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Relation	

Title:

(English)

Examination of Exercise Load for Recovering Decreased Muscle Strength Caused by Static Stretching

(French)

Examen de la charge d'exercice pour la récupération de la force musculaire réduite via un étirement statique.

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Summaries

(English)

Objectives.

Several studies have demonstrated that muscle strength decreased immediately after static stretching (SS). Therefore, additional exercise is encouraged when SS is performed for warm-up. However, the recommended level of intensity for the additional exercise is unknown. This study aimed to examine the exercise intensity necessary for recovering muscle strength loss following SS.

Equipment and methods.

Eighteen healthy men of recreation sports level (21.4 ± 2.0 years, 173.8 ± 4.5 cm, 67.4 ± 7.7 kg) participated in a randomized crossover trial comprising rest task and two exercise tasks (high- and low-load task). SS comprised left ankle joint plantar flexion for 90 s at an angle of 80% of the maximum angle. Three tasks were set after SS; Rest task and high-load task (120°/s of isokinetic exercise) and low-load task (240°/s of isokinetic exercise). The isokinetic torque of ankle joint plantar flexion and ankle dorsiflexion range of motion (ROM) were measured before stretching (pre-stretching), immediately after stretching (post-stretching), and 5 min after stretching (after 5 min). The three tasks were performed between post-stretching and after 5 min.

Results.

Compared with pre-stretching measurements, isokinetic torque during rest task was significantly lower after 5 min. No significant difference was observed in isokinetic torque between pre-stretching and after 5 min measurements during high-load task. In addition, isokinetic torque of high-load tasks at after 5 min was significantly higher than rest task ($p < 0.05$). No significant difference was observed in ROM between pre-stretching and after 5 min during each task.

Conclusions.

This finding suggested that muscle strength was recovered by high-load task. Exercise at greater intensity is necessary for the recovery of muscle strength.

Keywords: isokinetic torque; range of motion; recovery

(French)

Objectif

Plusieurs études ont montré que la force musculaire se réduisait immédiatement après un étirement statique (ES). Bien qu'un exercice supplémentaire soit recommandé quand un ES est pratiqué pendant un échauffement, le niveau d'intensité recommandé d'un tel exercice n'est pas clair. Le but de cette étude était de vérifier l'intensité d'exercice requise pour la récupération de la force musculaire réduite après un ES.

Méthodes

18 hommes en bonne santé (d'un âge de 21,4±2,0 ans, 173,8±4,5cm, 67,4±7,7kg) de sports récréatifs ont participé à cette étude. L'ES du fléchisseur plantaire de l'articulation de la cheville gauche a été pratiqué à un angle à 80% de l'angle maximal, à 90 secondes d'intervalles. Le couple isocinétique du fléchisseur de l'articulation de la cheville ainsi que l'amplitude de mouvement (AM) de la dorsiflexion de l'articulation de la cheville ont été mesurés pré-étirement, post-étirement et 5 minutes après l'étirement (après 5mn). Trois tâches ont été assignées après l'ES: une tâche de repos, une tâche de charge élevée (mouvement uniforme de 120°/s) et une tâche de charge basse (mouvement uniforme de 240°/s).

Résultats

Le couple isocinétique de la tâche de repos était considérablement plus bas même après 5mn, en comparaison au pré-étirement. Aucune différence significative n'a été trouvée entre pré-étirement et après 5mn pour le couple isocinétique de charge élevée. Par ailleurs, le couple isocinétique de charge élevée passé 5mn était considérablement plus haut que pour la tâche de repos ($p < 0.05$). Aucune différence significative n'a été trouvée entre pré-étirement et après 5mn pour l'AM.

Conclusion

Les résultats de l'étude suggèrent que la force musculaire a été récupérée via la tâche de charge élevée. Un exercice de plus grande intensité est requis pour la récupération de la force musculaire.

Mots-clés: couple isocinétique; amplitude de movement; récupération

1. Introduction

Stretching is performed as a warm-up before exercise and sporting events. It is expected to improve range of motion (ROM)[1] and reduce injury risk by combining other conditioning approaches during warm-up[2]. Previous studies regarding static stretching (SS) have focused on the acute effects of measured muscle strength and performance before and after SS. Many studies have established that muscle strength reduces immediately after SS[3]. A meta-analysis of muscle strength loss associated with SS has concluded that SS has a negative effect on muscular strength[4].

In contrast to SS, Dynamic stretching (DS) has not been found to cause muscle strength loss. Dynamic stretching is a stretching method in which the antagonist muscle is contracted at will, with the goal of relaxing the muscle by reciprocal suppression[5]. DS suggests that muscle strength[6] and muscle activity[7] increase. These findings are important when considering stretching methods before physical activity. Although there is report indicating that short-duration stretches do not cause muscle strength loss[4], a systematic review has shown that if the total stretch time exceeds 60 seconds, not only muscle strength but performance declines. Many researchers do not recommend stretching because the total time for stretching can exceed 60 seconds[3,8].

SS has some advantages as it effectively expands ROM and improves flexibility. In a study comparing stretching methods and ROM effects, SS has been found to be more effective than DS[9]. Improvement in ROM is particularly important for chronic sports injury caused by imbalance and lack of flexibility and SS is an effective means to prevent injury. In fact, for some chronic pain, such as low back pain[10] and baseball elbow[11], and muscle injuries, including muscle strain, loss of flexibility is indicated as a risk factor. By improving flexibility, chronic pain may be prevented. Similarly, for hamstring muscle strain, the loss of flexibility has been reported as an occurrence factor, and stretching before performing an activity is important[12]. In addition, diseases related to growth, such as Osgood-Schlatter disease, are believed to occur due to a lack of muscle flexibility relative to bone growth[13].

The relationship between performance and flexibility has not been established; however, several studies have reported that flexibility affects performance. In particular, ankle joint flexibility can effect jump height[14], posture of the jump landing[15], and dynamic stability[16]. Furthermore, flexibility is important in sports that require a large range of joint movement during the game, such as gymnastics. Therefore, during warm-up, a combination of dynamic stretch and static stretch is performed. When performing SS, additional exercises are encouraged. However, the level of intensity at which the exercise should be performed is unknown. Although the actual warm-up includes sprinting and light exercise in addition to the stretching session, few studies have investigated whether exercise after stretching can restore stretching-induced loss of muscle strength. Viale et al. investigated whether immediate exercise after stretching could reduce stretching-induced loss of muscle strength, and they found that recovery of reduced muscle strength did not occur[17]. However, the only exercise used in the study was knee flexion and extension, which was a low-load exercise. Therefore, it should be confirmed whether a high-load exercise contributes to the recovery of muscle strength. It is difficult to quantitatively set the load and define the optimal exercise intensity necessary for recovery, such as sprints performed during warm-up. In addition, the movement is not isometric and requires dynamic movement. This study aimed to examine the acute effects of resistive exercise on muscle strength following SS and to determine whether the effect differs based on the exercise intensity. If loss of muscle strength due to stretching can be recovered by additional exercise, it can be expected that there will be more options for stretching events. Previous studies investigating the causes of muscle weakness due to SS demonstrate a wide range of effects, such as reduction in firmness caused by the "force-length relationship,[18,19]" physiological factors due to metabolite accumulation[20] or injury,21], and neural factors due to muscle activity reduction[22]. Among them, it has been proven that the influence of neural factors is strong[23]. Neural factors are prominent for 15 min after stretching and have been reported to reach about 40% of the total decrease[24]. As a result of reviewing the neurological effects of SS, Guissard et al.[25] reported that presynaptic and postsynaptic suppression are major changes. These findings indicate that motor neuron hypoexcitability, increased presynaptic and postsynaptic suppression, and changes in spinal cord levels are considered to be the main causes for muscle loss. The excitability of motor neurons such as spinal level has been reported to be dependent on muscle activity[26]. Therefore, muscle activity may recover muscle strength through the action of the nervous system that controls active inhibition mechanisms[27]. It was hypothesized that compared with low-intensity exercise, high-intensity exercise would increase muscle recovery.

2. Material

2.1. Design

A randomized crossover trial design with three types of tasks was used. Participants completed a rest task and two exercise tasks following SS. To determine the effects of varying intensities of the exercise tasks, two types of loading (high- and low-load task) were used. The same protocol for each task was completed with an inter-task interval of at least 3 days.

2.2. Patients or Participants

Eighteen healthy men (19–25 years old) participating in recreational-level sports were recruited by random sampling. Plantar flexion muscles of the left ankle joint were targeted during tasks. Individuals with a severe skeletal muscle injury of the legs within the past 6 months and those with a history of sustained trauma affecting muscle function and exercise capacity were excluded. Participants had a mean age of 21.4 ± 2.0 years, mean height of 173.8 ± 4.5 cm, and mean body weight of 67.4 ± 7.7 kg. All participants were informed of the summary, significance, and risks of the investigation and provided informed consent in writing prior to the experiment. The present study was performed with the approval of the Ethical Review Board of Rehabilitation College Shimane (ID: 20170001).

2.3. Procedures

Figure 1 displays the measurement procedure. Each subject completed warm-up for 5 min on a treadmill before starting the experiment. Muscle strength and ROM were evaluated before stretching (pre-stretching), immediately after stretching (post-stretching), and 5 minutes after stretching (after 5 min). Pre-stretching muscle strength and ROM were used as baseline values. Participants completed a rest task and two exercise tasks following SS. Exercise intensity was set for isokinetic exercise at different angular velocities. The angular velocity for high-load tasks was set to 120°/s and that for low-load tasks was set to 240°/s. Effects of exercise tasks were verified by comparing muscle strength and ROM among all three periods (pre-stretching, post-stretching, and after 5 min).

[insert Figure 1 here]

2.4. Isokinetic torque

The isokinetic torque (Nm/kg) of ankle joint plantar flexion was measured using the Biodex System 3 (Biodex Medical Systems, Inc., USA). Each subject sat on the Biodex seat with the knee in the extended position (0°) and their femur immobilized with a belt. Angular velocity was set to 180°/s[28], and the mean value was calculated from three measurements. The isokinetic torque was normalized by body weight. The rate of change from the pre-stretching values, i.e., baseline values, is shown for post-stretching values and values after 5 min.

2.5. Dorsiflexion ROM of the Ankle Joint

Measurement of the dorsiflexion ROM of the ankle joint was performed in the same position as that in which isokinetic torque measurements were performed. Maximum dorsiflexion angle of the ankle joint was defined as the angle when the test subject's ankle joint was passively extended until the point of discomfort was reached[29]. Dorsiflexion ROM was measured to the nearest tenth of a degree using a digital inclinometer DL-155V (STS, Inc., Japan) installed on the footplate axis of Biodex System 3 (Fig. 2A).

[insert Figure 2 here]

2.6. SS Protocol

Ankle joint plantar flexor muscles were extended for SS using the Biodex System 3 (Fig. 2B). Stretching angle was considered at 80% of the maximum dorsiflexion angle. This stretch protocol was chosen because previous studies showed that a similar stretching angle shown reduce muscle strength[28]. The mean stretching angle of each test subject was 16.9° ± 6.9°. Extension involved continued extension for 90 s, in accordance with the method used by Papadopoulos et al.[30].

2.7. Exercise Task

The exercise task consisted of two exercise tasks (high- and low-load task) and a rest task. This study used isokinetic movement as a dynamic movement task. Pervious study results have demonstrated that angular velocity and load are related[31], and high- and low-load task are defined by angular velocity. The Biodex System 3 was used to perform exercise tasks, such as isokinetic exercise at 120°/s (high-load task) and 240°/s (low-load task). Load setting was selected in reference to a study that analyzed the relationship between maximal isometric strength and isokinetic strength. The 120°/s strength was reported to be approximately 50% of the strength output with maximal isometric contraction and was employed to avoid high strength fatigue[32]. An earlier study exploring the relationship between angular velocity and load has reported that the load increases as the angular velocity decreases[31]. Therefore, the 240°/s condition resulted in a lighter load than the 120°/s condition because the angular velocity was faster. Two sets of five repetitions of high- and low-load task were performed. The inter-set interval was 30 s. Both exercise tasks were completed in the first 2 min of a 5 min period. To avoid potential effects of fatigue, the remaining 3 min were allowed for rest. Rest-task was defined as rest for 5 min on the Biodex seat.

2.8. Statistical Analyses

All data are shown as mean ± SD. Statistical analyses were performed using the Statistical Package for the Social Sciences version 20.0 (SPSS Inc., USA). 3 × 2 repeated measurement ANOVA was used to determine differences between task (rest, high, low) and time (pre, post, after 5 min). When a significance was observed, bonferroni post-hoc analysis was used for the post-hoc test. The significance level was set at an alpha level of 0.05. Effect sizes were calculated using the Cohen d statistic, where $0.2 \leq d \leq 0.5$, $0.5 \leq d \leq 0.8$, $d \geq 0.8$ represent small, moderate, large effects[33].

3. Results

3.1. Isokinetic torque

Changes in isokinetic torque for each task are shown in Table 1. Pre-stretching was not significantly different between each task (rest task: 0.63 ± 0.10 Nm/kg, high-load task: 0.64 ± 0.10 Nm/kg, low-load task: 0.62 ± 0.10 Nm/kg). Although isokinetic torque during all tasks significantly reduced post-stretching (rest task: 0.53 ± 0.10 Nm, high-load task: 0.54 ± 0.11 Nm, low-load task: 0.52 ± 0.11 Nm) compared with pre-stretching ($p < 0.05$), no significant difference was noted among the tasks. Similarly, post-stretching rate of change showed no significant difference among the tasks (rest task: -15.2 ± 7.3 %, high-load task: -15.3 ± 8.0 %, low-load task: -16.5 ± 8.6 %). Isokinetic torque at rest task did not significantly differ from that at post-stretching and after 5 min. In contrast, during high-load tasks, isokinetic torque was significantly higher at after 5 min than at post-stretching ($p < 0.05$). This confirmed that exercise tasks enable the recovery of the lost muscle strength. However, during the low-load task, isokinetic torque remained lower at after 5 min than at pre-stretching. During the high-load task, isokinetic torque at after 5 min was not significantly different compared with that at pre-stretching and was recovered to baseline values (rate of change; rest task: -14.7 ± 6.8 %, high-load task: 0.0 ± 10.0 %, low-load task: -11.5 ± 6.6 %).

[insert Table 1 here]

3.2. Dorsiflexion ROM of the Ankle Joint

Dorsiflexion ROM of the ankle joint for each task is shown in Table 2. No difference was observed among the tasks at pre-stretching, post-stretching, and after 5 min. In all tasks, dorsiflexion ROM of the ankle joint was significantly greater at post-stretching than at pre-stretching ($p < 0.05$). Dorsiflexion ROM after 5 min was not significantly different from that post-stretching, and ROM was maintained.

[insert Table 2 here]

4. Discussion

The effect of SS on muscle strength has been well-reported, with studies focused on analyzing the stretching intensity and methods required to minimize muscle strength loss due to SS. Irrespective of the fact that additional exercises are recommended, the effect of muscle strength when exercise tasks are performed after SS is unknown. Thus, this study aimed to examine the effect of exercise tasks on muscle strength following SS. The study only included male subjects to exclude the sex-related differences. Novel findings obtained from this study indicated that exercise tasks restore muscle strength loss caused by SS and that the recovery of muscle strength requires high-intensity exercise tasks.

To analyze the effect of SS on reduced muscle strength, isokinetic torque was measured over time for three tasks (rest, high-, and low-load tasks). Isokinetic torque at post-stretching was reduced from that at pre-stretching during all tasks, and no significant difference was noted in the rate of change in muscle strength among the tasks. This indicated that the effect of SS was equivalent among the tasks. The rate of change in isokinetic torque is reportedly dependent on the stretching intensity[34]. Weir et al.[35] investigated the relationship between stretching angle and stretch-induced muscle strength loss and have reported that stretching at 80% intensity of maximum angle results in a 14.1 % reduction in muscle strength. The rate of change in isokinetic torque in the present study was in the range of 15.2% – 16.5%, consistent with that in previous studies.

The results of this study indicated that isokinetic torque was recovered by exercise tasks. To our knowledge, this is the first study to observe that the decrease in the muscle strength associated with stretching is recovered by exercise. In particular, isokinetic torque during the high-load task was not significantly different between pre-stretching and after 5 min and was restored to baseline values. As mentioned in the introduction, many studies that investigated the causes of muscle strength loss have been reported. Reported causes of muscle strength loss include mechanical factors[18,19], physiological factors[20,21], and neural factors[22]. However, although the detailed mechanism that causes muscle strength loss is unclear, a previous study has demonstrated that neural factors have a strong influence[23]. It has been well established that muscular contraction contributes to motor neuron excitability[36] and that muscle contraction increases excitability on a spinal cord level. Guissard et al.[37] reported that an ankle dorsiflexion of >10°reduces motor cortex excitability, affecting not only spinal level changes but also cortical level changes. Recent studies have confirmed that in movements of peripheral joints, such as the fingers, motor cortex excitability increases, suggesting that both the spinal cord and the brain are affected. One study that examined periodic changes in EMG and recovery of muscle strength has demonstrated that EMG and recovery of muscle strength occur simultaneously[38]. Based on these reports, it was hypothesized that the recovery of isokinetic torque increases due to motor neuron stimulation by muscle contraction.

Other effects, such as changes in muscle elasticity, are thought to impact muscle strength[39]. Cramer et al.[24] found a positive correlation between muscle-tenoid complex stiffness and torque generation rate, indicating that the mechanical properties of the tendon may account for up to 30% of RTD variability. Acute muscle stretching is hypothesized to decrease the stiffness of the muscle tendon according to the force-length relationship. In this study, the effect of changes in muscle elasticity was confirmed by simultaneously measuring the dorsiflexion ROM of the ankle joint. In all tasks, no significant difference was observed in the dorsiflexion ROM of the ankle joint at after 5 min and post-stretching. This suggested that although exercise tasks impacted isokinetic torque, effects on changes in elasticity were small. Accordingly, in the recovery of isokinetic torque through exercise tasks, neural changes may be more impactful than changes in elasticity. Results obtained in a previous study that examined periodic changes in ROM and muscle strength associated with SS are comparable to our findings, and it has been reported that the recovery of ROM and muscle strength is inconsistent. Although the cause of stretching-induced reduction in muscle strength remains controversial, the results of this study will be useful to understand the mechanism of stretching-induced loss in muscle strength. However, the present study did not measure electromyography. We were unable to determine the cause of muscle strength recovery. Although our study indicated that post-stretching activity may potentially contribute to recover muscle strength, additional studies are warranted to confirm this factor.

Isokinetic torque during the low-load task at after 5 min remained lower than that at pre-stretching. In contrast, isokinetic torque during the high-load task at after 5 min was not significantly different from that at pre-stretching, and recovery to baseline level was observed. This suggested that the recovery of muscle strength lost due to SS requires high-intensity exercise. Exercise intensity was set based on angular velocities of 120°/s and 240°/s. Other studies examining the effects of post-stretching exercise have found that light exercise does not restore muscle strength[17]. Previous studies investigating the relationship between angular velocity and muscle activity have also shown that decreasing angular velocity increases muscle activity[40]. High peak torque causes high muscle activity and increases motor neuron stimulation. Therefore, reduced muscle strength caused by SS is recovered most efficiently through the 120°/s task. Based on this result, exercise intensity of moderate load of ≥120°/s is recommended to recover the muscle strength lost due to SS. It is assumed that this result contributes to the setting of exercise intensity after stretching.

In a recent meta-analysis, a short stretching period of <45s was shown to have less effect on muscle strength[3,4]. A systematic review has shown that stretch periods of over 60 seconds are detrimental to athletic performance[3]. Thus, SS for short period can be executed during warm-up. However, the time covered in these studies is the total time of the stretch, and the actual warm-up may not finish in a short time . In particular, it is likely to be a competition that requires a large joint movement area during the competition like gymnastics[41]. Another study examining the relationship between SS duration and enlarged ROM angle has reported that SS for ≥30 s is effective, SS performed for a short period has no effect[42]. Although SS performed for a short period might not affect muscle strength, the improvement in ROM is a topic worth exploring. In the study by Behm et al.[29] focusing on injury prevention, SS performed for a long time has been found to be more effective for injury prevention than that performed for a short time. If the purpose of stretching during warm-up is to improve ROM and prevent injury, sports coaches and specialists must acknowledge that sufficient stretching time is merited. Our study results indicated that isokinetic torque recovers with exercise tasks following SS. In some studies, SS is not recommended as a warm-up exercise; however, considering that the loss in muscle strength due to SS can be recovered with exercise, it can be used for warm-up. This result may be useful when considering stretching methods in warm-up prior to sports activities.

We used constant-velocity exercise to quantify exercise load, but this study had limitations. Although constant-velocity exercise was selected as the dynamic exercise load, the exercise speed of 120°/s was higher load than 240°/s, but the movement speed was slower. The exercise time was different between the tasks because both exercises had the same number of repetitions, and 120°/s took twice as long as 240°/s. Therefore, it is difficult to completely control exercise load and time. In addition, this study showed strength recovery at 120°/s, which has not been investigated using actual exercise. It is unclear how much of the whole-body exercise does this exercise represent. Therefore, our future study will examine how much whole-body movement contributes to recovery.

5. Conclusion

In the majority of studies to date, SS was avoided during warm-up because of the associated muscle strength loss, regardless of the fact that SS is more effective than DS for improving ROM and preventing injury. Thus, the present study verified the effect of exercise task performances after SS on the recovery of isokinetic torque.

Our results demonstrated that exercise following SS recovers the lost muscle strength. Furthermore, recovery differs according to the exercise intensity. High-intensity exercise was found to help recover muscle strength lost due to SS.

Disclosure of interest

The authors declare that they have no competing interest.

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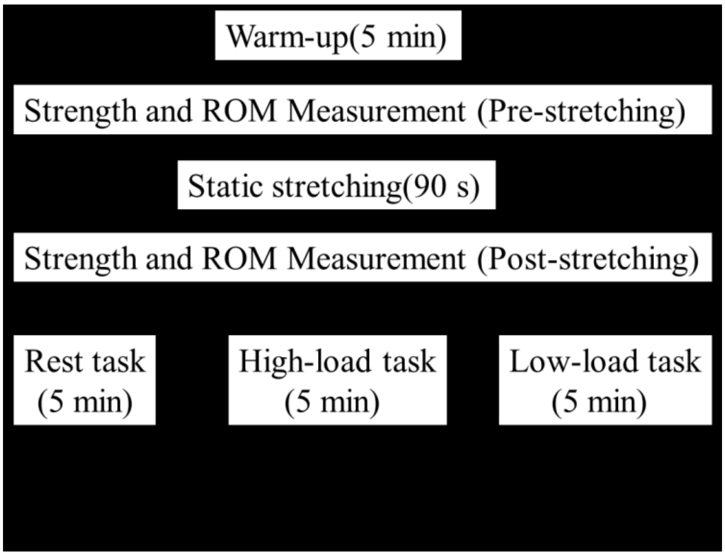

Figure 1　Flow chart of experimental protocol

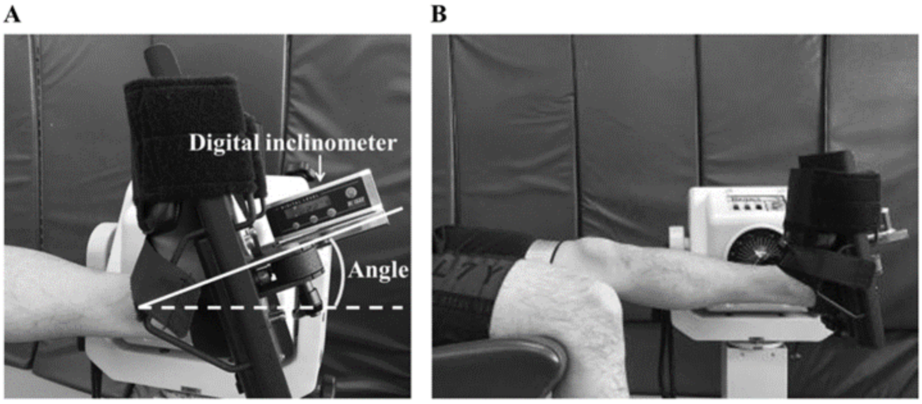

Figure 2. ROM measurement and stretching setting

(A) Device setting and angle used for ROM measurement.

The joint angle was defined the angle between the horizontal line and the instrument axis

(B) Stretching position.

The SS was fixed at an angle of 80% of the maximum angle.

Table 1. Isokinetic torque (Nm/kg) at pre-stretching, post-stretching, and 5 min after stretching period (±SD)

Task	Rest	High	Low	p value group	p value time
Pre- stretching	0.63 (0.10）	0.64 (0.10)	0.62 (0.10)	n.s.	(Pre vs Post) Rest: $p<0.05$, ES=0.94 High: $p<0.05$, ES=0.93 Low: $p<0.05$, ES=0.94
Post- stretching	0.53 (0.10)	0.54 (0.11)	0.52 (0.11)	n.s.	（Post vs After 5min） High：$p<0.05$, ES=-0.84
After 5 min	0.54 (0.10)	0.64 (0.13)	0.55 (0.10)	(Rest vs High) $p<0.05$, ES=-0.60	(Pre vs After 5 min) Rest：$p<0.05$, ES=0.89

Table 2. Dorsiflexion ROM of the ankle joint (°) at pre-stretching, post-stretching, and after 5 min (±SD)

Task	Rest	High	Low	p value group	p value time
Pre-stretching	22.8 (4.3)	22.1 (4.3)	21.6 (4.3)	n.s.	(Pre vs Post) Rest: $p<0.05$, ES=0.96 High: $p<0.05$, ES=0.95 Low: $p<0.05$, ES=0.91
Post-stretching	26.9 (4.3)	26.4 (4.8)	25.7 (4.7)	n.s.	n.s.
After 5 min	26.7 (4.4)	26.1 (4.6)	25.6 (5.0)	n.s.	(Pre vs After 5 min) Rest: $p<0.05$, ES=0.91 High: $p<0.05$, ES=0.90 Low: $p<0.05$, ES=0.86

No significant difference was observed between tasks for dorsiflexion ROM of the ankle joint among the three periods.