Proof of Concept: Response surface methodology reveals changing motor control strategies during a single leg squat.

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Category: New Tools and Techniques

Introduction

Response surface methodology (RSM) is a technique relating the interaction of two variables to an output and is classically used to optimize crop yield and chemical processes [1]. Stergiou et al. introduced the application of this technique for analyzing motor controls strategies during single leg hopping [2]. Our study seeks to further explore RSM as a technique to characterize joint stiffness and compare motor control strategies between healthy controls and subjects with hemophilia during a single leg squat.

Clinical Significance

Hemophilia is a bleeding disorder resulting from clotting factor deficiency. Joint bleeding and long-term damage can occur in a person with hemophilia (PwH), leading to movement alterations from pain, swelling, and arthritis in weight-bearing joints that reduce range of motion and increase joint stiffness. To determine how motor control may change in PwH, pilot data from control subjects were collected to characterize the motor control strategies during repeated single leg squats (SLS).

Methods

Controls (n = 13) and a PwH (n=1) performed 20 SLS, with rest as needed to avoid fatigue effects. Trajectories from the Vicon full body marker set were recorded using eight Vicon Vantage cameras and kinetics recorded using a Bertec force plate. Kinematic and kinetic data was temporally normalized, and the concentric and eccentric phases of the hop identified using joint angles. Joint stiffness was calculated for each subject's dominant leg's hip, knee, and ankle by dividing joint moment by joint angle. Total leg stiffness is the sum of the hip, knee, and ankle stiffnesses. Pairings of joint's stiffness data (hip-knee, hip-ankle, knee-ankle) were then fitted using 2nd order, nonlinear regression in Mathematica. Surfaces were categorized based on calculated eigenvalues as a maximum (maximizing variables to optimize the response), minimum (minimizing variables), or saddle (mixed behavior of variables) [3]. A two-tailed, unpaired t-test was performed comparing the respective joint and total leg stiffnesses between the control cohort and the PwH for both the concentric and eccentric phases of the SLS.

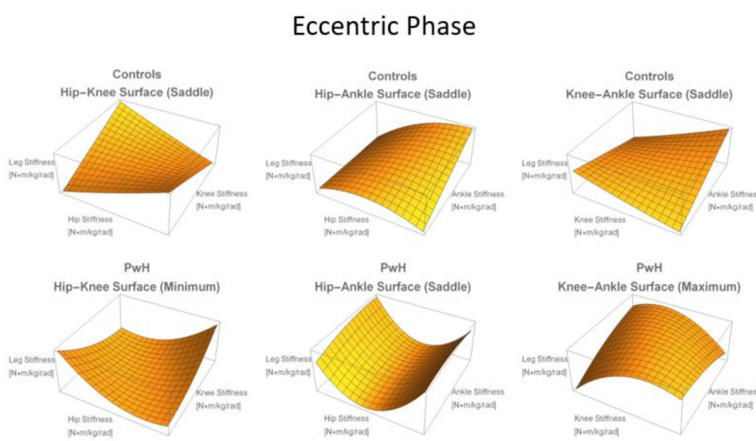

Figure 1: Response Surfaces for Eccentric Phase of Squat. Row 1: Control Subjects, Row 2: PwH

Demonstration

There was no significant difference ($p > 0.1$) between the individual joint and total leg stiffnesses between the controls and PwH. However, RSMs revealed that different motor control strategies were adopted (Figure 1). The surfaces for the eccentric phase of the squat for the PwH was different than what was seen in the control cohort. For these subjects, the majority of the surfaces for the eccentric phase were saddles while the PwH had a minimum, maximum, and saddle surface. Upon further investigation of the individual surfaces in the control cohort, some subjects had a maximum surface. However, none of the controls had a minimum surface in the eccentric phase of the squat and was only seen in the PwH (Figure 2). Although more subjects with hemophilia will be studied in this ongoing investigation, the differences in stiffness strategies during the eccentric phase of the SLS between controls and the PwH suggest RSM may offer clinically useful insights. RSM may elucidate motor control strategies adopted to compensate for hemophilia caused joint damage by reducing multiple joints' kinematic and kinetic variables into a low dimensional descriptor.

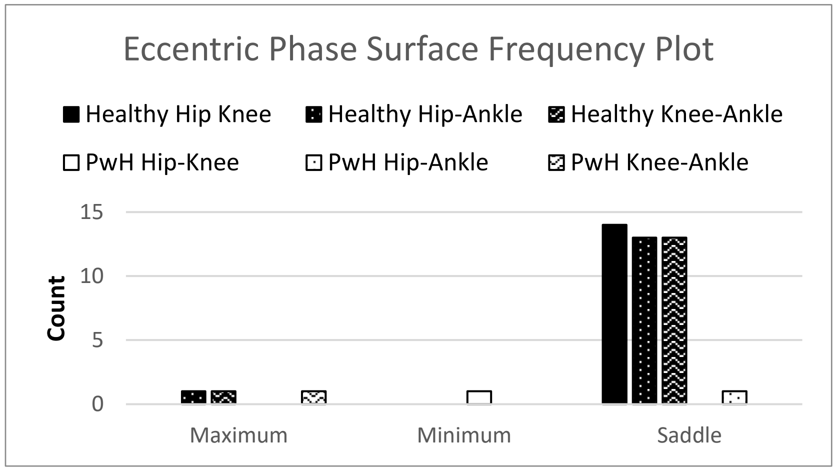

Figure 2: Frequency plot of surfaces in the eccentric phase

Summary

This investigation explored the use of RSM to evaluate motor control strategies in control subjects compared to a PwH. While traditional kinematic and kinetic data may not detect changes in motor control, RSM shows promise in revealing changes in movement strategies for populations with movement impairments relating to joint stiffness.

References

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[2] Stergiou, Nicholas, ed. Nonlinear analysis for human movement variability. CRC press, 2018.

[3] Myers, Raymond H., Douglas C. Montgomery, and Christine M. Anderson-Cook. Response surface methodology: process and product optimization using designed experiments. John Wiley & Sons, 2016.

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Disclosures

The authors have no relevant conflicts of interest to declare.