PREDICTING OUTCOMES OF TREATMENT FOR STIFF-KNEE GAIT USING SUPERVISED LEARNING

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INTRODUCTION

Stiff-knee gait is a prevalent, debilitating consequence of cerebral palsy in which swing-phase knee flexion is substantially diminished. Approximately 3 out of every 1,000 children manifest one or more of the symptoms of cerebral palsy (CDC, 2004). Stiff knee gait results in a number of related gait problems including tripping and foot-dragging due to inadequate toe clearance (Sutherland and Davids, 1993).

Outcomes following surgical treatment for stiff-knee gait are inconsistent. Some patients achieve dramatic gains in knee flexion while others show no improvement or suffer further impairment. At present, stiff-knee treatment recommendations are based on qualitative observations of the patient's gait, physical examination of muscle spasticity, inspection of gait analysis measurements, and the intuition and experience of the clinical team.

This study presents the use of supervised learning, an objective and quantitative tool, to predict treatment success for stiff-knee gait. Our goal was to determine combinations of preoperative gait measurements, or predictors, that mathematically classify the postoperative outcome, or response.

METHODS

The subjects analyzed in this study had previously undergone routine treatment-planning gait analysis at Gillette Children's Specialty Healthcare – Center for Gait and Motion Analysis, St. Paul, MN. Using inclusion and stiff-knee definitions of Goldberg *et al.* (2006) and requiring equal numbers of *good* (i.e., not-stiff) and *poor* (i.e., stiff) outcomes following treatment for stiff-knee gait, 62 subjects were identified who met these criteria.

Significant features of preoperative gait measurements separating the good and poor outcome groups were determined in two ways. First, kinematic and kinetic factors correlated with improved knee flexion (Goldberg *et al*., 2006) were extracted from existing data. Second, kinematic, kinetic, and joint power data having the largest test statistics from a two-sample *t*-test were extracted as well.

Linear discriminant analysis (i.e., linear regression in the two-class outcome case) was used to determine the linear combination of preoperative predictors that best fits good and poor postoperative outcomes. The resulting coefficients were then used to predict postoperative outcomes for a separate set of subjects. Due to the relatively small data set, cross-validation with the 20% holdout method was used to determine performance.

RESULTS AND DISCUSSION

Several combinations of preoperative gait parameters correctly predicted postoperative outcomes at a rate higher than the inherent 50% probability of the input data (Table 1, Figure 1). The rate was highest (87.9% correct) using the combination of hip flexion and power after initial contact, knee power at peak knee extension, knee flexion velocity at toe-off, and hip internal rotation in early swing.

These preliminary results have significant clinical impact. More than 87% of treatment outcomes were predicted correctly using only five preoperative gait measurements. Nearly

70% of outcomes were predicted by a single measurement. Knee flexion velocity at toe-off was one of the most noteworthy single predictors. Good outcomes resulted in ⅔ of subjects with preoperative knee flexion velocities at toe-off above 1.2°/(% of gait cycle).

The potential to use supervised learning to predict treatment outcomes for stiff-knee gait is exciting. This study provides specific and useful preoperative predictors of postoperative outcome. Future studies are needed to determine the optimal set of predictors and if supervised learning can improve treatments.

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Table 1. Summary of cross-validated correct response rates for best combinations of 5 or fewer preoperative gait measurements separating the good and poor outcome groups.

Predictor (Portion of Gait Cycle)		Combination	Rate (%)
Goldberg *et al*. (2006) factors correlated with stiff-knee gait		G1-G2	**68.1**
G1. Knee flexion velocity (toe-off)		G1	67.8
G2. Average hip flexion moment (double support)		G1-G2-G5	66.4
G3. Average hip flexion moment (early swing)		G1-G2-G3-G4	63.8
G4. Average knee extension moment (double support)			
G5. Average knee extension moment (early swing)		G1-G2-G3-G4-G5	63.5
Two-sample *t*-test comparing good and poor outcome groups		T1-T2-T3-T4-T5	**82.6**
T1. Knee flexion (48.5%)	T8. Hip internal rotation (71.4%)		
T2. Knee flexion (80.8%)	T9. Hip flexion (92.9%)	T6-T7-T8-T9	79.5
T3. Hip power (43.2%)	T10. Pelvic tilt (18.7%)	T2-T10-T11	78.3
T4. Knee abduction moment (51.6%)	T11. Hip flexion (52.0%)		
T5. Knee power (2.1%)	T12. Ankle power (48.3%)	T10-T11	74.1
T6. Hip power (4.4%)	T13. Hip flexion (4.4%)		
T7. Knee power (40.7%)		T12	68.2
		G1-T6-T7-T8-T13	**87.9**
Combination of Goldberg *et al*. (2006) factors correlated with stiff-knee gait		G1-T8-T10-T13	87.0
and two-sample *t*-test comparing good and poor outcome groups		G1-T6-T10	81.9
		G1-T10	77.2

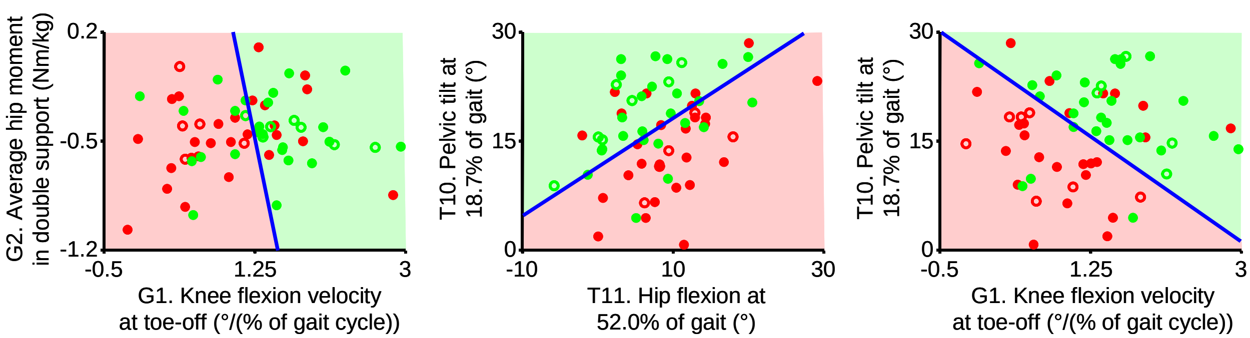

Figure 1. Scatter plots of best combinations of two preoperative gait measurements separating the good and poor outcome groups. Filled circles represent training data and open circles represent test data for one instance of cross-validation. Circle colors indicate good (green) and poor (red) postoperative outcomes. Blue lines divide the good (green shaded) and poor (red shaded) outcome prediction regions.