REPEATABILITY OF A VISUAL ANALGOUE SCALE TO MEASURE COMFORT OF AN EXOSKELETON

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Introduction

While important, user-perceived exoskeleton comfort is often ignored, in part because a validated metric does not exist. Visual analogue scales (VAS) are a reliable method to measure comfort in other contexts, such as footwear[1] and acute pain[2]. The primary objective was to quantify the repeatability of a VAS exoskeleton comfort score. The secondary objective was to determine if the comfort signal-to-noise ratio was high enough to test predictions.

Methods

Experimental: Two young, male subjects wore a pneumatically powered ankle exoskeleton on their right leg and an identical, unpowered (due to technical difficulties) exoskeleton on their left leg while walking at 0.50 m/s. The exoskeleton torque was $k_P\theta$, where k_P was the virtual stiffness and θ was the ankle angle in degrees. During each experimental session of 8 trials, we tested k_P values of 0 to 0.9 N·m/deg in 0.15 N·m/deg increments plus 1.0 N·m/deg. Thus, we had a total of 16 conditions = 8 k_P levels × 2 subjects since different subjects were expected to have different comfort scores for a given k_P. After each 3 min trial, subjects responded to ten 100mm horizontal VAS questions on a tablet, and then the next trial began immediately with a new k_P. Each subject completed 7 sessions, 5 with randomly varying k_P and 2 staircase sessions where k_P was increased sequentially.

Analysis: This abstract only analyzed the first question: "How comfortable are you?" due to high correlations between question scores. To quantify repeatability[3], the repeatability coefficient $RC = 2.77\sqrt{MSE}$, where MSE was the within-condition mean square error calculated using a one-way ANOVA, was computed. 95% of comfort scores were expected to be within $\pm RC$ of each other for repeated measures of the same condition. Repeatability was also quantified using the error $e = c - \mu_{k_P}$, where c was the comfort score and μ_{k_P} was the corresponding mean comfort for that condition[3]. The 50%, 90%, and 95% error thresholds were the errors that corresponded to the percentage of trials with errors below the threshold. To determine if predictions are possible, we performed quadratic regression since we expect comfort to be highest for moderate k_P. Thus, a strictly negative 95% confidence interval (CI) for the quadratic term suggests that there was a sufficient signal despite the noise to confirm the prediction.

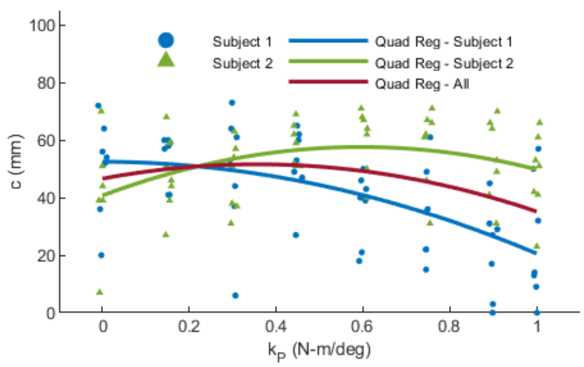

Figure 1: Comfort score c vs. k_P, where $c = 0$ is very uncomfortable and $c = 100$ is very comfortable. Despite considerable noise in the data, the quadratic regressions were concave down.

Results and Discussion

The range of comfort scores was [0, 73] mm (Fig. 1), with similar ranges between random and staircase sessions and for individual subjects. There was no apparent drift in comfort scores between sessions. Each subject had different k_P ranges that were most comfortable, as expected. RC was 45mm (Fig. 2), which was significantly larger than the 9 to 20mm RC for acute pain[2]. Consistent with the high RC for comfort, 50% of trials had errors within 10mm, 90% were within 28mm, and 95% were within 36mm. Thus, the repeatability was poor. A quadratic fit using all of the data had a strictly negative 95% CI for the quadratic term, indicating that the fit was concave down as expected (Fig. 1). However, the R^2 value was 0.094, representative of the low repeatability. Despite the noise, this suggests that there was a sufficient signal to test predictions using data from multiple sessions. For individual sessions, comfort scores from a random session did not reliably produce fits with a strictly negative 95% CI for the quadratic term. Conversely, 3 out of the 4 staircase sessions did, indicating that the staircase sessions may have more repeatable comfort scores. Since comfort likely has an aspect of comparison[1], this was not surprising since the staircase trajectory kept Δk_P constant, but the random sessions did not.

Significance

A comfortable exoskeleton may be more acceptable, motivating the creation of a comfort metric. Despite promising results from other fields, using a VAS to measure exoskeleton comfort had poor repeatability, particularly when k_P was tested randomly. It was still possible to find statistically significant regressions given sufficient data, suggesting that there was an underlying true signal. Nevertheless, further work to develop a comfort metric and an appropriate experimental protocol is required.

Acknowledgments

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References

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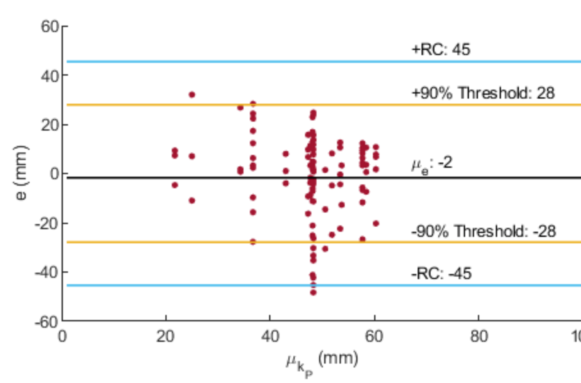

Figure 2: Error vs. mean comfort for that condition. There were significant deviations among responses, signifying poor repeatability.