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Comparison of the Duration of Maintained Calf Muscle Flexibility After Static Stretching, Eccentric Training on Stable Surface, and Eccentric Training on Unstable Surfaces in Young Adults With Calf Muscle Tightness

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Abstract

The objective of this study was to determine the duration of maintained calf muscle flexibility gained in young adults with calf muscle tightness, as measured by increases in ankle active and passive dorsiflexion range of motion (DFROM) after three stretching interventions. Twenty subjects (5 men and 15 women) with calf muscle tightness received the following three stretching interventions in one leg (assigned at random): static stretching (SS), eccentric training on stable surface (ETS), and eccentric training on unstable surfaces (ETU). The subjects received all three interventions to the same leg, applied in a random order. Each intervention had a break of at least 24 h in-between, in order to minimize any carryover effect. Each intervention used two types of stretching: with the calf muscle stretched and both knees straight, and with the knee slightly bent in order to maximize the activation of the soleus muscle. All three interventions were performed for 200 seconds. We measured the duration of maintained calf muscle flexibility through active and passive ankle DFROM before intervention, immediately after intervention (time 0), and then 3, 6, 9, 15, and 30 min after intervention. We found a difference in the duration of maintained calf muscle flexibility between the three interventions. In the ETS and ETU interventions, a significant improvement in calf muscle flexibility, both ankle active and passive dorsiflexion ranges of motion (ADFROM and PDFROM), was maintained for 30 min. In the SS intervention, however, ADFROM before 9 min and PDFROM before 6 min were statistically different from the baseline. Our results suggest that ETS and ETU may be more effective than SS for maintaining calf muscle flexibility in young adults.

Key Words: Ankle dorsiflexion; Calf muscle tightness; Eccentric training; Static stretching; Unstable surface.

Introduction

The calf muscle is composed of the gastrocnemius and the soleus muscle that attach to the strong calcaneal (achilles) tendon (Biel and Dorn, 2005). It plays an important role in postural control and in gait. Calf muscle tightness (i.e., decreased flexibility or increased stiffness) is associated with a decrease in ankle dorsiflexion as well as many disorders such as shin splints, achilles tendinitis, plantar fasciitis, and muscle and joint sprains (Middleton and Kolodin, 1992).

Reduced ankle dorsiflexion range of motion (DFROM) can affect gait and physical activity and is associated with falls (Johnson et al, 2007). Based on kinematic gait analyses of normal gait, 5 to 10 degrees of ankle dorsiflexion is required to progress from mid-stance to terminal stance (Neumann, 2010). Greater ranges of motion (ROM) are required for rapid activities, such as running, and jumping, during

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which maximum ankle dorsiflexion increases to approximately 20 degrees at mid-stance (Novacheck, 1998). It therefore follows that a lack of ability to progress from mid-stance to terminal-stance shortens the stride length, produces unsteadiness, and contributes to reduced gait speed (Hunter et al, 2004). In addition, gait alterations may lead to compensatory changes such as increased pronation or early heel rise (Karas and Hoy, 2002). Because of this, identifying successful physical therapy interventions to improve ankle ROM is important (Johnson et al, 2007).

Many previous studies have demonstrated that calf muscle stretching exercises, as well as warming up before participation in sporting activities, increases ankle dorsiflexion and reduces the symptoms of calf muscle tightness (Thacker et al, 2004). The benefits of stretching are thought to include an increased flexibility in tight calf muscles that subsequently reduces the risk of injury associated with achilles tendinitis and gastrocnemius strain, enhances sporting injury prevention, and may positively influence the functional activities of daily living (Gajdosik, 2006).

Stretching interventions for increasing calf muscles flexibility included static stretching (SS), ballistic stretching, proprioceptive neuromuscular facilitation, eccentric training (ET), and balance board training (Samukawa et al, 2011). A better option for improving flexibility, according to recent studies, would be an action that is more active than passive (Nelson, 2006). Static stretching seats muscles in their lengthened positions and maintains those positions for a certain period of time (Kisner and Colby, 2002), and it has been shown to increase ROM effectively and safely around the joint (Power et al, 2004). However, static stretching has been found to have negative effects on maximal muscle strength, balance and reaction times, as well as leg power (Yamaguchi and Ishii, 2005). By contrast, eccentric training consists of performing active lengthening of the muscle-tendon unit (Alfredson and Lorentzon, 2000), and recent studies have indicated that eccentric training could increase sporting or functional performance (Nelson and Bandy, 2004). Balance board training is performed on unstable surfaces and platforms, and has been shown to be effective for increasing sensorimotor control of the soft tissues that stabilize the ankle joint and activate a range of muscle fibers (Anderson and Behm, 2005). Furthermore, the American College of Sports Medicine (ACSM) recommends that a progressive increase in the levels of balance training exercise difficulty can be achieved by performing dynamic movements, stressing postural muscles, or reducing the sensory input (Chodzko-Zajko et al, 2009).

Previous studies have demonstrated the immediate effects of various stretching protocols. These studies were limited study with specific aim of comparison of immediate ROM changes after stretching. However, more recent reports have shown that the post-intervention maintenance of muscle flexibility varies with time (Nelson, 2006; Depino et al, 2000) Therefore, it would be useful to know which stretching interventions maintained increased ROM over longer periods of time. In addition, to date, the benefits of SS, ETS, and ETU have not been compared.

The purpose of this study was to compare the effects of SS, ETS, and ETU on the duration of maintained calf muscle flexibility in young adults with calf muscle tightness. Furthermore, given the widespread use of calf-stretching exercises in sports, fitness, and rehabilitation, it is surprising that basic scientific information has not been previously published regarding the effects of calf stretching interventions. Our three hypotheses were: 1) these three interventions would have different effects on the duration of maintained calf muscles flexibility; 2) ET will be more effective than SS; and 3) ETS will be significantly different from ETU.

Methods

Subjects

Twenty subjects participated in this study (Table

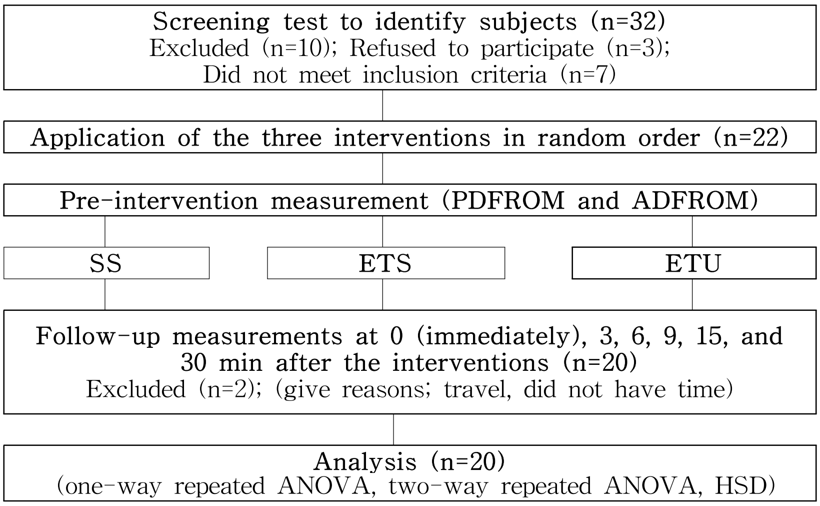

Figure 1. Flowchart illustrating the study protocol (PDFROM: passive dorsiflexion range of motion, ADFROM: active dorsiflexion range of motion, SS: static stretching, ETS: eccentric training on stable surface, ETU: eccentric training on unstable surfaces, ANOVA: analysis of variance, HSD: Tukey's honesty significant difference).

1). To be included in the study subjects had to (1) have calf muscle tightness, defined as ankle passive dorsiflexion range of motion (PDFROM) of less than 10 degrees as delineated by Elveru et al (1988); (2) be functionally independent; (3) be injury-free in the ankle, hip, or lower extremities for at least 6 months prior to the study; and (4) report no history of orthopedic, neurologic disorders involving the ankle, back, or lower extremities. Subjects were excluded if they had participated in sport activities (eg., aerobics, running, or exercise) less than 4 hour before testing. The left or right ankle of each subject was randomly arbitrated by using block randomization procedure (Muir et al, 1999). In the study, all subjects read the study guidelines and gave informed consent prior to participation. All subjects signed consent forms approved by the University Institutional Review Board, Committee for the Protection of Human Subjects, at Daejeon University, Daejeon (Approval Number: 1040647-201312-HR-065-03).

Table 1. Characteristics of the subjects (N=20)

	Men (n_1=5)	Women (n_2=15)	p
Age (year)	24.2±.5[a]	21.93±.9	5.0
Height (㎝)	173.8±4.6	162.47±5.5	4.2
Weight (㎏)	70.4±4.6	53.67±4.1	7.6

[a]mean±standard deviation.

Ankle dorsiflexion range of motion measurements (DFROM)

Ankle DFROM was defined as the angle between the proximal axis (from the head of the fibula to the lateral malleolus) and the distal axis (from the base to the head of the 5th metatarsal). Calf muscle flexibility, as determined by ankle passive dorsiflexion range of motion (PDFROM) and active dorsiflexion range of motion (ADFROM,) was measured in the intervention ankle, assigned in random order. Subjects were positioned supine on a treatment table with their knees fully extended. The researcher secured the tibia and fibula of the lower extremity using 10-㎝-wide straps to prevent knee motion. The intervention ankle was maintained in a subtalar joint neutral position during the measurements and subjects were instructed not to provide active assistance. Initially, the subjects flexed the calf muscles as far as possible. Next, the researchers pushed back with the sufficient strength to encounter notable tension in the calf muscle. Each measurement was repeated three times, and the mean was used for statistical analyses. All pre-post intervention universal goniometric measurements were taken from the intervention ankle by the same tester, in order to provide good intra-tester reliability for ankle DFROM. In addition, a hand-held dynamometer (Dualer IQ the smarter inclinometer; JTECH Medical, Salt Lake City, USA) was applied to maintain a constant resistance at the maximum height range in front of the sole of the foot. The testers undertaking the measurements were blinded to the purpose of the study, and tester had high reliability (intra-tester correlation coefficients from .84 to .99).

Stretching interventions for calf muscle flexibility

Stretching methods

All the subjects received three interventions with the same leg, applied in a random order: SS, ETS, ETU. Each intervention had a break at least 24 h in-between in order to minimize any carryover effect. Two types of stretching is used on each intervention: the calf muscle stretched and both knees straight, and bending the knee slightly in order to maximize the activation of the soleus muscle. All the three interventions were performed for 200 sec (total stretch time : 150 sec, total rest time : 50 sec).

Ankle static stretching (SS)

Two types of SS were used (Figure 2A). The subjects stood with one leg in front of the intervention leg, placed the hands against a wall, and slowly moved towards the wall by bending the front leg further whilst keeping the knee on the intervention leg straight with the heel pressed to the floor. The subjects held the maximally stretched calf muscle in that each position for 30 sec followed by a 10 sec rest interval. The stretch was repeated 5 times. The time of SS intervention was applied arbitrary in order to be same with other two interventions which were applied 200 sec totally.

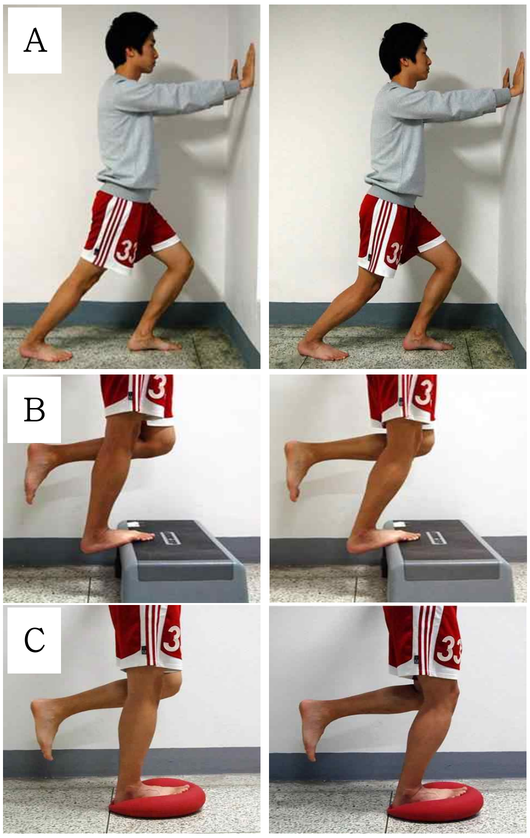

Figure 2. Three stretching interventions for calf muscle flexibility [A: static stretching (SS), B: eccentric training on stable surface (ETS), C: eccentric training on unstable surface (ETU)].

Eccentric training on stable surface (ETS)

Two types of ET were used (Figure 2B). This ETS intervention has been described by Fahlström et al (2003). The interventions start from upright body position, and standing with whole bodyweight on the anterior half-part of the foot, with the ankle joint in plantar flexion lifted by the non-intervention leg. Then the ankle of the intervention leg is lowered to full dorsiflexion and returned to its original position with the assistance of the non-intervention leg. We loaded the calf muscle of the intervention leg only eccentrically, without concentric loading. The subjects were told to continue stretching despite experiencing

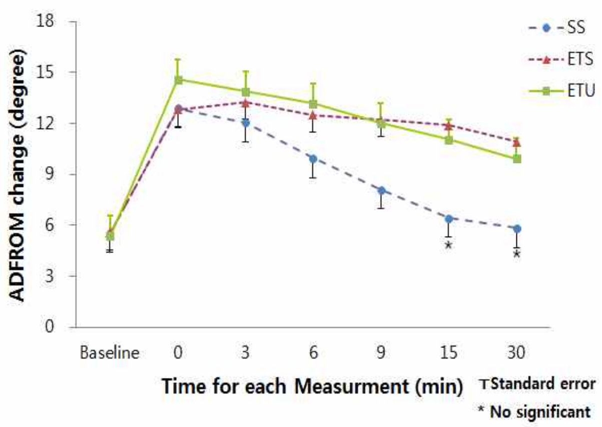

Figure 3. Active ankle dorsiflexion range of motion (ADFROM) in degrees after the three interventions (SS: static stretching, ETS: eccentric training on stable surfaces, ETU: eccentric training on unstable surfaces).

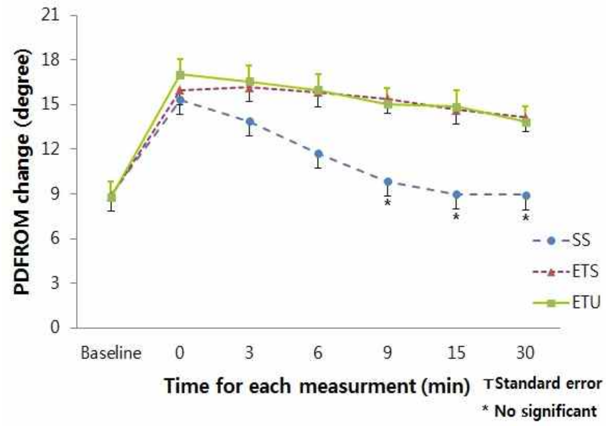

Figure 4. Passive ankle dorsiflexion range of motion (PDFROM) in degrees after the three interventions (SS: static stretching, ETS: eccentric training on stable surface, ETU: eccentric training on unstable surfaces).

discomfort during the ET. Each of the two ET types included 15 repetitions over 50 sec in three sets (3×15 repetitions).

Eccentric training on unstable surfaces (ETU)

We used ET modified intervention for two types of ETU (Figure 2C). ETU was executed on the intervention leg using a cushion (Dynair ball (33 ㎝), TOGU, Prien, Germany). The non-intervention leg was placed on a stable surface at the cushion height. Each of the two ETU types included 15 repetitions over 50 sec in three sets (3×15 repetitions).

Data analysis

Collected data were analyzed using SPSS ver. 18.0 software. An independent t-test was used to analyze differences between the general characteristics, including age, height, weight between the sex (man/woman). One-way repeated analysis of variance (ANOVA) was performed on the ankle ADFROM and PDFROM angle measurements to identify significant differences within interventions and between times. The interaction times between the three interventions were analyzed using two-way repeated ANOVA. Tukey's honesty significant difference (HSD) post-hoc analysis was performed to determine significant differences. Statistical significance was set at $p=.05$.

Results

Twenty-two subjects were recruited, 20 of whom completed the SS, ETS, and ETU interventions and were included in the statistical analysis.

ADFROM comparison among calf muscle stretching interventions

ADFROM was analyzed using multivariate ANOVA to evaluate intervention differences for SS, ETS, and ETU across the 7 time intervals. Comparison between stretching interventions and measurements time were also performed. We found differences in the duration of maintained muscle flexibility of the three interventions. Table 2 and Figure 3 show that ankle ADFROM was significantly different after SS, ETS, and ETU at 6 min ($p<.05$). In the ETS and ETU interventions, a significant improvement in calf muscle flexibility was maintained for 30 min after the stretching protocol compared to the improvement in calf muscle flexibility in the SS intervention, which lasted for only 9 min ($p<.05$). Interaction between the interventions and measurement time was identified ($F=4.64$, $p<.01$).

Further analysis using Tukey's post hoc procedure revealed significant differences between the SS, ETS, and ETU interventions.

PDFROM comparison among calf muscle stretching interventions

The immediate active calf muscle flexibility effect of ETU was greater than that of SS and ETS. In addition, We found differences in the duration of maintained calf muscle flexibility between the three interventions. Table 3 and Figure 4 show that ankle PDFROM was significantly different after SS, ETS, and ETU at 3 min ($p<.05$). In the ETS and ETU interventions, a significant improvement in calf muscle flexibility was maintained for 30 min after the stretching protocol compared to the improvement in calf muscle flexibility in the SS intervention, which lasted for only 6 min ($p<.05$). Interaction between the interventions and measurement time was identified ($F=6.76$, $p<.01$). Further analysis using Tukey's post hoc procedure revealed significant differences between the SS, ETS, and ETU interventions.

Discussion

Calf muscle tightness (i.e., decreased flexibility or increased stiffness) is associated with decreases in ankle dorsiflexion and several other complaints (Middleton and Kolodin, 1992). Our study was con-

Table 2. Active ankle dorsiflexion range of motion in degrees after SS, ETS, and ETU (N=20)

Time (min)	SS[a]	Increment (%)	ETS[b]	Increment (%)	ETU[c]	Increment (%)	F
Baseline	5.53±3.34[d]		5.56±3.95		5.36±2.82		.02
Immediately	12.88±3.84*	132.9	12.83±2.95*	130.8	14.58±3.27*	172.0	1.74
3	12.05±3.97*	117.9	13.23±2.73*	137.9	13.88±2.66*	159.0	1.71
6	9.95±3.02*	79.9	12.50±3.39*	124.8	13.18±2.64*	145.9	6.29†
9	8.10±3.39*	46.5	12.20±3.38*	119.4	12.01±3.10*	124.1	9.86†
15	6.43±2.44	16.3	11.88±3.84*	113.7	11.06±3.31*	106.3	16.35†
30	6.43±2.44	16.3	10.93±4.05*	96.6	9.93±3.60*	85.3	11.36†
F	26.27†		14.99†		49.49†		4.64†

[a]static stretching, [b]eccentric training on stable surfaces, [c]eccentric training on unstable surfaces, [d]mean±standard deviation, *significantly different from baseline ($p<.05$), † significantly different between the interventions ($p<.05$).

Table 3. Passive ankle dorsiflexion range of motion in degrees after SS, ETS, and ETU (N=20)

Time (min)	SS[a]	Increment (%)	ETS[b]	Increment (%)	ETU[c]	Increment (%)	F
Baseline	8.86±1.77[d]		8.83±1.70		8.76±1.84		.02
Immediately	15.33±3.71*	73.0	15.98±3.62*	81.0	17.01±3.29*	94.2	1.15
3	13.90±3.41*	56.9	16.18±3.47*	83.2	16.56±3.17*	89.0	3.68†
6	17.70±2.77*	99.8	15.85±3.58*	79.5	15.98±3.71*	82.4	10.19†
9	9.85±2.32	11.2	15.41±3.24*	74.5	15.05±4.17*	71.8	17.48†
15	8.96±2.06	1.1	14.63±4.49*	65.7	14.88±3.52*	69.9	18.24†
30	8.93±2.17	.8	14.15±3.76*	60.2	13.85±4.05*	58.1	14.57†
F	25.76†		26.85†		47.45†		6.76†

[a]static stretching, [b]eccentric training on stable surfaces, [c]eccentric training on unstable surfaces, [d]mean±standard deviation, *significantly different from baseline ($p<.05$), † significantly different between the interventions ($p<.05$).

ducted to examine the duration of maintained calf muscle flexibility following three different stretching interventions in young adults with limited calf muscle flexibility. This study was designed to answer three hypotheses.

The first hypothesis was that the duration of maintained calf muscles flexibility would differ with the three interventions. We found a difference in the duration of maintained calf muscles flexibility between the three interventions. ETS and ETU significantly increased active and passive calf muscle flexibility for up to 30 min post-treatment. In contrast, SS did not significantly increase muscle flexibility, and the flexibility gained after SS was only achieved for up to 9 min (ADFROM) and 6 min (PDFROM). Our findings indicate that the increase in ankle active and passive DFROM obtained from active control strategies can be maintained for a relatively long period. Similarly, previous findings support the results of our study. Depino et al (2000) reported that four consecutive 30 sec intervals of static stretching were helpful in increasing hamstring flexibility, but this effect lasted only 3 min. Sperrnoga et al (2001) demonstrated a hold-relax technique, which increased hamstring flexibility lasting for a duration of only 6 min. However, we could not clearly explain the differences of duration of maintained calf muscle flexibility with our three interventions. Since our study consisted of a relatively small number of patients, further study with additional patients and further clinical evidence will be required to confirm these findings.

The second hypothesis was that eccentric training will be more effective than static stretching. In this study result, ankle DFROM was significantly greater after static stretching and eccentric training compared with before stretching ($p<.05$). However, the improvement in calf muscle flexibility was maintained for longer with ETS. Our findings indicate that the increases in ankle active and passive DFROM obtained from eccentric training can be maintained for a relatively long period. Some studies have recognized the effects of stretching the calf muscles (gastrocnemius and soleus) by observing resultant changes within the ankle joint ROM. Gajdosik et al (2006) found a significant increase in the dorsiflexion range of motion after 8 weeks of static stretching. Mahieu et al (2007) demonstrated that the ankle dorsiflexion of healthy subjects increased after 6 weeks of eccentric training. The two previous studies examined the effects of static and eccentric stretching on flexibility, respectively.

Static stretching has been established as an effective means to increase ROM around the ankle joint and muscle flexibility (Bandy et al, 1998). This prolonged stretching increases muscle flexibility thus allowing the muscle spindle to adapt over time and stop firing. Sustained passive stretching takes advantage of the inverse myotatic reflex, which promotes muscle relaxation, and hence allows further stretching and ROM. It also controls movement, allowing the stretch to be performed safely, with reduced risk of injury when compared to other types of intervention (Smith, 1994). Conversely, a number of testers have concluded that stretching has no effect on injury prevention. Avela et al (1999) suggested that the decrease in H-reflex recovered quickly and was only limited to the duration of the static stretch. This means that a decrease in the excitatory drive from the Ia afferents onto the alpha motor neurons decreases excitation of the motor-neuron pool, possibly due to reduced resting discharge of the muscle spindles via increased compliance of the muscle-tendon unit. Less responsive muscle spindles could result in a decrease in the number of muscle fibers that are activated later (Beedle et al, 2008).

By contrast, eccentric training involves active lengthening of the muscle-tendon unit (Maffulli et al, 2008). Eccentric contractions are used to decelerate the movement of a body segment from a higher speed to a slower speed or to stop the movement of a joint already in motion. Since the muscle is lengthening as opposed to shortening, the relatively recent change in terminology from muscle contraction to muscle action is becoming more commonly accepted (Nancy and Timothy, 2011). Several hypotheses of eccentric training have been mentioned in previous literature. First, eccentric training could increase such sarcomeres in series, thus increasing the compliance of the muscle fibers (Lynn and Morgan, 1994). Secondly, the effect of eccentric training might lead to increased tensile strength and tendon hypertrophy. Thirdly, the effect of the stretching component of the eccentric training may have a significant influence on the elastic characteristics of the tendon (Paschalis et al, 2007). In previous studies, Nelson (2006) reported that eccentric training (gain=9.48°) through a full range of motion improved hamstring flexibility better then the gains made by a static stretch group (gain=5.05°) or a control group (gain=-1.08°), and our findings corroborate this.

The third hypothesis was that eccentric training will be significantly different from eccentric training on unstable surfaces. We combined eccentric training with balance training to examine the effect of ETS and ETU on calf muscle flexibility. Although there were no significant differences between the interventions, the difference observed was sufficient to determine the clinical value of ETS and ETU. This showed that ETU is a more effective pain-free stretching intervention than ETS. Some previous studies reported greater ankle muscle activation with unstable supportive environments. For example, Anderson and Behm (2005) reported higher soleus activation when squats were performed on an unstable surface rather than a stable surface. Wahl and Behm (2008) also found that an unstable surface induced greater soleus activation in comparison to a stable surface. Calf muscles have traditionally been considered the source of muscle proprioceptive information, which signal changes in body position (Lakie et al, 2003). Muscle sensory organs (i.e. muscles spindle and golgi tendon organs) play a key role in the proprioception of movement. The calf muscle tendon units are sensitive to changes in muscle tension while the spindles are sensitive to changes in muscle fiber length (Proske, 2006). So, it is considerd that if it is trained in lack of stability, it can affect to the length of the muscle fiber because of the operation of spindle. Unfortunately, to our knowledge, no previous randomized studies have compared two stretching interventions on imitated calf muscle flexibility. Therefore, there are no studies with which to compare our results. We cannot explain why the post-intervention findings for ETS and ETU produced no significant results.

Our study on the effects of SS, ETS, and ETU on calf muscle flexibility had several limitations. Firstly, our sample size was small; therefore, the results should be treated with caution, and a larger study should be performed. Secondly, only young subjects were used in the present study, and different age groups might produce different results. Thirdly, carry-over effect could not be minimized. Fourthly, dominant and non-dominant of foot characteristics could not be consider. Fifthly, did not consider loads or stress that applied to the ankle ligaments and around calf muscles. Finally, since we measured the effect on calf muscle flexibility immediately and at 3, 6, 9, 15, and 30 min, the results do not include any long-term effects that may persist beyond 30 min after stretching.

Further study, as well as a longer follow up period, will be necessary to determine which method is more effective. Although these stretching interventions can be described by stretch mechanisms and mechanical muscle properties, it does not seem to be reasonable to compare their stretching effects owing to the present lack of clinical evidence. This study provides a framework upon which further studies can be based in the future.

Conclusion

We found a difference in the duration of maintained calf muscle flexibility between the three interventions. In the ETS and ETU interventions, a significant improvement in calf muscle flexibility (ADFROM and PDFROM) was maintained for 30 min. However, in the SS intervention, ADFROM after 9 min and PDFROM after 6 min were not statistically different from baseline. Our results suggest that ETS and ETU may be more effective than SS for maintaining calf muscle flexibility in young adults.

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