Chapter 9
Assessing Joint Stability from Eigenvalues Obtained from Multi-Channel EMG: A Spine Example

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ABSTRACT
Electromyographic (EMG) signals have many uses. This chapter addresses the role of EMG signals to assess joint stability. Low back pain assessment and treatment interventions often involve the concepts of stability and/or joint stiffness. Using muscle activation and lumbar spine posture to calculate segmental stiffness and potential energy of the spine, eigenvalues can be linked to quantitative stability. It is reasoned that if a relationship exists between eigenvalues and individual muscles, then this approach can guide customized clinical intervention for people with defined spine instability.

INTRODUCTION
EMG can be used to obtain force and stiffness estimates from which stability of joints can be estimated. Using the lumbar spine as an example, EMG from the trunk muscles can be used to calculate joint stiffness, which is recognized as universally enhancing stability and the ability to withstand a perturbation. The flexible column does not have sufficient stiffness to support the weight of the upper body without buckling unless muscles are activated and stiffened around the column (Lucas & Bresler, 1961). Perturbed muscle activation patterns leading to instability have been shown to be both a cause and consequence of low back pain. Addressing the perturbed patterns with corrective exercise appears, at least in some patients, to reduce or eliminate their pain immediately. Insufficient stability is thought to allow micro movements in the spine motion seg-
ments resulting in painful stress concentrations of innervated tissues (McGill, 2007). Further understanding of quantitative spine stability could potentially assist in clinical interventions of individuals with spine instability.

Some investigations of spine stability use a potential energy approach to evaluate the eigenvalues (EV) derived from the segmental stiffness and potential energy of the spinal column and joints. However, it is unknown whether specific muscles can be represented by specific EVs, obtained from EMG, such that their evaluation could guide clinical approaches to modify muscle activation/stiffness and thus the stability state of the joint. This chapter will examine this and establish a theoretical framework for understanding the links between posture and muscle activity, which results in force and ultimately spine load and stability/stiffness. It was hypothesized that:

1. Individual muscles affect specific EVs, but no one muscle can be associated with one EV level
2. Specific muscles do affect specific planes of stability/stiffness
3. EVs are affected by posture
4. Overactivating muscles by increasing muscle activation to 100% maximum voluntary contraction (MVC) negatively affects the EVs
5. The relationship between muscles and specific EVs obtained during simulation remains with real subjects performing loaded tasks.

The hypotheses were evaluated in two stages. First, synthetic muscle activation levels enabled a sensitivity analysis of the variables that affect the EVs. Second, the sensitivity analysis was repeated with actual muscle activation and spine posture data obtained from a carrying task.

BACKGROUND

Quantifying joint stability, particularly that of the spine, involves the interpretation of stiffness enhancing the ability to survive a perturbation. Some investigations using this potential energy based approach evaluate the EVs derived from the segmental stiffness and potential energy of the column and joints. Thus, stability was defined as the ability of the spinal column to withstand perturbation while resisting buckling behavior. Joint stiffness is recognized as universally enhancing stability and is the second derivative of potential energy. EVs, when positive, indicate a sufficiently stiff state to prevent unstable behavior in the elastic spinal column. The number of EVs corresponds to the degrees of freedom (in this study, the number of spinal levels, multiplied by the three rotational orthopedic axes of each joint – i.e. six lumbar levels by three axes of flexion/extension, lateral bend and twist renders 18 EVs).

Beyond indicating whether a stable state is present or not, this study attempted to probe the EVs for any additional information content, including whether specific muscles are better reflected in specific EVs. If this is true, then the value of the EVs for a given patient could provide clues when choosing optimal muscle based interventions.

Anders Bergmark (1989) pioneered the potential energy approach to assess spine stability with joint stiffness and 40 muscle stiffness coefficients to calculate energy minima from total joint stiffness. Bergmark simplified the potential energy approach conceptually by using the analogy of a ball rolling on a surface. The ball seeks a state of minimum potential energy by rolling and eventually coming to rest in the bottom of a local “bowl.” The steeper the sides of the bowl, the greater the external perturbation is required to influence the ball out of the bowl and therefore, it is more stable. The system is potentially unstable if the perturbation is large enough to cause the ball to roll out of the bowl and into the next “energy well”