ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

ΤΜΗΜΑ ΕΠΙΣΤΗΜΗΣ ΦΥΣΙΚΗΣ ΑΓΩΓΗΣ ΚΑΙ ΑΘΛΗΤΙΣΜΟΥ

Η Επίδραση των στατικών διατάσεων στη δύναμη της γροθιάς.

The effect of static stretching on the force of a punch.

ΓΑΤΣΑΣ ΑΘΑΝΑΣΙΟΣ

ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ

ΤΣΙΟΚΑΝΟΣ ΑΘΑΝΑΣΙΟΣ

Μεταπτυχιακή Διατριβή που υποβάλλεται στο καθηγητικό σώμα για τη μερική εκπλήρωση των υποχρεώσεων απόκτησης του μεταπτυχιακού τίτλου του Προγράμματος Μεταπτυχιακών Σπουδών «ΕΦΑΡΜΟΣΜΕΝΗ ΚΙΝΗΣΙΟΛΟΓΙΑ ΣΤΙΣ ΕΝΟΠΛΕΣ ΔΥΝΑΜΕΙΣ» του Τμήματος Επιστήμης Φυσικής Αγωγής και Αθλητισμού του Πανεπιστημίου Θεσσαλίας.

ΤΡΙΚΑΛΑ

2016

Περίληψη

Η παρούσα μελέτη διερεύνησε την οξεία επίδραση των στατικών χαμηλού όγκου διατάσεων στην δύναμη της γροθιάς, τον χρόνο κορύφωσης της δύναμης και την αύξηση της δύναμης. Δεκατρία άτομα χωρίστηκαν τυχαία σε δύο ομάδες: στατικών διατάσεων και την ομάδα ελέγχου (25,3 ± 7,68 χρόνων, 1.786 ± 0,04 m, 78,36 ± 12,02 kg και 7,23 ± 8,24 χρόνια εμπειρίας). Όλα τα άτομα εκτέλεσαν αερόβια προθέρμανση (τρέξιμο, σκιαμαχία, περιστροφές των αρθρώσεων), που ακολουθήθηκαν από στατικές διατάσεις (20sec ανά μυϊκή ομάδα) για την ομάδα των διατάσεων και έξι δοκιμές πραγματοποιήθηκαν (μετά το ζέσταμα, μετά από στατικές διατάσεις, μετά από μια περίοδο ανάπαυσης ενός λεπτού και τρεις φορές μετά από ένα λεπτό σκιαμαχία και ένα λεπτό ανάπαυσης). Για τις ασκούμενες δυνάμεις, δεν παρατηρήθηκαν στατιστικά σημαντικές διαφορές μεταξύ των έξι επαναλήψεων στις δύο ομάδες. Δεν παρατηρήθηκαν σημαντικές διαφορές επίσης για την άνοδο των δυνάμεων . Στατιστικά σημαντικές διαφορές αποκαλύφθηκαν μεταξύ των έξι επαναλήψεων για την παράμετρο του χρόνου και στις δύο ομάδες. Τα αποτελέσματα αυτής της μελέτης δείχνουν ότι εφαρμογή ενός χαμηλού όγκου στατικών διατάσεων δεν έχει καμία επίδραση στη δύναμη της γροθιάς.

Abstract

This study investigated the acute effect of low-volume static stretching on the force of a punch, time from impact to peak force and rise of force. Thirteen subjects were randomly divided into two groups: static stretching and control group (25.3 ± 7.68years, 1.786 ± 0.04 m, 78.36 ±12.02 kg and 7.23 ±8.24 years of experience). All subjects performed aerobic warm-up(jogging, shadowboxing, rotation of the joints) , followed by static stretching(20sec per muscle group) for the stretching group and six tests were performed(after the warm up, after static stretching, after a rest period of one minute and three times after one min shadowboxing and one min rest). For the exerted forces, no statistically significant differences were revealed between six repetitions for the two groups. No significant differences were revealed also for the rise of forces . Statistically significant differences were revealed between the six repetitions for the time parameter for both the groups. The results of this study suggest that a low volume static stretching has no effect on the force of a punch.

Contents

Περίληψη 2

Abstract 2

Contents 3

List of Tables 4

List of abbreviations 4

List of figures 4

1.Introduction 5

2.Review 6

2.1.ROM 6

2.2.Rehabilitation 6

2.3Injury risk 6

2.4Effects of static stretching on force production 7

2.5Significance and purpose of the proposed study 7

3.Methods 7

3.1Participants 7

3.2Stretching exercises 8

3.3Procedures 9

3.4Data collection 10

3.5Statistical analysis 10

4.Results 11

5.Discussion 16

5.1Limitations 18

6.Conclusion 18

7.References 19

8.Appendix 24

Stretching Exercises 24

List of Tables

Table 1	Physiological characteristics of the participants
Table 2	Descriptive statistics of F components
Table 3	Descriptive statistics of F/t components
Table 4	Descriptive statistics of t components

List of abbreviations

AIBA	Association Internationale de Boxe Amateur (International Boxing Association)
CG	Control Group
ROM	Range of Motion
SG	Stretching Group
SS	Static stretching

List of figures

Figure 1: Variation of F mean values in stretching and control groups

Figure 2: Variation of F/t mean values in stretching and control groups

Figure 3: Variation of t mean values in stretching and control groups

1.Introduction

An individual's physical fitness depends on a vast number of components. Flexibility is only one of these and stretching is the most effective way of developing and retaining flexible muscles and tendons. Stretching exercises are usually included in the warm up routine before practice in various sports with the aims of increasing joint ROM [1], reducing injury risk[2] and rehabilitation after injury[3]. Among the most widely used stretching exercises, is static stretching. SS involves moving a limp to the end of its range of motion and holding the stretched position for 15-60 s [4, 5]. It has been shown that stretching increases the range of motion and can also decrease musculotendinous stiffness even with short-duration stretches of 5-30 s [6, 7] The benefits of pre-exercise muscle stretching have been debated after reports of significant post-stretch decrements in performance [8-14],reports of performance enhancement [15-17] and reports of no effects on performance [18-22]. The acute effects of SS on performance depend on many factors, which the most important are 1) the stretching duration and intensity, 2) the training background of the participants and 3) the post-stretch activity[23, 24]. The stretch durations that are commonly performed in a pre-exercise routine are less than 30s[25, 26] and usually don't exceed 20 sec per muscle group in football, baseball, basketball[27-29] and boxing [30]. Boxing is a combat sport where two athletes compete for the victory by throwing punches and punching force is one of the performance indicators[31, 32] of this sport. Punching is not only seen in boxing, but also in various combat sports.

2.Review

2.1.ROM

SS has been demonstrated as an effective means to increase ROM about the joint [1, 33]. Acute increases after SS have been attributed to concomitant increase in the capacity to tolerate loading prior to stretch termination [34] and to changes in mechanical properties[35]. However, our understanding of the underlying mechanisms remains limited.

2.2.Rehabilitation

Stretching exercises seem also to be important in rehabilitation programs. Malliaropoulos et al.[36] found that the group which carried out a more intensive stretching program, was found to have a statistically significant shorter time of regaining normal ROM and rehabilitation period. Other researches showed positive effects of static stretching on rehabilitation programs too[37, 38].

2.3Injury risk

Another benefit of SS is proposed to be the prevention [39] or reduction of injury [40]. However, some studies have demonstrated that SS has no effect on injury prevention[41, 42] and others that the most flexible individuals were more likely to suffer injuries[43].

2.4Effects of static stretching on force production

A considerable body of literature shows deficits in performance on activities which require strength and power after static stretching, such as countermovement jump height, one maximum repetition and peak torque output[10, 14, 44-50] .

2.5Significance and purpose of the proposed study

Stretching exercises as part of a warm up routine are a common practice among trainers and athletes. The benefits of pre-exercise muscle stretching have been recently questioned after reports of significant post-stretch reductions in force production. Even the American College of Sports Medicine's guidelines[51] suggested the removal of SS as a part of a warm-up routine when strength or power was important to performance. There has been no relevant research to clarify if SS has negative or positive effects on the force of a punch, thus , it is important to know these effects, because punching force is paramount to a fighter's victory[32, 52]. The purpose of this study is to examine the effect of static stretching on the force of a punch. Our hypothesis is that SS will reduce the force of a punch.

3.Methods

3.1Participants

Thirteen male amateur boxers participated in this study and five of them were the CG. Their mean age, height, weight and years of experience were 25.3 ± 7.68years, 1.786

± 0.04 m, 78.36 ±12.02 kg and 7.23 ±8.24 years(one year minimum), respectively. One year of boxing experience was thought to be essential because, within that period, the participants were able to master the punching technique and for us to be sure that all punches were performed the same way. This study was approved by the Ethics Committee of the Department of P.E. and Sport Sciences and written informed consent was obtained from all participants.

TABLE 1. Physiological characteristics of the participants

	Stretching group (N=8)	Control group (N=5)
Age (years)	27.85 ± 8.02	21.2 ±5.49
Height (cm)	1.78 ±0.04	1.79 ±0.06
Weight (kg)	80.25 ±11.78	75.36 ±13.13
Experience	16 ±9.78	5.3 ±5.33

3.2Stretching exercises

Punching is a complex motion which requires the participation of many muscles. For the lead arm straight punch to the head we have 1) a shift of the body weight from rear leg to the lead leg, 2) rotation of the body toward the rear side, 3) extension of the lead arm straight out to the target[AIBA coaches manual]. But, given the fact that in the warm up routine stretching is performed for both the upper and lower body[30][AIBA coaches manual], we did not isolate the muscles which are activated

in punching and conducted SS for all the major muscle groups(Appendix), 20 sec per muscle group, beginning from the legs to the upper body and finally the testing arm.

3.3Procedures

The participants warmed up without any stretching by 5 min jogging, side steps and rotation of all the joints (wrists, forearms, arms etc.) .Then they shadowboxed for 2, 1.5 and 1 min with one minute rest between respectively. During the warm up they hit the target as many times as they want, so as they would be familiarized with the process and the target. Then, after the warm up, they rested for a minute and they hit the target with full-effort with their lead hand without taking a step (stationary position). This procedure showed us the force of a punch affected by warm up without stretching. Immediately SS (20sec per muscle) for the whole body followed and after it was completed, the participants stroke again with full effort. This procedure showed us the effect of SS on the force of a punch. A rest period of one minute followed and the subjects stroke again to see the effect of the passing minute. Then, we continued with one minute shadowboxing, one minute rest and strike for 6 minutes. This procedure showed us the effects of the passing time with dynamic activity after the stretching protocol. The CG followed the same procedure except the part of stretching, where in that time they shadowboxed and rested for one minute before they hit the target. All participants were instructed to use maximum effort at all punches .Each participant performed all the strikes from the same distance and same glove with double wrapped hands for better protection and did not perform any physical activity at the testing day.

3.4Data collection

All the data were collected at 1000hz from a wall-mounted force plate (Bertec 4060-15). The height of the force plate was adjusted to the height of the participant's head. At each test two strikes were performed with 20sec rest between each trial and the mean force(F), mean time from the moment of impact to peak force(t) and mean rise of force(F/t) of the two trials were collected for analysis.

3.5Statistical analysis

All collected data was analyzed using PASW Statistics 18. Descriptive statistics analysis was conducted separately for the stretching and control group. One-way repeated measure ANOVAs were used to test for differences between the six repetitions for all parameters (the punching force, the time from first contact to peak force and the rise of force). The Friedman test (the nonparametric test, equivalent of the one-way within-subjects Anova) was used where the Anova's conditions were not met. A Bonferoni method was also used for post-hoc comparisons, if Anova revealed significant differences. The level of significance for all analyses was set at 0.05.

4.Results

One-way within-subjects Anova was used for comparisons of all parameters of the SG. For the exerted forces, no statistically significant differences were revealed between six repetitions ($F_{(5,35)} = 0.996$, $p = 0.434$). For the CG were used Friedman tests for comparisons of all parameters because the fact that Anova's conditions were not met (normality test). For the exerted forces, no statistically significant differences were revealed between six repetitions ($X^2 = 5.000$, $df = 5$, $p = 0.416$).

Figure 1 :Variation of F mean values in stretching and control groups

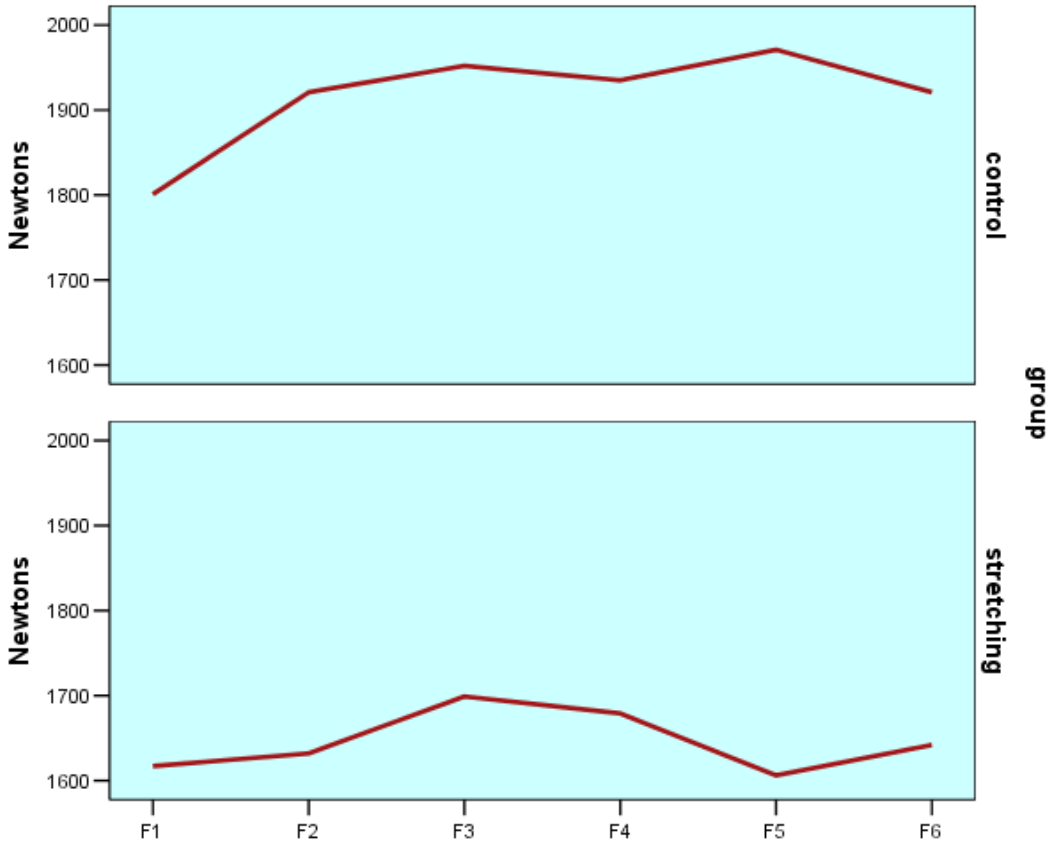

TABLE 2. Descriptive statistics of F components

	Stretching group (N=8)	Control group (N=5)

F_1	1617 ± 490	1801 ± 674
F_2	1632 ± 504	1921 ± 602
F_3	1699 ± 519	1952 ± 805
F_4	1679 ± 538	1935 ± 538
F_5	1606 ± 498	1971 ± 523
F_6	1642 ± 530	1921 ± 566

All F scores of the control group are higher than corresponding scores of stretching group (no statistically significant differences were revealed).

No significant differences were revealed also for the rise of forces ($F_{(5,35)} = 1.71$, $p = 0.178$) for the SG. No statistically significant differences were revealed also between the six repetitions for the rise of force ($X^2 = 9.229$, $df = 5$, $p = 0.100$) for the CG.

Figure 2 :Variation of F/t mean values in stretching and control groups

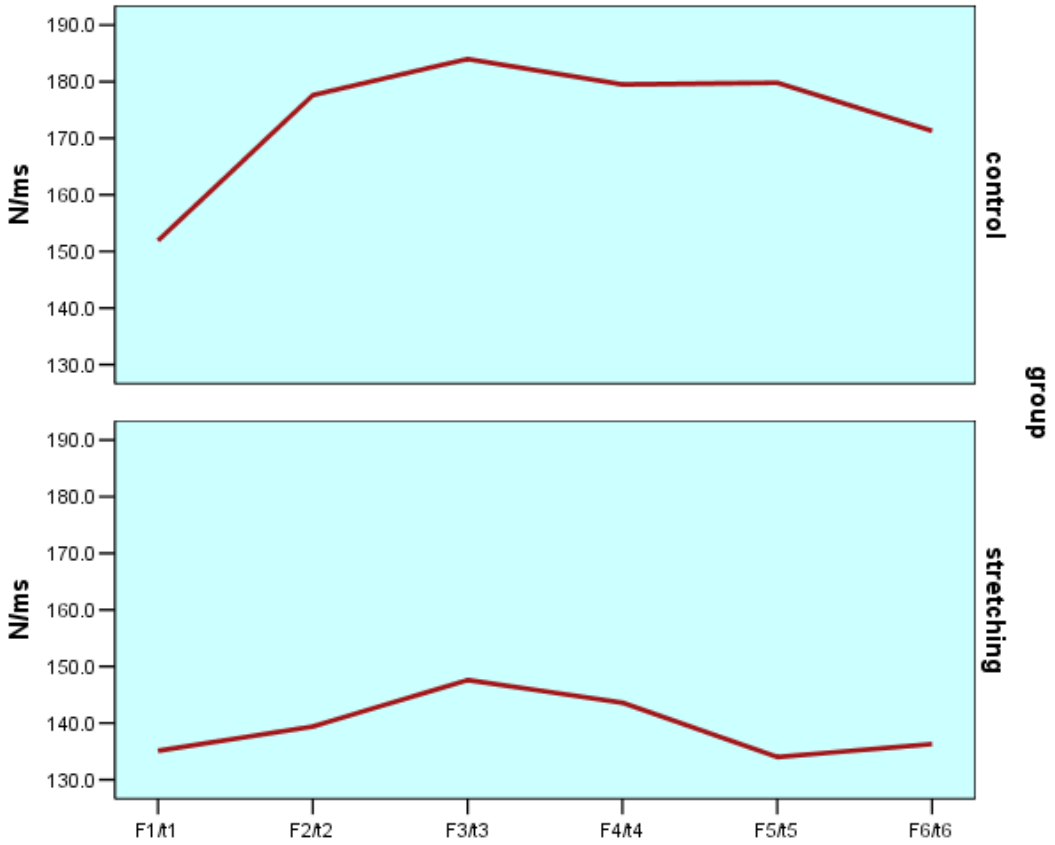

TABLE 3. Descriptive statistics of F/t components

	Stretching group (N=8)	Control group (N=5)
F_1/t_1	135.1 ± 68.3	151.9 ± 83.0
F_2/t_2	139.4 ± 73.5	177.6 ± 85.7
F_3/t_3	147.6 ± 83.6	184.0 ± 107.1
F_4/t_4	143.6 ± 78.7	179.5 ± 77.6
F_5/t_5	134.0 ± 70.4	179.8 ± 59.1

$\mathbf{F_6/t_6}$	136.3 ± 73.8	171.3 ± 68.2

All F/t values of the control group are higher than corresponding values of stretching group (no statistically significant differences were revealed). This means that the rise of the force occurs faster in control group in comparison to the stretching group.

Statistically significant differences were revealed between the six repetitions for the time parameter ($F_{(5,35)} = 4.540$, $p = 0.036$) for the SG. Post hoc comparisons with Bonferoni method revealed that the Anova significance due only to differences between t1 and t2 ($t_4 = 6.0$, $p = 0.004$). Statistically significant differences were revealed between the six repetitions for the time parameter ($X^2 = 11.186$, $df = 5$, $p = 0.048$) for the CG also. Post hoc nonparametric comparisons revealed that the Friedman test significance due to differences between t1 and t2 ($Z = 2.121$, $p = 0.034$), t1 and t3 ($Z = 2.032$, $p = 0.042$), t1 and t4 ($Z = 2.060$, $p = 0.039$).

Figure 3:Variation of t mean values in stretching and control groups

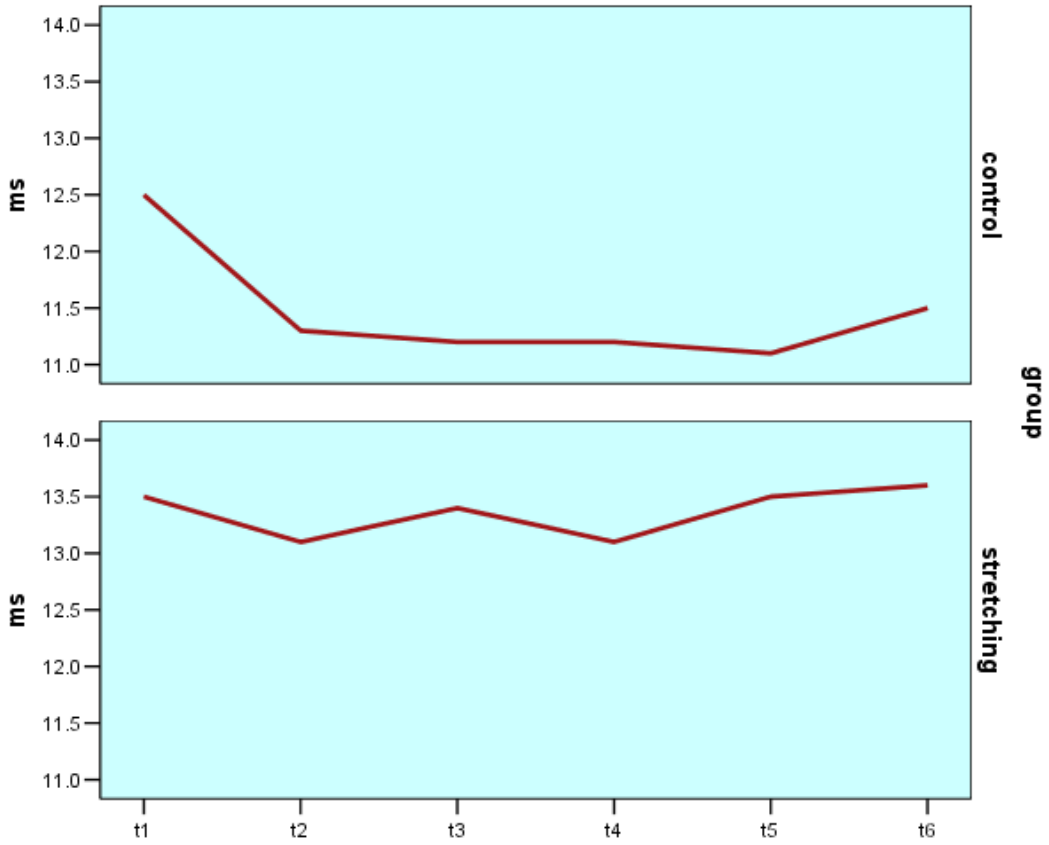

TABLE 4. Descriptive statistics of t components

	Stretching group (N=8)	Control group (N=5)
t_1	13.5 ± 4.4	12.5 ± 1.7
t_2	13.1 ± 4.0	11.3 ± 1.4
t_3	13.4 ± 4.5	11.2 ± 1.3
t_4	13.1 ± 3.4	11.2 ± 1.2

t_5	13.5 ± 3.7	11.1 ± 0.7
t_6	13.6 ± 3.8	11.5 ± 1.0

All t values of the control group are lower than corresponding values of stretching group (no statistically significant differences were revealed). This means that the force peak occurs faster in control group in comparison to the stretching group.

5.Discussion

The objective of this study was the acute effects of SS on the force of a punch. To our knowledge this is the only study that has examined this topic. Optimal warm-up routines are normally associated with well-defined physiological benefits. The traditional warm up involves an aerobic warm up, static stretching and dynamic specific to the sport's movements. So in this study all these procedures were included, except the part of stretching for the CG. In this study it was shown that SS does not reduce nor improves the force of a punch. Same findings were made for the control group. So our hypothesis that SS will reduce the force of a punch was rejected. Several theories have been proposed to explain the stretching-induced force loss mechanisms. It has been hypothesized that acute muscle stretching reduces tendon stiffness, forcing the muscle to work at shorter and weaker lengths[53]. Another hypothesis supports that changes in tendon stiffness influences electromechanical delay and thus reduces the rate of force production [54]. But, most researches that shown negative effects on performance[33, 49, 55-58] used stretches which exceeded the stretching durations used in common practice and it has been shown that ROM

benefits are similar for 15, 30, 45 and 120 sec stretches [59, 60]. Our findings are consisted with previous similar researches, which utilized no more than 30 sec stretching for each muscle, examining the effects of stretching on muscle force production of the hamstring muscles[61], on plantar flexor explosive force production[62],on maximal strength[63], on isokinetic peak torque production of soccer players[64], on a one maximum repetition in the bench press[22], on multiple sets in the bench press[20], on a maximum voluntary contraction and jump performance[65], on an overhead medicine ball throw or a lateral medicine ball throw[22]. Two reviews concluded that total stretch duration per muscle of less than 30 sec may not negatively affect performance [23, 24]. On the other hand, a research which used different stretching protocols with stretching durations of 90 sec showed negative effects on the medicine ball throw, but this impairment was abolished if static stretching was performed together with warm up exercises[66]. As previously mentioned, punching is a complex motion and three studies concluded that skills which require complex neuromuscular patterns seem not to be affected by stretching [67-69]. Although a stretch-shortening cycle occurs in punching [70], we did not exclude shadowboxing from the warm up procedure because it is well known that warm up routines must include dynamic specific to the sports' movements[4], which is also recommended in the warm-up routine for boxers[AIBA Coaches Manual], and thus shadowboxing is essential for a fighter's preparation to the main training session or prior to competition. . The one-minute rest that was given to the participants before the test was sufficient for the participants to recover and is exactly the same time of rest given to the boxers and kickboxers between each round. Although the striking surface was hard, the double wrapped hands and the soft material of the glove was enough to prevent any injury and to motivate the participants to strike as powerfully

as they can. To this motivation, antagonism played some role and the verbal exhortation from the researchers to punch as hard as they can too. Also none of them, when the tests finished, when they were asked if they gave their best, reported a negative answer. Although there was a slight difference between trials, but not statistically important, is something natural, even though they were experienced. For example even elite javelin throwers or sphere throwers don't accomplice the same performance at repeated trials. Future studies is essential to also examine the effect of SS on the punching speed and the time from the start of the strike to its completion, because performance in boxing is also dependent on the speed at which a punch can be delivered[71]. Furthermore we should also examine the effects of dynamic stretches on the force and speed of a punch, with the aim to create the most beneficial warm up routine for boxers and generally combat sports where punching is a key component activity.

5.1Limitations.

There were no females in this study and all participants were experienced and highly trained.

6.Conclusion

The results of the current study show that SS does not reduce the force of a punch, nor improves it, when performed after a warm-up routine. So we don't recommend against static stretching prior to training or competition.

7.References

1. Bandy, W.D., J.M. Irion, and M. Briggler, *The effect of time and frequency of static stretching on flexibility of the hamstring muscles.* Physical therapy, 1997. **77**(10): p. 1090-1096.
2. McHugh, M.P. and C. Cosgrave, *To stretch or not to stretch: the role of stretching in injury prevention and performance.* Scandinavian journal of medicine & science in sports, 2010. **20**(2): p. 169-181.
3. Jonhagen, S., G. Nemeth, and E. Eriksson, *Hamstring injuries in sprinters the role of concentric and eccentric hamstring muscle strength and flexibility.* The American Journal of Sports Medicine, 1994. **22**(2): p. 262-266.
4. Young, W.B. and D.G. Behm, *Should Static Stretching Be Used During a Warm-Up for Strength and Power Activities?* Strength & Conditioning Journal, 2002. **24**(6): p. 33-37.
5. Norris, C.M., *The complete guide to stretching*. 2015: Bloomsbury Publishing.
6. Bandy, W.D., J.M. Irion, and M. Briggler, *The effect of time and frequency of static stretching on flexibility of the hamstring muscles.* Phys Ther, 1997. **77**(10): p. 1090-6.
7. Kay, A.D. and A.J. Blazevich, *Reductions in active plantarflexor moment are significantly correlated with static stretch duration.* European Journal of Sport Science, 2008. **8**(1): p. 41-46.
8. Taylor, K.-L., et al., *Negative effect of static stretching restored when combined with a sport specific warm-up component.* Journal of Science and Medicine in Sport, 2009. **12**(6): p. 657-661.
9. Cornwell, A., et al., *Acute effects of passive muscle stretching on vertical jump performance.* Journal of Human Movement Studies, 2001. **40**(4): p. 307-324.
10. Curry, B.S., et al., *Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women.* The Journal of Strength & Conditioning Research, 2009. **23**(6): p. 1811-1819.
11. Pearce, A.J., C. Latella, and D.J. Kidgell, *Secondary warm-up following stretching on vertical jumping, change of direction, and straight line speed.* European Journal of Sport Science, 2012. **12**(2): p. 103-112.
12. Torres, J., et al., *Acute effects of static stretching on muscle strength.* Biomedical Human Kinetics, 2009. **1**: p. 52-55.
13. Serra, A.J., et al., *Experience in resistance training does not prevent reduction in muscle strength evoked by passive static stretching.* The Journal of Strength & Conditioning Research, 2013. **27**(8): p. 2304-2308.
14. Barroso, R., et al., *Maximal strength, number of repetitions, and total volume are differently affected by static-, ballistic-, and proprioceptive neuromuscular facilitation stretching.* The Journal of Strength & Conditioning Research, 2012. **26**(9): p. 2432-2437.

15. Pacheco, L., et al., *The acute effects of different stretching exercises on jump performance.* The Journal of Strength & Conditioning Research, 2011. **25**(11): p. 2991-2998.
16. Sandberg, J.B., et al., *Acute effects of antagonist stretching on jump height, torque, and electromyography of agonist musculature.* The Journal of Strength & Conditioning Research, 2012. **26**(5): p. 1249-1256.
17. O'connor, D., M. Crowe, and W. Spinks, *Effects of static stretching on leg power during cycling.* Journal of sports medicine and physical fitness, 2006. **46**(1): p. 52.
18. Alpkaya, U. and D. Koceja, *The effects of acute static stretching on reaction time and force.* J Sports Med Phys Fitness, 2007. **47**(2): p. 147-50.
19. Samuel, M.N., et al., *Acute effects of static and ballistic stretching on measures of strength and power.* The Journal of Strength & Conditioning Research, 2008. **22**(5): p. 1422-1428.
20. Ribeiro, A.S., et al., *Static stretching and performance in multiple sets in the bench press exercise.* The Journal of Strength & Conditioning Research, 2014. **28**(4): p. 1158-1163.
21. Knudson, D.V., et al., *Stretching has no effect on tennis serve performance.* The Journal of Strength & Conditioning Research, 2004. **18**(3): p. 654-656.
22. Torres, E.M., et al., *Effects of stretching on upper-body muscular performance.* The Journal of Strength & Conditioning Research, 2008. **22**(4): p. 1279-1285.
23. Behm, D.G. and A. Chaouachi, *A review of the acute effects of static and dynamic stretching on performance.* European journal of applied physiology, 2011. **111**(11): p. 2633-2651.
24. Kay, A.D. and A.J. Blazevich, *Effect of acute static stretch on maximal muscle performance: a systematic review.* Med Sci Sports Exerc, 2012. **44**(1): p. 154-164.
25. Alter, M.J., *Science of flexibility*. 2004: Human Kinetics.
26. Taylor, D.C., et al., *Viscoelastic properties of muscle-tendon units the biomechanical effects of stretching.* The American journal of sports medicine, 1990. **18**(3): p. 300-309.
27. Ebben, W.P. and D.O. Blackard, *Strength and conditioning practices of National Football League strength and conditioning coaches.* The Journal of Strength & Conditioning Research, 2001. **15**(1): p. 48-58.
28. Simenz, C.J., C.A. Dugan, and W.P. Ebben, *Strength and conditioning practices of National Basketball Association strength and conditioning coaches.* The Journal of Strength & Conditioning Research, 2005. **19**(3): p. 495-504.
29. Ebben, W.P., M.J. Hintz, and C.J. Simenz, *Strength and conditioning practices of Major League Baseball strength and conditioning coaches.* The Journal of Strength & Conditioning Research, 2005. **19**(3): p. 538-546.
30. Werner, D. and A. Lachica, *Fighting Fit: Boxing Workouts, Techniques, and Sparring*. 2000: Tracks Publishing.
31. Lenetsky, S., N. Harris, and M. Brughelli, *Assessment and contributors of punching forces in combat sports athletes: Implications for strength and conditioning.* Strength & Conditioning Journal, 2013. **35**(2): p. 1-7.
32. Smith, M.S., *Physiological profile of senior and junior England international amateur boxers.* J Sports Sci Med, 2006. **5**(CSSI): p. 74-89.
33. Power, K., et al., *An acute bout of static stretching: effects on force and jumping performance.* Medicine and science in sports and exercise, 2004. **36**: p. 1389-1396.
34. Magnusson, S.P., et al., *Mechanical and physiological responses to stretching with and without preisometric contraction in human skeletal muscle.* Archives of physical medicine and rehabilitation, 1996. **77**(4): p. 373-378.

35. Morse, C.I., et al., *The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit.* The Journal of physiology, 2008. **586**(1): p. 97-106.
36. Malliaropoulos, N., et al., *The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up.* Medicine and science in sports and exercise, 2004. **36**(5): p. 756-759.
37. KHALIL, T.M., et al., *Stretching in the rehabilitation of low-back pain patients.* Spine, 1992. **17**(3): p. 311-317.
38. Wu, Y.-N., et al., *Combined passive stretching and active movement rehabilitation of lower-limb impairments in children with cerebral palsy using a portable robot.* Neurorehabilitation and neural repair, 2011. **25**(4): p. 378-385.
39. Smith, C.A., *The warm-up procedure: to stretch or not to stretch. A brief review.* Journal of Orthopaedic & Sports Physical Therapy, 1994. **19**(1): p. 12-17.
40. Safran, M.R., M.A.V. Seaber, and W.E. Garrett Jr, *Warm-up and muscular injury prevention an update.* Sports Medicine, 1989. **8**(4): p. 239-249.
41. Gleim, G.W. and M.P. McHugh, *Flexibility and its effects on sports injury and performance.* Sports medicine, 1997. **24**(5): p. 289-299.
42. Small, K., L. Mc Naughton, and M. Matthews, *A systematic review into the efficacy of static stretching as part of a warm-up for the prevention of exercise-related injury.* Research in Sports Medicine, 2008. **16**(3): p. 213-231.
43. Cowan, D., et al., *The epidemiology of physical training injuries in US Army infantry trainees: methodology, population, and risk factors*, 1988, DTIC Document.
44. Behm, D.G. and A. Kibele, *Effects of differing intensities of static stretching on jump performance.* European journal of applied physiology, 2007. **101**(5): p. 587-594.
45. Behm, D.G., et al., *Relative static stretch-induced impairments and dynamic stretch-induced enhancements are similar in young and middle-aged men.* Applied Physiology, Nutrition, and Metabolism, 2011. **36**(6): p. 790-797.
46. Bradley, P.S., P.D. Olsen, and M.D. Portas, *The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance.* The Journal of Strength & Conditioning Research, 2007. **21**(1): p. 223-226.
47. Brandenburg, J., *Duration of stretch does not influence the degree of force loss following static stretching.* Journal of Sports Medicine and Physical Fitness, 2006. **46**(4): p. 526.
48. Carvalho, F.L., et al., *Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance.* The Journal of Strength & Conditioning Research, 2012. **26**(9): p. 2447-2452.
49. Cramer, J.T., et al., *Acute effects of static stretching on peak torque in women.* The Journal of Strength & Conditioning Research, 2004. **18**(2): p. 236-241.
50. Winchester, J.B., A.G. Nelson, and J. Kokkonen, *A single 30-s stretch is sufficient to inhibit maximal voluntary strength.* Research quarterly for exercise and sport, 2009. **80**(2): p. 257-261.
51. Medicine, A.C.o.S. and J.K. Ehrman, *ACSM's resource manual for guidelines for exercise testing and prescription*. 2010: Wolters Kluwer Health/Lippincott Williams & Wilkins.
52. Pierce, J.D., et al., *Direct measurement of punch force during six professional boxing matches.* Journal of Quantitative Analysis in Sports, 2006. **2**(2).
53. Cramer, J.T., et al., *An acute bout of static stretching does not affect maximal eccentric isokinetic peak torque, the joint angle at peak torque, mean power, electromyography, or mechanomyography.* journal of orthopaedic & sports physical therapy, 2007. **37**(3): p. 130-139.

54. Waugh, C.M., et al., *Rapid force production in children and adults: mechanical and neural contributions.* Med Sci Sports Exerc, 2013. **45**(4): p. 762-71.
55. Endlich, P.W., et al., *Acute effects of static stretching in dynamic force performance in young men.* Revista Brasileira De Medicina Do Esporte, 2009. **15**(3): p. 200-203.
56. Franco, B.L., et al., *Acute effects of different stretching exercises on muscular endurance.* The Journal of Strength & Conditioning Research, 2008. **22**(6): p. 1832-1837.
57. Magnusson, S.P., P. Aagaard, and J.J. Nielson, *Passive energy return after repeated stretches of the hamstring muscle-tendon unit.* Medicine and science in sports and exercise, 2000. **32**(6): p. 1160-1164.
58. Bacurau, R.F.P., et al., *Acute effect of a ballistic and a static stretching exercise bout on flexibility and maximal strength.* The Journal of Strength & Conditioning Research, 2009. **23**(1): p. 304-308.
59. Madding, S.W., et al., *Effect of duration of passive stretch on hip abduction range of motion.* Journal of Orthopaedic & Sports Physical Therapy, 1987. **8**(8): p. 409-416.
60. Bandy, W.D. and J.M. Irion, *The effect of time on static stretch on the flexibility of the hamstring muscles.* Physical therapy, 1994. **74**(9): p. 845-850.
61. Ogura, Y., et al., *Duration of static stretching influences muscle force production in hamstring muscles.* The Journal of Strength & Conditioning Research, 2007. **21**(3): p. 788-792.
62. Young, W., G. Elias, and J. Power, *Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion.* Journal of Sports Medicine and Physical Fitness, 2006. **46**(3): p. 403.
63. Beedle, B., et al., *Pretesting static and dynamic stretching does not affect maximal strength.* The Journal of Strength & Conditioning Research, 2008. **22**(6): p. 1838-1843.
64. Zakas, A., et al., *Acute effects of static stretching duration on isokinetic peak torque production of soccer players.* Journal of Bodywork and Movement Therapies, 2006. **10**(2): p. 89-95.
65. Stafilidis, S. and M. Tilp, *Effects of short duration static stretching on jump performance, maximum voluntary contraction, and various mechanical and morphological parameters of the muscle–tendon unit of the lower extremities.* European journal of applied physiology, 2015. **115**(3): p. 607-617.
66. Mascarin, N.C., et al., *Stretch-induced reductions in throwing performance are attenuated by warm-up before exercise.* The Journal of Strength & Conditioning Research, 2015. **29**(5): p. 1393-1398.
67. Young, W., et al., *Acute effects of static stretching on hip flexor and quadriceps flexibility, range of motion and foot speed in kicking a football.* Journal of Science and Medicine in Sport, 2004. **7**(1): p. 23-31.
68. Williams, M., et al., *The Acute Effects of Upper Extremity Stretching on Throwing Velocity in Baseball Throwers.* Journal of sports medicine, 2013. **2013**.
69. Haag, S.J., et al., *Effects of acute static stretching of the throwing shoulder on pitching performance of national collegiate athletic association division III baseball players.* The Journal of Strength & Conditioning Research, 2010. **24**(2): p. 452-457.
70. Turner, A., E. Baker, and S. Miller, *Increasing the impact force of the rear hand punch.* Strength & Conditioning Journal, 2011. **33**(6): p. 2-9.
71. Dyson, R., et al. *Differences in lead and rear hand punching forces, delivered at maximal speed relative to maximal force, by amateur boxers*. in *ISBS-Conference Proceedings Archive*. 2008.

8.Appendix

Stretching Exercises

LEANING HEEL BACK CALF STRETCH

Technique

Stand upright and lean against a wall. Place one foot as far from the wall as is comfortable and make sure that both toes are facing forward and your heel is on the ground. Keep your back leg straight and lean towards the wall.

Muscles being stretched

Primary muscle: Gastrocnemius.

Secondary muscles: Tibialis

STANDING REACH DOWN HAMSTRING STRETCH

Technique

Stand with your feet shoulder-width apart. Bend forward and reach towards the ground.

Muscles being stretched

Primary muscles: Semimembranosus. Semitendinosus. Biceps femoris.

Secondary muscles: Gastrocnemius. Gluteus maximus. Iliocostalis lumborum. Spinalis thoracis. Interspinales. Multifidus.

STANDING QUAD STRETCH

Technique

Stand upright while balancing on one leg. Pull your other foot up behind your buttocks and keep your knees together while pushing your hips forward. Hold on to something for balance.

Muscles being stretched

Primary muscles: Rectus femoris. Vastus medialis, lateralis, and intermedius.

Secondary muscles: Iliacus. Psoas major.

PARALLEL ARM SHOULDER STRETCH

Technique

Stand upright and place one arm across your body. Keep your arm parallel to the ground and pull your elbow towards your opposite shoulder.

Muscles being stretched

Primary muscles: Trapezius. Rhomboids. Latissimus dorsi. Posterior deltoid.

Secondary muscles: Infraspinatus. Teres minor.

REACHING-UP SHOULDER STRETCH

Technique

Place one hand behind your back and then reach up between your shoulder-blades.

Muscles being stretched

Primary muscles: Supraspinatus. Infraspinatus.

Secondary muscles: Pectoralis major. Teres minor. Anterior deltoid. Coracobrachialis.

PARALLEL ARM CHEST STRETCH

Technique

Stand with your arm extended to the rear and parallel to the ground. Hold on to an immovable object and then turn your shoulders and body away from your outstretched arm.

Muscles being stretched

Primary muscles: Pectoralis major and minor. Anterior deltoid.

Secondary muscles: Biceps brachii. Brachialis. Brachioradialis. Coracobrachialis.

TRICEPS STRETCH

Technique

Stand with your hand behind your neck and your elbow pointing upwards. Then use your other hand to pull your elbow down.

Muscles being stretched

Primary muscle: Triceps brachii.

Secondary muscles: Latissimus dorsi. Teres major and minor.

FINGERS-DOWN FOREARM STRETCH

Technique

Hold onto your fingers and turn your palms outwards. Straighten your arm and then pull your fingers back using your other hand.

Muscles being stretched

Primary muscles: Brachialis. Brachioradialis. Pronator teres. Flexor carpi radialis. Flexor carpiulnaris. Palmaris longus.

Secondary muscles: Flexor digitorum superficialis. Flexor digitorum profundus. Flexor pollicislongus.

FINGERS-DOWN WRIST STRETCH

Technique

Hold on to your fingers while straightening your arm. Pull your fingers towards your body.

Muscles being stretched

Primary muscles: Extensor carpi ulnaris. Extensor carpi radialis longus and brevis. Extensor digitorum.

Secondary muscles: Extensor digiti minimi. Extensor indicis.

STANDING LEAN-BACK STOMACH STRETCH

Technique

Stand upright with your feet shoulder-width apart and place your hands on your buttocks for support. Look upwards and slowly lean backwards at the waist.

Muscles being stretched

Primary muscles: External and internal intercostals. External and internal obliques. Transversus abdominis. Rectus abdominis.

Secondary muscles: Psoas major and minor. Iliacus.

STANDING KNEE-TO-CHEST STRETCH

Technique

While standing, use your hands to bring one knee into your chest.

Muscles being stretched

Primary muscle: Gluteus maximus.

Secondary muscle: Iliocostalis lumborum.

STANDING LATERAL SIDE STRETCH

Technique

Stand with your feet about shoulder-width apart and look forward. Keep your body upright and slowly bend to the left or right. Reach down your leg with your hand and do not bend forward.

Muscles being stretched

Primary muscles: Quadratus lumborum. External and internal obliques.

Secondary muscles: Iliocostalis lumborum. Intertransversarii. Rotatores. Multifidus.