Improvements in Hip Flexibility Do Not Transfer to Mobility in Functional Movement Patterns

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Abstract

Moreside, JM and McGill, SM. Improvements in hip flexibility do not transfer to mobility in functional movement patterns. *J Strength Cond Res* 27(10): 2635–2643, 2013—The purpose of this study was to analyze the transference of increased passive hip range of motion (ROM) and core endurance to functional movement. Twenty-four healthy young men with limited hip mobility were randomly assigned to 4 intervention groups: group 1, stretching; group 2, stretching plus hip/spine disassociation exercises; group 3, core endurance; and group 4, control. Previous work has documented the large increase in passive ROM and core endurance that was attained over the 6-week interventions, but whether these changes transferred to functional activities was unclear. Four dynamic activities were analyzed before and after the 6-week interventions: active standing hip extension, lunge, a standing twist/reach maneuver, and exercising on an elliptical trainer. A Vicon motion capture system collected body segment kinematics, with hip and lumbar spine angles subsequently calculated in Visual 3D. Repeated measures analyses of variance determined group effects on various hip and spine angles, with paired *t*-tests on specific pre/post pairs. Despite the large increases in passive hip ROM, there was no evidence of increased hip ROM used during functional movement testing. Similarly, the only significant change in lumbar motion was a reduction in lumbar rotation during the active hip extension maneuver ($p < 0.05$). These results indicate that changes in passive ROM or core endurance do not automatically transfer to changes in functional movement patterns. This implies that training and rehabilitation programs may benefit from an additional focus on "grooving" new motor patterns if newfound movement range is to be used.

Key Words core endurance, hip ROM, core stability, dynamic activity

Introduction

Rehabilitation and fitness workers often focus on improving hip flexibility and core strength for a variety of reasons. One assumption is that this effort will assist in injury prevention. But it is also recognized that movement patterns are the result of many anatomical and biomechanical variables, modulated by a lifetime of experience: both physical and emotional. It is thought that patterns of movement develop that are energy efficient, relying on passive structures for energy storage, musculotendinous structures for generation and control of movement, and neurological control to coordinate smooth movement (21). The question arises as to whether these improvements in flexibility or strength will transfer to function. Specifically, if a person presents with limited hip mobility, is there any evidence that improvements in hip range of motion (ROM) or core endurance will alter functional movement patterns?

The literature indicates that hip extension measurements obtained passively do not reflect those used during dynamic activity (14,22). Similarly, research into anterior cruciate ligament injury prevention has shown that a general knee strengthening program does not alter jump-landing kinematics (9). Although there seems to be a recent focus in rehabilitation to include core endurance exercises with lower limb rehabilitation (10,19), there is little objective evidence that combined improvements in hip mobility and core endurance will be reflected in volitional functional activity. For a new motor pattern to become spontaneous, old patterns of movement must be overcome (2,5,20); thus, it may not be enough simply to improve hip mobility or core endurance without specifically focusing on preferred movement patterns.

This study sought to determine if improvements in passive hip ROM would result in changes to hip and spine motion during functional movements. The question at the heart of this study is whether any increase in ROM obtained with

This study was approved by the University Office for Research Ethics and conducted at the University of Waterloo.

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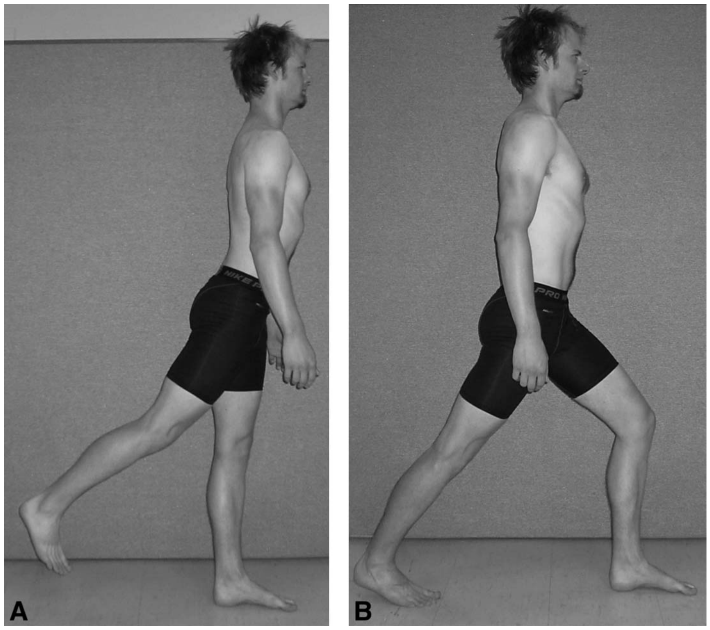

Figure 1. Examples of the (A) active hip extension and (B) forward lunge dynamic activities.

a stretching program will be used in real life. Specific hypotheses were investigated: (a) increased passive hip extension and rotation will result in increased hip ROM used during specific functional movements; and (b) improved core endurance and hip/spine disassociation will result in decreased lumbar rotation and flexion/extension during functional movements.

Methods

Experimental Approach to the Problem

The overall design incorporated a training trial to determine if significant improvements in passive hip ROM (extension and rotation) or core endurance would transfer to changes in hip and lumbar spine motion during dynamic activities. Details of the exercise intervention protocols and subsequent changes in passive hip ROM and core endurance have been previously described in detail for the interested reader (17). Briefly, 250 participants were screened for hip ROM to find candidates with low ranges of motion to partake in a training trial. The following study focused on the 24 participants with the smallest hip ROM. Participants were randomly assigned to 4 groups: group 1, hip stretching only; group 2, hip stretching and hip/spine disassociation exercises; group 3, core endurance and hip/spine disassociation exercises; and group 4, control. After 6 weeks of training, the exercise intervention, passive hip extension, and rotation ROM significantly improved in groups 1 and 2, whereas group 3 also demonstrated significant improvements in passive hip internal rotation (IR) (17). Average improvements in endurance during a plank, right/left side bridge, and back extension exercises ranged from 38 to 53% (17). Those participants in group 2 also progressed through a series of increasingly difficult exercises aimed at improving the awareness of hip vs. spine motion.

To determine if these changes in total hip motion transferred to changes in functional movement patterns, hip and spine motion was monitored during 4 dynamic activities. Each activity was chosen

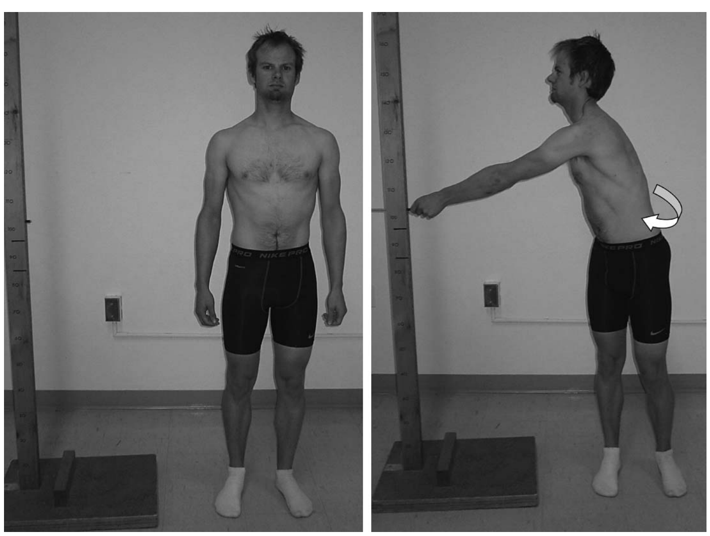

Figure 2. Example of the twist and reach dynamic activity. Although only the right rotation is shown, the maneuver was also repeated to the left.

Table 1. Mean (*SD*) peak hip and lumbar spine range of motion during 4 dynamic activities, before and after a 6-week exercise intervention protocol (groups 1 to 4; $n = 6$ participants per group).*†

	1: Hip stretching			2: Hip stretch with hip/spine disassociation			3: Core endurance			4: control		
	Pre	Post	C-*d*	Pre	Post	C-*d*	Pre	Post	C-*d*	Pre	Post	C-*d*
Lunge												
Hip ext	23.5 (8)	23.1 (6)	0.06	21.5 (7)	20.8 (6)	0.11	7.1 (13)	20.3 (5)	−0.68	14.3 (5)	21.3 (4)	−**1.50**
L-ext	3.7 (9)	8.4 (7)	−0.58	10.4 (12)	12.5 (12)	−0.17	6.4 (4)	17.5 (3)	−0.07	10.4 (10)	11.4 (9)	−0.11
Hip ext												
Hip ext	9.7 (6)	7.5 (7)	0.33	5.1 (9)	4.3 (5)	0.11	4.5 (3)	5.2 (6)	−0.15	3.1 (6)	4.6 (5)	−0.27
Hip rot	4.6 (4)	5.2 (4)	−0.15	3.4 (6)	5.9 (5)	−0.45	5.6 (8)	7.6 (6)	−0.28	4.3 (3)	0.6 (3)	**0.89**
L-ext	9.2 (5)	15.1 (4)	−**1.30**	15.1 (4)	13.1 (7)	0.35	7.3 (2)	11.2 (9)	−0.60	12.8 (5)	10.7 (3)	0.51
L-rot‡	10.7 (6)	8.0 (3)	0.56	8.3 (2)	4.2 (3)	**1.39**	6.1 (3)	3.1 (5)	0.75	8.4 (1)	8.4 (3)	0.00
Twist and reach												
Hip Fl	25.9 (9)	25.7 (8)	0.02	21.8 (6)	20.7 (5)	0.20	20.8 (5)	27.9 (11)	−**0.83**	29.5 (7)	21.8 (4)	**1.35**
Hip rot	30.4 (4)	25.8 (7)	**0.81**	30.8 (9)	31.2 (9)	−0.04	30.2 (7)	32.5 (4)	−0.40	31.4 (3)	32.3 (6)	−0.19
L-flex	18.5 (10)	16.9 (7)	0.19	15.3 (9)	13.9 (16)	0.11	22.8 (6)	18.5 (6)	0.72	21.8 (8)	23.4 (8)	−0.20
L-rot	23.6 (9)	24.0 (9)	−0.04	28.7 (17)	28.8 (9)	−0.01	22.2 (4)	25.4 (13)	−0.33	19.2 (7)	32.8 (25)	−0.74
L-side bend	29.7 (9)	23.7 (6)	0.78	24.7 (6)	17.7 (4)	**1.37**	21.8 (7)	21.4 (6)	0.06	29.4 (12)	32.5 (15)	−0.22
Elliptical												
Hip ext	8.8 (6)	8.7 (7)	0.02	10.1 (4)	9.2 (7)	0.15	7.6 (3)	5.6 (6)	0.42	4.4 (5)	9.4 (4)	−**1.10**
Hip rot	13.1 (4)	10.8 (1)	0.79	14.3 (4)	12.7 (4)	0.40	11.1 (2)	13.5 (3)	−**0.94**	12.1 (3)	12.9 (3)	−0.27
Hip fl/ext	55.5 (7)	55.2 (4)	0.05	55.4 (7)	54.7 (3)	0.13	50.7 (5)	55.2 (5)	−**0.90**	52.7 (7)	54.4 (3)	−0.31
L-fl/ext	9.9 (3)	10.6 (4)	−0.20	10.5 (3)	9.6 (3)	0.30	9.5 (4)	9.4 (2)	0.03	11.5 (1)	12.6 (3)	−0.49
L-rot	28.4 (7)	27.8 (5)	28.4	31.6 (11)	29.6 (9)	0.20	27.3 (7)	25.3 (4)	−0.35	29.1 (4)	31.7 (4)	−0.65

*C-*d* = Cohen's *d* effect size; ext = extension; L = lumbar; rot = rotation; Fl = flexion; fl/ext = combined total of peak flexion and extension.
†Values in bold indicate C-*d* of greater than 0.8, indicating a large effect.
‡Significant main effect across all groups ($p < 0.05$).

for its ability to challenge either rotation or extension of the hip and/or spine during a functional activity that was relatively familiar to the participant. Foot position was standardized, as was hand position when relevant, thus aiding reproduction of the testing position between participants and between test days. The 4 positions included: (a) active hip extension in upright standing (Figure 1A); (b) lunging (Figure 1B); (c) a standing "twist and reach" maneuver (Figure 2); and (d) exercising on the elliptical trainer. Outcome measures varied with the activity and included dynamic peak hip flexion/extension and rotation, as well as peak lumbar spine flexion/extension, rotation, and side flexion. Each activity was tested, and joint angles were calculated, before and after the 6-week intervention protocol. Thus, the independent variables were "pre" and "post" intervention timing, and the dependent variables were the joint angles of interest for each specific functional activity.

Subjects

Recruiting from the university population and surrounding area via posters and word of mouth, participants were selected who demonstrated hip mobility of less than the 50th percentile, ideally in both extension and total rotation (IR plus external rotation [ER]), based on normative data published by Moreside and McGill (16). In total, approximately 250 men between the ages of 19 and 30 years were measured in an attempt to find participants who fit the criteria. Twenty-seven participants were identified with limited hip mobility who were willing to commit to a longer term study. Two participants dropped out because of other commitments and 1 participant because of illness, resulting in a total of 24 participants completing the study (mean height: 178.3 [7.1] cm, mean weight: 81.2 [15.05] kg). These were randomly assigned to the 4 experimental groups. All participants were healthy without current hip or back pain or past pathology in these regions. Participants completed a written informed consent document approved by the University Office for Research Ethics.

Procedures

Data Collection. In addition to the passive hip ROM, torso endurance, and hip/spine disassociation measurement protocols that took place at the beginning and end of the 6-week intervention (17), data characterizing several dynamic movements were also collected. Although passive ROM outcomes were collected on the same day as the dynamic movement testing, the endurance outcomes were collected approximately 2 days after the dynamic to minimize any effect the endurance and dynamic tasks might have on performance of the other.

The dynamic activities were as follows: actively extend their right hip to their perceived maximum while in an upright standing posture (Figure 1A). Minimal guidance as to how to perform the action was given, other than to attempt to keep their upper body erect (i.e., avoid leaning the trunk forward). Each activity was performed twice, with the second repetition being used for analysis. This hip extension activity was chosen to observe active peak hip extension, together with associated spine extension and rotation. Next, participants completed a forward lunge: from standing position, the floor was marked at a distance 1.5× their shin length in front of the left foot. They were instructed to step forward with the left foot until their toe reached the floor marking and lunge down into forward left hip flexion (right hip extension) as low as was comfortable while keeping their upper body erect (Figure 1B). Right heel raise was permitted, but they were to maintain full right knee extension. Of interest was the amount of peak sagittal motion of the hip and back, recognizing that the hip extension in this maneuver was more of a passive stretch, thus less concentric in nature than the previous active hip extension. The third functional trial was a twist and reach activity: 2 poles were set up aside the participants in their frontal plane. The distance between the poles was 110% times their body height, with the participant standing in the middle, feet

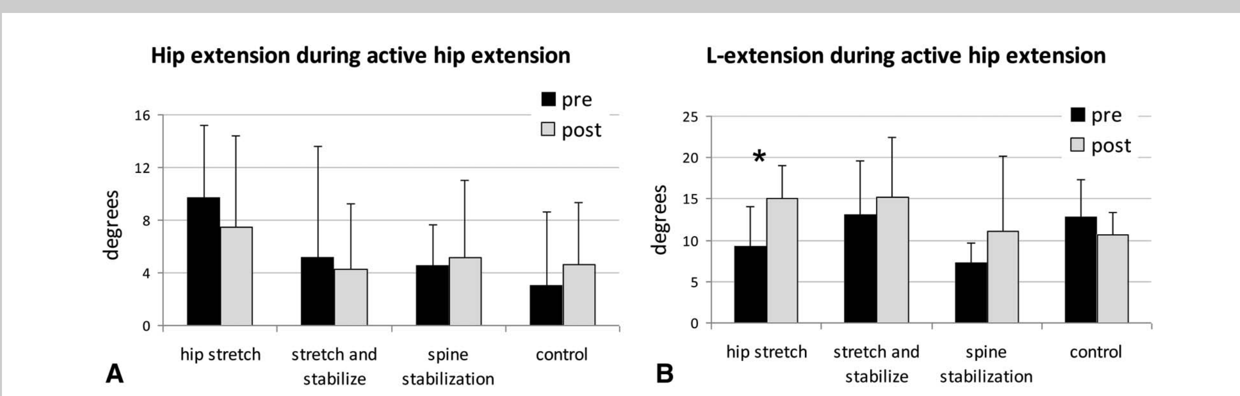

Figure 3. Average amount of (A) right hip extension and (B) lumbar extension used during an active hip extension maneuver before and after a 6-week exercise intervention ($n = 6$ per group). *Significant difference between the preintervention and postintervention measurements ($\alpha = 0.0125$).

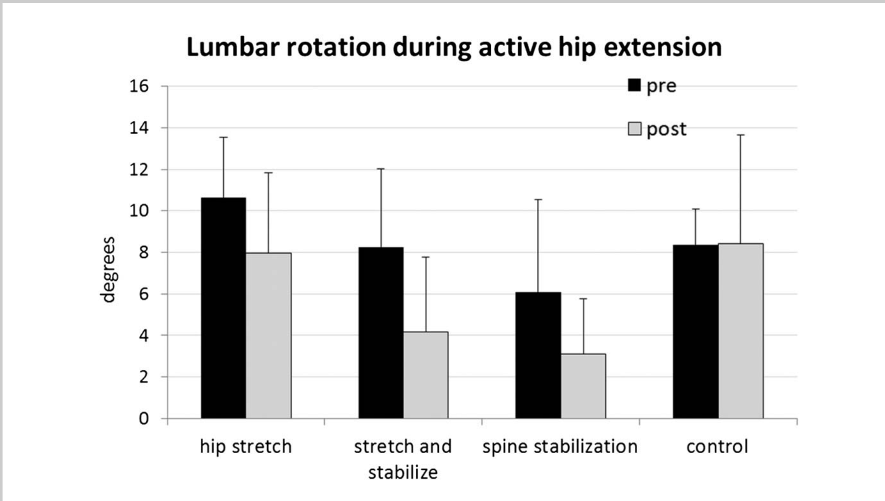

Figure 4. Average amount of lumbar rotation used during an active hip extension maneuver before and after a 6-week exercise intervention ($n = 6$ per group).

shoulder width apart. Small knobs on the poles were secured at approximately the participant's waist height. They were instructed to reach around and touch the knob on the right pole with their left hand, and the left pole with the right, without moving their feet (Figure 2). The focus of this activity was hip and lumbar rotation, as well as associated hip/spine flexion and lumbar side bending.

Finally, participants exercised on the elliptical trainer (Octane Fitness, Brooklyn Park, MN USA) at a self-selected speed: one which they would choose if expecting to exercise for 30 minutes. This speed varied from 40 to 70 cycles per minute with a mean speed of 53 (7) cycles per minute. Although the stride length, hand position, and speed were varied at the time, the results being discussed in this study used the 66 cm stride length, a speed 30% faster than self-selected, with hands holding onto the oscillating handles of the elliptical trainer. Once they were up to speed and appeared comfortable with the activity, the motion was sampled twice, capturing 4 cycles. The elliptical trainer was chosen, in that the resulting motion is somewhat similar to one used in walking, but with slightly increased sagittal and transverse motion in the lumbar spine (18). It was also thought that variability resulting from arm motion, stride length, and velocity would be less, in that the hand and foot positions are constrained when using the elliptical trainer, as well as offering digital velocity feedback.

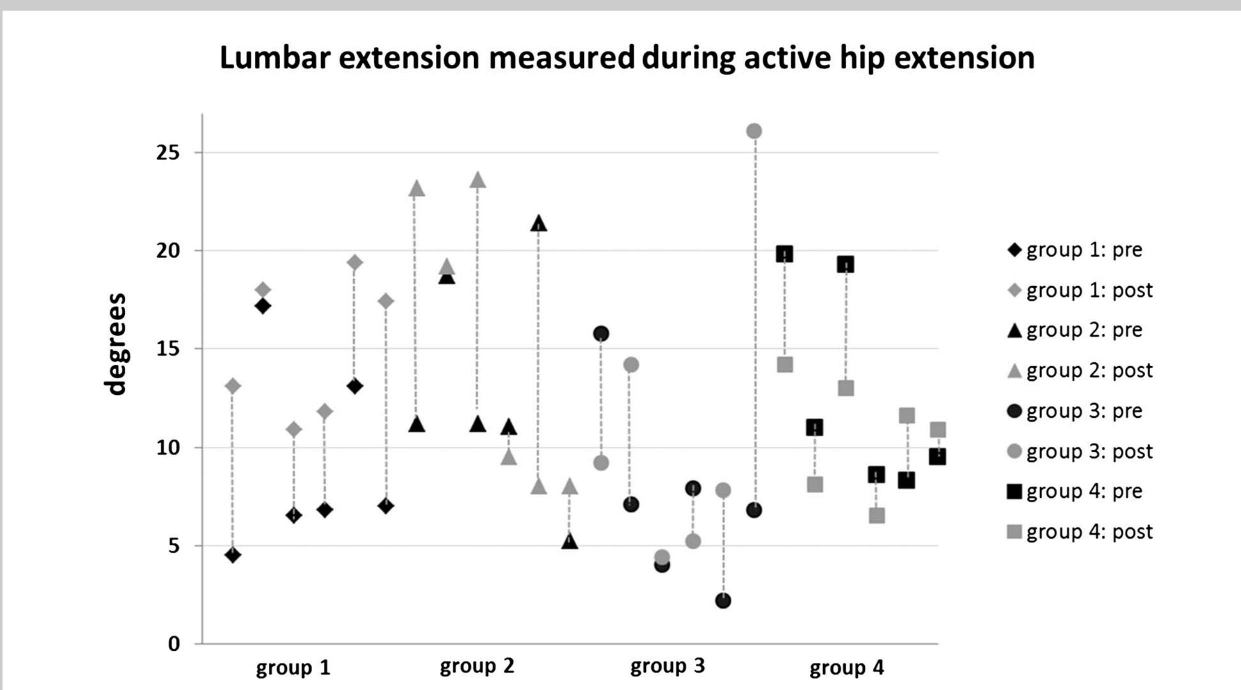

Figure 5. Degrees of peak lumbar rotation measured during an active hip extension maneuver for each participant, preintervention and postintervention.

Motion Capture. A Vicon MX Motion System and Nexus software (Vicon Motion Systems, Oxford, United Kingdom) were used for capturing body segment kinematics via 8 infrared cameras, collecting at a frequency of 60 Hz. Rigid plates with 4 reflective markers on each were attached via elastic straps to body segments bilaterally as follows: shin, thigh, foot, hand, upper arm, and overlying the midline of the posterior pelvis, T12, and forehead. In addition, single markers for calibration purposes only were attached over the posterior right (Rt) scapula, C7 spinous process, sternal notch, and bilaterally over the medial and lateral aspects of each ankle, knee, wrist, elbow, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanters, acromions, and earlobes. The local coordinate system of the pelvis was defined by markers atop the ASIS and PSIS, with the x, y, and z axes being posterior/anterior, right/left, and vertical, respectively.

Kinematics. Marker data were initially processed using the Vicon Nexus software and then exported to Visual 3D (C-Motion Inc., Kingston, Canada) for further processing. Three-dimensional lumbar and hip angles relative to the pelvis were calculated using a Visual 3D algorithm with a Cardan sequence of rotations. Joint angles were filtered with a 6-Hz dual-pass Butterworth filter. Signals were screened for abnormalities, processing errors, and marker movement. For the elliptical trials, maximum and minimum joint angles were taken from the entire capture time, unless the signal drifted over time because of body position changes (i.e., neck flexion, which tended to increase lumbar flexion), in which case the maximum/minimum joint angles were extracted from a complete cycle deemed representative of the normal scope of motion. Symmetry was assumed in the elliptical and twist trials, and the right leg was used for statistical analysis. For the lunge and hip extension trials, joint angles were calculated at the instant where relevant peak joint motion occurred: that is, for a left leg forward lunge, spine and right hip angles were calculated at the moment of peak left hip flexion. Similarly during the right hip extension trials, angles were calculated at the instant of peak right hip extension. For the twist conditions, maximum and minimum angles were calculated based on the entire trial.

Statistical Analyses

A series of repeated measures analyses of variance (SPSS, version 17; Chicago, IL, USA) were performed for each dependant variable (relevant spine and hip angles) using a within-subject factor of pretreatment/posttreatment and between-subject factor of treatment group. Paired t-tests were conducted on individual pairs of preresults and postresults of interest, with Bonferroni adjustments. Significance level was chosen at $\alpha = 0.05$. Cohen's d effect sizes were also calculated to aide with intervention outcome interpretations.

Results

Functional Hip Motion

Despite large increases in passive hip mobility in groups 1 and 2, there were no significant increases in hip extension or

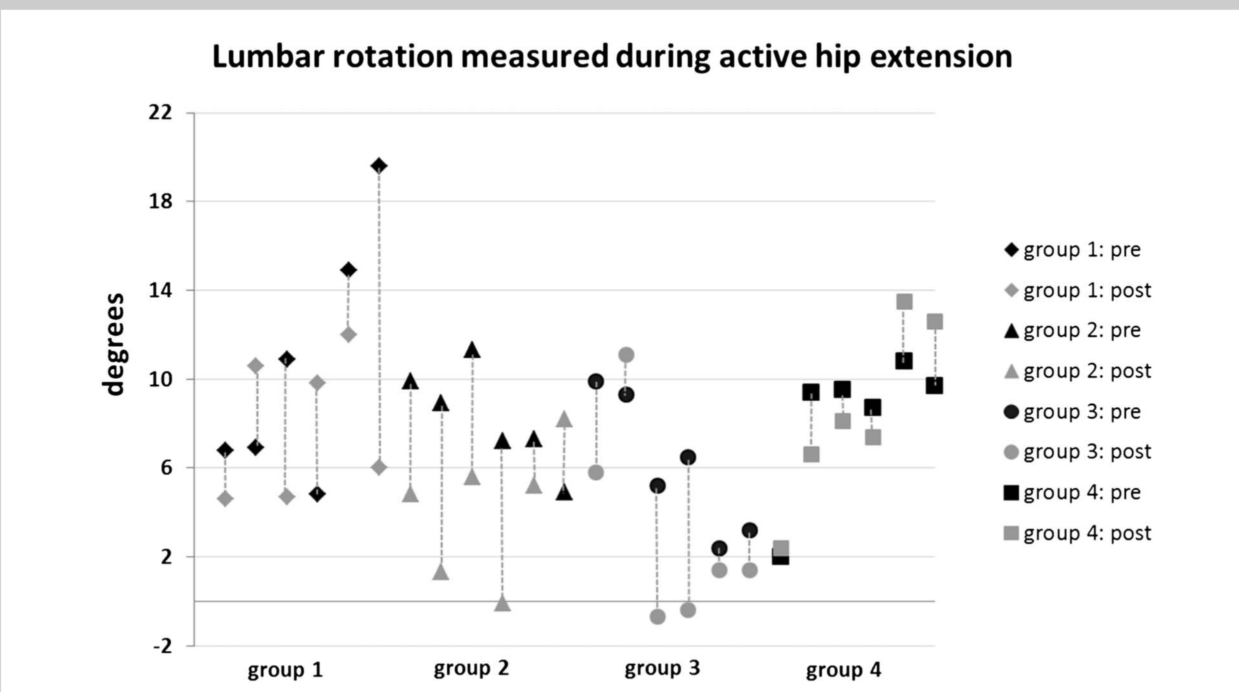

Figure 6. Degrees of peak lumbar extension measured during an active hip extension maneuver for each participant, preintervention and postintervention.

rotation used during dynamic activities (Table 1); mean (*SD*) (in degrees) of increased ROM for extension: 14.0 (6)° and 10.3 (8)°; IR: 7.7 (4)° and 11.1 (4)°; ER: 14.2 (5)° and 12.4 (7)° for groups 1 and 2, respectively. Instead, average peak hip extension actually decreased an average of 2.2° and 0.8° in groups 1 and 2, respectively, during the active hip extension trials (Figure 3A) while changing less than 1° in the elliptical and lunge trials. Similarly, there was no evidence of increased hip rotation being used during the elliptical and twist/reach trials. Instead, total hip rotation decreased 2.3° and 1.6° for groups 1 and 2, respectively, on the elliptical trainer. In the twist/reach trials, group 1 hip rotation averaged a decrease of 4.6° (effect size = 0.81), whereas group 2 demonstrated a nominal increase of 0.4° (Table 1).

Functional Spine Motion

There was only one instance where lumbar motion was significantly different across all groups postintervention: lumbar rotation associated with active hip extension was less ($p = 0.015$, power = 0.72) (Figure 4). The largest change was demonstrated in group 2, who received both stretching and disassociation exercises, reducing their lumbar rotation from an average (*SD*) of 8.3(2)° to 4.2(3)° (effect size = 1.39; $p = 0.105$ with *t*-tests). As shown in Figure 6, 5 of the 6 participants in both groups 2 and 3 demonstrated decreased lumbar rotation during active hip extension after the 6-week intervention. Group 2 also demonstrated a 7° decrease in side bending during the twist and reach maneuver, resulting in a large effect size of 1.37 ($p = 0.029$; not significant because of the stringent 0.0125 level of significance required with Bonferroni adjustments). There was also a large increase in lumbar extension demonstrated by group 1 (stretching only) during the active hip extension trials (Figure 3B). As shown in Figure 5, every group 1 participant demonstrated increased lumbar extension when asked to extend their hip, with pregroup and postgroup measurements averaging 9.2 (5)° and 15.1 (4)°, respectively (effect size = −1.30; $p = 0.04$) (Figure 3B).

Discussion

The first hypothesis that increased passive hip extension and rotation would result in increased hip ROM used during functional movements was rejected. Large increases in passive hip extension were achieved with training but were not used during active hip extension or lunging, both of which would be expected to result in full hip extension. Surprisingly, the 2 stretching groups averaged less hip extension postintervention during the lunge, elliptical, and active hip extension maneuvers, although not significantly so. Comparing Figures 3A and B, both stretching groups tended to decrease the amount of hip extension used during active hip extension while increasing the associated lumbar extension after 6 weeks. Thus, although they may have been focusing on positioning the right leg further behind, it seems they did not differentiate between hip and spine motion. It is notable that group 3 (core endurance) demonstrated the most consistent increase in dynamic hip ROM over the numerous trials: in 7 of the 8 hip measurements, group 3 demonstrated increased dynamic hip ROM used post-intervention, with 6 of those being greater than improvements in either groups 1 or 2 (Table 1). Interestingly, some of the largest hip ROM changes occurred in peak flexion or total flexion/extension, with flexion not expected to be directly affected by the stretching routines of groups 1 and 2. However, it is in keeping with the previous findings of this research group, that 6 weeks of core stabilization exercises resulted in improved range of passive hip rotation, and adds a further dynamic component to the suggestion that improved proximal stability will facilitate increased distal mobility, as suggested by Kibler et al. (12).

Although the participants seemed to have difficulty distinguishing hip from spine extension, all intervention groups demonstrated less lumbar rotation during the active hip extension maneuver postintervention, thus the second hypothesis can be partially accepted. This finding suggests that the concept of restraining lumbar rotation may be more readily incorporated into movement, perhaps because it provides greater visual feedback and oscillates around an obvious midpoint of 0°. Constraining lumbar flexion/extension, however, was a much more difficult concept for the participants to incorporate into movement patterns, yet is one of the motions known to be injurious to the lumbar spine and intervertebral discs (3,6,27). Anecdotally, many participants tended to rotate their pelvis in an anterior or posterior tilt (i.e., around a medial/lateral axis) as they "set" their posture before the unilateral stance required for active hip extension. This type of pelvis rotation would affect both the hip and lumbar extension angles, at a time when unweighting of the right leg had not yet taken place.

Much of the literature discussing changes to movement patterns subsequent to an exercise routine is sport specific (8,13,15). In addition to basic stretches, participants in those studies practiced movements that were required of their sport, thus having more of a chance to "groove" new motor patterns. Although objective improvements in core endurance and hip flexibility were documented in the previous study (17), changing movement patterns requires that preferred modes of coordination be replaced with new patterns, which are characterized by efficiency and maximum exploitation of the passive structures (2,5,20). In our study, the elliptical trainer and twist/reach motions were not part of the motor control exercise routine. Doing so may have improved participants' ability to transfer newfound motion to functional movement. The lunge and active hip extension were both an exercise (groups 2 and 3) and a test, yet the only improvement seen in spine control was lumbar rotation. No significant improvement in control of spine flexion/extension was detected after 6 weeks of intervention, despite the fact that these 2 exercises were specifically chosen as a sagittal and rotational challenge to spine control. These findings are similar to those of Frost et al. (7) in their analyses of Functional Movement Screen (FMS) scores before and after

12 weeks of exercise training/coaching. In both studies, participants were given latitude as to how they chose to move during specific dynamic activities, as opposed to the motion being highly cued. Because both studies documented minimal post-intervention changes in FMS score or kinematics, the suggestion arises that allowing natural movement may permit excessive between-test variability to movement patterns (11), as evidenced in both studies by the large *SD*s and similar changes in the control groups, thus precluding statistical or biological significance.

This seems to be one of the first studies suggesting that increasing the ROM of a joint may not translate into function or change a default movement pattern. A limitation for interpretation of the data is that the subject numbers are low. Nonetheless, more robust studies can now be designed to better isolate and identify the variables that influence the effectiveness and application of stretching protocols. Studies on stretching have questioned the efficacy for injury resilience and performance enhancement (24,25). Perhaps, the data reported here will augment the interpretation of this collection of works. Furthermore, healthy young adults were chosen to participate in this study in an attempt to reduce the likelihood that reduced hip mobility was because of arthritic change. Results may not transfer to an older population or those with low back pain. Male participants were chosen to reduce the number of variables, as hip/spine movement patterns differ between sexes (1,4,23,26). As seen in the outcome graphs, variability in hip/spine motion is high. Despite attempts to standardize motion with movements relative to anthropometric measurements (lunge and twist distances), it was noticed that people moved differently from trial to trial, let alone day to day. Similarly, intersubject variability was high, as indicated by the *SD*s. Yet to constrain motion further would have interfered with "normal motion." This biological variability compromises statistical analysis power, yet it was essential that freedom of movement choice not be compromised and individual response be recognized.

Practical Applications

Stretching and core endurance protocols are incorporated into many rehabilitation and training programs, but evidence of their transference to function is lacking. This study suggests that, although both flexibility and endurance may be improved over a 6 week intervention, there was minimal evidence that these changes resulted in changes to functional movement patterns: large improvements in passive hip extension and rotation did not result in greater use of this newfound range during functional activities that were specifically chosen to challenge these motions. Similarly, although improved core endurance resulted in decreased lumbar rotation during a hip extension maneuver, there was no reduction in lumbar rotation or flexion/extension during other activities. In fact, many participants seem to have difficulty differentiating hip motion from spine motion when doing an active hip extension maneuver, suggesting that a greater focus on practicing and creating default peripheral joint motion on a stable trunk is warranted. These findings imply that a successful stretching or core endurance program may require simultaneous movement repatterning: practicing the desired movement patterns to ensure that the newfound mobility or core endurance is incorporated into functional movement patterns.

Acknowledgments

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