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Agonistic and antagonistic interaction in speed/accuracy tradeoff: A delta-lognormal perspective

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ABSTRACT

This paper reports the results of a model-based analysis of movements gathered in a 4 × 4 experimental design of speed/accuracy tradeoffs with variable target distances and width. Our study was performed on a large (120 participants) and varied sample (both genders, wide age range, various health conditions). The delta-lognormal equation was used for data modeling to investigate the interaction between the output of the agonist and the antagonist neuromuscular systems. Empirical observations show that the subjects must correlate more tightly the impulse commands sent to both neuromuscular systems in order to achieve good performances as the difficulty of the task increases whereas the correlation in the timing of the neuromuscular action co-varies with the size of the geometrical properties of the task. These new phenomena are discussed under the paradigm provided by the Kinematic Theory and new research hypotheses are proposed for further investigation of the speed/accuracy tradeoffs.

1. Introduction

Almost 60 year ago, Fitts, in a seminal publication (Fitts, 1954), used an analogy between the human motor system and a communication channel to model the movement generation into the context of the Information Theory. This representation lead the way to the discovery of what is now known as Fitts' law:

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$$MT = a + b\log_2\left(\frac{2A}{W}\right) \quad (1)$$

For a movement performed as fast as possible, this relationship allows the prediction of the average of the movement duration (*MT*) from the knowledge of the width of a target (*W*) and the distance between the stating position and the center of the targeted zone (*A*). From then on, many formulations have been proposed to obtain better predictions, such as Shannon's formula (MacKenzie, 1992):

$$MT = a + b\log\left(\frac{A}{W} + 1\right) \quad (2)$$

the quadratic equation of Plamondon and Alimi (1997):

$$aln^2(MT) + bln(MT) = ln\left(\frac{2A}{W}\right) - c \quad (3)$$

and the power law of Kvalseth (1980):

$$ln(MT) = a + bln\left(\frac{2A}{W}\right) \quad (4)$$

Plamondon and Alimi (1997) have listed 13 different formulations, not counting their own one and Fitts' original one.

A lot of different works have also been published on the analysis of the movements involved in a Fitts' task, that is, a pointing motion performed as fast as possible with the distance and the width of the target being the two independent variables and the movement duration being the dependent variable (Plamondon and Alimi (1997) proposed a comprehensive review of the early publications on that topic). These studies investigated what happens to the speed/accuracy tradeoff implied by Fitts' law under various conditions such as in the presence of obstacles (Jax, Rosenbaum, & Vaughan, 2007; Vaughan, Barany, Sali, Jax, & Rosenbaum, 2010), with or without visual feedback (Wu, Yang, & Honda, 2010), with different configurations of target geometry (Bohan, Longstaff, van Gemmert, Rand, & Stelmach, 2003), in the presence of visual illusions (Longstaff & Isaac, 2011; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005; van Donkelaar, 1999), with moving targets (Chiu et al., 2011), and so on. This paradigm has also served to test various aspects of motor control such as motor learning (Brenner & Smeets, 2011) and the presence of metacognition in motor control (Augustyn & Rosenbaum, 2005). Also, aside from the original tradeoff studied by Fitts, variations of this task has been used to study situations where different choices are made regarding which variables are dependent and which are independent, such as in Howarth, Beggs, & Bowden (1971), where both MT and W are considered as independent variables or in temporally constrained task where MT is chosen as dependent variable (Newell, Hoshizaki, & Carlton, 1979; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979).

Although these studies are quite interesting and useful in many respects, new insights about the fundamental properties of this kind of motion could be highlighted if model-based analysis of the Fitts' task was performed. In that line of thought, we used a delta-lognormal ($\Delta\Lambda$) modeling to investigate the behavior of the agonist–antagonist relationship of the neuromuscular system as the experimental conditions (i.e., the value of *W* and *A*) are changed. This is a new and complementary point of view for the study of the Fitts' task. In this context, it would be difficult to derivate predictions from most existing theories on this topic (e.g. the impulse variability (Schmidt et al., 1979) or the terminal corrections (Howarth et al., 1971) models) since (1) the proposed representations do not generally have any concepts that can be linked to the agonist or the antagonist components of the motor control, (2) the submovements they postulate cannot be associated solely to one or to the other of the neuromuscular systems, and (3) these models do not propose any mechanism to analyze the synergy of the opposite (i.e. agonist and antagonist) neuromuscular systems involved in the productions of the asserted submovements. Nevertheless, as will be discussed more thoroughly in Section 4.3, the properties of the Fitts' task, the delta-lognormal modeling of the reaching motion as well as the presence of a signal-dependent neuromuscular noise – as hypothesized by many investigators (Charles & Hogan, 2010; Guigon, Baraduc, & Desmurget, 2008; Harris & Wolpert, 1998; Kirsch & Hennighausen, 2011; Medina & Lisberger, 2007; Tee, Franklin, Kawato, Milner, & Burdet, 2010; van Beers, 2008; White &