Correctly Applying Fitts' Law to Brain Control Interfaces

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Abstract. Fitts' Law is a popular performance metric in neural interface movement control studies. However, no studies have investigated whether movement trajectories in neurally-controlled dwell-to-select tasks conform to the Fitts' Law empirical model. We show that Fitts' Law applies to best-case performance in a typical neural cursor control task, only if a correction is made for the dwell-to-select behavior. A trend of movement times consistent with Fitts' Law is seen in experimental data containing many sub-optimal trials using a peak fitting method. We also show that the information transfer rate (ITR) is often incorrectly assessed.

Keywords: Performance Metric, Fitts' Law

1. Introduction

We evaluate the ability of Fitts' Law to describe trajectories observed in manual- and brain-controlled cursor positioning tasks performed by a macaque. To our knowledge, only one study has evaluated brain-controlled cursor positioning performance at multiple difficulty levels [Simeral et al., 2011]. For a survey of recent studies using Fitts' Law, see supplement to [Gilja et al., 2012]. Trials at multiple difficulty levels are necessary for evaluation of the predictive power of the Fitts' Law model, which in turn is a prerequisite for its valid use as a performance metric.

Fitts' Law [Fitts, 1954] predicts movement time T for a range of precision positioning tasks as a function only of movement distance D and target width W:

$$T = a + b \times ID = a + b \log_2 \left(\frac{D}{W} + 1 \right) \tag{1}$$

where a and b are free parameters, and the Index of Difficulty term (ID) captures task difficulty as a function of only the *ratio* between target distance and width. The above Shannon formulation was developed by [MacKenzie, 1992], and uses a slightly different ID definition from the original study. Movement times consistent with Fitts' Law are observed in a wide range of pointing and positioning tasks, yet the model is known to be fragile in that it holds over only a restricted set of IDs, target widths, and distances. Further, the original study observed a departure from model predictions below an ID of 2, but many BCI studies since use an ID of 1.5 or less, depending upon the ID formulation used.

To create a task compatible with Fitts' Law and also feasible under neural control, many studies replace the *click-to-select* behavior with *dwell-to-select*. In a dwell-to-select task, movement trajectories are effectively terminated when the cursor crosses the target boundary (without subsequently exiting the target area). In 1D, this has a consequence of allowing zero movement time when the target boundary is located at the movement start point, i.e. when $D = W/2$. We will investigate whether a correction to the ID definition is required for dwell-to-select tasks in Section 3.

2. Experiment Design

Manual isometric and neural velocity-controlled 1D cursor control tasks were performed by a macaque. A 1s dwell was required for selection of circular targets of varying width and distance. Neural control used 4 single units, selected based on firing rate and strength of tuning to wrist torque, with deviations from baseline firing rates mapped to horizontal cursor velocity.

Candidate Fitts' Law models were fit to the data using a peak fitting method, thus selecting the most common trial time at a given ID. Trial time histograms at each ID were filtered with the highest-bandwidth Gaussian filter at which the tallest peak was also the lowest time peak, using the same filter at all IDs.

3. Results

We first validate the peak fitting method using manual control data. In figure 2, a standard Fitts' Law regression to trial time histogram peaks shows good quality of fit. However, some trial times are predicted to be negative, consistent with the fact that trials below an ID of 0.585 will begin inside of the target. To fix this, we can calculate *ID* using distance to the target boundary, obtaining a similar quality of fit and non-negative trial times at all non-negative *ID* values.

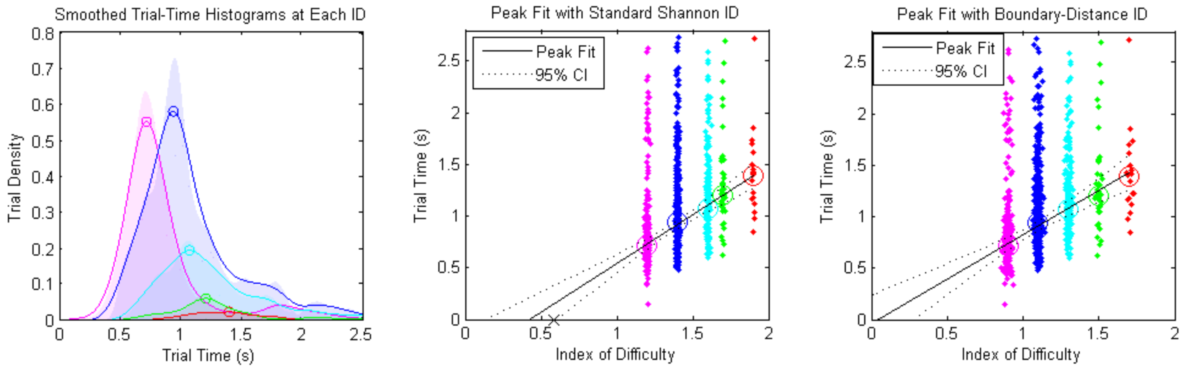

Figure 1: *Fitts' Law evaluation of manual cursor task.* Left, *histograms of trial times at different IDs. Shading reflects optimal smoothing at each ID; solid line denotes histograms smoothed with same filter at all IDs.* Center, *standard Fitts' Law regression to histogram peaks (*$R^2 = 0.98$*), with individual trials shown with added jitter for context. Black '*$\times$*' denotes ID at which target boundary is at start location.* Right, *Fitts' Law regression with ID calculated using distance to target boundary (*$R^2 = 0.98$*).*

Next, we apply the corrected Fitts' Law model to brain control performance on two different days. Under lower brain-control performance, the distribution of trial times is more uniform, perhaps due to increased difficulty of achieving successful dwell relative to executing the gross movement. On days with lower overall performance and poorer motivation, more uniform trial times were observed under manual control as well.

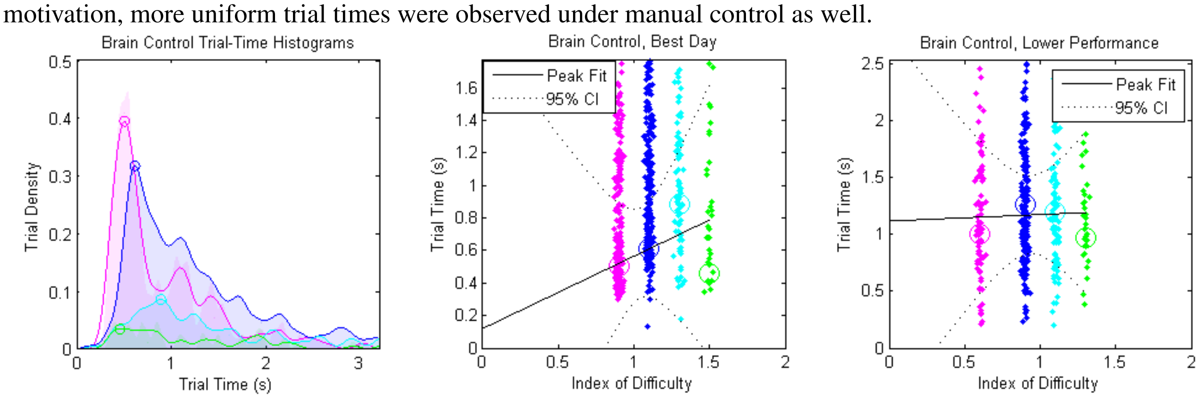

Figure 2: *Fitts' Law evaluation of brain control task.* Left, *histograms of trial times at different IDs.* Center, *Fitts' Law peak fit (*$R^2 = 0.38$*) on same day as above manual performance.* Right, *brain control on day with manual Fitts' Law model fit* $R^2 = 0.90$.

4. Discussion

We have shown that a simple adjustment of Fitts' Law is needed to restore reasonable (non-negative) predictions of movement times in dwell-to-select tasks. Our results suggest that the explanatory power of Fitts' Law should be verified in every experiment when there is any uncertainty about task proficiency and motivation. In particular, one recent study assumed a zero y-intercept of the model [Gilja et al., 2012], while our data and other Fitts' Law studies indicate otherwise. Finally, without strong predictive power of the model, claims about information transmission rates of a given brain control interface cannot be made.

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