©Journal of Sports Science and Medicine (2014) 13, 403-409
http://www.jssm.org

Research article

Acute Effects of Static and Dynamic Stretching on Balance, Agility, Reaction Time and Movement Time

Dimitris Chatzopoulos [1]✉, Christos Galazoulas [1], Dimitrios Patikas [2] and Christos Kotzamanidis [1]
[1] Department of Physical Education and Sport Sciences, [2] Department of Physical Education and Sport Sciences at Serres, Aristotle University of Thessaloniki, Greece

Abstract
The purpose of this study was to compare the acute effects of three different stretching protocols on balance, agility, reaction time and movement time of the upper limbs. Participants were thirty one female high school athletes (age = 17.3 ± 0.5 yr.). All participants performed one of the following protocols on different days: (a) 3 min jogging followed by 7 min static stretching (SS), (b) 3 min jogging followed by 7 min dynamic stretching (DS), and (c) 3 min jogging followed by 7 min of rest (NS). After the protocols participants performed the following tests: dynamic balance, 505 agility test, reaction time (time between a sound stimulus and release of a button) and movement time (movement of the upper extremity over a 0.5 m distance). The order of stretching protocols and performance tests were counterbalanced to avoid carryover effects. Repeated measures analysis of variance revealed significant main effects for all variables except reaction time. The DS protocol compared to SS performed significantly better in balance, agility and movement time. Additionally, the DS protocol compared to NS performed significantly better in agility. According to the results of the study, a DS protocol is more appropriate than SS for activities that require balance, rapid change of running direction (agility) and movement time of the upper extremities.

Key words: Warm-up exercise, muscle stretching exercises, sports performance, adolescents.

Introduction

High school athletes often begin their exercise with a warm-up protocol, which typically consists of jogging one or two laps around the gym followed by a series of static stretches (Walter et al., 2011). It is widely believed that pre-exercise static stretching (SS) reduces the risk of injury and enhances performance (Woods et al., 2007). However, recent studies reported that pre-exercise SS decreases maximal force production (Leone et al., 2012), jump height (Perrier et al., 2011) and speed (Little and Williams, 2006).

The negative effects of SS are attributed to mechanical factors (e.g. changes in muscle stiffness) and neuromuscular factors such as decreased motor unit activation and altered reflex sensitivity (Avela et al., 2004; Cramer et al., 2005). However, the literature is not unanimous in reporting stretch-induced performance impairments. Recently, a number of studies suggest that SS has no significant effect (Dalrymple et al., 2010; Handrakis et al., 2010) or can improve performance (Costa et al., 2009). The divergent findings are attributed to various factors such as subject's training status (Costa et al., 2009), age (Handrakis et al., 2010), gender, the stretch duration and intensity of the protocol (Behm and Chaouachi, 2011).

The controversy regarding the potential performance impairments of SS, raised the interest for dynamic stretching (DS). DS involves controlled movement through the active range of motion (ROM) for a joint, and incorporates callisthenics movements (e.g. lunging) and running drills that include forward, lateral, and change-of-direction movements (Behm and Chaouachi, 2011). Studies regarding DS reported positive effects on power (Manoel et al., 2008), sprint (Fletcher and Anness, 2007), and jump performance (Perrier et al., 2011). However, these studies have mainly examined the effects of stretching on maximal strength and power performance (squats, bench press, speed, jump etc.). To the authors' knowledge, there is no research investigating the acute effects of DS on balance. Maintaining balance requires fast and accurate movements of upper and lower extremities (arm-leg coordination). Stretch-induced changes to muscle-tendon unit (MTU) length and stiffness would be expected to affect the ability to react effectively to stability challenges (Behm et al., 2004).

Currently, limited studies have investigated only the acute effect of SS on balance (Costa et al., 2009). Behm et al. (2004) and Nagano et al. (2006) reported that balance control was impaired after SS. On the contrary, Costa et al. (2009) reported that SS produced a significant improvement in balance compared to the NS condition. The few studies regarding the effect of SS on balance and the absence of studies evaluating the effect of DS on balance was one of the reasons for conducting this study.

Apart from balance, a more compliant MTU due to SS could alter reaction time (RT) and movement time (MT) (Behm et al., 2004). However, only a limited number of studies have investigated this issue. Specifically, Behm et al. (2004) reported impairment in RT and MT after SS, whereas Alpkaya and Koceja (2007) and Perrier et al. (2011) showed no significant effect of SS on RT. The controversial findings and the limited number of studies indicate the importance of additional research on the effects of stretching on RT and MT. Furthermore, the above mentioned studies have examined the effects of stretching on RT of the lower limbs. To the authors' knowledge, no study has compared the effects of DS and SS on RT and MT of the upper limbs. In many sports upper limb RT and MT play an important role for a successful outcome (e.g. basketball, volleyball etc.).

Received: 13 January 2014 / Accepted: 31 January 2014 / Published (online): 01 May 2014

Moreover, RT, MT and agility are often practiced in the same physical education lesson or training unit (Darst and Pangrazi, 2009). Van Gelder and Bartz (2011) reported that a DS protocol for the lower limbs compared to SS improves significantly agility performance. Similar results reported Little and Williams (2006) and McMillian et al. (2006). Conversely, Chaouachi et al. (2010) reported no significant differences between DS and SS regarding agility performance. Generally, agility is defined as a rapid whole-body movement with change of running direction in response to a stimulus (Van Gelder and Bartz, 2011). The movements of the upper and lower limbs are crucial in order for someone to change the running direction rapidly without the loss of balance (Allum et al., 2002). However, none of the conducted studies included a stretching protocol for upper and lower limbs. Furthermore, a stretching protocol of a regular physical education lesson or training unit comprises exercises for the whole-body and not just for the lower-body musculature (National Association for Sport and Physical Education, 2011).

In addition, the literature has focused mainly on the effects of stretching on male subjects (Behm et al., 2011; Handrakis et al., 2010). Only Costa et al. (2009) investigated the effect of SS on balance in adult women. However, the effects of stretching on adolescent females' balance, RT and MT have not been examined. Therefore, the purpose of the present study was to compare the acute effects of a whole-body SS and DS protocol on balance, agility, RT and MT of the upper limbs in adolescent female athletes. Since SS results in a longer and more compliant MTU (Cramer et al., 2005), it was hypothesized that SS would deteriorate balance, agility, RT and MT. In contrast, DS enhances motor unit excitability and kinaesthetic awareness (Jaggers et al., 2008) and therefore it was hypothesized that DS would improve the above mentioned parameters.

Methods

Participants

Thirty one female high school athletes volunteered to take part in the study (age = 17.3 ± 0.5 yr, body mass = 55.9 ± 5.4 kg, height = 1.66 ± 0.05 m). The students participated in state-mandated physical education program (twice per week for 45 min) and in after-school sport activities, at least 3 times per week (minimum of 1 hour). Eleven participants were basketball players, 8 volleyball, 8 handball and 4 track and field athletes (sprint and long jump). No athlete withdrew because of injury or any other adverse experiences. The procedures used in this study were conducted in accordance to the ethical guidelines of the Aristotle University of Thessaloniki, Greece and informed consent was obtained from both the students and their parents.

Experimental set-up

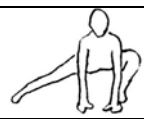
Prior to data collection, the participants attended 3 physical education lessons, in which they were familiarized with the stretching procedures. During these orientation sessions they also practiced the tests for balance, agility, RT and MT. All study procedures took place in the gymnasium between 10:00-14:00 hours. After the familiarization period, the participants performed the following protocols counterbalanced, in three different days: (a) 3 min jogging followed by 7 min SS, (b) 3 min jogging followed by 7 min DS, and (c) 3 min jogging without stretching, followed by 7 min of rest (NS). The 3 protocols were administered 2 to 4 days apart. After completing one of the stretching protocols, participants proceeded to the performance testing stations. Similar experimental set-up has been used by Faigenbaum et al. (2006b) and Perrier et al. (2011).

Stretching protocols

All protocols started with 3 min jogging at a self-selected moderate intensity, with comfortable pace (distance: 400 m approximately). Jogging intensity was monitored and adjusted for each participant by a physical education teacher using the talk-test, which determines the exercise intensity based on the ability of a person to carry on a conversation during exercise (Foster et al., 2008). According to the talk-test, if a participant can talk during the exercise, then the intensity of the exercise is moderate (Foster et al., 2008). When a participant can no longer speak comfortably, then the intensity of an activity is vigorous. After 3 min jogging participants performed for 7 min SS or DS session, whereas the ones belonging to the NS sat quietly for 7 min.

SS protocol: The participants performed a stretching routine used commonly by physical education teachers (Faigenbaum et al., 2006b). Each stretch was held for 30 sec at a point of mild discomfort and all stretches were performed for both sides (Table 1).

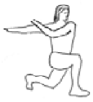
Table 1. SS protocol

Front deltoid and pectoral stretch. From a standing position subjects positioned the arm horizontally abducted with the palm flat against a wall. To begin the stretch, they turned their body away from the arm on the wall, and kept a slight bend in their elbow throughout the stretch.	
Side deltoid stretch. From a standing position subjects held the left arm horizontally across the chest, grasped the elbow with the right hand and pushed it toward chest.	
Triceps and side-bend stretch. From a standing position, subjects brought the right arm overhead with the elbow bent. Then with their left hand they grasped the right elbow and gently pulled as they bent slightly toward the left side.	
Adductor stretch. Subjects stood with their feet as wide apart as is comfortable. Relying with their hands on the floor they flexed the left knee keeping the right leg straight.	
Modified hurdlers stretch. From a seated position subjects extended their left leg straight and placed the right leg on the inside of the straight leg. Then they bent forward with the back flat.	

Quadriceps wall stretch. From a standing position near a wall for support, subjects bent one knee and brought heel towards buttocks, holding the foot with one hand.	
Calf stretch. From a standing position facing a wall, subjects placed their hands on the wall at chest level. They put the left foot slightly behind them, keeping heel on the floor. Then they leaned forward bending slightly the right knee and keeping the left leg straight with the heel on the floor.	

DS protocol: The DS protocol included exercises that stretch the same muscle groups as in the SS protocol and was based on the protocol used by Faigenbaum et al. (2006b) (Table 2). The exercises were performed from the one side-line to the opposite side-line and back of a volleyball court (total distance of 18 m), with 10 sec intervals in between.

Table 2. DS protocol

Side/front arm crossover. Subjects swung both arms out to their sides and then crossed them in front of their chest, while moving forward.	
Walking lunge with rotation. Subjects took a big step forward and at the same time rotated their arms horizontally.	
Triceps and side-bend stretch. Subjects brought the right arm overhead with the elbow bent and bent slightly toward the left side.	
Lateral shuffle. Subjects moved laterally without crossing feet.	
Frankenstein walks. Subjects are walking with both hands extended in front of the body, palms down. They kick with the extended leg towards hands.	
Heel-ups. Subjects kicked heels towards buttocks while moving forward.	
Inch worms (hand walk). Starting position push-ups. Keeping legs extended they walk towards hands, and then they walk hands forward while keeping limbs extended (6 repetitions).	
Modified shuttle run. Subjects run to the opposite line at a moderate pace (50% maximum speed), bend to touch the line, and return back gradually accelerating (75%) and touch the starting line. After touching the starting line, they run to the opposite line accelerating to near maximum speed (90%), touch the line and return back to the starting line walking.	

Performance testing

Balance was assessed on a stability platform (Lafayette Instrument, 1620), which consists of a swinging platform (65X105 cm) on the medial axis (Figure 1). When the platform deviated more than 10 degrees from the horizontal plane, it was considered as loss of balance. The time started counting as soon the subject was able to stay within the 10 degree boundary. The outcome variable was the total time that the subject could remain within 30 sec. Subjects completed one practice attempt and two trials on the day of testing with a 1 min break between trials (Cronbach's Alpha ICC a = 0.88).

Figure 1. Balance test.

RT and MT were measured using a reaction timer apparatus (Lafayette Instruments Co., model 63017). The apparatus comprises of a control device and two switches (start and stop button, placed 50 cm sidewise). The participant was pressing the start button with her dominant index finger from a standing position. A standby visual signal (LED lighting) was shown, and after an auditory stimulus at a random period of 2–4 sec the participant released the start button and moved her finger to touch the stop button. The time between the sound stimulus and release of the start button defined the RT, whereas the time between the initiation of movement and pressing the stop button defined the MT. Participants completed one practice attempt and three trials on the day of testing with 30 sec rest periods (Cronbach's Alpha ICC RT: a = 0.79; MT: a = 0.80).

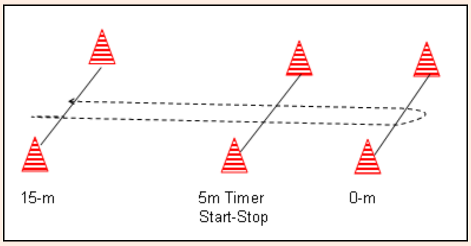


Figure 2. The 505 agility test.

The 505 agility test was selected because of its high correlation to acceleration, which is widely considered as an important component of agility (Sheppard &

Young, 2006). In order to conduct the 505 agility test cones were placed at 0 m, 5 m and 15 m (Figure 2). Electronic timer was positioned at the 5 m cone (photocells and reflectors Tag Heuer, Marin, Switzerland). Subjects sprinted from the 15 m cone and timing began as they passed the 5 m cone. When subjects reached the 0 m cone they made an 180^o turn and sprinted back towards the 5 m cone, at which point the timer was stopped. Participants completed one practice attempt and two trials with 2 minutes' rest between each trial (Cronbach's Alpha ICC: a= 0.82).

In all tests the best score was used for data analysis.

Statistical analyses

Sample size was determined using G*Power (version 3.1.7, F. Faul, University Kiel, Germany) setting effect size at 0.27, based on previously reported data (McMillian et al., 2006) , alpha at 0.05, and power at 0.80. In order to investigate differences between the three protocols, data were analysed using one-way Analysis of Variance (ANOVA) for repeated measures. Post hoc analyses were conducted using Bonferroni pairwise comparisons. All statistical analyses were conducted using SPSS (version 20) and significance was set at $p \leq 0.05$.

Results

Descriptive statistics of the dependent variables are presented in Table 3.

Table 3. Balance, agility RT and MT values of the three protocols. Values are mean (± SD).

	Static	Dynamic	No stretching
Balance (sec)	15.34 (5.54)*	17.49 (5.11)	16.97 (5.16)
Agility (sec)	3.11 (.21)	3.00 (.20)*	3.08 (.18)
RT (ms)	.187 (.036)	.186 (.035)	.187 (.032)
MT (ms)	.419 (.055)	.394 (.053)†	.404 (.051)

*Significant difference from the other two protocols (p<.05).
†Significant difference from static protocol (p<.05).

Balance: Repeated measures ANOVA indicated a significant difference between the protocols ($F = 5.03$, $p < 0.01$, partial eta squared $\eta_p^2 = 0.14$, observed power = 0.79). Bonferroni test revealed that DS (p = 0.01, Cohen's d = 0.40: small) and NS (p = 0.04, Cohen's d=.30: small) were significantly better compared to the SS protocol.

RT: There were no significant differences between the three protocols (p = 0.997).

MT: Repeated measures ANOVA showed a significant difference between the protocols ($F = 4.10$, $p = 0.02$, $\eta_p^2 = 0.12$, observed power = 0.70). Bonferroni test indicated that the DS protocol was significantly better than SS (p = 0.04, Cohen's d=.46: medium).

Agility: Repeated measures ANOVA revealed a significant difference between the protocols ($F = 5.73$, $p < 0.01$, $\eta_p^2 = 0.16$, observed power = 0.84). Bonferroni test indicated that the DS protocol was significantly better than NS (p = 0.01, Cohen's d=.41) and SS protocol (p = 0.03, Cohen's d=.50: medium).

Discussion

The current study demonstrated that SS produced significant performance deterioration in balance, agility and MT compared to DS condition. Furthermore, DS performed better in agility compared to the NS condition.

Regarding balance, according to the results of the study, DS and NS performed significantly better than SS. The findings of the present study are not consistent with those of Costa et al. (2009) and Handrakis et al. (2010), who compared the effects of SS with NS protocol. Costa et al. (2009) reported that a 3X15 sec SS protocol improved balance performance compared to the NS condition. On the contrary, our finding that SS has a negative effect on balance performance is consistent with those of Behm et al. (2004) and Nagano et al. (2006). Specifically, Behm et al. (2004) reported negative effects on balance, after 3 sets of SS with 45 sec duration. Similar negative effect on balance performance reported Nagano et al. (2006), after a single 3 min SS of the calf muscle. The differences in outcomes could be due to (a) different stretching durations applied in the studies and (b) the different testing devices. For example, Costa et al. (2009) measured balance using a circular platform which could tilt 20° from horizontal in all directions and as an outcome measure they used the average tilt in degrees from the centre of the platform. On the contrary, Behm et al. (2004) applied a wobble board placed on a metal plate, and the outcome parameters were the contacts' duration and frequency of the board perimeter with the metal plate during a 30 sec test.

Another possible explanation for the divergent findings of the studies could be the different age of the subjects. Handrakis et al. (2010) reported that a SS protocol improved balance performance of middle-aged adults (40–60 yr). The enhancement of balance was attributed to the differences of muscle stiffness and viscoelastic properties of the middle-aged adults compared to the university age subjects of Behm et al. (2004), who reported SS induced impairments. According to Kubo et al. (2001) the tendon structures in adolescents are more compliant than those in adults. Therefore, adolescents perhaps respond differently from adults to stretching because of differences in the viscoelastic properties and stiffness of the MTU. The subjects of our study were adolescent females, whereas those of Costa et al. (2009) were adult women. Hence, the divergent findings between our study and those of Costa et al. (2009) could be attributed to the different age of the subjects. However, Behm et al. (2011) reported that SS induced impairments are similar in young and middle-aged men. The present study is the first that focused on the effects of stretching on adolescent females' balance performance. Based on the sparse number of studies examining adolescent or adult women, it is apparent that more studies are necessary in this area to draw useful conclusions.

In the review paper of Kay and Blazevich (2012) it is argued that a SS duration shorter than 30 sec per muscle group might not be detrimental to maximal strength performance and speed. However, maintaining balance on an unstable platform (e.g. the balance task of our study) requires fast and accurate movements of upper and lower extremities (coordination). Thus, even a short-duration of

SS (30 sec per muscle group) with exercises for the whole body could possibly be harmful to coordination of upper and lower extremities. Therefore, more studies are needed to clarify the acute effects of stretching on balance and coordination of extremities (arm-leg).

Although most of the studies reported that balance is negatively affected by SS, it is difficult to specify the underlying mechanisms. One possible explanation could be that SS increases ROM which results in decreased MTU stiffness (Herda et al., 2011). Changes in the MTU length and stiffness could alter the ability to detect and respond promptly to changes of an unstable environment. A compliant MTU increases electromechanical delay and hence increases the time from the muscle excitation to the initiation of the movement (Cramer et al., 2005). Furthermore, mechanical changes in MTU may alter the sensory input from muscle spindles and Golgi tendon organs which play an important role for postural maintenance (Behm et al., 2004). For example, Guissard and Duchateau (2006) reported that SS decreases the reflex activity of the stretched muscle and reduces spinal reflex excitability.

An explanation for the better balance performance of DS compared to SS could be that DS elevates muscle temperature (Fletcher and Jones, 2004) and stimulates the nervous system (Jaggers et al., 2008). Herda et al. (2008) reported that DS increased electromyographic amplitude, which may reflect a positive effect of DS on muscle activation. Although neuromuscular function was not measured in our study, it could be speculated that the better balance scores of the DS condition could be attributed to an enhancement of muscle activation.

In relation to RT the results of our study revealed no significant differences between the treatments. Our hypothesis that DS would improve RT whereas SS would impair it was not confirmed. This result is consistent with the findings of Perrier et al. (2011), who reported no significant findings between DS (2 repetitions of 30 sec), SS and NS in RT of countermovement jumps. Furthermore, Alpkaya and Koceja (2007) demonstrated that 3 sets of 15 sec duration of SS resulted in no significant changes in RT. On the contrary, Behm et al. (2004) reported that SS (3 repetitions of 45 sec duration) has a negative effect on RT. These conflicting results may be attributed to the different stretching durations. In Behm et al. (2004), the total duration of SS of a single muscle group was 145 sec. Whereas, studies that indicated no significant impairments on RT used less than 60 sec duration of SS (Alpkaya and Koceja, 2007; Perrier et al., 2011). Considering the few studies which have investigated the effects of DS and SS on RT, we should be cautious regarding the potential effects of the different treatments on RT.

The present study revealed that the DS protocol performed significantly better on MT of upper extremities than the SS protocol. To the authors' knowledge, this is the first study which compared the effects of DS and SS on MT of the upper extremities. Behm et al. (2004) compared the effects of SS and NS on movement time of lower limb muscles and reported also stretch-induced impairments. Static stretch-induced impairments in MT may be related to similar mechanisms as the disturbance in balance (longer and more compliant MTU, and longer electromechanical delay).

In relation to agility, the results of the study verified our hypothesis that DS significantly improves the performance compared to SS condition. This finding is in accordance with those of Van Gelder and Bartz (2011) and McMillian et al. (2006). On the contrary, Faigenbaum et al. (2006a) and Chaouachi et al. (2010) reported no significant differences between DS and SS for agility. Chaouachi et al. (2010) attributed the lack of significant differences to the recovery interval between stretching and testing. Specifically, they suggested a more than 5 min recovery period between SS and performance. Recently, some investigators suggested that post-activation potentiation (PAP) may be a contributing factor for the better performance of the DS protocol (McMillian et al., 2006). PAP can be defined as an increase in the efficiency of the muscle to produce force after a submaximal or maximal contraction (Chatzopoulos et al., 2007). The DS protocol of the current study incorporated similar movements to the agility test performed with a submaximal intensity (e.g. modified shuttle run). The pre-test contractions may have elicited a PAP response contributing to the significant differences between DS and SS protocol.

Conclusion

Based on the present investigation, SS has a negative effect on balance, agility and movement time compared to DS. In case the content of the training unit or game comprises balance activities and rapid change of running direction, then DS is perhaps more appropriate than the SS protocol. Taking our findings into account, coaches and physical education teachers may reconsider the incorporation of SS before a game, where rapid movements of the upper extremities and agility are basic factors for a positive outcome.

References

Allum, J., Carpenter, M., Honegger, F., Adkin, A. and Bloem, B. (2002) Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. *The Journal of Physiology* **542**, 643-663.

Alpkaya, U. and Koceja, D. (2007) The effects of acute static stretching on reaction time and force. *The Journal of Sports Medicine and Physical Fitness* **47**, 147-150.

Avela, J., Finni, T., Liikavainio, T., Niemelä, E. and Komi, P.V. (2004) Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. *Journal of Applied Physiology* **96**, 2325-2332.

Behm, D.G., Bambury, A., Cahill, F. and Power, K. (2004) Effect of acute static stretching on force, balance, reaction time, and movement time. *Medicine and Science in Sports and Exercise* **36**, 1397-1402.

Behm, D.G. and Chaouachi, A. (2011) A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology* **111**, 2633-2651.

Behm, D.G., Plewe, S., Grage, P., Rabbani, A., Beigi, H.T., Byrne, J.M., et al. (2011) Relative static stretch-induced impairments and dynamic stretch-induced enhancements are similar in young and middle-aged men. *Applied Physiology, Nutrition, and Metabolism* **36**, 790-797.

Chaouachi, A., Castagna, C., Chtara, M., Brughelli, M., Turki, O., Galy, O., et al. (2010) Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in

trained individuals. *The Journal of Strength & Conditioning Research* **24**, 2001-2011.
Chatzopoulos, D.E., Michailidis, C.J., Giannakos, A.K., Alexiou, K.C., Patikas, D.A., Antonopoulos, C.B. and Kotzamanidis, C.M. (2007) Postactivation potentiation effects after heavy resistance exercise on running speed. *The Journal of Strength & Conditioning Research* **21**, 1278-1281.
Costa, P.B., Graves, B.S., Whitehurst, M. and Jacobs, P.L. (2009) The acute effects of different durations of static stretching on dynamic balance performance. *The Journal of Strength & Conditioning Research* **23**, 141-147.
Cramer, J., Housh, T., Weir, J., Johnson, G., Coburn, J. and Beck, T. (2005) The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *European Journal of Applied Physiology* **93**, 530-539.
Dalrymple, K.J., Davis, S.E., Dwyer, G.B. and Moir, G.L. (2010) Effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. *The Journal of Strength & Conditioning Research* **24**, 149-155.
Darst, P.W. and Pangrazi, R.P. (2009) *Dynamic Physical Education for Secondary School Students*. San Francisco, Pearson/Benjamin Cummings.
Faigenbaum, A.D., Kang, J., McFarland, J., Bloom, J.M. and Magnatta, J. (2006a) Acute effects of different warm-up protocols on anaerobic performance in teenage athletes. *Pediatric Exercise Science* **18**, 64-75.
Faigenbaum, A.D., McFarland, J.E., Schwerdtman, J.A., Ratamess, N.A., Kang, J. and Hoffman, J.R. (2006b) Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. *Journal of Athletic Training* **41**, 357.
Fletcher, I.M. and Jones, B. (2004) The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *The Journal of Strength & Conditioning Research* **18**, 885-888.
Fletcher, I.M. and Anness, R. (2007) The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. *The Journal of Strength & Conditioning Research* **21**, 784-787.
Foster, C., Porcari, J.P., Anderson, J., Paulson, M., Smaczny, D., Webber, H., et al. (2008) The talk test as a marker of exercise training intensity. *Journal of Cardiopulmonary Rehabilitation and Prevention* **28**, 24-30.
Guissard, N. and Duchateau, J. (2006) Neural aspects of muscle stretching. *Exercise and Sport Sciences Reviews* **34**, 154-158.
Handrakis, J.P., Southard, V.N., Abreu, J.M., Aloisa, M., Doyen, M.R., Echevarria, L.M., et al. (2010) Static stretching does not impair performance in active middle-aged adults. *The Journal of Strength & Conditioning Research* **24**, 825-830.
Herda, T.J., Cramer, J.T., Ryan, E.D., McHugh, M.P. and Stout, J.R. (2008) Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *The Journal of Strength & Conditioning Research* **22**, 809-817.
Herda, T.J., Costa, P.B., Walter, A.A., Ryan, E.D., Hoge, K.M., Kerksick, C.M., et al. (2011) The effects of two modes of static stretching on muscle strength and stiffness. *Medicine and Science in Sports and Exercise* **43**, 1777-1784.
Jaggers, J.R., Swank, A.M., Frost, K.L. and Lee, C.D. (2008) The acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. *The Journal of Strength & Conditioning Research* **22**, 1844-1849.
Kay, A.D. and Blazevich, A.J. (2012) Effect of acute static stretch on maximal muscle performance: a systematic review. *Med Sci Sports Exerc* **44**, 154-164.
Kubo, K., Kanehisa, H., Kawakami, Y. and Fukanaga, T. (2001) Growth changes in the elastic properties of human tendon structures. *International Journal of Sports Medicine* **22**, 138-143.
Leone, D., Pezarat, P., Valamatos, M., Fernandes, O., Freitas, S. and Moraes, A. (2012) Upper body force production after a low-volume static and dynamic stretching. *European Journal of Sport Science*, 1-7.
Little, T. and Williams, A.G. (2006) Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *The Journal of Strength & Conditioning Research* **20**, 203-307.
Manoel, M.E., Harris-Love, M.O., Danoff, J.V. and Miller, T.A. (2008) Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. *The Journal of Strength & Conditioning Research* **22**, 1528-1534.
McMillian, D.J., Moore, J.H., Hatler, B.S. and Taylor, D.C. (2006) Dynamic vs. static-stretching warm up: the effect on power and agility performance. *The Journal of Strength & Conditioning Research* **20**, 492-499.
Nagano, A., Yoshioka, S., Hay, D.C., Himeno, R. and Fukashiro, S. (2006) Influence of vision and static stretch of the calf muscles on postural sway during quiet standing. *Human Movement Science* **25**, 422-434.
National Association for Sport and Physical Education (2011) *Physical Education for Lifelong Fitness*. Champaign, IL, Human Kinetics.
Perrier, E.T., Pavol, M.J. and Hoffman, M.A. (2011) The acute effects of a warm-up including static or dynamic stretching on countermovement jump height, reaction time, and flexibility. *The Journal of Strength & Conditioning Research* **25**, 1925-1931.
Sheppard, J. and Young, W. (2006) Agility literature review: classifications, training and testing. *Journal of Sports Sciences* **24**, 919-932.
Van Gelder, L.H. and Bartz, S.D. (2011) The effect of acute stretching on agility performance. *The Journal of Strength & Conditioning Research* **25**, 3014-3021.
Walter, T., Quint, A., Fischer, K. and Kiger, J. (2011) Active Movement Warm-Up Routines. *Journal of Physical Education, Recreation & Dance* **82**, 23-31.
Woods, K., Bishop, P. and Jones, E. (2007) Warm-up and stretching in the prevention of muscular injury. *Sports Medicine* **37**, 1089-1099.

Key points

- Static stretching has a negative effect on balance and agility performance compared to dynamic stretching.
- There was no effect of the stretching protocols on reaction time.
- Dynamic stretching was more effective than static stretching for increasing movement time of the upper extremities.

AUTHORS BIOGRAPHY

Dimitris CHATZOPOULOS
Employment
Lecturer at Aristotle University of Thessaloniki, Department of Physical Education and Sport Science
Degree
PhD
Research interests
Stretching, warm-ups, fitness training.
E-mail: chatzop@phed.auth.gr

Christos GALAZOULAS
Employment
Assistant Professor at Aristotle University of Thessaloniki
Department of Physical Education and Sport Science
Degree
PhD
Research interests
Coaching, conditioning and fitness training
E-mail: galaz@phed.auth.gr

Dimitrios PATIKAS
Employment
Assistant Professor at Aristotle University, Department of Physical Education and Sport Sciences at Serres
Degree
PhD
Research interests
Strength, conditioning and fitness training
E-mail: dpatikas@auth.gr

Christos KOTZAMANIDIS
Employment
Professor at Aristotle University of Thessaloniki, Department of Physical Education and Sport Science
Degree
PhD
Research interests
Coaching and Neuromuscular Control
E-mail: kotzaman@phed.auth.gr

✉ **Chatzopoulos Dimitris**
Department of Physical Education and Sport Sciences, Aristotle University, Thessaloniki 57001, Greece