PREDICTING USER COMFORT OF AN ANKLE EXOSKELETON USING A MODIFIED VISUAL ANALOGUE SCALE

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Introduction

Optimizing exoskeleton control parameters using soft metrics, such as user comfort, is desirable[1]. Measuring comfort is difficult, but visual analogue scales (VAS) produced reliable measurements for footwear[2]. To evaluate the use of a modified VAS[3] in the context of ankle exoskeleton comfort, two predictive models were created. The primary objective of this abstract was to assess and compare the accuracy of both models.

Methods

Three young adult subjects (S1, S2, S3) completed 20 to 30 3-minute trials. Subjects walked on a slow treadmill with pneumatically powered ankle exoskeletons on both legs. The exoskeletons generated torque $k_P(\theta_c - mt)$, where k_P was the virtual stiffness, θ_c was the current ankle angle, and m was the slope. mt saturated at a set-point that changed depending on the phase of the gait. The control parameters (k_p, m) and treadmill speed[4] were scaled using subject height and/or mass. k_p ranged from 0 to 1.5 (~3 Nm/deg) and m ranged from 0 to 13 (~30 deg/s). Pilot testing indicated that these ranges encapsulated the locus of maximum comfort. New parameters were chosen for each trial following a roughly spiral pattern (Fig. 1). After each trial, subjects responded electronically to a two-question, 100mm VAS survey which displayed the previous trial's answers[3] (Tab. 1).

Each subject's VAS responses were modeled using quadratic regressions (QR) and linear interpolations (LI). The predictor variables were k_P and m. Approximately 70% of the data was used to generate the models. The remaining data was used to calculate the error between actual and estimated comfort. Errors were not normally distributed, hence the median ($\tilde{x}$) and inter-quartile range (IQR) were used to describe model errors. For further evaluation of the QR model, the confidence intervals (CI) for the quadratic terms were calculated because they were expected to be strictly negative.

Results and Discussion

S3's data was excluded due to frequent exoskeleton collisions causing most control conditions to be equally uncomfortable. In contrast, the other subjects reported a range of responses (S1 ~55 mm, S2 ~30 mm, Tab. 1).

In general, both models underestimated comfort as indicated by mostly negative $\tilde{x}$. The IQR was typically lower for the LI model, suggesting that it was more precise. This was not surprising since the responses were highly nonlinear (Fig. 1). Possibly due to the nonlinearity, neither model was particularly accurate. While $\tilde{x}$ was generally small (often $\leq 10\%$ of the response range), IQR was generally large (~50% of the response range). In addition, very few of the quadratic coefficients were statistically significant. This suggests that quadratic models are a poor fit for comfort data and/or that the collected data is too noisy to identify a signal.

We anticipated the variability in Q1. We hoped that Q2 would be more consistent while staying sufficiently correlated with comfort. The two questions were moderately correlated (r = 0.64). Neither question consistently had a smaller $|\tilde{x}|$ or IQR. Thus, there is no advantage to using Q2 as a proxy for Q1.

Significance

There is a complex and noisy relationship between comfort and control parameters. It is still unclear how much of the apparent nonlinearity is noise versus a truly nonlinear signal.

Acknowledgments

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References

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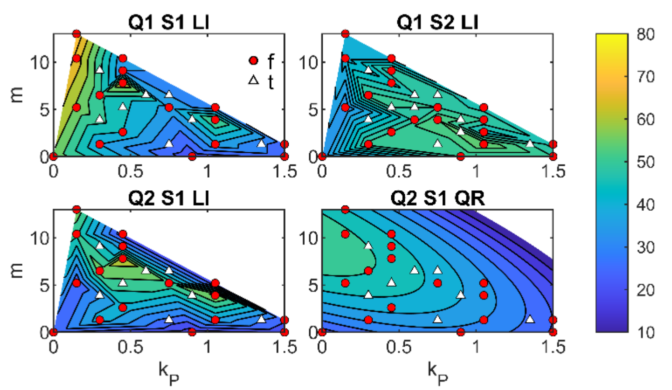

Figure 1: Representative contour plots of comfort with tested data points shown. Points used to create the models are red circles (f) and the points are white triangles (t).

Table 1: Summary statistics of responses and models.

Question	Group	Response Min	Response Max	QR R^2	QR CI, k_P	QR CI, m	QR $\tilde{x}$	QR IQR	LI $\tilde{x}$	LI IQR
Q1: "How comfortable are you?"	S1	18	74	0.56	-22.2, 67.1	-0.8, 0.5	10	28	7	22
	S2	34	61	0.6	-34.5, -5.8	-0.3, 0.1	-2	8	-2	13
	All	18	74	0.01	-31.0, 23.9	-0.6, 0.2	-1	14	1	17
Q2: "How helpful was the exoskeleton at toe-off?"	S1	17	71	0.2	-79.4, 44.0	-1.2, 0.5	1	32	-2	26
	S2	40	70	0.56	-65.4, -10.3	-0.7, 0.1	-2	10	-3	5
	All	17	71	0.14	-75.6, -3.4	-0.8, 0.2	-5	23	-1	23