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Violations of Fitts’ Law in a Ballistic Task

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ABSTRACT. The authors explored changes in the postural preparation and movement times during jumps into targets of different sizes located at different distances from the participant. Both movement and preparation times scaled with movement distance. Neither movement nor preparation time showed an effect of target size, although preparation time showed a tendency to increase for smaller targets. These observations show that the classical Fitts’ law can be violated in tasks that involve a ballistic component. The data corroborate a hypothesis that Fitts’ law originates at the level of movement planning.

Keywords: Fitts’ law, jumping, postural adjustments, speed-accuracy trade-off

Fitts’ law is one of the most respected quantitative laws of motor behavior. It was introduced on the basis of ideas from classical information theory more than 50 years ago (Fitts, 1954). The law links movement time (MT) to movement distance (D) and target size (W) assuming that the participant is trying to be as fast and accurate as possible: MT = a + b × log2(2D/W), where a and b are constants. Commonly, Fitts’ law is also written as MT = a + b × ID, where ID stands for the index of difficulty. Over the past 50 years, Fitts’ law has been supported in a large number of experimental studies involving different tasks, effectors, force fields, and participant populations (for a review, see Plamondon & Alimi, 1997). Several recent studies (Duarte & Freitas, 2005; Duarte & Latash 2007; Freitas, Duarte, & Latash, 2006; Gorniak, Duarte, & Latash, 2008) have cast doubt on the universal nature of Fitts’ law by showing that the dependence of MT on W and D could not be reduced to a single equation: MT depended on W as predicted by the Fitts’ law but only for a given distance. When D changed, the coefficients a and b in the equation changed as well.

In one of the previously mentioned studies, researchers explored the dependence of the duration of postural adjustments preceding movement (anticipatory postural adjustments, APAs; reviewed in Massion, 1992) on D and W in foot pointing tasks performed by standing participants (Duarte & Latash, 2007). The study showed scaling of the APA duration (TAPA) with D and W that was qualitatively similar to the scaling of MT. These observations were interpreted as supporting a hypothesis that the Fitts’ law reflects selection of movement parameters at the level of movement planning (Duarte & Latash, 2007; Gutman, Latash, Almeida, & Gottlieb, 1993) and speaking against hypotheses that try to describe Fitts’ law as a consequence of consecutive movement corrections in the course of movement execution (Meyer, Abrams, Kornblum, Wright, & Smith, 1988).

In the present study, we explore the dependence of MT and TAPA on D and W when participants try to follow the fast and accurate instruction while performing hops into targets drawn on the floor. Note that the ballistic nature of a hop after the take-off effectively prevents the participants from making adjustments in MT. However, there is a possibility to adjust MT for hops over the same distance by varying the height of the hop. Hence, our first hypothesis (H1) was that the participants would comply with Fitts’ law by adjusting the flight time (MT) to ID changes induced by changes in W (MT scaling with D is a direct consequence of physics). On the basis of the previously mentioned studies with foot pointing, we also expected participants to scale TAPA with W and D (H2).

Method

Participants

Participants were 15 male students of the Academy of Physical Education in Katowice. Their average age was 22.5 years (SD = 1.5 years), and their average height and mass were 1.76 m (SD = 0.052 m) and 71.9 kg (SD = 7.7 kg), respectively. They had no neurological, musculoskeletal, or any other postural disorders. The experiment was approved by the Bioethics Committee of the Academy. Participants agreed to volunteer for the experiment and the experimenter explained the purpose of the study and obtained written informed consent.

Apparatus

A force platform (Kistler, AG Winterthur, Schweiz, Model 9281C) was used in the experiment to measure the vertical component of ground reaction forces (Fz). The signal was sampled at 1 kHz. A contact plate with a fixed lateral dimension of 0.5 m was used as a target. Its width (W) in the direction from the participant varied across trials as well as the distance (D) from the participant’s initial position. Two electrodes (1-cm wide each) were attached along the shorter axis of the foot to the shoe soles at the middle of metatarsus. The midline of each electrode was marked with a narrow band wrapped around the foot (see Figure 1). The line was used as a landing point indicator and was clearly visible to the participant. The moment of landing was registered when...
FIGURE 1. The experimental setup and participant initial position with feet aligned with starting line. The insert shows the location of the electrodes that were used to define the moment of landing.

the participant touched the contact plate with an electrode. The participants were instructed to land with both feet simultaneously, but the first foot touch was used to define the end of the movement. We used a personal computer with Bioware software (version 2.0) to collect the data.

Procedure

Prior to the main experiment, we measured maximal forward jump of the participants. After a 5-min warm-up, each participant performed two maximal jumps, and the average distance (D_{MAX}) was used as the baseline to set the target distances for each participant. In the study, we used two distances (D) representing 20% and 40% of D_{MAX}. Four different widths of the target (W) were used in the experiment: 6, 10, 15, and 20 cm, resulting in a total of eight ID values. Note that the ID values were slightly different for different participants because of the variation in D_{MAX}. The average D_{MAX} and its standard deviation were 2.64 m and 0.18 m, respectively.

Before each series of jumps, the participants performed 2 practice jumps. The participants were instructed to jump in a self-paced manner, any time within 10 s after a “ready” signal, and hit the target with both feet such that the narrow bands corresponding to the midline of the electrodes were both within the target. In the initial position, the participant was standing comfortably, prone and comfortable with the hands clenched behind the back. After each trial, the participant received feedback regarding accurate versus inaccurate performance. Actual landing distance was also measured. One series consisted of 15 consecutive jumps. There were a total of eight series (2 Distances x 4 Targets). The series were presented in a balanced order. We provided 30-s breaks between jumps within a series, which was enough to return to the initial position on the force plate and prepare for the next jump. If a participant missed the target twice within one series, he was asked to repeat the whole series. After each series, there was a 2-min break to avoid fatigue. During this time, participants were asked to rest in sitting position. Participants did not report fatigue, even though the task involved making 120 jumps.

Data Processing

We used MatLab (The Mathworks, Natick, MA) software package to process the data. The vertical component of ground reaction forces (F_{Z}) was used to estimate participant’s weight (Q) by averaging data over 0.5 s while the participant stood quietly. Movement initiation time (T_{START}) was defined as the time when the magnitude of F_{Z} deviated from Q by more than 10% in either direction. The take-off time (T_{OFF}) was defined as the time when F_{Z} became zero. The landing time (T_{LAND}) was defined as the time when the first contact was made by one of the electrodes and the contact plate. MT was defined as MT = T_{LAND} - T_{OFF}. T_{APA} was defined as T_{APA} = T_{OFF} - T_{START}.

Statistics

We used standard methods of descriptive statistics. Two-way analyses of variance (ANOVAs) with repeated measures were used to analyze MT and T_{APA} with the factors distance (two levels) and width (four levels). The level of significance was set at \( p = .05 \).

Results

The participants were able to perform the task within the requested accuracy constraints, not more than two landings outside the target zone within a series of 15 jumps. Series had to be repeated in only two cases.

Overall, MT scaled with distance but not with target width. Figure 2A shows averaged across participants data for MT across the two distances and four target sizes. We analyzed the data in two ways. First, we fitted the MT(ID) relations with a classical linear equation: \( MT = a + b \times ID \) for the pooled data within each participant and for the data for each distance separately. On average, the regression coefficient \( b \) was 0.033 when the data over the two distances were used and nearly an order of magnitude smaller (0.0044, not significantly different from 0) when the data within each distance were used. The former value was significantly positive \( (p < .05) \) and higher than the latter one (Wilcoxon’s signed-rank test, \( p < .05 \)).
Violations of Fitts’ Law

**FIGURE 2.** Averaged across participants (with standard error bars), values of the movement time (MT; A) and anticipatory postural adjustment time (TAPA; B) for the two jumping distances (short and long) and four target sizes are shown. Note the scaling of both MT and TAPA with distance, no drop in MT with an increase in target size, and a tendency of TAPA to decrease with an increase in target size.

Further, we ran a two-way ANOVA with the factors distance and width. The ANOVA showed a significance effect of distance, $F(1, 14) = 199.0, p < .001$, but no effect of width and no interaction.

The TAPA, defined as the time from the first changes in the ground reaction force to the take-off, showed a tendency to scale with both distance and target size (Figure 2B). Two-way ANOVA showed a significance effect of distance, $F(1, 14) = 24.5, p < .001$, and a close to significant effect of width, $F(3, 42) = 2.47, p = .075$, without an interaction.

**Discussion**

Our observations speak against $H_1$ and provide tentative support for $H_2$. MT scaled with movement distance but not with target width, in violation of the classical Fitts’ law, whereas preparation time (TAPA) showed scaling with distance and a close to significant scaling with target width.

Note that the longer distance (40% of the maximal jump length) was about 1 m, whereas the smallest target size was 6 cm. This corresponds to a rather broad range of the index of difficulty. For example, the study of foot pointing (Duarte & Latash, 2007) used target distances ranging between 0.1 and 1 m and target width ranging between 0.02 and 0.1 m, resulting in ID values ranging between 1.00 and 6.64. In our experiment, ID values ranged from about 2.3 to 5.1. We did not use easier tasks because the largest target size was already very easy for the participants. Harder tasks (smaller target sizes) were avoided because the participants struggled with meeting the criterion of having only two errors per series. Overall, the range of ID values in our study allowed us to expect MT scaling with both distance and target size. However, only the former occurred.

For a given distance, the physics of the task allowed only limited interventions on the part of the participant after the take-off. In particular, the participant could flex and extend the legs and thus affect slightly the timing of the landing using corrective submovements (cf. Meyer et al. 1988). The flight time (MT) was mostly defined by the moment of take-off and could be modulated only by changing the vertical velocity component at $T_{OFF}: MT = \frac{2g}{V_z}$, where $V_z$ is vertical velocity component, $g$ is the gravity constant, and air resistance is ignored. For a given target distance, MT and $V_z$ could only be modulated by adjusting the angle of the velocity vector; however, this did not happen in the experiment. Only the natural, expected scaling of MT with distance was observed in the experiment.

Note that, by our definition, $V_z$ was defined during the postural adjustment. Hence, MT modulation, if any, could only be expected during TAPA. However, our results suggest that $V_z$ did not show reproducible modulation with target size, whereas TAPA showed a tendency toward such a modulation (Figure 2B). Physics do not require scaling of TAPA as long as the same $V_z$ is reached by the take-off. Hence, this scaling belongs to the realm of psychology. As suggested by Goodman and colleagues (Gutman et al., 1993), scaling of MT with target size—the classical Fitts’ law—happens because of adjustments of control parameters prior to the action. In other words, participants are scared of moving to small and distant targets and, consequently, they slow down. This hypothesis received support in recent studies that showed scaling of postural adjustments with ID (Duarte & Latash, 2007). Our results may be interpreted within the same scheme: The participants prolonged the preparation phase when they faced smaller targets, but they ultimately reached similar velocity vectors leading to similar MT values for jumps over the same distance. The nearly significant result makes this conclusion sustainable.
The ballistic nature of the task may have mitigated the scaling of $T_{APA}$ with target size because the participants knew that trying to affect MT for targets placed at the same distance was rather futile.

Overall, our results show that the classical Fitts’ law can be violated during ballistic movements. They corroborate the hypothesis that scaling of MT with $D$ and $W$ occurs at the level of planning (i.e., being scared of moving fast to small, distant targets). A more convincing test of this hypothesis would involve manipulation of perceived difficulty without changing $D$ and $W$. For example, this could be accomplished by placing targets at different heights so that the task will look more dangerous. Another possibility is to manipulate friction—targets of the same size will be associated with different perceived difficulty for more slippery landing surfaces.

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