportverlag Strauß.

Wirth, K., Keiner, M., Fuhrmann, S., Nimmerichter, A. and Haff, G. G. (2022) Strength Training in Swimming. *International Journal of Environmental Research and Public Health* **19(9)**, 5369. https://doi.org/10.3390/ijerph19095369

Wirth, K., Keiner, M., Hartmann, H., Sander, A. and Mickel, C. (2016) Effect of 8 weeks of free-weight and machine-based strength training on strength and power performance. *Journal of Human*

Kinetics **53(1)**, 201-210. https://doi.org/10.1515/hukin-2016-0023

Wohlann, T., Warneke, K., Hillebrecht, M., Petersmann, A., Ferrauti, A. and Schiemann, S. (2023) Effects of daily static stretch training over 6 weeks on maximal strength, muscle thickness, contraction properties and flexibility. *Frontiers of Sports and Active Living* **5**. https://doi.org/10.3389/fspor.2023.1139065

Yahata, K., Konrad, A., Sato, S., Kiyono, R., Yoshida, R., Fukaya, T., Nunes, J. P. and Nakamura, M. (2021) Effects of a high-volume static stretching programme on plantar-flexor muscle strength and architecture. *European Journal of Applied Physiology* **121(4)**, 1159-1166. https://doi.org/10.1007/s00421-021-04608-5

Young, K. P., Haff, G. G., Newton, R. U., Gabbett, T. J. and Sheppard, J. M. (2015) Assessment and Monitoring of Ballistic and Maximal Upper-Body Strength Qualities in Athletes. *International Journal of Sports Physiology and Performance* **10**, 232-237. https://doi.org/10.1123/ijspp.2014-0073

Young, K. P., Haff, G. G., Newton, R. U. and Sheppard, J. M. (2014) Reliability of a Novel Testing Protocol to Assess Upper-Body Strength Qualities in Elite Athletes. *International Journal of Sports Physiology and Performance* **9(5)**, 871-875. https://doi.org/10.1123/ijspp.2013-0332

Key points

- Static stretching of the pectoralis major for 15min/day for 8 weeks induced bench press 1RM strength (7.4%) and shoulder ROM (9.8%) increases.
- Strength adaptations occurred with an unsupervised, home static stretching program.
- Static stretching is not recommended as a strength training replacement to increase strength, but may be a possible alternative to individuals not willing, do not have access to strength training equipment or are less trained and therefore not able to perform bodyweight training.

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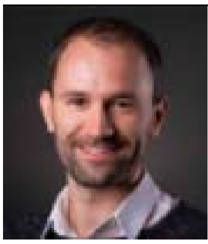

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