Invited Commentary

The authors should be commended for a paper attempting to explain the effects of an intervention targeting neuromuscular responses in subjects with anterior cruciate ligament deficiency (ACLD). Despite the success of unique subjects with ACLD who tolerate high demand tasks, long-term nonsurgical rehabilitation of people with ACLD remains controversial. This study provides further support for nonsurgical management of targeted subjects with ACLD (“potential copers”) by suggesting how knee kinematics and muscle activation are altered by perturbation training.

In summary, this paper extends a previous work published by these authors on the effect of a perturbation training program on subjects with ACLD. In the present article, the authors suggest that a perturbation training program (10 sessions) results in increases in knee flexion angle (<2°) and co-contraction indexes of pairs of lower-extremity muscles during walking tasks. Two of the walking tasks simulate a forward and lateral slip event during walking, provoking specific neuromuscular responses.

The following commentary reviews the results and several points raised by the authors to support their effort to advance nonsurgical patient care for people with ACLD. Although alternative views are offered here, the expertise and leadership of this group in advancing nonsurgical care of people with ACLD are gratefully acknowledged.

Study Results
This study primarily relied on previous studies of electromyography (EMG) activation to define the neuromuscular control observed in subjects classified as potential copers. For the key dependent variables in this study, which were EMG co-contraction indexes (vastus lateralis-lateral hamstring muscle [VL-LH] and vastus lateralis-medial gastrocnemius muscle [VL-MG]), the authors decided to relax the alpha level to .10. This may mean that fewer subjects with ACLD showed the desired result of decreased co-contraction indexes after perturbation training than would normally be acceptable in clinical trials.

The authors justify the increased alpha level by noting the increased variance of the ACLD and control groups, which is a common finding in EMG studies. At the relaxed alpha level of .10, 5 of the 12 comparisons listed in Table 3 showed a decreased co-contraction index after perturbation training. Notably, the VL-LH co-contraction index is higher before training and decreased after training in both the lateral and anterior conditions. The combination of the high variability and relaxed alpha level raises the possibility that only a portion of the intervention group benefited from the intervention (ie, decreased VL-LH co-contraction index after training) or that several subjects changed minimally. To address these issues, the authors may consider reporting the percentage of potential copers who showed a positive response to perturbation training (ie, decreased co-contraction index). Furthermore, they may consider reporting the percentage who showed a positive response to perturbation training by a specified amount. This would enhance the ability of a clinician to anticipate whether perturbation training may affect co-contraction indexes in an individual patient and by how much.

EMG Activation and Co-contraction Indexes
The results of a previous study of surface platform perturbations suggested that potential copers demonstrate abnormal EMG co-contraction indexes. What is not clear in the results of the present study is the source of the high co-contraction indexes (VL-LH and VL-MG). As described by the authors, co-contraction indexes are ratios expressing the activation of one muscle relative to another (eg, assuming VL activation was higher than LH activation, VL-LH expresses LH activation relative to VL activation). Although there are several different indexes, this is a common approach to examine muscle activation across muscles. Further analyses of each muscle are necessary to determine which muscle or muscles contribute to the co-contraction. For example, in this study, the potential copers may have used lower VL activation and status quo LH activation, resulting in a higher co-contraction index before training. Alternatively, the LH muscle may be responsible for a higher VL-LH co-contraction index, or changes in both muscles could contribute. The results of a previous study by these authors suggested higher quadriceps femoris muscle activation during walking in response to perturbation training, not alterations in hamstring muscle activation.

What activation is contributing to the co-contraction indexes observed in this study?

Variability of EMG Activation
As pointed out by the authors, high variability of EMG activation patterns during dynamic tasks is a common finding. What is unclear is the cause of this variability in this study and in other studies. The results of a recent study of highly trained athletes by McNitt-Gray et al suggest that lower-extremity EMG patterns can vary significantly from athlete to athlete. In their study, one athlete used a combination of the gluteus maximus and hamstring muscle activation to extend his hip during a drop landing task. In contrast, an equally trained athlete used a strong hamstring muscle contraction for the same...
task. What is important about this observation is that the hip and knee joint loads (reflected in the joint angles and moments) were similar, suggesting that the task demands did not explain the variability in muscle recruitment. When averaging data across subjects, this flexibility in muscle recruitment is ignored, contributing to high variability. This source of variability suggests that the potential copers and subjects who are healthy may use more than a single EMG co-contraction strategy to control forward and lateral slip events as examined in this study. These differences in patterns may potentially be reflected in the high variability of the VL-LH and VL-MG co-contraction indexes of the potential copers during weight acceptance of the anterior and lateral conditions. Given the potential for this source of EMG variability, how are average co-contraction indexes best interpreted?

**Joint Stiffness**
The increased co-contraction indexes of the potential copers relative to the control subjects is explained as a possible “joint-stiffening” strategy. The assumption is that higher co-activation results in higher muscle forces that increase resistance to joint flexion or extension movements (torsional stiffness = change in joint moment/change in joint angle). Further evidence of a “joint-stiffening” strategy is associated with the knee flexion angle, which is reduced (<2°) in the subjects classified as potential copers before training. This hypothesis is tenuous because of the complex relationship between EMG activation and muscle force during dynamic movements. For example, a validated subject-specific forward dynamic model suggests that increased quadriceps femoris muscle EMG activation may not always lead to destabilizing forces at the knee. McLean et al applied a subject-specific modeling approach to determine the load on the anterior cruciate ligament (ACL) during a side-step cutting task. Despite perturbing the model using “worst case scenarios” (ie, knee-extended position with no hamstring muscle force), they were unable to achieve ACL loads higher than 900 N (2,000 N was the cutoff for ACL injury). In the knee-extended position, the anterior (destabilizing) component of the patellar tendon angle of pull was counteracted by shortening of the quadriceps femoris muscle, which reduced the muscle’s ability to generate force. Therefore, high quadriceps femoris muscle activation at a knee-extended position was not destabilizing to the knee during a dynamic side-step cutting task. Similarly, with known alterations in hip angles and moments possible in people with ACLD, the relationship between hamstring muscle activation and force at the knee is ambiguous. Although a “joint-stiffening” strategy is one possibility given the alterations of EMG activation observed, further muscle force modeling approaches are needed to evaluate this hypothesis.

**Motor Control Theory**
The authors argue that the high VL-LH and VL-MG co-contraction indexes may be associated with the subjects attempting to freeze degrees of freedom, supporting the view that the subjects are in the first stage of skill acquisition (assuming the target skill is knee stabilization). The authors cite a study of subjects learning a slalom-like movement in which the subjects were observed to increase the range of joint movement over a 7-day period. Recent studies, however, have challenged Bernstein’s original hypotheses, suggesting that it is the task that dictates whether the degrees of freedom increase or decrease in the initial stage of skill acquisition. For example, increased degrees of freedom are associated with tasks such as slow sinusoidal (anteroposterior) platform movements. Ko et al argued that the increased degrees of freedom are associated with an exploratory phase, where people use increased degrees of freedom to determine the most efficient strategy during the initial stage of skill acquisition. Given this, should perturbation training also facilitate increased degrees of freedom as a component of the initial stage of training? For example, the protocol evaluated by Fitzgerald et al also included varied perturbation speeds (slow and quick); therefore, are the slow perturbations as important as the short, quick perturbations?

In the diseased state, task goals may conflict and people may have difficulty learning a satisfactory strategy or prioritizing a disease-specific strategy such as “joint stiffening.” For example, in this article, the authors suggest the subjects with ACLD may focus on the task goal of establishing a knee stabilization strategy through co-contraction, in addition to the task goal of maintaining balance during the perturbation training. Is the high variability of VL-LH and VL-MG co-contraction indexes of the potential copers associated with this group’s failure to identify a single efficient strategy that satisfies both goals of balance and knee stabilization?

Although the perturbation training was successful in a clinical trial, I felt the authors’ motor learning perspective was intriguing and agree that this line of research may lead to improvements in rehabilitation. Because of the research of this group, a classification scheme exists to separate “copers” from “noncopers” and aspects of neuromuscular control that are unique to these individuals have been identified. The emphasis on perturbation training is supported by the clinical trial performed by this group that suggests perturbation training plus rehabilitation is better than rehabilitation alone. However, further improvements in training depend on our ability to manipulate neuromuscular control with training in individual patients. The success of this approach partially depends on our ability to define clinically meaningful variables of neuromuscular
control,2,3,21 which led to this study focusing on co-contraction indexes. Understanding how skill acquisition is altered by ACL deficiency or develops differently in subjects classified as copers and noncopers may lead to further improvements in training for these patients. For example, data gained from understanding how skill acquisition develops in subjects with ACL deficiency may assist in the development of a more individualized perturbation training program, where dosage (frequency and intensity) can be tailored to each patient.

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References