



## The test-induced warm-up effect on hamstring flexibility tests

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**Background:** Although the effect of active warm-up (WU) on acute flexibility enhancement is well documented, the test-induced WU effect in muscle length test has not been widely studied.

**Objective:** This study aimed to verify the test-induced WU effect on hamstring flexibility tests.

**Methods:** The active knee extension (AKE) was performed using the right leg, whereas the straight leg raise (SLR) was performed using the left leg. Ten trials of AKE or SLR were performed: two as the pre-intervention trials (Pre); six as the WU intervention; and another two trials as the post-intervention (Post). During WU, subjects in the WO-Hold group performed six trials of the AKE or SLR without hold, and those in the W-Hold group performed six trials of the AKE or SLR with a 5 s hold.

**Results:** A significant difference was noted between Pre-AKE and Post-AKE, and between Pre-SLR and Post-SLR, respectively, in both the groups. The effect of WU is clear when performing consecutive AKE or SLR without any additional hold.

**Conclusion:** Practitioners should be cautious in interpreting the testing result to avoid overestimation of the treatment effect since the test itself may induce substantial WU effect to the target tissues.

**Keywords:** Active knee extension; muscle tightness; range of motion; straight leg raise.

## Introduction

Both active knee extension (AKE) and straight leg raise (SLR) tests can be used to measure muscle length without the need for a specialized, high-cost equipment.<sup>1</sup> The intra-trial reliability has been shown to be high between individuals with muscle tightness and those with normal muscle length.<sup>2–5</sup> The AKE and SLR tests have long been used in clinical practice to diagnose hamstring tightness. However, there are currently no specific guidelines addressing whether warm-up (WU) should be performed before measurements.

The traditional method of WU generally involves a short period of light running or stair climbing, which would slightly increase body temperature at submaximal intensity.<sup>6,7</sup> Increased body temperature is known to increase nerve conduction velocity and enzymatic cycling.<sup>8</sup> However, the increase in hamstring flexibility following stretching was not maintained simply through walking, as reported in a previous study.<sup>9</sup> Additionally, passive WU with an increase in superficial temperature prompted by a thermal modality did not significantly affect hamstring flexibility.<sup>10</sup> For measuring inherent muscle length, WU with a more direct impact on the muscle–tendon unit (MTU) appears to be necessary. For the SLR test, traditional active and passive WU methods are still widely used. On the other hand, some studies have attempted more direct methods that deviate from conventional practice for the AKE test.<sup>11,12</sup> Depino incorporated six trials of AKE as WU before static stretching, considering the 6th measurement as the baseline.<sup>13</sup> Spernoga also incorporated six trials of AKE before proprioceptive neuromuscular facilitation (PNF) stretching, considering the 6th measurement as the baseline, similar to Depino.<sup>14</sup> These two studies, however, did not include muscle length measurements before WU, while applying WU to more accurately measure inherent muscle length in individuals. As such, the actual effect of WU could not be identified. It is noteworthy that as time passed after WU, the control group without stretching exhibited a gradual decrease in flexibility. The variation was approximately 7.5° after 30 min in the study of Depino and approximately 8.9° after 32 min in the study of Spernoga. These findings indirectly suggest that WU exhibited an effect of causing a certain level of increased flexibility. If such a positive effect of WU is verified, it should be recommended as a mandatory step

preceding the tests<sup>8</sup>; otherwise, inherent muscle length may be under-evaluated, which may in turn overestimate the effect of the intervention.

This study aimed to verify the test-induced WU effect on hamstring flexibility tests. Two types of WU were applied: in one group, subjects performed six consecutive trials of the AKE or SLR test, while subjects in the other group were required to perform six consecutive trials of the AKE or SLR test with a 5 s hold upon reaching the maximal range of motion (ROM).

## Methods

### Subjects

Thirty healthy collegiate students with hamstring tightness ( $\text{AKE} > 20^\circ$ ) participated in this study (Table 1). Individuals with a history of surgery of the hip, knee, and ankle joint(s) and those who experienced pain in the lower extremity within the previous 6 months were excluded. This study was approved by the Institutional Review Board of Woosong University, and informed consent was obtained from all subjects.

### Procedures

Subjects were randomly assigned to two groups, with the AKE test performed on the right leg and the SLR test performed on the left leg (Fig. 1). In each group, the AKE or SLR test was performed for a total of 10 trials. First, for educational purposes before WU, the AKE (Pre-AKE) or SLR (Pre-SLR) test was performed twice in total. A 2 min rest was given after two trials. Next, for the purpose of WU, six trials (WU-AKE or WU-SLR), which were used in the previous studies,<sup>13–15</sup> were

Table 1. Subject characteristics. In the WO-Hold group, the AKE (or SLR) test was performed without hold. In the W-Hold group, the AKE (or SLR) test was performed with hold (5 s at the maximal ROM).

Group	Age (year)	Height (cm)	Weight (kg)
WO-Hold ( $n = 15$ )	$21.3 \pm 2.5$	$167.9 \pm 8.3$	$63.1 \pm 11.7$
W-Hold ( $n = 15$ )	$22.4 \pm 2.2$	$166.2 \pm 8.4$	$61.8 \pm 12.3$

*Notes:* In the WO-Hold group, the AKE (or SLR) test was performed without hold. In the W-Hold group, the AKE (or SLR) test was performed with hold (5 s at the maximal ROM).

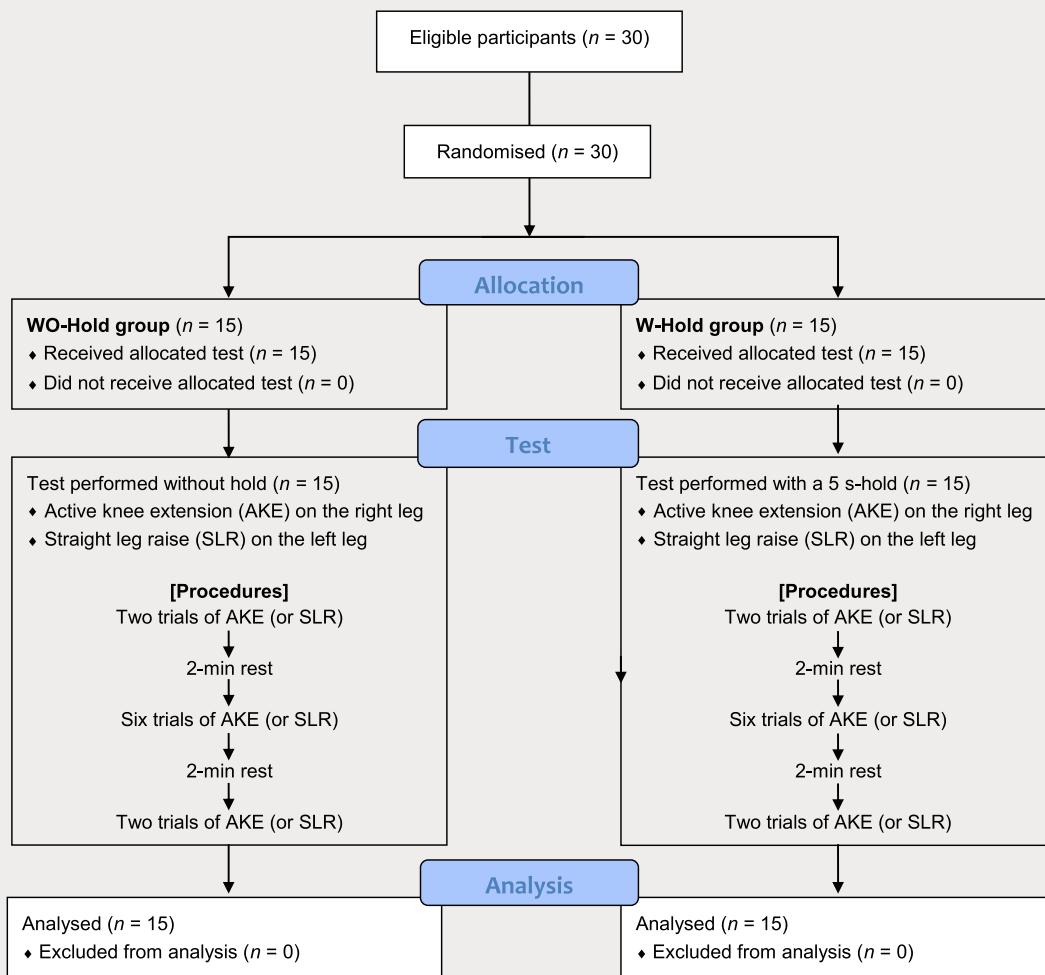


Fig. 1. CONSORT flowchart diagram of this study. Subjects were randomly assigned to two groups.

performed in addition. After six trials, a 2 min rest was given. Then, the AKE (Post-AKE) or SLR (Post-SLR) test was performed twice in total once again. During WU, in the WO-Hold group, six trials of the AKE or SLR test were performed without hold (less than 1 s at the maximal ROM). In the W-Hold group, six trials of the AKE or SLR test were performed with hold (5 s at the maximal ROM).<sup>16</sup> The trials were consecutive without rest or hold between trials.

For the AKE test, subjects were in the supine position, with the pelvis and left leg securely fixed to the table using straps. After 90° flexion of the hip and knee joints on the right leg, subjects slowly performed knee extension with the ankle relaxed in plantar flexion. The end point was reached when they could no longer extend their knees without myoclonus.<sup>17</sup> Hip flexion was maintained at 90° using a metal frame. To measure ROM, a clinometer application (Plaincode Software Solutions, Stephanskirchen, Germany) installed on an iPhone

11 (Apple Inc, Cupertino, CA, USA) was used. This application has been shown to be highly reliable and valid in measuring joint ROM and the smartphone devices provide comparable results to traditional manual testing.<sup>18,19</sup> The smartphone was placed on the axis of the lateral epicondyle of the femur, parallel to the lateral malleolus of the fibula.<sup>3</sup> The calculation for AKE was “90° — measured angle by smartphone”.<sup>20,21</sup>

Similarly, for SLR test, subjects were placed in the supine position, but with the pelvis and right leg securely fixed to the table using straps. Subjects slowly performed hip flexion with the ankle relaxed in plantar flexion. The end point was reached when they could no longer raise their legs any further without a stretch sensation in their posterior thigh.<sup>22</sup> ROM was measured at maximal hip flexion using the clinometer. The smartphone was placed on the axis of the femoral greater trochanter, parallel to the midline of the femur in reference to the lateral epicondyle. The

“measured angle by smartphone” was recorded for SLR.<sup>23,24</sup>

Both AKE and SLR tests have excellent test-retest reliability.<sup>4</sup> The tests in this study were conducted by a physical therapist who has 15 years of clinical and experimental experience and has participated in similar studies several times.<sup>18,19</sup>

## Data analysis

The Shapiro-Wilk test was used to assess data normality. The Mann-Whitney U test was used to examine the difference in age between WO-Hold group and W-Hold group. The independent samples *t*-test was used to examine the difference in height and weight. The repeated measures ANOVA was used to examine the difference in the AKE and SLR measured before, during, and after WU. The paired-samples *t*-test was used to examine the difference in AKE between the 1st and 6th trials of AKE during WU. Additionally, the repeated measures ANCOVA with the independent samples *t*-test (normalized to 1st trial of WU) was performed to examine differences in the AKE and SLR between WO-Hold group and W-Hold group. Data analysis was performed using SPSS version 25 (IBM Corp., Armonk, NY, USA), and differences with *p* < 0.05 were considered to be statistically significant. Values are presented as mean ± standard deviation, except in the figures, in which they are expressed as mean ± standard error.

## Results

No significant differences were noted in age, height, or weight between subjects in the WO-Hold group and W-Hold group (Table 1). In the WO-Hold

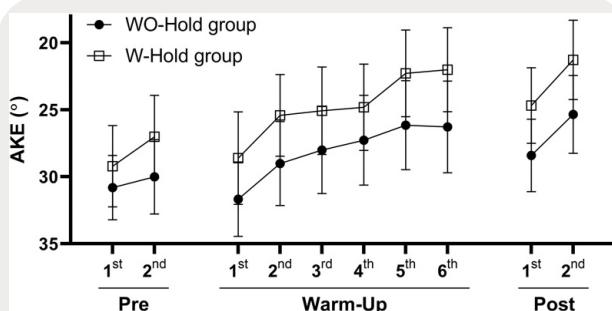


Fig. 2. Changes in AKE over trials. The AKE was performed in a total of 10 trials: Two trials before and after WU and six trials during WU.

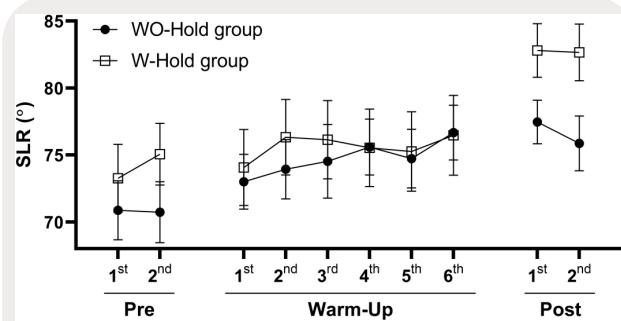


Fig. 3. Changes in SLR over trials. The SLR was performed in a total of 10 trials: Two trials before and after WU and six trials during WU.

group, a significant difference was noted in AKE between Pre-AKE and Post-AKE (*p* = 0.027) and between the 1st and 6th trials of WU-AKE (*p* = 0.008) (Fig. 2) and in SLR between Pre-SLR and WU-SLR (*p* = 0.001), between Pre-SLR and Post-SLR (*p* = 0.008), and between the 1st and 6th trials of WU-SLR (*p* = 0.010) (Fig. 3). In the W-Hold group, a significant difference was noted in AKE between Pre-AKE and Post-AKE (*p* = 0.025) and between the 1st and 6th trials of WU-AKE (*p* = 0.014), and also noted in SLR between Pre-SLR and Post-SLR (*p* < 0.001) and between WU-SLR and Post-SLR (*p* = 0.001). In the tests of between-subjects effects, the analysis shows that the effect of the group on AKE was not significant (*p* = 0.449) and the effect of the group on SLR was also not significant (*p* = 0.580). The normalized 2nd trial of AKE was not significantly different between groups (*p* = 0.753), but that of SLR was significantly different between groups (*p* = 0.029). Cohen's *d* effect sizes for the between-groups comparison of the Pre-post changes of AKE and Pre-post changes of SLR was 0.234 and 0.412, respectively.

## Discussion

The AKE or SLR was performed in a total of 10 trials: two as the pre-intervention trials (Pre); six as the WU intervention; and another two trials as the post-intervention (Post). In a clinical setting, one or two trials can be performed before official documentation for the purpose of demonstration. As such, to ensure as similar a progression as possible, two trials were performed before WU.<sup>25</sup> In addition, measurements are often repeated in a short period immediately after a single bout of stretching, therefore, two additional trials are

performed after WU for a similar progression.<sup>21,26</sup> In this study, a significant increase was noted in flexibility for both the AKE and SLR because the WU imparted direct physical stress on the MTU. The increase was gradual through the six consecutive trials, and once increased flexibility, did not immediately decrease even after a set period of rest. Interestingly, the Post-AKE and Post-SLR values recorded after a 2 min rest were significantly higher than the Pre-AKE and Pre-SLR values, respectively. This suggests that repetitive testing procedures potentially induce the WU effects from physiological perspective (e.g., increase of tissue temperature) and psychological perspective (e.g., increase of pain tolerance) that lead to the enhanced flexibility measurement. In clinical practice, clinicians who frequently use warm up should be aware that an insufficient interval between WU and consecutive flexibility tests could induce an increase in flexibility.<sup>13,14</sup> The reason for retention of the increased level of flexibility, even after a set period of rest, is presumably the paradoxically low intensity of the physical stress imparted by WU. In a previous study, PNF stretching was performed at 100%, 70%, 40%, and 10% of maximal voluntary isometric contraction intensity, and an increase in flexibility was observed 3 min after stretching at the moderate-low intensities of 40% and 10% rather than that at the high intensity of 100%.<sup>26</sup> In the stress-strain curve, the relevant tissue may not fully return to its original length at the toe region even if physical stress is ceased.<sup>27,28</sup> However, if more stress is imposed beyond the toe region, the tissue strongly tends to return to its original length.<sup>29</sup> This elastic force is produced by stretched non-contractile tissues, which comprise a series of elastic and parallel elastic components. Given that the low-intensity stretch mainly focuses on series elastic components such as titin whereas the tendency to return to the original length could vary according to stress intensity as each intensity of physical stress may elicit a response from different tissues.<sup>30</sup> Apparently, our findings somewhat concur that moderate-to-low intensities of test-induced WUs without holding at the end range were sufficient to enhance hamstring flexibility especially for subjects with muscle tightness. Care should be exercised, however, because the effect of WU may be maintained for a certain period. If an intervention is applied immediately after WU, the therapeutic effect may not be entirely representative of the intervention.

To mimic the real-life clinical situation where typically a few seconds are required for reading and recording the testing results, W-Hold condition was adopted. It was supposed to reflect the existence of an additional test-induced WU effect after holding at the end range for 5 s, as previous studies showed clear flexibility enhancement effects using 5 to 6 s of isometric contraction.<sup>31–33</sup> In contrast to the prediction, no significant effect was found for AKE; but Post-SLR showed a significant difference in normalized flexibility between groups. The SLR demands that the entire lower extremity withstand gravity to maintain hip flexion, thereby requiring a relatively higher intensity of isometric contraction, as observed in this study.<sup>26</sup> On the other hand, the AKE can be performed with low-intensity isometric contraction since it involves only knee extension while the hip is fixed at 90° flexion.<sup>34</sup> Despite the lack of significant variation in AKE, it is noteworthy that the overall flexibility was greater in the W-Hold group. Given that significant differences were identified in the SLR, it could be inferred that the “with a 5 s hold” condition may be considered a more effective approach. However, “without hold” condition has already demonstrated a substantial increase in flexibility, and further increments could potentially lead to stretching rather than WU, hence it is not recommended. Specifically for the SLR, participants might unnecessarily activate the trunk muscles to maintain maximal hip flexion with full knee extension for 5 s.<sup>35,36</sup> Consequently, it was determined that performing “six trials without hold” was more appropriate, aligning with the study’s goal of selectively assessing hamstring length.

In this current study, the muscle flexibility was exclusively assessed through physical examinations/maneuvers such as the AKE and SLR. Further researches should consider incorporating electromyography and/or ultrasound for more comprehensive and specialized analyses. Electromyography can provide insights into the neuro-mechanical function of muscles, and ultrasound-based shear wave elastography measures muscle stiffness, including the hamstrings and quadriceps.<sup>37,38</sup> Furthermore, it is advisable to include control group in future research, with groups using an active WU consisting of running and/or a passive WU using a heat modality. To minimize the potential for bias, the order in which AKE and SLR tests are administered should be randomized.

Two different test-induced WU were examined in this study. Both resulted in a significant enhancement in flexibility over six consecutive trials. Unlike AKE, only an indirect WU is performed prior to SLR. However, as shown in this study, test-induced WU effect on muscle flexibility was significantly effective. Since the increased flexibility persisted for a minimum of 2 min following the six consecutive trials, it may be necessary to control the number of WU repetitions to assess the pure effect of interventions (e.g., stretching). Notably, performing the WU with a 5 s hold could potentially induce an additional test-specific WU effect on the target muscle that may mask part of the treatment effect.

## Conflict of Interest

The author has no conflict of interest.

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## Author Contributions

Conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing, visualization, and funding acquisition were carried out by Wootaek Lim.

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