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The movement speed-accuracy relation in space-time

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ABSTRACT

Two experiments investigated a new approach to decomposing the contributions of spatial and temporal constraints to an integrated single space-time performance score in the movement speed-accuracy relation of a line drawing task. The mean and variability of the space-time performance error score were lowest when the task space and time constraint contributions to the performance score were comparable (i.e., middle range of velocities). As the contribution of either space or time to the performance score became increasingly asymmetrical at lower and higher average velocities, the mean performance error score and its variability increased with a greater trade-off between spatial and temporal movement properties. The findings revealed a new U-shaped space-time speed-accuracy function for performance outcome in tasks that have both spatial and temporal demands. The traditional speed-accuracy functions for spatial error and temporal error considered independently map to this integrated space-time movement speed-accuracy function.

1. Introduction

The relation between movement speed and accuracy is one of the most robust phenomena in human motor performance. The essence of the speed-accuracy relation, no matter the particular theoretical perspective and details of the proposed function for movement error, is that with an increase in movement speed there is concomitant decrease in movement accuracy. This leads to the

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well-established notion of a speed-accuracy trade-off, whereby an individual performer can increase movement accuracy by decreasing (trading) movement speed and vice-versa. Over more than 100 years of study there has been a large number of experimental investigations (e.g., Beggs & Howarth, 1970; Carlton, 1992; Fitts & Peterson, 1964; Woodworth, 1899) and several theoretical perspectives (e.g., Fitts, 1954; Flach, Guisinger, & Robison, 1996; Guiard, 1993; Hancock & Newell, 1985; Plamondon & Alimi, 1997; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; Woodworth, 1899) of the movement speed-accuracy relation.

The speed-accuracy relation is couched in the context of movement spatial error that is typically determined relative to a particular spatial target of a task. It is, however, the case that human movement takes place in both space and time thereby providing a context for the potential of a movement temporal error in certain tasks. In movement timing tasks it has been shown that an increment of movement velocity within the same movement time leads to a decrement of movement timing error (Ellis, Schmidt, & Wade, 1968; Kim, Carlton, Liu, & Newell, 1999; Newell, Hoshizaki, Carlton, & Halbert, 1979), rather than a speed related increase as established for spatial error. Thus, there is a paradox in the effect of movement speed on accuracy in that the directional effect depends on whether spatial or temporal accuracy is being measured (Newell, 1980).

Hancock and Newell (1985) proposed a space-time account of the movement speed-accuracy relation. Theoretically, it is based on the space-time principle that spatial error is always measured with respect to time and that properties of movement timing are always measured with respect to space (Minkowski, 1908). Operationally, invoking this principle in the movement domain leads to the need for a careful consideration of the dimensions of how the contributions of space and time to movement error are determined as well as how the space-time properties of movement are measured.

The space-time approach to movement error is most relevant in tasks where both the spatial and temporal dimensions of movement outcome are part of the task criteria (e.g., Kim et al., 1999; Newell, 1980; Zelaznik, Mone, McCabe, & Thaman, 1988), including interceptive tasks (Tresilian, Plooy, & Marinovic, 2009). Moreover, there are some motor tasks where the space-time criterion makes it difficult if not nonsensical to separate the spatial and temporal measures of the movement outcome. Consider the interceptive task of swinging a baseball bat to hit the pitched ball. Does it make any sense to say that while the performer missed the ball by 10 ms he/she should not worry because he/she missed it spatially by only 1 cm (Hancock & Newell, 1985)? And, even if this statement made sense, how would one generate the measurement of performance error to support this statement?

In this article, we develop and investigate a new space-time approach to weighting and decomposing the contributions of the dimensions of space and time to an integrated space-time performance score. There are several ways that movement space-time relations could be determined in the measurement of movement outcome. We investigate here two approaches to the consideration of spatial and temporal constraints on the movement speed-accuracy relation. One is the relation between spatial error and movement time (e.g., Fitts, 1954) and the other is a task having dual space-time error criteria that requires moving to a fixed spatial target in a criterion time that affords the determination of spatial and temporal error (Lai, Mayer-Kress, & Newell, 2006).

In the experiments reported here we investigate the role of movement speed on a unified space-time dimension that integrates the contribution of space and time to performance outcome, but also affords the examination of the independent contributions of spatial and temporal movement properties. Given that increments of movement speed increase spatial error and decrease timing error, respectively, when considered independently (Kim et al., 1999; Newell, 1980), it was hypothesized that the movement velocity in the mid range would lead to the minimum of an integrated space-time performance score and a new U-shaped movement speed-accuracy function. It was anticipated that such a U-shaped function for the space-time performance error score would hold for the different task criteria of the two experiments.

2. Experiment 1

In this experiment we investigated the speed-accuracy relation in space-time through an aiming task that required the production of a particular movement space-time outcome relation. The dual