



Original Research

Jack-knife stretching and active knee extension stretching equally improve the relative flexibility of the hamstring muscles between the low back: A randomized controlled trial

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1. Introduction

The relative flexibility between muscles acting on the lumbar spine and those muscles in adjacent areas has gained considerable research interest because impaired dynamic control of the lumbar spine may be associated with low back pain (LBP) (Miller, Sahrman, & Avers, 2017; Van Dillen et al., 2001; Van Dillen, Maluf, & Sahrman, 2009). Some stratified models of care for LBP include assessments of dynamic control of the lumbar spine (Comerford & Mottram, 2012; Sahrman, 2001); the hamstring muscle is one example. During hamstring stretching, we should consider the influence of the relative flexibility between the hamstring muscles and the low back.

Several methods for hamstring stretching can be considered; in particular, Jack-knife stretching (JKS) is an increasing concern (Sairy et al., 2012). JKS has appeared in mass-media, popular magazines, and educational news for children and has been undertaken in physical education classes as a warm-up exercise in all elementary schools, junior high schools, and high schools in one

prefecture in Japan (Nagasaki Prefecture Action Report in 2018, 2019). Effects of JKS on the finger-floor distance (FFD) (Nishimoto et al., 2016; Sairy et al., 2013; Wakabayashi et al., 2017), lumbopelvic rhythm during flexion in standing (Matsunaga, Okubo, & Kaneoka, 2013), and injury prevention (Mori, Wakabayashi, Osuga, & Aoki, 2013; 2014) have been reported over the last five years. Sairy et al. (2013) demonstrated that a 4-week intervention with this stretch increased FFD to the average of 22.2 cm in young people.

JKS initiates with a full squat while holding the ankle joints with both hands. Subsequently, the knees are extended, with the chest remaining in contact with the thighs. However, the low back is stretched during the JKS or at least at the initial position, which may decrease the gain in the relative flexibility between the hamstring muscles and the low back. However, Kendall, McCreary, Provance, Rodgers, and Romani (2005) recommended active unilateral knee extension in the sitting position while maintaining the lumbar spine in a neutral position (AKES) hamstring stretching. This procedure was additionally proposed by Comerford and Mottram (Comerford & Mottram, 2012) and Sahrman (Sahrman, 2001) as an exercise to improve dynamic control of the lumbar spine. Thus, AKES may increase the relative flexibility between the hamstring muscles and the low back more than JKS.

The investigation of exercises that effectively increase the relative flexibility between the hamstring muscles and the low back can support the identification of optimal exercises for dynamic control of the lumbar spine. This study aimed to compare the effects of JKS and AKES on the relative flexibility between the hamstring muscles and the low back.

2. Materials and methods

2.1. Design

This study was a single-center, assessor-blinded, parallel group randomized controlled trial (RCT), where two groups received JKS and AKES, respectively. All participants provided written consent before data collection. This study was granted ethical approval by an institutional review board (No. 27780) and was pre-registered in

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the UMIN Clinical Trials Registry (UMIN000019343). The target sample size information was updated in this registry following sample size estimation.

2.2. Participants

Using convenience sampling, we recruited participants with lumbar kyphosis that occurred during right knee extension to 10° flexion, which is suspected to be impaired function (Kendall et al., 2005). Participants were recruited by advertising within the university from October 2015 to March 2016. Inclusion criteria were as follows: 1) age, 18–75 years and 2) no symptoms or mobility deficits in the hips or knees. Exclusion criteria were altered lumbar curvature or with any change in symptoms during active unilateral knee extension to 10° flexion in the sitting position (AKEiSit) while changing the ankle position from dorsiflexion to plantarflexion.

2.3. Measures

The primary outcome measure of the relative flexibility between the hamstring muscles and the lower back was assessed using lumbopelvic sagittal alignment (θ) during the AKEiSit test. We assessed the θ value during the AKEiSit test at baseline and at a 5-week follow-up. Reliability of the θ value during the AKEiSit test was demonstrated using a flexible ruler in previous studies (Yasuda, Nishimoto, Hori, Noguchi, & Takasaki, 2017; Takasaki, Kikkawa, & Hall, 2018). In this study, we used an established procedure (Yasuda et al., 2017) for determining the θ value. Briefly, we standardized the 10° angle of knee flexion with a metal orthosis (Fig. 1) [8] and traced the lumbopelvic curvature from Th12 to S2 during the AKEiSit test on paper using a flexible ruler (Shinwa Rules Co., Ltd., Tsubame, Niigata, Japan). Previous studies have demonstrated that five repetitions were required to obtain stable, reliable mean values for this procedure (Takasaki et al., 2018; Yasuda et al., 2017). Therefore, an examiner who was blinded to participants' allocations repeated the measurement five times, and the mean



Fig. 1. Standardization for the measurement of active right knee extension to 10° flexion in the sitting position.

Source: Yasuda M, Nishimoto K, Hori M, Noguchi T, Takasaki H. The effect of active knee extension in sitting on lumbopelvic curvature in individuals with clinically tight hamstring muscles: A cross-sectional reliability study. *Open Journal of Therapy and Rehabilitation*. 2017; 5: 139–147.

value of the five data points was used as a representative value for each participant. We calculated the θ value using two different methods: the 2-point-method and max-method. The detailed information of these methods has been described in previous studies (Takasaki et al., 2018; Yasuda et al., 2017). The 2-point-method reflects the Cobb angle on the X-ray while standing (intra-class correlation coefficient [ICC] = 0.94–0.96) (Eslam, Aslan, Zahra, & Saleh, 2012); in contrast, the max-method is more convenient than the 2-point method. For the 2-point-method, ICCs for inter-examiner and inter-session reliability were 0.93 (95% confidence interval [CI] = 0.84–0.97) and 0.97 (95% CIs = 0.92–0.98), respectively (Yasuda et al., 2017); for the max-method, they were 0.91 (95% CIs = 0.79–0.96) and 0.91 (95% CIs = 0.81–0.96), respectively (Takasaki et al., 2018).

In brief, in the 2-point-method, we calculated the angle between two tangential lines at the Th12 and S2 vertebral levels drawn on a trace line of the lumbopelvic curvature using the ImageJ software (National Institute of Mental Health, Bethesda, USA) (Fig. 2). In the max-method, we calculated the length between the Th12 and S2 vertebral levels (L) and the maximum depth to the curvature (H) from the trace line and determined the θ value (Fig. 2) using the following formula:

$$\theta = 4 \text{ Arc tan } \frac{2H}{L}$$

A positive and negative θ value indicated lumbar kyphosis and lordosis, respectively. An examiner who was blinded to the participants' group allocations calculated the θ values.

L, length between the Th12 and S2 vertebral levels; H, the maximum depth to the curvature from the trace line of the lumbopelvic curvature.

The secondary measure was the presence of LBP and demographics. At the baseline assessment, we asked participants if they had experienced at least one episode of LBP during the previous one month. Furthermore, we asked participants to record the occurrence of any episodes of LBP during the 5-week follow-up period. The operational definition of an episode of LBP was pain in the low back with an intensity >2 on the 11-point numerical rating scale lasting for >2 consecutive days (de Vet et al., 2002; Stanton, Latimer, Maher, & Hancock, 2009, 2011). We categorized the participants of the two stretching groups into four subgroups (1–4) according to LBP status: 1) at least one episode of LBP during the month before the baseline assessment with no further episodes of LBP in the five weeks prior to the follow-up assessment; 2) no episodes of LBP during the month before the baseline assessment or in the five weeks prior to the follow-up assessment; 3) at least one episode of LBP during the month before the baseline assessment and at least one episode during the five weeks prior to the follow-up assessment; and 4) no episodes of LBP during the month before the baseline assessment with at least one episode of LBP in the five weeks prior to the follow-up assessment. Demographics included age, sex, and body mass index (BMI) calculated based on height and weight.

2.4. Interventions

Garber et al. (2011) recommended stretching exercises for 60 s per day for >2 days per week. A previous study (Sairy et al., 2013) using a protocol based on JKS for 50 s per day every day for four weeks demonstrated significant differences from baseline in FFD and pelvic forward inclination angle. Therefore, our study included interventions that at least matched the intensity of those used in the previous study (Sairy et al., 2013). Regarding a protocol for the active stretching method, Roberts et al. (1999) demonstrated that

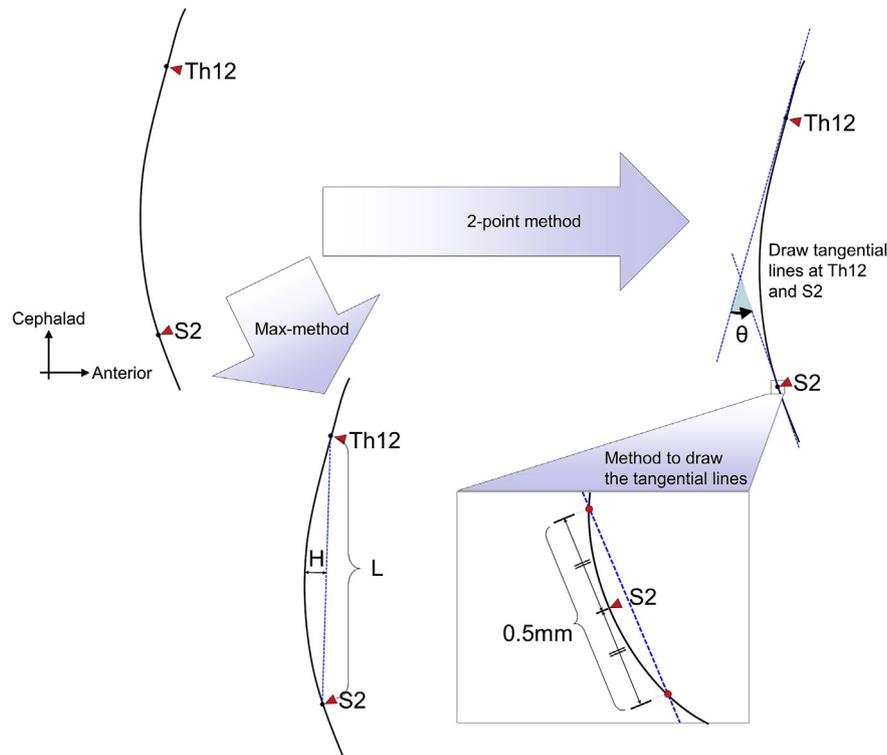


Fig. 2. Schema for calculations of the angle of the lumbopelvic curvature angle during unilateral active knee extension in the sitting position (θ) using the ImageJ 1.6 software.

stretching exercises with holding for 15 s had a greater stretching effect than those with holding for 5 s. Furthermore, they demonstrated a stretching effect with exercises performed for 45 s per day for five weeks (Roberts & Wilson, 1999); thus, in our study, a 5-week intervention was considered to be appropriate to detect exercise effects in either group. However, the total stretch time of 45 s that Roberts et al. (1999) used was shorter than that reported by Garber et al. (2011). Therefore, to achieve a robust effect in our study, stretching exercises were performed for 60 s (holding for 15 s with four repetitions) per day as proposed by Garber et al. (2011). We estimated an exercise compliance rate of 33.3%. Therefore, a total stretching time of at least 60 s was achieved by asking participants to perform stretching exercises three times per day. The final stretching protocol for each group included stretching exercises with holding for 15 s with four repetitions and three sets per day for five weeks. We asked participants to record the completion of each set in an exercise diary. The time of the exercise was not controlled.

In the JKS procedure (Fig. 3), the initial posture was a full squat with feet apart and hands holding onto the ankles. Subsequently, participants actively extended the knee as much as possible while the chest and thighs remained in contact, with holding for 15 s.

In the AKES procedure (Fig. 3), the participants actively tilted the pelvis anteriorly as much as possible in the sitting position. Subsequently, participants actively extended one knee as far as possible while holding the anterior pelvic rotation for 15 s. This was performed on both sides.

2.5. A priori-sample size estimation

We estimated the sample size estimation using an internal pilot study with 10 participants as recommended by Sandvik, Erikssen, Mowinckel, and Rodland (1996). Using data from 10 participants in each group, G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007)

was used to demonstrate that 36 participants were required in the max-method (effect size, $f = 0.65$) and 44 participants in the 2-point-method ($f = 0.57$) to detect an interaction effect ($\alpha = 0.01$; $\beta = 0.05$; number of groups = 2; number of measures = 2; correlations among repeated measures = .5). Considering a 20% drop-out rate, we decided to recruit 27 participants in each group in the final study, for a total of 54 participants. We included the 10 participants from the pilot study in each group in the final study because the data collection method remained the same.

2.6. Randomization

We conducted randomization using a sealed opaque envelope system to maintain concealed group allocation. Written consent was obtained from each participant, following which a baseline assessment with the AKEiSit test was conducted. From a box, each participant then withdrew a sealed envelope containing a completely blinded card denoting the allocated group. Each participant opened the envelope to read the group allocation (JKS or AKES) and was provided with instructions regarding the stretching procedure. We asked participants not to reveal their intervention group to any examiners for the AKEiSit test.

2.7. Statistics

We performed intention-to-treat analyses for the θ value, where the same θ value at the baseline assessment was used at the follow-up assessment; furthermore, we performed a two-way repeated measures analysis of variance for the θ value. We calculated the effect size of partial η^2 , where partial η^2 values of 0.10, 0.6, and 0.14 represent small, medium, and large effect sizes, respectively (Cohen, 1988).

A two-tailed dependent sample t -test was used to investigate comparability of the θ value, age, and BMI at baseline and of the

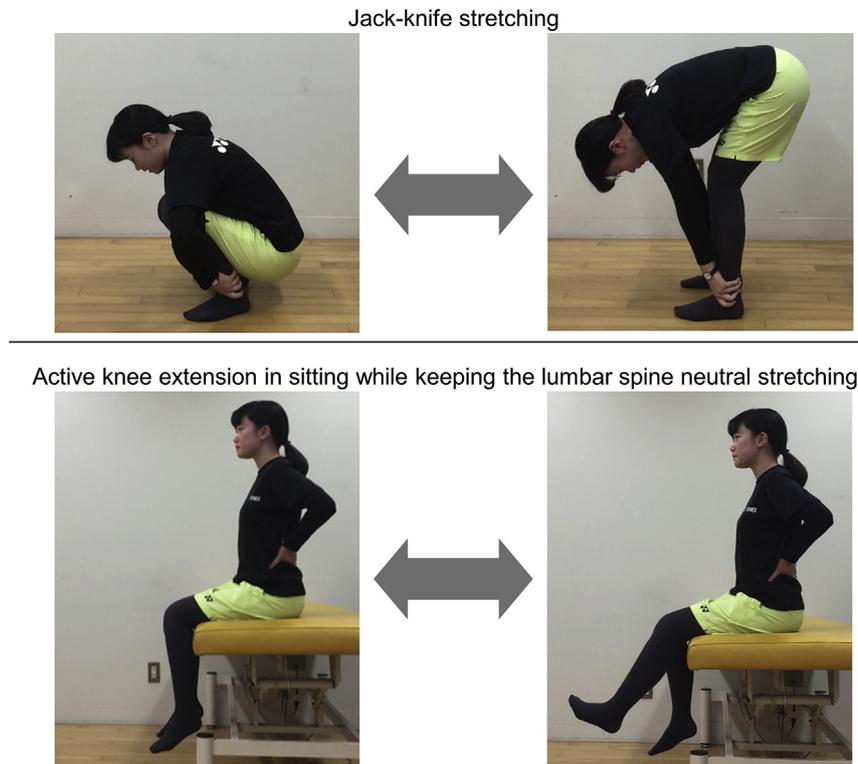


Fig. 3. The two stretching procedures.

exercise compliance rate. Comparability of the proportions of sex and participants with at least one episode of LBP was assessed using the Chi-squared and Fisher's exact tests, respectively. For other measures, we used descriptive analysis. SPSS version 21.0 (IBM Corporation, New York, USA) was used for statistical analyses, where the alpha value was set at 5%. The mean exercise compliance rate for five weeks was calculated from the exercise diary, where 100% indicated compliance with three sets of the exercise per day.

3. Results

Fig. 4 presents a flow chart of the study participants, who were university students. Among the 54 randomized participants, none had LBP at the baseline assessment. The drop-out rate was 11% and 15% in the JKS and AKES groups, respectively. One participant (Participant A) in the AKES group had a sports-induced ankle injury in the intervention period and withdrew consent. Two participants in each group withdrew consent along with Participant A because of anxiety that participation in the current study may have influenced Participant A's sports-induced injury. One participant in each group withdrew consent for unknown reasons.

Table 1 presents the baseline comparability of the groups, with ages in the range of 19–24 years (JKS) and 19–33 years (AKES).

Table 2 shows LBP prevalence in the four subgroups. No participant had an episode of LBP because of a traumatic event. In all participants with an episode of LBP, the LBP intensity was too mild to request pain management, and no participants reported an increase in LBP during the stretching exercises.

Table 3 presents the θ values in each group at baseline and follow-up. Within-group changes and between-group differences in θ values are presented in the Appendix. No statistically significant interaction effect was detected in the 2-point- ($P = .47$, partial $\eta^2 = 0.10$) and max-methods ($P = .18$, partial $\eta^2 = 0.03$);

furthermore, no statistically significant main effect of intervention was observed in the 2-point- ($P = .62$, partial $\eta^2 = 0.005$) and max-methods ($P = .64$, partial $\eta^2 = 0.004$). However, a statistically significant main effect of time was detected in the 2-point- ($P < .001$, partial $\eta^2 = 0.29$) and max-methods ($P < .001$, partial $\eta^2 = 0.22$). In post-hoc analysis, we assessed the power of the interaction effect (Pearson's r between pre and post θ values, 0.78 in each method). Using $\alpha = 0.05$, correlations among repeated measures ($r = 0.78$) and nonsphericity correction ($\epsilon = 1$), the calculated power was .99 and .97 in the 2-point- and max-methods, respectively.

4. Discussions

To our knowledge, this was the first study to compare the effects of two hamstring stretching exercises on the relative flexibility between the hamstring muscles and the low back. We hypothesized that AKES could increase the relative flexibility between the hamstring muscles and the low back more effectively than JKS. However, based on the θ values, no statistically significant interaction effect or main effect of the intervention was observed; only a main effect of time was detected. In the absence of a wait-and-see control group, the challenges in differentiating whether the pre-post difference was caused by the interventions or influenced by repeating the AKEiSit test can be debated. However, we did not presume that the pre-post difference was caused by a learning effect of repeating the AKEiSit test because of the high intersession reliability of the θ values during the AKEiSit test (Takasaki et al., 2018; Yasuda et al., 2017). The lack of statistical significance in the interaction effect was unexpected considering the priori sample size estimation. However, post-hoc analyses demonstrated a power of $\geq .97$ in the interaction effect, regardless of the two measurement methods. These results indicate that our JKS and AKES exercise protocols equally increased the relative flexibility between the

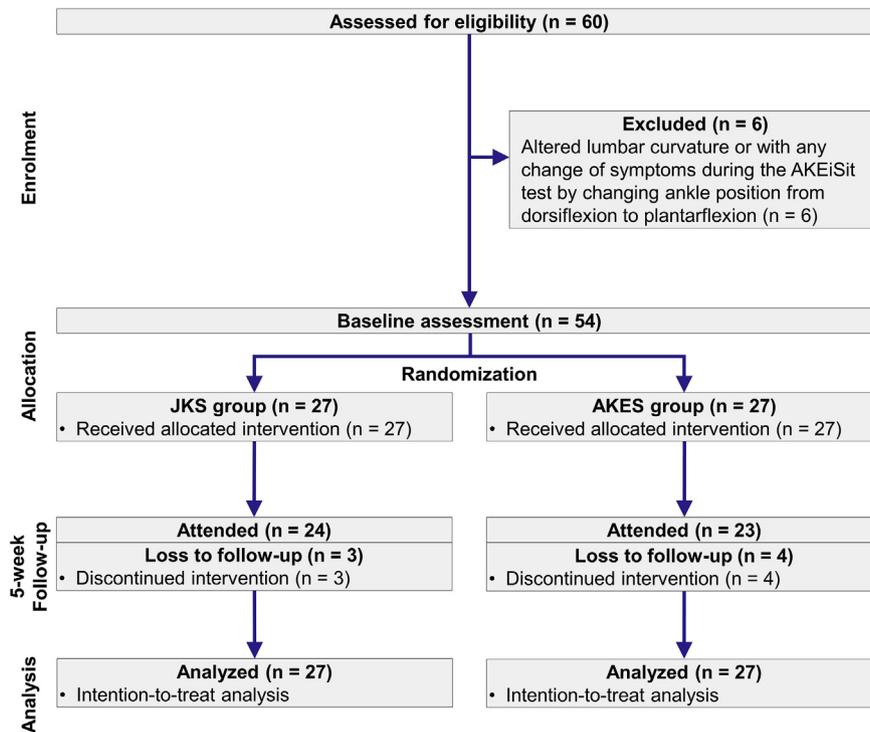


Fig. 4. Flow of the study participants.

Abbreviation AKEiSit, active right knee extension to 10° flexion in the sitting position; JKS, Jack-knife stretching; AKES, active unilateral knee extension stretching while controlling the spine.

Table 1
Baseline comparability.

Variable	JKS group (n = 27)	AKES group (n = 27)	P-value
Age (yr), mean (SD)	20.1 (3.0)	20.3 (1.1)	.73
Sex (n of men), (%)	12 (44.4)	14 (51.9)	.59
BMI (kg/m ²), mean (SD)	21.1 (2.3)	20.9 (1.4)	.70
Episode(s) of LBP during the month before the baseline assessment (n of participants), (%)	5 (18.5)	9 (33.3)	.35
Exercise compliance rate (%), mean (SD)	81.4 (31.6) ^a	76.2 (41.7) ^b	.57
θ value using the 2-point-method at the baseline assessment (°), mean (SD)	8.0 (12.8)	7.1 (13.1)	.98
θ value using the max-method at the baseline assessment (°), mean (SD)	15.3 (14.2)	15.3 (18.8)	.99

Abbreviations: JKS group, group with Jack-knife stretching; AKES group, group with active unilateral knee extension stretching while controlling the spine; BMI, body mass index; LBP, low back pain; θ value, lumbopelvic sagittal alignment during active right knee extension to 10° knee flexion in the sitting position, where a positive and negative value indicated lumbar kyphosis and lordosis, respectively.

^a n = 24.

^b n = 23.

Table 2
Prevalence of low back pain (LBP).

Subgroup of participants	JKS group (n = 24)	AKES group (n = 23)
Group 1 (n of participants), (%)	5 (20.8)	5 (21.8)
Group 2 (n of participants), (%)	15 (62.5)	13 (56.5)
Group 3 (n of participants), (%)	3 (12.5)	3 (13.0)
Group 4 (n of participants), (%)	1 (4.2)	2 (8.7)

Abbreviations: JKS group, group with Jack-knife stretching; AKES group, group with active unilateral knee extension stretching while controlling the spine; Group 1, at least one episode of LBP during the month before the baseline assessment with no further episodes of LBP in the five weeks prior to the follow-up assessment; Group 2, no episodes of LBP during the month before the baseline assessment or in the five weeks prior to the follow-up assessment; Group 3, at least one episode of LBP during the month before the baseline assessment and at least one episode during the five weeks prior to the follow-up assessment; Group 4, no episodes of LBP during the month before the baseline assessment with at least one episode of LBP in the five weeks prior to the follow-up assessment.

hamstring muscles and the low back. Considering that the SD values were higher than the mean values, the lack of interaction effect and main effect of the intervention on the θ values may be because of high individual variability.

The difference in the probability of LBP changes in the four subgroups appeared to be negligible (Table 2). This indicated a negligible difference in the effect of the two stretching exercises on the LBP status. However, whether the two stretching exercises can increase the risk of LBP remains unknown. A wait-and-see control group is required to investigate this in a future study.

We used the max-method and the 2-point method (which tends to reflect the Cobb angle on X-ray (Eslam et al., 2012)) to facilitate a prudent interpretation of the data. In the follow-up assessment, 95% CIs in the max-method were positive, indicating that most participants had lumbar kyphosis during the AKEiSit test and did not achieve to optimal function as suggested by Kendall et al. (Kendall et al., 2005), regardless of the intervention. The actual compliance rates in this study were higher (81.4% in the JKS group

Table 3
Lumbopelvic sagittal alignment (θ) during active right knee extension to 10° knee flexion in sitting.

Methods	Groups	Baseline	Follow-up
2-point-method ($^{\circ}$), mean (SD) [95% CIs]	JKS group (n = 27)	8.0 (12.8) [2.8 to 13.1]	3.3 (13.8) [-2.3 to 8.8]
	AKES group (n = 27)	7.1 (13.1) [1.9 to 12.4]	0.7 (12.9) [-4.6 to 5.9]
Max-method ($^{\circ}$), mean (SD) [95% CIs]	JKS group (n = 27)	15.3 (14.2) [9.6 to 21.0]	11.6 (13.7) [6.1 to 17.2]
	AKES group (n = 27)	15.3 (18.8) [7.7 to 22.9]	7.6 (17.4) [0.6 to 14.6]

Abbreviations: JKS group, group with Jack-knife stretching; AKES group, group with active unilateral knee extension stretching while controlling the spine; 95%CIs, 95% confidence intervals.

A positive and negative θ value indicated lumbar kyphosis and lordosis, respectively.

and 76.2% in the AKES group) than our initial expectation (33.3%), indicating that a more intense stretching protocol may be feasible. With a more intense stretching protocol, we may have detected differences in the interaction effect, a main effect of the intervention, or success with the gain of optimal function as suggested by Kendall et al. (Kendall et al., 2005).

4.1. Study limitations

There were three limitations to the current study. The first is the lack of careful controls for potential confounding factors of the sample. This study did not conduct stratified randomization considering LBP; age and sex are known to influence hamstring flexibility (Adegoke, Akpan, & Mbada, 2012; Vazirian, Van Dillen, & Bazrgari, 2016). However, no participant had LBP at the baseline; moreover, no statistically significant differences in age, proportion of men and women, or proportion of participants with an episode of LBP during the month before the baseline assessment were observed between the two groups. Therefore, we assumed that these uncontrolled potential confounding factors would not influence our study conclusions. However, the cohort of the current study was young and without LBP, and whether the same results would have been obtained with older individuals and patients with disabilities aggravated by lumbar flexion or extension and requirement for treatment due to LBP remains unknown. Future studies should examine the effects of these stretching exercises in patients with moderate to severe disabilities due to LBP, with robust criteria for eligibility that account for subgroups with different effects of limb movements on the lumbar spine (Sahrmann, 2001; Sahrmann, Azevedo, & Dillen, 2017; Van Dillen et al., 2009; Van Dillen, Gombatto, Collins, Engsborg, & Sahrmann, 2007).

The second limitation was that the mechanisms of LBP development during the intervention period were unknown; thus, for the cause of the development and elimination of LBP was unclear.

The third limitation was associated with the reliability of the exercise compliance rate. We asked participants to record the completion of each set in an exercise diary. Such self-reported data may not have reflected the true exercise compliance rate.

5. Conclusions

No difference was observed with regard to increased relative flexibility between the hamstring muscles and the low back following 5-week JKS and AKES exercise protocols. These results indicate that an ability to control the lumbar spine during knee movements can be increased with nonspecific exercises rather than specific exercises, maintaining the lumbar spine in the neutral position.

Declarations of interest

None.

Ethical approval

The ethical clearance of this study was approved by the human research ethics committee in the Saitama Prefectural University (No. 27780).

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Appendix. Within-group changes and between-group differences of the lumbopelvic sagittal alignment (θ) during active right knee extension to 10° knee flexion in the sitting position.

Methods	Groups	Within-groups changes Mean (95% CIs)	Between-group differences Mean (95% CIs)
2-point-method ($^{\circ}$)	JKS group (n = 27)	-4.7 (-8.7 to -0.8)	1.7 (-3.1 to 6.7)
	AKES group (n = 27)	-6.5 (-9.6 to -3.4)	
Max-method ($^{\circ}$)	JKS group (n = 27)	-3.7 (-7.6 to 0.2)	4.0 (-1.9 to 10.0)
	AKES group (n = 27)	-7.7 (-12.4 to -3.0)	

Abbreviations: JKS group, group with Jack-knife stretching; AKES group, group with active unilateral knee extension stretching while controlling the spine; 95%CIs, 95% confidence intervals.

A positive and negative θ value indicated lumbar kyphosis and lumbar lordosis, respectively.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ptsp.2019.05.002>.

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