©Journal of Sports Science and Medicine (2019) **18,** 52-57
http://www.jssm.org

Research article

Effects of Dynamic Stretching with Different Loads on Hip Joint Range of Motion in the Elderly

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Abstract
The purpose of this study was to investigate the immediate and sustained effects of static stretching (SS), dynamic stretching (DS) with no-load (DSNL), DS with a light load (DSLL, 0.25 kg), and DS with a heavy load (DSHL, 0.5 kg) on the hip joint range of motion (ROM). Sixteen participants (63.2 ± 7.13 years) were randomly assigned to perform SS, DSNL, DSLL, and DSHL exercises. The ROM for passive flexion and extension of the right hip joint was measured at pretest, as well as immediately after and at 60 min after completing the exercise. Additionally, the ROM of hip flexion and extension during the stretching exercise was evaluated by kinematic analysis of video-captured images. Passive ROM measurements reveals that the hip flexion ROM was higher after DSNL than after DSLL and DSHL at both time points (DSNL vs. DSLL, DSHL: 0 min: 7.0% vs. -1.8%, -3.9%; 60 min: 7.8% vs. -2.1%, -1.4%, $p < 0.05$), as well as higher than after SS at 60 min after exercise (DSNL vs. SS: 7.8% vs. 1.0%, $p < 0.05$). Compared to SS, all types of DS demonstrated a more sustained effect of ROM improvement at 60 min (DSNL, DSLL, DSHL vs. SS: 8.0%, 5.6%, 7.0% vs. 1.6%, $p < 0.05$). These results suggest that all DS modes can effectively improve hip extension ROM in the elderly. DSNL may be the most effective exercise for improving hip flexion ROM, providing sustained effect for over 60 min.

Key words: Flexibility, lower limbs, duration, passive stretching.

Introduction

Middle-aged and elderly individuals (aged 45 years or above) currently account for 13% of the global population and are predicted to account for 21% by 2050 (Harper, 2014; Singh et al., 2015; United Nations, 2011). Such individuals commonly experience deterioration of the range of motion (ROM) of joints (Nonaka et al., 2002; Shields et al., 2010). While severe deterioration of joint ROM generally occurs after the age of 71 years, the onset and rate of progression of such degradation in the joints of the upper and lower body vary in each individual (Stathokostas et al., 2013). Reduced ROM is associated with increased risk of falling among middle-aged and elderly individuals (American College of Sports Medicine, 2013), and falls are recognized as a major risk factor for accidental death and trauma in the elderly (World Health Organization, 2007). Indeed, the World Health Organization reported falling as the second cause of accidental injury and revealed that, every year, one of every three elderly individuals would experience a fall (World Health Organization, 2007; Zhao and Chung, 2016).

Stretching can maintain joint flexibility and ROM, thereby effectively decreasing the risk of injury (Behm et al., 2016) and increasing the quality of body movement. Static stretching (SS) can improve joint ROM (Behm et al., 2011; 2016; Bouvier et al., 2017; Kay et al., 2012; Reid et al., 2018) and prevent damage to the muscle and tendons, thus serving as the safest form of stretching (Beaulieu, 1981; Weerapong et al., 2004). Dynamic stretching (DS) can also improve joint ROM, achieve the warm-up effect relatively quickly, promote flexibility, and decrease passive muscle tension (Chen, 2006; Stanziano et al., 2009; Weerapong et al., 2004; Yamaguchi and Ishii, 2005). Meanwhile, previous studies indicated that strength training is associated with increased adaptation response of neuromuscular and connective tissue, as well as with improved flexibility of tendons and ligaments (Fowles et al., 2000; Kubo et al., 2002; Simao et al., 2011). Several studies have confirmed that strength training with appropriate loading improves joint ROM (Leite et al., 2017; Simao et al., 2011). Morton et al. (2011) have suggested that 5-week resistance training regimens involving appropriate and full joint ROM improve flexibility. Leite et al. (2017) have observed that 72 sessions of resistance training confer increased joint flexibility. Swank et al. determined that the Body Recall program, which consists of strength training, posture exercise, and breathing exercise three times per week for 10 weeks, improved hip flexion ROM when the lower limbs were loaded with 0.91 kg (Swank et al., 2003). However, Raab et al. (1988) observed no beneficial effect on hip flexion ROM for training with a 2.15-kg load, possibly because this load may have been excessively heavy for elderly individuals with relatively low muscle strength.

Morton et al. (2011) agreed that, if stretching is conducted within an appropriate and full joint ROM, it may positively influence the efficiency of joint motion. However, previous studies did not document the motion angles of the hip joint during DS and did not evaluate whether the participants achieved adequate and full joint ROM during DS with various loads. Therefore, it remains unknown whether the effectiveness of stretching interventions for ROM improvement is related to the loads used. We hypothesized that, compared to SS, DS would demonstrate more immediate response and sustained effects for improving hip flexion and extension in the elderly, and that the effect of DS would differ with the load used. The present study evaluated the immediate response and sustained effect of a single session of SS and DS with various loads, analyzed the kinematics parameters of stretching motion under

Received: 01 October 2018 / Accepted: 06 November 2018 / Published (online): 01 March 2019

various loads, and determined the optimal stretching strategy for increasing hip joint ROM in elderly individuals through group exercise courses.

Methods

Participants

Sixteen participants (age, 63.2 ± 7.13 years; body mass index, 21.7 ± 6.81 kg/m^2) were recruited in this study. Each participant performed a single session of each type of stretching exercise, in random order. The inclusion criteria were as follows: (a) absence of conditions possibly affecting hip joint flexion or extension, including problems with the upper limb, lower limb, or back skeletal muscles; (b) independent ambulation; (c) independent, community-living; (d) absence of severe cardiovascular disease or central nervous system disease. Prior to initiating the study, all prospective participants received detailed instructions and were informed of the study procedure, as well as of the benefits and risks of the investigation; those who chose to participate signed an institutionally approved informed consent document to participate in the study. This study was approved by the research ethics committee of the local university (NTU-REC No.: 201305HS008).

Procedures

First, the reliability of hip joint ROM measurements was assessed using intraclass correlation coefficients. Subsequently, precision was assessed in terms of coefficient of variation. The ROMs of flexion and extension in the right hip joint were measured in eleven participants for four different stretching modes. The intraclass correlation coefficients for hip flexion and hip extension ROM measurements were 0.97 and 0.73, respectively (n = 44). Regarding measurement precision, the coefficients of variation for hip flexion and hip extension ROM were 3.07% and 7.65%, respectively (n = 44).

Each participant performed four stretching exercises, namely SS, dynamic stretching with no-load (DSNL), DS with a light load (DSLL, 0.25 kg), and DS with a heavy load (DSHL, 0.5 kg), in random order. DSLL and DSHL were conducted with light packs (0.25 kg) and heavy packs (0.5 kg), respectively, fixed at the ankle. DSNL was conducted without any pack at the ankle. Measurements were conducted at the same time each day. The time interval between tests was 48 h, and all four exercises were completed within 1 month. In this study, SS was designed to stretch the hamstrings by adopting a forward flexion position while sitting in a chair, and to stretch the iliopsoas by adopting a forward lunge position. Each SS exercise set included six 30-s long repetitions of stretching exercise, with 30 s of rest between repetitions. The three repetitions for iliopsoas stretching were performed after the three repetitions for hamstring stretching. DS was designed to stretch the hip flexors and extensors by adopting a neutral standing posture centered over the left foot while holding onto the back of a chair to maintain balance and performing stretching motions for hip flexion and hip extension, respectively. The DS session consisted of one set of hip flexion exercise and one set of hip extension exercise, with each set containing fifty repetitions performed to the rhythm of a metronome, and with 30 s of rest between sets. In each set, the first five repetitions were performed at half the speed of the subsequent ten repetitions (55 and 110 beats/min, respectively), as recommended by Yamaguchi and Ishii (2005). One repetition was completed within four metronome beats. In total, three sets were performed and the DS trial covered 130.8 s (43.6 s × 3 sets). Stretching intensity was evaluated using the rating of perceived exertion (RPE). The participants were instructed to stretch the hamstring as much as possible but not as much as to cause pain (RPE of 13–14). Throughout the test, the environment temperature was 21.1 ± 0.78 °C and humidity was 58.3% ± 3.43%.

Measurement of ROM of passive hip flexion

With the participant lying on their back, the thighs and calves completely supported by the bed surface, the locating point was defined as the most protruding point located 5–10 cm up the thigh from the top of the knee cap. In the initial position, both thighs and calves were close to bed surface. The evaluator slowly lifted the participant's foot away from the bed surface without bending the knee joint, up to the maximum flexed position that the participant could endure without feeling pain in the hamstring (RPE of 13–14); the participant was instructed to maintain the knee joint naturally straight but not rigidly locked. Hip flexion ROM was obtained as the difference between the hip flexion angles in the initial and final positions of passive flexion of the hip joint.

Measurement of ROM of passive hip extension

With the participant in prone position, with the arms held high over the head or extended outward to hold onto the bed edge, the locating point was defined in the bending area located 5–10 cm up the thigh from the rear of the knee joint. In the initial position, both thighs and calves were close to the bed surface. The evaluator slowly lifted the participant's leg away from the bed surface, causing the pelvis to bend forward, up to the maximum extended position that the participant could endure without feeling pain in the hamstring (RPE of 13–14). Hip extension ROM was obtained as the difference between the hip extension angles in the initial and final positions of passive extension of the hip joint.

Hip motion angle during stretching exercise

For the hip flexion test, each participant assumed supine position as the initial position, with horizontal position of the hip joint, and was instructed to lift the right leg as high as possible. The motion angle of hip flexion during stretching exercise was obtained as the ROM between the initial and highest position. For the hip extension test, the participant assumed prone position, with horizontal position of the hip joint, and was instructed to lift the right leg as high as possible. The motion angle of hip extension during stretching exercise was obtained as the ROM between the initial position and the highest position. The hip joint motion angles in the first and third sets of stretching exercises were recorded, and all motion angles in all sets were averaged.

Statistical analysis

In this study, 11 participants were tested. A power calculation was conducted using G Power version 3.1. Considering a testing power of 0.8, the minimum sample size was 13. Data were expressed as mean ± standard error. The experimental data were analyzed using SPSS version 18.0 (SPSS Inc, Chicago, IL, USA). Statistical significance was set a prior at α = 0.05 ($p < 0.05$). Two-factor variance analysis with the pretested values for common variables was conducted to compare the efficacy of different modes of stretching on hip joint ROM at different time points. The motion angles during DS at different loads were analyzed using Siliconcoach version 7.0 (Silicon coach Ltd, New Zealand). The ROM for hip flexion and extension during DS under various loads was compared using a one-way repeated measures analysis of variance.

Results

Hip joint flexion ROM

Hip flexion ROM at 0 min was higher after DSNL than after DSLL and DSHL (DSNL vs. DSLL, DSHL: 7.0% vs. -1.8%, -3.9%, $p < 0.05$). Hip flexion ROM at 60 min was higher after DSNL than after DSLL, DSHL, and SS (DSNL vs. DSLL, DSHL, SS: 7.8% vs. -2.1%, -1.4%, 1.0%, $p < 0.05$). Regarding sustained efficacy, only the effect of DSNL lasted for 60 min (DSNL: 7.8%, $p < 0.05$). For DSHL was lower at 0 min than at pretest (DSHL: -3.9%, $p < 0.05$) (Table 1).

Hip joint extension ROM

Hip extension ROM at 0 min was higher than at pretest for all stretching modes (SS: 12.1%; DSNL: 6.2%; DSLL: 10.6%; DSHL: 9.1%, $p < 0.05$), but DSNL, DSLL, and DSHL had a better sustained effect than that provided by SS at 60 min (DSNL, DSLL, DSHL vs. SS: 8.0%, 5.6%, 7.0% vs. 1.6%, $p < 0.05$). SS had only an immediate effect on hip extension ROM (SS: 12.1%, $p < 0.05$) (Table 2).

Kinematic parameters

No differences were observed among the three DS modes regarding the kinematic parameters of hip flexion and extension (Table 3).

Table 3. Comparison of hip flexion and extension angles during DS with different loads.

Movement	Mode	Angle (°)
Hip flexion	DSNL	74.7 ± 2.43
	DSLL	69.2 ± 2.78
	DSHL	73.0 ± 5.81
Hip extension	DSNL	17.2 ± 0.98
	DSLL	15.7 ± 1.026
	DSHL	17.0 ± 1.285

ROM, range of motion; SS, static stretching; DSNL, dynamic stretching with no load; DSLL, dynamic stretching with a light load; DSHL, dynamic stretching with a heavy load.

Table 1. Comparison of passive hip flexion ROM evolution after stretching exercise.

Movement	Mode	Pretest (°)	0 min (°) (ES)	60 min (°) (ES)
Hip flexion	SS	108.1 ± 4.04‡	112.1 ± 4.13 (0.38)	109.1 ± 4.91‡ (0.10)
	DSNL	104.5 ± 4.21	111.0 ± 5.06† (0.55)	112.4 ± 4.99*† (0.71)
	DSLL	109.1 ± 3.92‡	107.5 ± 4.78‡ (0.23)	107.0 ± 4.75‡ (0.26)
	DSHL	109.3 ± 4.30‡	105.3 ± 4.81†‡ (0.72)	108.0 ± 5.20‡ (0.18)

ROM, range of motion; ES, effect size; SS, static stretching; DSNL, dynamic stretching with no load; DSLL, dynamic stretching with a light load; DSHL, dynamic stretching with a heavy load. * Significant difference from SS ($p < 0.05$). † Significant difference from Pretest ($p < 0.05$). ‡ Significant difference from DSNL ($p < 0.05$)

Table 2. Comparison of passive hip extension ROM evolution after stretching exercise.

Movement	Mode	Pretest (°)	0 min (°) (ES)	60 min (°) (ES)
Hip extension	SS	24.9 ± 0.58	27.8 ± 0.94† (0.89)	25.1 ± 0.62 (0.09)
	DSNL	25.4 ± 0.52	26.9 ± 0.73† (0.55)	27.3 ± 0.70*† (0.55)
	DSLL	26.1 ± 0.45	27.8 ± 0.66† (0.77)	27.2 ± 0.74*† (0.52)
	DSHL	25.9 ± 0.67	28.3 ± 1.14† (0.72)	27.6 ± 0.77*† (0.61)

ROM, range of motion; ES, effect size; SS, static stretching; DSNL, dynamic stretching with no load; DSLL, dynamic stretching with a light load; DSHL, dynamic stretching with a heavy load. * Significant difference from SS ($p < 0.05$). † Significant difference from Pretest ($p < 0.05$)

Discussion

The major finding of this study is that DSNL resulted in significantly improved hip flexion ROM immediately after exercise, and this effect was maintained for 60 min. Furthermore, at 60 min after stretching, the effect on hip flexion ROM was greater for DSNL than for SS, DSLL, and DSHL. All stretching modes enhanced hip extension ROM (i.e., vs pretest). At 60 min after stretching, hip extension ROM was greater for DS than for SS, but there was no difference among DS modes with different loads.

Hip flexion ROM

This study demonstrated that in the elderly, compared to SS, DSNL exerts a more sustained effect on hip flexion ROM, possibly because the DS mode used in this study involved continuous swing of the hip joint during flexion and extension. In DSNL, the unilateral leg performed a no-load inertial swinging, which may have increased the swing amplitude of hip flexion, thereby increasing hip flexion ROM after exercise. The effect of DSNL lasted for up to 60 min, which represents superior sustained efficacy compared to previous observations, which suggest that the ROM effect of DS lasts 9-25 min (Ford and McChesney, 2007; Lin, 2011; Zhao, 2008); this discrepancy may be attributable to the different modes of DS used in the present study and other studies. Specifically, in the present study, DS was performed with lateral leg swing to increase hip ROM through inertia. By contrast, in other studies, DS involved raising the leg straight leg raised in the process of walking forward. In such a mode, the hip flexion angle may be restricted to ensure smooth walking motion, resulting in reduced hip joint ROM may be restricted; therefore, this particular mode of stretching resulted in reduced effect and relatively short period of sustained efficacy of stretching exercise on hip joint ROM. Furthermore, the variability of physical fitness and training experiences among participants is expected to be reflected in the degree of effectiveness of stretching exercise. Therefore, another possible explanation for the relatively long sustained effect of DSNL noted in the present study is that the participants were elderly individuals with relatively low ROM, whereas other studies enrolled relatively young participants with a wide range of exercise habits. A previous study revealed that the positive health effect was most significant for inactive or unfit individuals (Wahid et al., 2016). Another, study indicated that both muscle strength training alone and combined training of muscle strength and flexibility are ineffective for improving joint ROM on well-trained women (Leite et al., 2015). The participants in the present study were elderly individuals without training habits, which likely explains why stretching was clearly effective for improving ROM. However, the hip flexion ROM immediately after DSHL was lower than that before exercise. One study conducted in 2006 demonstrated that the hip flexion ROM decreased at 6 min after high intensity resistance training (Fatouros et al., 2006). Raab et al. (1988) also reported that increased load at the wrist joint and ankle joint provided no additional benefit in terms of ROM among elderly individuals; moreover, the effect on shoulder abduction was lower for load training than for no-load training. This may be due to the co-activation or co-contraction response induced by stretching with a heavy load, which resulted in increased momentum (mass × angular velocity). Under such conditions, the joint ROM may by lower due to the co-contractile response, which occurs as a compensation mechanism to avoid joint injury caused by greater momentum. Indeed, previous studies have indicated that, while appropriate loading helps to improve joint stability, excessive loading may induce co-contraction or co-activation response, resulting in joint stiffness and decreasing joint ROM (McGill et al., 2003, Granata and Marras, 2000).

SS is generally the preferred mode for promoting flexibility among elderly individuals because this stretching mode is considered the safest (Beaulieu, 1981; Weerapong et al., 2004). In the present study, SS did not increase the ROM of hip flexion (Table 1), which is not in agreement with previous findings that the sustained effect of SS can last for 6-25 min (Chen, 2002; DePino et al., 2000; De Weijer et al., 2003; Ford and McChesney, 2007), the discrepancy may originate from differences in the SS protocol. In the present study, SS involved forward flexion in a seated position, with the feet separated; each stretch lasted 30 s and was repeated three times, with 30-s resting intervals between repetitions. Previous studies used more than three repetitions (Chen, 2002; DePino et al., 2000; Ford and McChesney, 2007) or involved shorter resting time (De Weijer et al., 2003), which are known to be associated with higher RPE. The present study used three stretching modes commonly employed in the communities that the participants belonged to. Compared with previous studies, the present study employed the lowest training volumes and intensities of SS, which may have led to a reduced effect on hip flexion ROM. Further investigation is warranted to determine whether a higher number of repetitions of SS has a more significant effect on ROM.

Hip extension ROM

Hip extension ROM is relevant in gait (Christiansen, 2008), with the normal values reported as 10°-30° (American College of Sports Medicine, 2013). If individuals with reduced hip extension ROM tend to have shorter stride, decreased walking stability, reduced walking speed, and slow gait (Li and Wu, 2015). The present study demonstrated that SS and various DS modes all exerted an immediate positive effect on hip extension ROM, and there was no difference among DS modes in terms of the positive effect on hip ROM among various stretch modes. This result is consistent with the findings of a study conducted in 2011, which reported that, for hip extension ROM, the effect exerted in the SS group and in the resistance training (full ROM) group was superior to that exerted in the control group; furthermore, there was no significant difference between the SS group and the resistance training group (Morton et al., 2011). In addition, the present study found that hip extension ROM at 60 min after SS was not different from that noted before stretching, suggesting that SS only exerts an immediate effect on hip extension ROM. On the other hand, hip extension ROM at 60 min was significantly higher after DS than after SS, which is in agreement with previous findings (Alter, 2004). One possible explanation is that hip flexion brings the hip extension swing toward the lower rear direction during the raising of the leg, while the center accelerates downward, resulting in increased hip ROM. Weerapong et al . (2004) as well as

Yamaguchi and Ishii (2005) indicated that DS can increase joint ROM and decrease passive muscular tension. In addition, DS may increase blood circulation in the muscles of the lower limbs, thereby increasing joint ROM. A novel aspect of the present study is that hip motion angles were also evaluated using kinematic analysis of video-captured images during DS with different loads. There was no difference in the motion angles achieved during DS with different loads (Table 4), which may explain why there was no difference between load and no-load DS regarding the effect on hip extension ROM at 60 min.

In this study, DS was designed to improve of hip flexion and extension. The participants performed DS by adopting a neutral standing position, shifting the body weight to the leg not being stretched, holding onto the back of a chair for balance, and performing a dynamic leg swing. This DS mode generates the maximum ROM while ensuring safety for elderly individuals. The present findings indicate that, among the three DS modes tested, DSNL exerts the optimal effect for promoting joint ROM for hip flexion and extension. The immediate effect on hip joint ROM is beneficial for stretching and warming-up, which can help to prevent injury. The sustained effect on hip ROM at 60 min reflects improved flexibility. Based on these findings, it is recommended to replace SS with DSNL in health promotion activities within elderly communities, in order to accelerate warm-up time and exert a positive effect on hip ROM. Additionally, further research is required to confirm the results of this study in a real-world setting, as well as to determine the optimal design of group training courses.

Conclusion

The present findings suggest that DSNL positively contribute to joint ROM for hip flexion and hip extension immediately and for up to 60 min after stretching in the elderly. No difference exhibited in hip extension ROM among DS with different loads.

Acknowledgements
The experiments comply with the current laws of the country in which they were performed. The authors have no conflicts of interests to declare.

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Key points

- All dynamic stretching (DS) modes can effectively improve hip extension range of motion of older adults in the present study.
- DS with no load (DSNL) may be the most effective exercise for improving hip flexion range of motion, providing sustained effect for over 60 min.
- We recommended to replace static stretching with DSNL in health promotion activities within elderly communities, in order to accelerate warm-up time and exert a positive effect on hip range of motion.

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