Original Article

Effects of proprioceptive neuromuscular facilitation (PNF) on swimmers leg mobility and performance.

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Abstract:

The warm up exercises comprise stretching. A stretching exercise is the proprioceptive neuromuscular facilitation (PNF). To examine the effect of PNF, 23 swimmers (11 boys and 12 girls), aged from 12 – 15 years participated in the training program that included this type of stretching. 11 swimmers (5 boys - 6 girls) performed for eight weeks, three times per week in addition to swimming training, six PNF exercises for the lower limbs with total duration 10 minutes (PNF) while the other 12 swimmers (6 boys - 6 girls) were the control group (C) following only the swimming workout. Leg's range of motion measured with electrical goniometer and performance evaluation test included 10 seconds, 2 and 10 minutes freestyle kick at maximum intensity with kickboard. The distance that were covered, the number of kicks and the blood lactate concentration, three minutes after the effort, were measured. The test protocol was carried out at the beginning, the 4th and the 8th week of investigation. The statistical analysis did not reveal a significant effect of PNF at leg mobility. The performance improved the same in both of groups (PNF, C). In conclusion, the use of distending stretching (PNF) did not affect positive or negative at the parameters that we study.

Key words: contract, relax, athletes, swimming.

Introduction

In swimming there are different warm up combined protocols in and out of water. The most of these combinations includes stretching exercises and swimming in different volumes and intensities. About the volumes and intensities of a warm up protocol found that a moderate level of these two parameters gives better results than a low or high volume and intensity level in swimming performance (Neiva et al., 2014a) and in 100m maximal freestyle effort (Neiva et al., 2014b). On the other hand a few studies show the effects of a warm up combination in and out of water. These combinations related especially the kick performance, with positive effects after the use of a warm up protocol with stretching and swimming content (Mookerjee et al., 1995 ; Olbrecht et al., 1985) . While a unique study Papadimitriou et al., 2015) found that only static stretching, without any warm up in water, can't improve 50m in maximal effort freestyle swimming performance. So an interesting part for study is the effectiveness or not of stretching exercises in acute effect as a warm up protocol or as a way to improve joints flexibility and swimming performance after chronic use.

Generally, a preheating method in sports is the area of stretching exercises. Most used stretching exercises have the dynamic type that includes swings and generally explosive and quick movements. Another type of stretching is the static. Static stretching includes active, passive, proprioceptive neuromuscular facilitation (PNF) and other more (Grosser et al., 2007). It is worth noting that the type of PNF stretching is used for joint and muscle stabilization and strengthening (Minshall et al., 2014). It is also a common technique in the field of physical therapy, is used to improve the articular mobility (Anastasiadis, & Gidaris, 1993). It consists of three phases starting with isometric pressure at 20% of maximum voluntary strength (Rubini et al., 2013), for 7 - 10 seconds with a maximum duration of 30 seconds, and then practitioner relaxes the joint which accepted the pressure and the final phase which is the stretching of muscle with pressure from fellow practitioners, for 10-30 seconds (Grosser et al., 2007).

The PNF technique is used both in sports and clinical environment with a number of positive effects on the increase of joint range of motion (Kay et al., 2015 ; Konrad et al., 2015 ; Mitchell et al., 2009), PNF is one of the most effective stretching techniques (Grosser et al., 2007). Repeatability once or twice a week is sufficient to achieve adaptations. Although, the most of the studies about PNF technique are considered the most effective compared with the other stretching techniques, there are few investigations do not confirm this effectiveness (Place et al., 2013). Also, the mechanisms operating in the PNF method are not clear yet (Sharman et al., 2006). Research to identify the mechanisms of PNF found to be due to inactivation of presynaptic neuronal muscle

command rather than Golgi apparatus, observing a relaxation of the muscle after the isometric contraction (Chalmers, 2004). It is clear that further research need to clarify these mechanisms Hindle et al., 2012).

Few studies mention about the effects of PNF on athlete's leg mobility and performance. In football, the PNF effects examined from the ankle and hip range of motion and from the execution of speed shots in 24 amateur teenage footballers (Akbulut and Agopyan, 2015). From the results showed that only the group which conducted the type PNF stretching exercises improved the range of motion on joints of the lower limbs and the execution of speed shots.

In the sport of gymnastics in 18 athletes sample were compared static and PNF stretching method, on vibration platform to determine if mobility of the lower limbs and the force by jumping from semi seat and swing improved. The results showed significant process using PNF. The improvement was almost 6,8 % and PNF was the best stretching method (Dallas et al., 2014).

In other study, a comparison carried between static stretching and PNF on 18 rugby players in hip mobility, stride length, stride frequency and contact time of the tread to the ground when running at 80% of maximum speed intensity. All of the parameters improved after the use of PNF by 7, 6%, 1,6%, 9,1% and 4,3% respectively. The protocol lasted for five weeks and had a frequency four times per week (Caplan et al., 2009).

On the other hand, in research with indoor soccer players the acute effects of PNF exercises compared to those of static stretching. The parameters that examined by electromyography immediately after using the three protocols with PNF stretching, static stretching and no stretching was the volitional muscle contraction of the vastus lateralis and rectus femoris after isometric contraction of the dominant leg. Also checked and muscle activation of these muscles. The results showed that short-term use of both exercises did not effect on the parameters examined (Reis et al., 2013]

Similar results showed on ballet athletes considering and this time the acute effects of static and dynamic stretching. Specifically after four different protocols for each group where included 30 seconds exercises with the same time break, the scholars showed that both methods improved the mobility of the lower limbs and particularly of the hip. However, no superiority was showed in PNF comparing to static stretching (Rubini et al., 2011)

In a pilot study with 12 college level female footballers were compared static stretching, PNF and no warm up on three different days to rest between each protocol. The factor which examined was agility (T-test). The results showed that and in this case no stretching method or protocol form this experiment improved the footballer's mobility (Wallmann et al., 2008).

Finally in swimming, only a study found which compared the use of static stretching and PNF. From the results, static stretching and PNF exercises did not contributed in swimmers performance at 50m freestyle in maximum effort (Costa et al., 2014).

It's concluded that an activity which showed reduced exploratory approach to this category of static stretching was swimming. Thus, because of the lack of bibliographical reference aim of the research was to study the effects of PNF in mobility and performance of the lower limbs at 12 – 15 year old swimmers.

Material and Methods

Participants

Twenty three high level swimmers with frequent presence at practice, aged 13 ± 2 years, healthy with no history of musculoskeletal or neurological diseases, with 6 ± 2 year training experience and 50m freestyle as their main event, participated in this study. The participants divided into two equal groups in order of their legs mobility and kick performance. The first group included 6 boys and 6 girls as control group (C) and does not record any stretching protocol just their swimming training. The second one included 5 boys and 6 girls that called stretching group (S) were making six PNF stretching exercises, on leg, before their swimming training in the water. All of the athlete's parents were informed of the nature purpose and possible injury risks involved in the study before giving their informed consent for participation. All tests were conducted according to the ethical guidelines of the Research committee of Aristotle University of Thessaloniki.

Procedures

The protocol duration was 8 weeks and had repeatability about 3 times each week with one day empty between. The 6 PNF exercises performed from stretching group (S) without some help from fellow practitioners (Wicke et al., 2004) and the total duration was about 10 minutes and all exercises were performed once. Each exercise lasted one minute, 10 seconds was the isometric contraction, 5 seconds relaxation of the joint that was receiving the contraction and 30 seconds static stretching of the same joint, until the point that the swimmers did not feel pain. Also, the total time duration of each exercise included the transfer time to the next exercise. On the other hand control group (C) did not perform these exercises. The PNF exercises performed without any special warm up before and used only the working muscles in freestyle kick like great gluteal, biceps femoris, semitendinosus, imiymenodis gluteus medius, biceps femoris, semitendinosus, imitenododis, igniakos, sewing, gastrocnemius soleus long plantaris, finger flexor and tibialis posterior [Olbrecht et al., 1985].

Measures

Test protocols took place at the beginning, the 4th and the 8th week of the experiment. The test protocol for mobility, and for kick performance, performed in three different consequents days between each test. At the first day, hip and ankle flexion and extension at supine and prone position, without help from partner, were measured by electronic goniometer. The measurements were performed in room with the temperature of 22 - 24 °C. To determine the freestyle kick performance, 10 seconds used for speed and 2 and 10 minutes for endurance. So, the second and third day, 10 seconds and 2 minutes freestyle kick and 10 minutes freestyle kick were performed respectively, with kickboard at maximum effort. For time counting we used Finis stop watch 3X-100M. From this test calculated the distance that swimmers covered. Moreover, the number of kick (NK) recorded by digital camera and calculated for the second 5m from the beginning in the 10 s trial and the fourth 5m for the other trials. For the determination of the athletes try after the kick tests we examine the lactate levels in a random period. So, based in bibliography (Kohji et al., 1992), lactate levels (LA) were determined 3 minutes after the end of kick protocols from the rail of the fingers. During the afore-mentioned training period, all groups followed the same swimming training regimen which involved 800 m kicking every day. Test schedule for mobility tests (MT) and freestyle kick (FK) showing in table 1.

Table 1. Test schedule for mobility tests (MT) and freestyle kick (FK).

Statistical Analysis

Data presented as mean $\pm$ standard deviation. The distribution of all parameters tested with Shapiro-Wilk test and found to be not significantly different from normal. To compare the parameters related to the mobility and performance in the legs among the two groups, (PNF) and (C), in the two protocols, used analysis of variance (Three Way ANOVA) on group, sex and time with repeated measures on time. Because of no significant main effects of sex and group were found, data of both sexes and groups were pooled to increase the power of analysis and one-way ANOVA was performed instead with repeated measures on time. The analysis was done with the statistical packet SPSS 22 (SPSS, Chicago, IL). The level of statistical significance was set at $p < 0.05$.

Results

The results in leg mobility, distance that covered, number of kick and blood lactate presented in the text as mean and standard deviation for all participants because of no statistical significantly differences between groups although the parameters presented at the tables 2, 3, 4, 5 and 6 as mean and standard deviation for each group separately.

Table 2 shows the results from hip curl and extension. High development showed in both of groups together only in left hip's curl, from the second to third measurement (100.1 ± 11 cm to 104.6 ± 11 cm, $p < 0.05$). Significant improvement was seen in the hip's extension, for both of legs, through the time (44.7 ± 12 to 48.2 ± 12 and 57.9 ± 9 cm for the left leg and 44.9 ± 11 to 47.7 ± 10 and 55.4 ± 11 cm for the right leg, $p < 0.05$).

Table 2. Hip curl and extension.

	Left hip curl (cm)			Right hip curl (cm)			Left hip extent (cm)			Right hip extent (cm)		
	0	4	8	0	4	8	0	4	8	0	4	8
PNF	100,3 ± 12	103,4 ± 12	103,1 ± 9	100,7 ± 11	102,4 ± 12	103,2 ± 9	48,5 ± 12	55,2 ± 9	57,1 ± 8	44,5 ± 14	52,5 ± 7	56,1 ± 13
C	99,3 ± 9	98,0 ± 9	105,9 ± 12	102,5 ± 12	99,3 ± 9	98,0 ± 9	41,1 ± 11	41,8 ± 11	58,7 ± 10	45,3 ± 8	42,7 ± 11	54,8 ± 9

Table 3 shows the results from plantar flexion and dorsiflexion. Significant improvement was seen for the plantar flexion, in both legs, through the time (58.9 ± 8 to 60.6 ± 11 and 75.3 ± 7 cm for the left and 60.0 ± 8 to 61.0 ± 14 and 75.7 ± 7 cm for the right leg, $p < 0.05$).

Table 3. Plantar flexion and dorsiflexion.

	Left plantar flexion (cm)			Right plantar flexion (cm)			Left plantar dorsi (cm)			Right plantar dorsi (cm)		
	0	4	8	0	4	8	0	4	8	0	4	8
Weeks												
PNF	61,8 ± 8	60,6 ± 10	76,7 ± 8	63,7 ± 7	63,1 ± 10	78,2 ± 6	11,5 ± 5	11,6 ± 5	11,9 ± 5	12,4 ± 5	11,7 ± 3	11,7 ± 5
C	56,2 ± 8	60,5 ± 13	74,0 ± 7	56,7 ± 7	59,0 ± 17	73,4 ± 8	11,4 ± 6	10,3 ± 5	11,8 ± 6	11,3 ± 4	10,6 ± 4	12,3 ± 4

Table 4 shows the results of distance covered, the number of kicks and lactate levels in ten minutes kick performance. The results showed significant increase in distance that covered between first to third trial (439 ± 66 to 447 ± 66 m, $p < 0.05$) and decrease on number of kicks between first to third and second to third trial (32 ± 4 to 27 ± 5 and 32 ± 6 to 27 ± 5 n, $p < 0.05$).

Table 4. Parameters in 10 min kicks trial.

	Distance (m)			NK (n)			LA (mmol/L)		
	0	4	8	0	4	8	0	4	8
Weeks									
PNF	450 ± 48	457 ± 55	462 ± 49	31 ± 3	31 ± 7	28 ± 6	6,7 ± 3	6,2 ± 3	5,2 ± 3
C	428 ± 80	433 ± 78	434 ± 79	34 ± 3	32 ± 6	27 ± 4	6,7 ± 3	6,1 ± 2	5,6 ± 2

Table 5 shows the results of distance covered, the number of kicks and lactate levels in ten seconds kick trial. The results showed significant fluctuation in the number of kicks between all trials (33 ± 5 to 26 ± 2 and 29 ± 3 n, $p < 0.05$). Moreover, significant variation showed in blood lactate levels between first to second and second to third trial (3.0 ± 1.1 to 4.6 ± 1.9 mmol/L and 4.6 ± 1.9 mmol/L to 3.1 ± 0.9 mmol/L, $p < 0.05$).

Table 5. Parameters in 10 seconds kick trial.

	Distance (m)			NK (n)			LA (mmol/L)		
	0	4	8	0	4	8	0	4	8
Weeks									
PNF	13 ± 1	13 ± 1	13 ± 2	34 ± 5	26 ± 1	29 ± 2	2,7 ± 1,2	4,3 ± 1,7	3,1 ± 1,0
C	12 ± 2	13 ± 2	13 ± 2	31 ± 2	25 ± 4	29 ± 2	3,2 ± 3,1	4,8 ± 2,0	3,1 ± 0,9

Table 6 shows the results of distance covered, the number of kicks and blood lactate levels in two minutes kick trial. The results showed significant increase from first to second and third measurement in distance that covered (96 ± 15 to 98 ± 15 and 99 ± 15 m respectively, $p < 0.05$). Significant decrease showed from first and second to third measurements (6.6 ± 2.4 and 7.4 ± 2.7 to 4.9 ± 2.5 mmol/ respectively, $p < 0.05$).

Table 6. Parameters in 2 min kick trial.

	Distance (m)			NK (n)			LA (mmol/L)		
	0	4	8	0	4	8	0	4	8
Weeks									
PNF	100 ± 12	102 ± 12	103 ± 11	33 ± 4	32 ± 4	32 ± 4	7,2 ± 2,7	8,0 ± 2,8	4,7 ± 2,6
C	91 ± 18	92 ± 17	93 ± 17	33 ± 6	36 ± 5	33 ± 5	6,1 ± 2,1	6,8 ± 2,7	5,0 ± 2,5

Discussion

The aim of the investigation was to study the effects of proprioceptive neuromuscular facilitation in mobility and performance of the lower limbs through mobility, speed and endurance tests in swimming kick. The results showed that PNF group mobility was not improved more than control group.

On mobility parameter it is known that girls have better mobility than boys so an increasing of angle in torso may improve their performance (Sifaki et al., 2014). Several studies presented both in rehabilitation and the sports. The focus of our research conducted at the sports and specifically at the effect of PNF in mobility of the lower limbs. Specifically in other investigating (Akbulut and Agopyan, 2015) examined the effect of PNF exercises in the range of the ankle and hip over eight weeks in 24 amateur level players. The results showed that improved mobility after PNF. That result is in common with our study because we found improvement in mobility. The methodology and the sample number were similar in both surveys. Possible explanations of these results converge in specific requirements in mobility at the sports of football and swimming. Mobility is essential in both sports, but swimming proposed stretching protocols frequently unlike the sport of football.

Furthermore, similar findings with our study found and in other investigation which showed positive results after the use of stretching exercises PNF after five weeks in legs mobility in rugby athletes. So, any attempt to improve mobility is suitable in sports that presented greater burdens of musculature complex (Caplan et al., 2009).

On the other hand there are not studies for the long term effects of PNF only. There are a few for short term effects. Specifically, investigation in indoor soccer players found no improvement of the mobility of the lower limbs. But an examination of the effect of PNF concerned the acute effect and not the long term effect (Reis et al., 2013).

However, different feature of our study with other (Reis et al., 2013), focuses on the fact that there is any improvement in mobility. So may PNF stretching exercises do not affect in a short term use period. Another investigation (Rubini et al., 2011), studied the acute effects of PNF exercises in ballet athletes. According to the results did not reveal any improvement in mobility of the lower limbs. The results are opposite with our study, although the period of use of stretching exercises were different. So we found that acute use of PNF does not affect the mobility of the lower limbs. That conclusion may be justified by a lack of stimulus for mobility improves.

In contrast, another study of Dallas et al. (2014), examined the acute effects of PNF exercises in gymnastic athletes. From the results found mobility improve in the lower limbs. Finding is contrary to the studies analyzed and related to the acute effect of PNF. The explanation for this result might be the case that the gymnastic athletes have a high level of mobility but on the other hand perform a sport with big charges in musculature system so caused direct truncations. So, the participation of athletes in stretching gives positive results since the athlete's level of mobility after a workout may be declining.

Finally, a key detail in the methodology of our research was the use of PNF by their selves. The same methodology followed from other researches (Wicke et al., 2009). The effects of ankle mobility were positive like our study. Moreover, in that investigation the sample's age was between 15 to 19 years, in contrast with our study sample which were 12 – 15 year old. Therefore, a possibility that may have influenced the results is that both of these ages can use by self these exercises.

From the result of our study showing that the mobility of the lower limbs has improved trend which is not statistically significant. There are studies with this result where there was no improvement in mobility of the lower limbs (Rubini et al., 2011 ; Reis et al., 2013). Of course, in the studies that the researchers agree with our results it is worth noting that the methodology concerning the acute effect, while our study is about long term effects of PNF.

About the performance regarding the stamina, with 2 and 10 minutes trials, our study is unique. So, according to the results, the factor of stamina found to be affected positively after the combination of swimming training and PNF. In general this result cannot be crossed with another study with PNF stretching exercises because of the lack of references. A possible explanation is that the training in or out of water improves the athlete's performance through changes in physiological parameters like blood lactate. In our study we found that the blood lactate levels decreased at the 2 and 10 minutes of kick trials indicating aerobic improvement. These results are common with few studies (Aubry et al., 2015).

Conclusions

Based on the statistical analysis, there wasn't any significant difference between control and PNF stretching groups. Moreover, no statistical differences found and in sex parameter. On the other hand found significant statistical differences in leg mobility, kick distance, number of kick and lactate levels between the tree measurements in an eight week period. So the results of this study showed that swimming training for eight weeks seems to help 12 - 15 year old swimmers to improve their ankle mobility and performance. Moreover the PNF stretching method with repeatability three times per week, ten minutes duration and use without help found that did not effect on parameters that studied. So the use or not of this method before swimming trainings lies in the habits of swimmers as well as in the training content that the coaches make.

References

- Akbulut T. and Agopyan A. Effects of an eight-week proprioceptive neuromuscular facilitation stretching program on kicking speed and range of motion in young male soccer players. *Journal of Strength and Conditioning Research*, 2015; 29(12):3412-23.
- Anastasiadis, A. & Gidaris, D. *The gymnastic in physical education*. Thessaloniki: Maiandros.1993
- Aubry A, Hausswirth C, Louis, J, Coutts AJ, Buchhei M, Le Meur Y. The Development of Functional Overreaching Is Associated with a Faster Heart Rate Recovery in Endurance Athletes, 2015; 21;10(10).
- Beltrão NB, Ritti-Dias RM, Pitangui AC, De Araújo RC. Correlation between acute and short-term changes in flexibility using two stretching techniques. *International Journal of Sports Medicine*, 2014; 35(14), 1151-4.
- Caplan N, Rogers R, Parr MK, Hayes PR. The effect of proprioceptive neuromuscular facilitation and static stretch training on running mechanics. *Journal of Strength and Conditioning Research*, 2009; 23(4), 1175-80.

- Chalmers G. Re-examination of the possible role of Golgi tendon organ and muscle spindle reflexes in proprioceptive neuromuscular facilitation muscle stretching. *Sports Biomechanics*, 2004; 3(1),159-83.
- Costa ESG, Silveira A, Novaes J, Di Masi F, Conceição M, Dantas E. Acute effects of static and proprioceptive neuromuscular facilitation stretching on sprint performance in male swimmers. *Medicine Sport*, 2014; 67:119-28.
- Dallas G, Smirniotou A, Tsiganos Tsopani D, Di Cagno, A, Tsolakis CG. Acute effect of different stretching methods on flexibility and jumping performance in competitive artistic gymnasts. *The Journal of Sports Medicine and Physical Fitness*, 2014; 54(6), 683-90.
- Grosser M, Starischka S, Zimmermann E. *Physics state training*. (Translate, Kellis). Thessaloniki: Salto. 2007.
- Hindle KB, Whitcomb TJ, Briggs WO, Hong J. Proprioceptive Neuromuscular Facilitation (PNF): Its Mechanisms and Effects on Range of Motion and Muscular Function. *Journal of Human Kinetics*, 2012; 31,105-13.
- Kay A.D, Husbands-Beasley J, Blazeovich AJ. Effects of PNF, Static Stretch, and Isometric Contractions on Muscle-Tendon Mechanics. *Medicine & Science in Sports & Exercise*, 2015; 47(10):2181-90.
- Kohji W, Komei I, Takayoshi Y, Masao U, Toshio M, Yoshiteru M, Mitsumasa M. Determination and validity of critical velocity as an index of swimming performance in the competitive swimmer. *European Journal of Applied Physiology and Occupational Physiology*, 1992; 64 (2).
- Konrad A, Gad M, Tilp M. Effect of PNF stretching training on the properties of human muscle and tendon structures. *Scandinavian Journal of Medicine & Science in Sports*, 2015; 25(3), 346-55.
- Minshull C, Eston R, Bailey A, Rees D, Gleeson N. The differential effects of PNF versus passive stretch conditioning on neuromuscular performance. *European Journal of Sport Science*, 2014; 14(3), 233-41.
- Mitchell UH, Myrer JW, Hopkins JT, Hunter I, Feland JB, Hilton SC. Neurophysiological reflex mechanisms' lack of contribution to the success of PNF stretches. *Journal of sport rehabilitation*, 2009; 18(3), 343-57.
- Mookerjee S, Bibi KW, Kenney G A, Cohen L. Relationship between isokinetic strength, flexibility, and flutter kicking speed in female collegiate swimmers. *Journal of Strength and Conditioning Research*, 1995; 9, 71-74.
- Neiva HP, Marques MC, Barbosa T M, Izquierdo M, Marinho DA. Warm-up and performance in competitive swimming. *Sports Medicine*, 2014; 44, 319-330.
- Neiva HP, Marques MC, Fernandes RJ, Viana JL, Barbosa TM, Marinho DA. Does warm-up have a beneficial effect on 100-m freestyle. *International journal of sports physiology and performance*, 2014; 9, 145-150.
- Nikolopoulos GA. *Swimming*. Athens: Artwork Public. 2006.
- Olbrecht J, Madsen O, Mader A, Liesen H, Hollmann W. Relationship between swimming velocity and lactic concentration during continuous and intermittent training exercises. *International Journal of Sports Medicine*, 1985; 6(2):74-7.
- Papadimitriou K, Tsalis G, Loupos D. The Acute Effects of Active or Passive Stretching Exercises in Swimming as a Unique Way of Warm Up Before 50m High Intensity. *Inquiries in Sport & Physical Education*, 2015; 13 (2), 1 – 10
- Place N, Blum Y, Armand S, Maffiuletti NA, Behm DG. Effects of a short proprioceptive neuromuscular facilitation stretching bout on quadriceps neuromuscular function, flexibility, and vertical jump performance. *Journal of Strength and Conditioning Research*, 2013; 27(2), 463-70.
- Reis E F, Pereira GB, de Sousa NM, Tibana RA, Silva MF, Araujo M, Gomes I, Prestes J. Acute effects of proprioceptive neuromuscular facilitation and static stretching on maximal voluntary contraction and muscle electromyographical activity in indoor soccer players. *Clinical Physiology and Functional Imaging*, 2013; 33(6), 418-22.
- Rubini EC, Souza AC, Mello ML, Bacurau RF, Cabral LF, Farinatti PT. Immediate effect of static and proprioceptive neuromuscular facilitation stretching on hip adductor flexibility in female ballet dancers. *Journal of Dance Medicine & Science*, 2011; 15(4), 177-81
- Sharman MJ, Cresswell AG, Riek S. Proprioceptive neuromuscular facilitation stretching : mechanisms and clinical implications. *Sports Medicine*, 2006; 36(11): 929-39.
- Sifaki O, Zafiriadis S, Tsalis G, Loupos D. Relationship of Physical and Kinetic Characteristics of the Ankle Joint and the Performance of Freestyle Kick in Pre-pubertal Swimmers and Water Polo Players. *Inquiries in Sport & Physical Education*, 2014; 12 (1), 9 – 16.
- Tsalis G, Koutlianos A, Koutlianos N, Loupos D, Alexiou S. Effects of stretching exercises on the ankle joint and on 50m freestyle kicking performance in adolescent swimmers. *Journal of Human Movement Studies*, 2004; 46, 373-383.
- Wallmann HW, Gillis CB, Martinez NJ. The effects of different stretching techniques of the quadriceps muscles on agility performance in female collegiate soccer athletes: a pilot study. *Journal of Orthopaedic & Sports Physical Therapy*, 2008; 3(1), 41-7.
- Wicke J, Gainey K, Figueroa M. A comparison of self-administered proprioceptive neuromuscular facilitation to static stretching on range of motion and flexibility. *Journal of Strength and Conditioning Research*, 2004; 28(1), 168-72.