

Improvement in off-axis neuromuscular control during functional tasks following six-week of pivoting elliptical training

^{1,2}Song Joo Lee, ²Yupeng Ren, ²Francois Geiger, ¹Alison H. Chang, ²Joel Press and ^{1,2}Li-Qun Zhang

¹Northwestern University, Chicago, IL, USA

²Rehabilitation Institute of Chicago, Chicago, IL, USA

email: l-zhang@northwestern.edu, web: <http://www.ric.org/research/centers/smpp/Staff/index.aspx>

INTRODUCTION

Although knee movements are mainly about the major axis of flexion/extension, knee injuries such as ACL injuries most commonly occur in pivoting sports, which involve strong and potentially excessive off-axis loads to the knee (knee valgus/varus and tibial rotation). Current research and training mostly focus on sagittal plane movement and there is a lack of research and training protocols for off-axis control and movements, which are closely related to potential injuries to the knee. The purpose of this study was to investigate off-axis neuromuscular control and conduct six-week off-axis training during functional tasks and evaluate the outcome.

METHODS

A novel pivoting and sliding elliptical machine was developed (1) to train individuals' off-axis neuromuscular control (2) to evaluate training outcome in terms of the subject's off-axis neuromuscular control and stability. Sixteen subjects without any musculoskeletal disorder participated in the study. Among them, 9 subjects in the study group participated in 18 sessions of off-axis training (3 times/week for six weeks). At the beginning, middle and after the trainings, off-axis neuromuscular control properties were evaluated quantitatively in terms of off-axis stability and off-axis energy, strength, proprioception, and EMG activities from muscles crossing the knee. Seven healthy individuals served as the control group and participated in only the 3 evaluation sessions at the same intervals.

All the subjects gave informed consent (approved by the Institute of Review Board at Northwestern University) prior to the beginning of the training program. All participants were examined for their

physical condition, particularly the knee to insure that their knees had a normal range of laxity, muscle strength, and free of any significant knee symptoms. After completing the clinical screening, individuals who did not have any other knee symptoms participated in the research program. Individuals in the control group were age and physical-activity level matched to the study group.

During the pre, mid and post training evaluation sessions, rotational stability, lateral stability, proprioception, and muscle activations were evaluated using the pivoting/sliding elliptical machine, with the EMG signals measured from the Biceps femoris, Semitendinosus, Medial Gastrocnemius, Lateral Gastrocnemius, Vastus Medialis Obliquus and Vastus Lateralis.

During each training session, the subject was asked to complete tasks under two different modes at several intensity levels at both lower limbs. In the first mode, the footplates were free to rotate with low friction (free rotation mode) or with assistive spring force. In the second mode, the footplates were perturbed to rotate with 1 Nm peak sinusoidal perturbation torque and 5 Nm offset torque in internal or external rotation. The subject was asked to maintain both footplates straight (aligning the second toe with the knee cap) during the functional stepping movement. In each training session, the subjects were first asked to do a few minutes of regular elliptical stepping movements without any pivoting movements, as a way of warming up and preparation for the training.

All footplate kinematic, kinetic and EMG data from the pre, mid, and post evaluations were analyzed in Matlab (Version 7.8). All data were segmented and time-normalized into percents of the elliptical cycle. Generally, data from 20-30 elliptical cycles per trial

were analyzed to make comparisons between different conditions including different modes of tasks and different evaluation sessions. Energy in pivoting for each foot was computed using the following equation.

$$Pivoting\ energy = \frac{1}{n} \sum_{i=1}^n |torque(i) * rotation\ angle(i)|$$

where n=1000 is the number of the data points in a trial. Since the tasks were “maintaining footplate straight”, ideally the pivoting energy should be zero.

Independent samples t-tests were used to compare between the groups per each evaluation session. One-way ANOVA tests were used to compare between evaluations per group with post hoc tests.

RESULTS AND DISCUSSION

Pivoting stability of the study group improved significantly following the six-week pivoting training (Fig. 1), while the control group did not show significant improvement (p<0.01). Pivoting energy reduced significantly after the 6-week training and the subjects better dealt with the perturbing torque in pivoting and maintained both feet straight during elliptical movements (Figure 2 and Table 1).

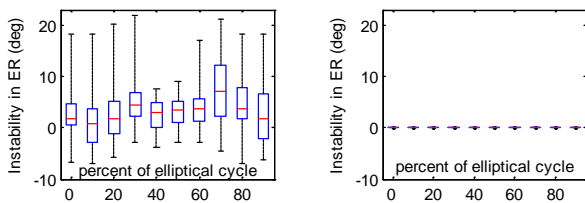


Figure 1: Representative data (from 30 elliptical cycles) showing improvement in rotational stability following the six-week pivoting training during free rotation mode (Left: Pre training evaluation, Right: Post training). The 2 tails indicate the max and min values and the box plot range indicates 25 and 75% of data. The red bar indicates the median values at 0, 10, 20, 30, 40, 50, 60, 70, 80 and 90% of the elliptical cycle.

Table 1: Reduction in pivoting energy (Nm*rad*%elliptical cycle⁻¹) during forward elliptical walking in the free rotation mode before/after the six week training. Reported values are in mean (±1STD). * indicates P<0.01 between the control and the training groups. Ψ indicates P<0.01 between evaluations.

| Group | Pre training Evaluation | Mid training Evaluation | Post training Evaluation | P value (between evaluations) |
|--------------------------|-------------------------|-------------------------|--------------------------|-------------------------------|
| Training (N=9) | 7.11 (3.80) | 1.42 (1.35) * | 1.48 (1.09)*, Ψ | <0.001 |
| Control (N=7) | 4.31 (2.56) | 4.54 (1.03) | 4.12(1.60) | 0.921 |
| P value (between groups) | 0.118 | <0.001 | 0.002 | |

Following the training, individuals in the study group showed reduced pivoting energy during the elliptical walking compared to the control group (p<0.01, Table 1).

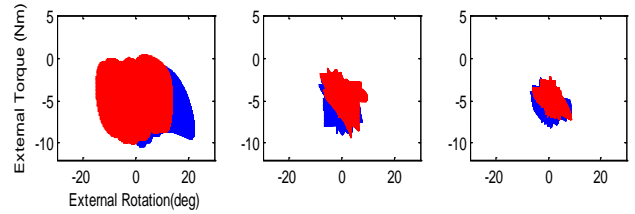


Figure 2: Reduction in pivoting energy following the 6-week training during forward elliptical walking under the external sinusoidal perturbations. The blue and red colors correspond to data from the left and right foot respectively (1st column: Pre training evaluation, 2nd column: Mid training, 3rd column: Post training).

CONCLUSIONS

Subjects in the study group improved their off-axis stability in tibial rotation significantly. Their improved off-axis neuromuscular control was associated with reduced pivoting energy during the elliptical stepping movements, indicating they could better perform the off-axis control with reduced energy/work involved.

Although muscle activation patterns are not reported here due to limited space, the reduced pivoting energy may be associated with more skilled but less muscle activities throughout elliptical cycles for trained subjects to maintain the footplates positions. Overall, the pivoting elliptical training (combining sagittal and transverse movements) can help healthy individuals to improve their off-axis stability and neuromuscular control with reduced energy/effort, which may help them to better deal with potential injuries associated with pivoting sports.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of NIH and NSF.