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How one breaks Fitts's Law and gets away with it: Moving further and faster involves more efficient online control

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ABSTRACT

Adam, Mol, Pratt, and Fischer (2006) reported what they termed "a violation of Fitts's Law" – when participants aimed to targets in an array, movement times (MTs) to the last target location (highest index of difficulty (ID)) were shorter than predicted by Fitts's Law. Based on the results of subsequent studies in which placeholders were present either during planning and/or execution stages of the movements, it was suggested that the violation may emerge because of context-dependent changes in planning processes. The present study examined this planning explanation by conducting detailed kinematic analyses of movements. Participants performed aiming movements to sets of 3 targets in different placeholder arrays with different movement amplitudes. Consistent with previous Fitts's Law violation findings, MTs were not significantly longer for movements to the last versus middle target location. Interestingly, the pattern of peak limb velocities (typically associated with planning processes) did not mirror the changes in MTs. On the other hand, analyses of the effector's spatial variability during the movement suggested greater involvement of online control processes when the target was in the last position. Based

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on these results, we suggest that the Fitts' Law violation observed here occurred because of more efficient online control processes.

1. Introduction

Fitts's Law captures what is known intuitively: there is a speed–accuracy trade-off in which an actor must move more slowly (and consequently have longer movement times [MTs]) to maintain accuracy when executing movements of greater difficulty. In his original task, Fitts asked participants to perform reciprocal aiming movements between two targets of the same width (Experiment 1: Fitts, 1954). Across different trials, the width of the two targets and the distance between the targets (i.e., movement amplitude) were systematically varied. For each trial, participants knew the specific target width/distance combination prior to movement initiation. Fitts observed that the time required to accurately complete the movements (i.e., MT) to targets with specific widths and movement amplitudes could be described mathematically as: MT = $a + b$(ID), where "a" refers to a base MT (i.e., y intercept) and "b" is the change in MT (i.e., slope) that is required to maintain accuracy with a change in the index of difficulty (ID). The ID defines the relationship between movement amplitude (A) and target size (W) as: ID = $\log_2(2A/W)$. In practical terms, to meet the accuracy constraints of the task, MT needs to increase when target width decreases and/or movement amplitude increases.

Over the last 60 years, Fitts's Law has been shown to hold for a wide range of tasks and populations (e.g., Drury & Woolley, 1995; Lambert & Bard, 2005; Langolf, Chaffin, & Foulke, 1976; Passmore, Burke, & Lyons, 2007). For example, Fitts's Law has been replicated when participants were asked to walk accurately through doorways of varied widths, to imagine their aiming movements, and to perform accurate pointing movements using a head-mounted computer mouse (e.g., Caeyenberghs, Wilson, van Roon, Swinnen, & Smits-Engelsman, 2009; Cowie, Limousin, Peters, & Day, 2010; Decety & Jeannerod, 1996; Passmore et al., 2007). Of specific interest to the present paper is the finding that Fitts's Law was also replicated using discrete aiming movements (Fitts & Peterson, 1964).

Despite the wide support for Fitts's Law in discrete aiming movements, a growing number of studies have reported a violation of Fitts's Law (e.g., Adam, Mol, Pratt, & Fischer, 2006; Bradi, Adam, Fischer, & Pratt, 2009; Pratt, Adam, & Fischer, 2007; Radulescu, Adam, Fischer, & Pratt, 2010). In the first paper to report this violation, Adam et al. (2006) demonstrated that, when given advance knowledge of a set of potential target locations via constantly visible placeholders, participants did not exhibit the increase in MT predicted by Fitts' Law when aiming to the last position of a placeholder array (the target with the longest amplitude and, hence, highest ID). Specifically, the time taken to reach the last target in the array was not significantly longer than the time taken to reach the second last target. In contrast, when no placeholders were present prior to target onset, MTs to the last target were consistent with Fitts's Law. That is, in the absence of placeholders, MTs towards the last target were significantly longer than those to the second last target. Thus, the presence of placeholders affected movement execution, increasing the efficiency with which movements to the last location were completed in some way.

Since the discovery of this violation, many researchers have examined it in a variety of circumstances to determine why it occurs. For example, Bradi et al. (2009) sought to determine if the violation was due to changes in movement planning or online control processes by comparing movements performed when the placeholders were: (1) removed at target onset, (2) removed at movement onset, or (3) available throughout the trial. Consistent with previous work, comparable MTs for the last and second last target positions were found when the placeholders were always visible. Interestingly, the violation persisted when the placeholders were removed at movement onset. When the placeholders were removed at target onset, however, there was no violation (i.e., no relative MT advantage) for movements to the last target position (see also Adam et al., 2006). Because removing the targets dur-