

Effects of static and dynamic stretching on lower-limb kinematics and dynamics during the concentric phase in amateur volleyball players

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Abstract

The purpose of this study was to assess the effects of a 6-week, dynamic versus a static stretching, (3×/week), on lower-limb kinematics and dynamics characteristics, in former amateur volleyball players. **Methods:** Randomized controlled trial with 42 healthy physical education students (age: 21.48±1.85 years, height: 1.82±0.06 m, mass: 81.23±9.31 kg and training age: 8.15±3.17 y). Groups: dynamic stretching (DS), static stretching (SS), control (CG). Pre/post isokinetic dynamometry (max concentric force) at Neuromechanics Lab, of the Department of Physical Education and Sports Science of the University of Serres. Kinematics: APAS, dynamics: Bioware/Bioanalysis. Data analysis: Repeated-measures ANOVA, t-tests (p≤0.05). **Results:** CG unchanged. DS/SS improved flexibility at maximum concentric force (p<0.05). DS uniquely reduced time-to-peak concentric force (p<0.05); SS inert dynamically. **Conclusion:** Both DS/SS enhance flexibility, DS superior for dynamic traits (3×/week, 6 wk). Dynamic stretching recommended for volleyball performance optimization.

Keywords: dynamic stretching, static stretching, kinematic analysis, volleyball

Introduction

In contemporary sports science, coaches pursue performance optimization through warm-up protocols that prepare athletes' physiological systems for activity, transitioning them from rest (Zakas, 2010). In athletic disciplines, warm-up protocols typically interpose static (and recently dynamic) stretching between general and specific phases to enhance joint flexibility (Knudson et al., 2000; Harvey et al., 2002; Chaouachi et al., 2015; Kamankesh & Shirinbayan, 2017; Behm et al., 2023a; Balay & Guillena, 2025), enabling biomechanically precise movements and maximal force application across full joint ROM (Van Gyn, 1986). Volleyball athletes commonly use stretching due to the critical role of high vertical jumps and explosive short sprints.

Stretching during warm-up remains a classic training procedure in sports to prepare athletes for practice or competition. Literature describes various techniques, (static, dynamic, ballistic, and proprioceptive neuromuscular facilitation). Yet static and, increasingly, dynamic types predominate (Hedrick, 2002; Sople & Wilcox, 2025).

Static stretching is executed either via the exerciser's own body weight and force or through external partner assistance (Tanigawa, 1972). Despite its widespread training application, numerous studies report acute performance decrements post-static stretching in maximal strength (Kokkonen, Nelson, & Cornwell, 1998), sprinting (Fletcher & Jones, 2004), jumping (Cornwell et al., 2001), throwing (Noffal, Knudson, & Brown, 2004), and kinematic characteristics (Alipasali et al., 2014, Alipasali et al., 2017).

Dynamic stretching, defined by Fletcher and Jones (2004) as controlled motion through joint range of motion, enhances acute performance (unlike static stretching) in power (Yamaguchi et al., 2008), sprinting (Turki et al., 2012), repeated explosive efforts (Faigenbaum et al., 2005), and jumping (Pearce et al., 2009; Turki et al., 2011; Carvalho et al., 2012) (Behm et al., 2016, Sople & Wilcox, 2025).

While abundant research examines acute effects of static/dynamic stretching on performance, chronic static stretching studies remain scarce (Worrell et al., 1994; Bazett-Jones et al., 2008; Yuktasir & Kaya, 2009), and dynamic stretching studies even rarer with contradictory results (Woolstenhulme et al., 2006; Herman & Smith, 2008; Laroche et al., 2008; Turki-Belkhiria et al., 2014). Muscle strength correlates with sprint and vertical jump performance (Wisloff et al., 2004). In volleyball, requiring speed, acceleration, sudden direction

changes, and high jumps, quadriceps and hamstring strength critically influence player performance. Knee extension force mirrors vertical jump force (Ito & Yoda, 1992), with knee extensors maximally activated during jumps and rapid eccentric-concentric transitions in agility maneuvers. Thus, evaluating quadriceps/hamstring eccentric/concentric strength constitutes a key parameter for coaches designing training programs and preventing musculoskeletal injuries (Dervisevic & Hadzic, 2012, Sople & Wilcox, 2025).

Earp et al. (2010) and Jiang et al. (2024), reported that muscle contraction speed and rapid force application improve with increased fiber length due to longer sarcomeres and greater sarcomere numbers. Taber (1995) noted eccentric lengthening during passive stretching and concentric hypertrophy during active stretching. Goktepe et al. (2010) and Kerckhoffs et al. (2012) found serial sarcomere addition with passive stretching and parallel myofibril deposition with active stretching. Finally, Medeiros & Lima (2017) linked muscle lengthening via flexibility gains to enhanced performance.

Literature consistently reports reduced muscle strength post-static stretching (Ogura et al., 2007; Herda et al., 2008; Winchester et al., 2009). Winchester et al. (2009) found decreased hamstring maximal strength in college students after 30-180s static stretching. Herda et al. (2008) observed reduced isometric torque in untrained men after 4×30s hamstring stretching. Ogura et al. (2007) noted decreased voluntary isometric contraction after 60s (but not 30s) hamstring stretching. Molacek et al. (2010) found no changes in soccer players after either 2×20s or 5×30s static stretching.

However, the aforementioned studies examined acute effects immediately post-static stretching. Research on performance after weeks-long static stretching protocols remains scarce with conflicting results (Worrell et al., 1994; Handel et al., 1997; Behm et al., 2006; Herman & Smith, 2008; Laroche et al., 2008). Herman & Smith (2008), Laroche et al. (2008), and Behm et al. (2006) found no quadriceps torque improvements after 4-week programs (3-5×/week). Similar null results were observed by Konrad et al. (2015) in plantar flexor isometric torque after 6-week PNF stretching (5×/week) in trained police recruits.

In contrast, Worrell et al. (1994) found increased eccentric/concentric isokinetic hamstring strength at low/medium velocities in university students after 3-week static stretching (5×/week). Handel et al. (1997) reported similar improvements in eccentric/concentric isokinetic and isometric strength of anterior/posterior thigh muscles at low/high velocities in swimmers, soccer players, and track athletes after 8-week PNF stretching (3×/week).

Dynamic stretching neither reduces muscle strength nor occasionally enhances it (Sekir et al., 2010). Sekir et al. (2010) found improved maximal eccentric/concentric isokinetic torque in women after slow/fast dynamic stretching (2×15 reps/leg). Herda et al. (2008) observed no changes in right hamstring isometric torque in untrained men after 4×30s dynamic stretching.

However, these studies examined acute effects immediately post-dynamic stretching. Long-term dynamic stretching research is scarce with conflicting results (Herman & Smith, 2008; Laroche et al., 2008; Turki-Belkhiria et al., 2014). Herman & Smith (2008) found quadriceps torque improvements in wrestlers after 4-week dynamic stretching (5×/week). Turki-Belkhiria et al. (2014) reported enhanced jump power/strength after 8-week dynamic stretching (3×/week). Laroche et al. (2008) found no lower-limb strength gains in men after 4-week dynamic stretching (3×/week). Given time constraints, equipment limitations, and evidence of performance improvements from weeks-long static/dynamic stretching programs, determining their effects on volleyball players' performance is valuable for coaches, as these interventions easily integrate into daily training regimens. Therefore, this study aimed to investigate the effects of 6-week static and dynamic stretching programs on the kinematic and dynamic characteristics of lower limbs muscle strength in volleyball players.

Material & Methods

Participants

Initially, 50 healthy physical education students (former amateur volleyball players participating in volleyball classes) volunteered. Participants were randomly assigned to three groups, informed of procedures, and provided written consent following familiarization. Eight were excluded (2 injuries, 6 non-completion), leaving 42 participants (age: 21.48±1.851 years; height: 1.821±0.064 m; weight: 81.229±9.310 kg; training experience: 8.15±3.174 years; Table 1). The study adhered to Aristotle University of Thessaloniki's Code of Ethics and procedures were accordance with the Declaration of Helsinki for research on human subjects.

N=42	Mean	Std
Age	21,48	±1,851
Training Age	8,15	±3,174
Height	1,821	±0,064
Weight	81,229	±9,310

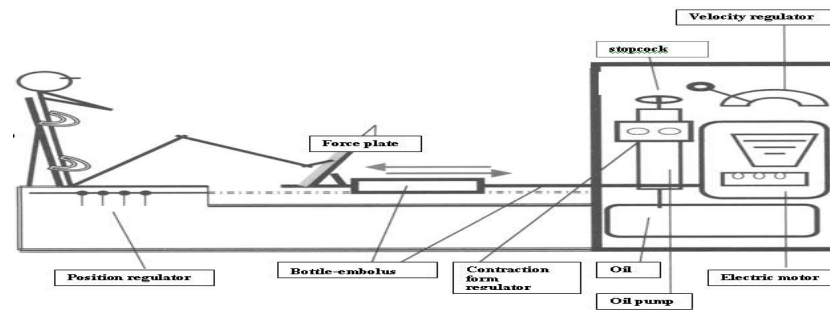
Table 1: Participants

Materials

Isokinetic dynamometer

A hydraulic isokinetic dynamometer (Ydromechaniki SA) Picture 1 at the Department of Physical Education and Sport Sciences at Serres, Aristotle University of Thessaloniki Neuromechanics Laboratory was employed.

The apparatus features a 15 PS electric motor, 200 L oil reservoir, and piston-driven platform with integrated dynamometer. Piston velocity was controlled at 0.20 m/s via flow regulation.



Picture 1: Isokinetic Machine

Forceplate

An AMTI force plate (model OR6-6-4000, serial no. 5157; 1000 Hz sampling; Picture 2) was mounted on a rigid metal frame attached to the isokinetic device at a 75° angle, driven by a metal shaft. The plate's elastic elements produce electrical charges under pressure, which are transmitted to a dedicated PC.



Picture 2: Isokinetic machine with Forceplate

Subjects underwent testing on the isokinetic dynamometer (Picture 2), measuring maximum concentric lower limb force ($F_{\max-syg}$). They were directed to push maximally against the retreating platform while stabilizing pelvis against the seat and feet on a tape-marked surface. Peak efforts at $F_{\max-syg}$ were selected for analysis.

Training Protocol

Six-week static (SS) and dynamic (DS) stretching programs, supervised by the principal investigator, followed literature standards for joint ROM gains (Rodriguez-Ruiz et al., 2011). SS/DS groups trained 3×/week alongside routine activities; controls abstained.

Static Stretching (SS): Six lower-limb exercises at maximal ROM (no soreness): 2×10 s each, 10-s rests for bilateral posterior tibialis, no rests for unilateral/alternating stretches (Alipasali et al., 2019), (Table 2).

Dynamic Stretching (DS): Similar ROM guidelines: bilateral posterior tibialis (2×10 s, 10-s rests), alternating anterior femoris (2×20 s, 10-s rests), unilateral/alternating per leg (2×, no rests) (Alipasali et al., 2019), (Table 2).

Table 2: Static and Dynamic Stretching Exercise		
Muscles	Static Stretching Exercises	Dynamic Stretching Exercises
Posterior tibial		
Anterior femoral		
Posterior femoral		
Hip extensor		
Iliopsoas		
Adductor		

Statistical analysis

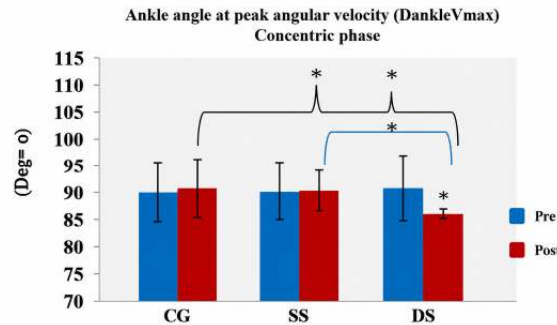
Statistical analyses were conducted using SPSS 20.0 ($\alpha = 0.05$). Repeated-measures ANOVA, paired t-tests, and independent t-tests evaluated intervention effects.

Results

Baseline one-way ANOVA revealed no significant differences across groups for ankle angle range at initial position (Dankle1: $F(2,39) = 0.176$, $p = 0.839$), knee ROM ($F(2,39) = 2.343$, $p = 0.109$), or ankle angle at peak velocity (DangleVmax: $F(2,39) = 0.064$, $p = 0.938$).

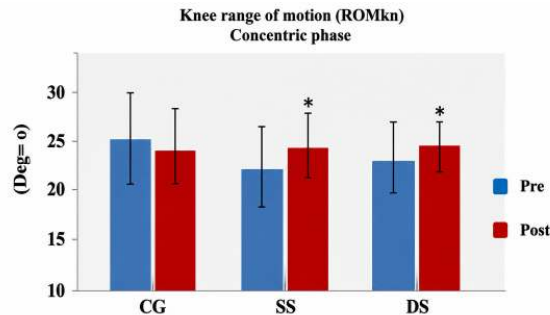
Post-hoc t-tests for (Dankle1) revealed dynamic stretching post-intervention mean ($M = 78.89^\circ$, $SD = 1.36^\circ$) significantly lower than static ($M = 85.92^\circ$, $SD = 2.47^\circ$; $t = 9.32$, $p < 0.001$, $d = 3.52$, $df = 20.196$) and control

($M=83.24^\circ$, $SD=5.96^\circ$; $t(14.35)=2.66$, $p=0.018$, $d=1.01$, $df=14.348$); static vs. control nonsignificant ($t=1.55$, $p=0.132$, $df=26$). Dynamic pre-post decrease (5.47°) significant ($t=7.02$, $p<0.001$, $d=1.88$, $df=13$); static/control changes nonsignificant (Graph 1).



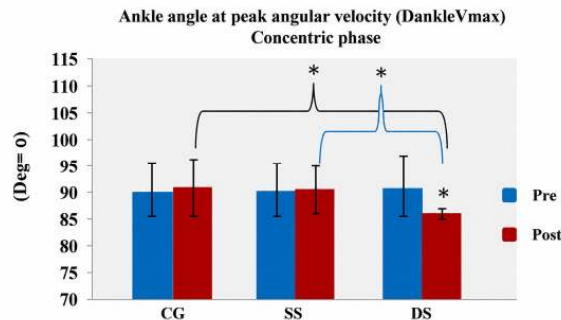
Graph 1. Change in (Dankle1), ankle angle at initial concentric position, pre- and post-stretching across groups. [*DS significantly lower: pre-DS vs. post-DS ($p<0.001$); post-DS vs. post-SS ($p<0.001$); post-DS vs. control ($p=0.018$)].

Knee ROM (ROMkcn), analysis revealed significant pre-post increases for dynamic stretching (DS: $t=2.54$, $p=0.025$, $d=0.68$, $df=13$; $+1.51^\circ$) and static stretching (SS: $t=2.55$, $p=0.024$, $d=0.69$, $df=13$; $+2.13^\circ$); control group decrease nonsignificant ($t=1.56$, $p=0.143$, $df=13$), (Graph 2).



Graph 2. Change in knee ROM (ROMkcn) during concentric phase, pre- and post-stretching program across groups. [*DS significantly higher: pre-DS vs. post-DS ($p=0.025$); *SS significantly higher: pre-SS vs. post-SS ($p=0.024$)]

(DankleVmax) post-hoc analysis: DS ($M=86.516$, $SD=0.853$) significantly lower than SS ($t=4.19$, $p=0.001$, $d=1.59$, $df=14.61$) and control ($t=3.17$, $p=0.007$, $d=1.20$, $df=13.80$); SS vs. control nonsignificant ($t(26)=0.14$, $p=0.891$). DS pre-post decrease significant ($t=3.03$, $p=0.010$, $d=0.81$, $df=13$); SS/control nonsignificant, (Graph 3).

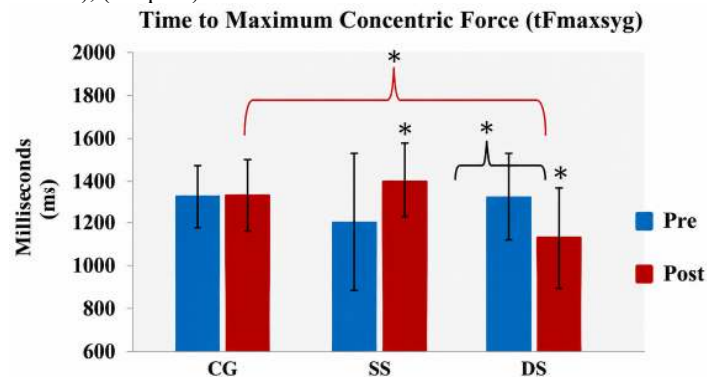


Graph 3. Change in DankleVmax (ankle angle at peak angular velocity) pre- and post-stretching across groups. [*DS significantly lower: pre-DS vs. post-DS ($p=0.010$); post-DS vs. post-SS ($p=0.001$); post-DS vs. control ($p=0.007$)]

A one-way ANOVA on baseline time to maximum concentric force (tFmax) yielded no significant differences among the three subgroups, $F(2,39)=1.998$, $p=0.149$.

Post-hoc analysis for time to maximum concentric force (tFmax) revealed that the dynamic stretching group post-intervention mean ($M=1131.07$ ms, $SD=247.32$ ms) was significantly lower than static stretching ($M=1395.00$ ms, $SD=196.13$ ms; $t=3.13$, $df=26$, $p=0.004$, $d=1.18$) and control ($M=1331.00$ ms, $SD=232.69$ ms; $t=2.20$, $df=26$, $p=0.037$, $d=0.83$). No significant difference emerged between static and control

groups ($t = 0.79$, $df = 26$, $p = 0.438$). Within-group changes showed significant reductions for dynamic stretching (pre: $M = 1318.86$ ms to post; $t = 2.62$, $df = 13$, $p = 0.021$, $d = 0.70$), significant increases for static stretching (pre: $M = 1173.64$ ms to post; $t = 2.35$, $df = 13$, $p = 0.035$, $d = 0.63$), and nonsignificant change for control ($t = 0.06$, $df = 13$, $p = 0.957$), (Graph 4).



Graph 4. Changes in time to maximum concentric force (tFmaxsyg) before and after the stretching program across all groups. (*DS was significantly lower), (pre-DS vs. post-DS, $p = 0.021$, $p = 0.021$; post-DS vs. post-SS, $p = 0.004$, $p = 0.004$; post-DS vs. control, $p = 0.037$, $p = 0.037$), whereas SS was significantly higher (pre-SS vs. post-SS, $p = 0.035$).

Discussion

The present study examined the effects of 6 weeks of dynamic and static stretching, performed three times weekly, on lower-limb kinematic and dynamic characteristics in former amateur volleyball players. In the dynamic stretching group, flexibility and explosiveness improved, with a reduced ankle joint angle at the initial position, greater knee range of motion, a lower ankle angle at peak angular velocity, and a shorter time to maximum concentric force (tFmax), indicating increased explosiveness.

Our findings are consistent with those of Turki-Belkhiria et al. (2014), who reported similar flexibility improvements in football players following an 8-week dynamic stretching program performed three times per week. However, our results contrast with those of Herman and Smith (2008), who found no improvement in flexibility, possibly because their protocol lasted only 4 weeks, a duration that may have been insufficient to induce lasting changes in joint range of motion (Laroche et al., 2008).

Our findings suggest that dynamic stretching positively affected ankle joint angle, knee range of motion, and explosiveness. Changes in joint range of motion have been associated with increased muscle fiber length, and consequently with improved performance and contraction velocity (Kokkonen et al., 2007). According to Earp et al. (2010), muscle contraction speed and the ability to apply force rapidly improve as muscle fiber length increases. Thus, the observed increase in joint range of motion may have enhanced flexibility and, in turn, explosiveness in the volleyball players examined in this study.

Although the mechanisms underlying performance improvements after dynamic stretching were not among the aims of this study, dynamic stretching appears to increase muscle blood flow and coordination during dynamic movements (Behm & Chaouachi, 2011), as well as kinesthesia and proprioception (Mann & Jones, 1999), while also promoting the reuse of elastic energy during the stretch-shortening cycle (Wilson, Elliott, & Wood, 1992).

The static stretching program, as applied in this study, positively affected athletes' kinematic characteristics at maximum concentric isokinetic force in the laboratory isokinetic multi-joint dynamometer, by increasing knee range of motion, without simultaneously improving explosiveness.

These findings are consistent with previous studies (Bazett-Jones et al., 2008; Herman & Smith, 2008; Marshall et al., 2011; Morton et al., 2011; Blazevich et al., 2014) and contrast with those of Worrell et al. (1994), Handel et al. (1997), and Kokkonen et al. (2007).

The conflicting findings may be attributed to methodological differences, such as the duration of the stretching programs, the type of stretching, and the participants' baseline physical condition. In the present study, the static stretching protocol lasted 6 weeks, whereas the study by Worrell et al. (1994) lasted only 3 weeks, which was considerably shorter, and measurements were performed at low and moderate angular velocities. According to these authors, the observed increase may have been due to the effects of stretching on the musculotendinous system, which may in turn have influenced neuromuscular transmission. In addition, according to Alipasali (2013), static stretching may affect joint movements performed at higher angular velocities more strongly. In the study by Handel et al. (1997), the stretching program lasted 8 weeks, was applied only to one limb, and consisted of proprioceptive neuromuscular facilitation. The improvement reported by these authors was observed in comparison with the other limb, which did not undergo any type of stretching and

served as the control limb. Finally, in the study by Kokkonen et al. (2007), the participants were untrained, and therefore may have had greater room for improvement.

The mechanisms underlying performance changes after static stretching do not appear to be fully clarified in the current literature. According to Shellock and Prentice (1985), increased muscle temperature seems to have a positive effect on rapid, dynamic, and explosive contractions. Thus, it remains unclear whether the observed performance decrement is due to static stretching itself or to the reduction in muscle temperature caused by the inactivity associated with static stretching. Performance decrements after static stretching within a training session may be attributable to neural factors (Avela, Kyröläinen, & Komi, 1999; Avela, Finni, Liikavainio, Niemelä, & Komi, 2004), reduced muscle stiffness, which may limit force transmission from the muscle to the skeleton (Wilson, Murphy, & Pryor, 1994), reduced blood flow during static elongation (Poole, Musch, & Kindig, 1997), and possibly increased calcium ion levels induced by repeated stretching (Westerblad, Burton, Allen, & Lannergren, 2000). The performance reduction after static stretching may also be related to muscle tissue damage. Smith et al. (1993) reported increased creatine kinase following prolonged static stretching.

Conclusion

When comparing the effects of the stretching programs applied to the lower-limb muscles of the study participants, it appears that the type of muscle stretching plays an important role in enhancing performance. The dynamic stretching protocol, as performed over 6 weeks, made the players faster and more explosive by improving their ability to generate force in a shorter time.

Declaration of generative AI and AI-assisted technologies in the writing process,

During the preparation of this work, Corresponding Author, Stergios N. Komsis used ChatGPT (OpenAI) to enhance the quality of figures and to assist with the refinement of formal English translations where appropriate. Following the use of this tool, all generated content was carefully reviewed and edited by the author, who assumes full responsibility for the accuracy and integrity of the final publication.

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