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Fitts' law in human standing: the effect of scaling

Frederic Danion[a,*], Marcos Duarte[b], Marc Grosjean[c]

[a]Department of Kinesiology, Recreation Hall 267, The Pennsylvania State University, University Park, Pennsylvania, PA 16802, USA
[b]Escola de Educacao Fisica e Esporte, Universidade de Sao Paulo, Av. Mello Moraes 65, 05508–900, Sao Paulo, SP, Brazil
[c]Department of Psychology, The Pennsylvania State University, University Park, Pennsylvania, PA 16802, USA

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Abstract

Fitts' law states that the movement time (*MT*) of an aiming movement is a linear function of the index of difficulty (*ID*), where *ID* = log2(2*A/W*), *A* is the movement amplitude, and *W* is the target width. This law implies that *MT* should remain unchanged as long as *A/W* remains constant (i.e. the absence of a scaling effect). The goal of this study was to investigate whether, during upright posture, reciprocal-pointing movements with the center of pressure location follow Fitts' law. Six subjects performed the task with six *ID*s factorially combined with four *A*s. The results showed that for each *A*, *MT* was a linear function of *ID*. However, the slopes of the linear-regression lines increased with decreases in *A*. These findings indicate the presence of a scaling effect which violates Fitts' law.

Keywords: Humans; Center of pressure; Posture; Scaling; Speed-accuracy trade-off; Motor control; Balance

The study of how speed and accuracy trade off in human movement has often focused on how movement time (*MT*) varies as a function of movement amplitude (*A*) and target width (*W*). The most well-known formulation of this relationship was introduced by Fitts [4], who proposed that $MT = a + b \cdot \log_2(2A/W)$, where a and b are empirical constants, and where $\log_2(2A/W)$ was termed the index of difficulty (*ID*). $1/b$ is considered an index of performance, since the higher its value, the less *MT* is affected by increases in task difficulty. As many other formulations of the speed-accuracy trade-off [2,8,12,16], this relationship predicts that as long as A/W is constant, *MT* should remain unchanged. Hence, functions of this type reject the presence of a scaling effect, i.e. changes in *MT* with changes in scales (*A*s and *W*s) for a given *ID*.

Though there exists studies reporting violations of this relationship [1,5,9,11], it has been verified in a wide variety of tasks and, for this reason, is currently known as Fitts' law (for a review see Ref. [14]). Most of the studies dealing with Fitts' law have considered upper limb movements (involving the arm, wrist, or finger). To our knowledge, there are only two reports of studies investigating aiming movements performed with the lower limbs [3,7], and none investigating whole body movements. The aim of the present experiment was to establish whether Fitts' law can also account for whole body movements in which the lower limb muscles are the prime movers.

Maintaining balance during upright standing is a complex task. The postural control system achieves this by integrating various types of information (visual, vestibular, and somatosensory) and relying on the passive properties of the musculo-skeletal system. The main parameter registered in balance studies is the center of pressure (*COP*) location using a force plate. The *COP* is the point of application of the resultant of vertical forces acting on the surface of support and represents the collective outcome of the postural control system and the force of gravity [17]. Aiming movements with online visual feedback of *COP* location is a common tool in the rehabilitation of patients with impaired balance [6,15]. In this study, we wanted to determine how fast and accurate people can displace their *COP* between targets of varying *A* and *W*. This task is challenging since even when people are asked to maintain their *COP* at their preferred location, the range of *COP* displacements is approximately 1 cm (see results later). The presence of such variability in the postural control system may be a limiting factor of performance when *A* and *W* approach this value.

Six healthy adult subjects (five males and one female) were asked to perform reciprocal-pointing movements

* Corresponding author. Tel.:/fax: +1-814-863-4424.
E-mail address: fxd5@psu.edu (F. Danion)

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with the *COP* location. The mean subject age, height, and mass were 28.5 ± 3.6 years, 176 ± 6 cm, and 71.2 ± 7.4 kg, respectively. None of the subjects had any known history of postural or skeletal disorders and they all provided informed consent prior to testing according to the Office of Regulatory Compliance of The Pennsylvania State University. The task was based on the original study of Fitts [4]. The subjects stood on a force plate where *COP* location was sampled at 50 Hz. Online visual feedback of *COP* location was displayed on a monitor adjusted at the subject's head height. Two targets were displayed on the screen as windows delimitated by two lines perpendicular to the antero-posterior (*a-p*) axis, while the *COP* location was represented by a cursor. The subjects' task consisted of performing oscillatory body movements, in such a way that they generated fore and back displacements of the cursor (*COP*) between the two targets (for a review of studies using similar virtual environments, see Ref. [14]). The subjects were asked to be as fast and as accurate as possible. A trial containing more than 10% of errors (over- or undershoots of the target) was rejected and repeated. The mean percentage of errors across the 24 trials was 4.6 ± 0.6%. During testing, the subjects stood barefoot in an upright bipedal posture with their arms at their sides. Prior to the experiment a training session was performed. A qualitative analysis revealed that the subjects used both hip and ankle strategies [13] to complete the task.

Each trial was defined by two parameters, the amplitude between the centers of the two targets (*A*) and the index of difficulty (*ID*). Four *A*s (3, 4.5, 6 and 9 cm) were factorially combined with six *ID*s (1.4, 1.7, 2.0, 2.3, 2.6 and 2.9). Each subject performed all conditions (24 trials) in a pseudo-random sequence. The duration of a trial was 40 s. The target positions were specified in relation to the preferred location of the subject's *COP*. The preferred location was determined as the mean position of the *COP* during 60 s of quiet standing without visual feedback. Due to known asymmetries of the stability limits along the *a-p* axis [6], the targets were positioned 2/3 forward and 1/3 backward with respect to the preferred location (our subjects were able to reach 11.1 ± 1.4 cm forward and 6.7 ± 1.9 cm backward without falling).

Data processing was performed as follows. The first 10 s of each trial were considered as an adaptation period and were discarded from the analysis. During the remaining 30 s, we counted the number of complete movement cycles performed. Then, considering each cycle as the concatenation of two sub-movements, the mean *MT* was calculated throughout this time window.

Within each amplitude condition, speed related to accuracy in accordance with Fitts' law: *MT* was an increasing linear function of *ID* (Fig. 1). (The datum for $ID = 2.9$ and $A = 6$ cm was considered an outlier and was not included in the linear regression analysis.) Correlation coefficients were significant at all *A*s (all *r*-values >0.93, all *P*-values <0.01). However, as *A* increased, the slopes (*b*) of the linear-regression lines decreased ($r = -0.98$, $P < 0.01$). The corresponding indices of performance were $1/b = 2.86$, 3.12, 4.69, and 7.96 *ID*/s for $A = 3$, 4.5, 6 and 9 cm, respectively. To further explore the effects of *ID* and *A*, a two-way repeated-measures ANOVA on *MT* was performed. Consistent with Fitts' law, there was a main effect of *ID* ($F(5, 25) = 26.23$, $P < 0.001$). However, there was also a main effect of *A* ($F(3, 15) = 16.27$, $P < 0.001$), which implies the presence of a scaling effect. Lastly, in accordance with the values we obtained for *1/b*, there was a significant $ID \times A$ interaction ($F(15, 75) = 5.23$, $P < 0.001$). This final result indicates that the regression lines for the different *A*s were not parallel.

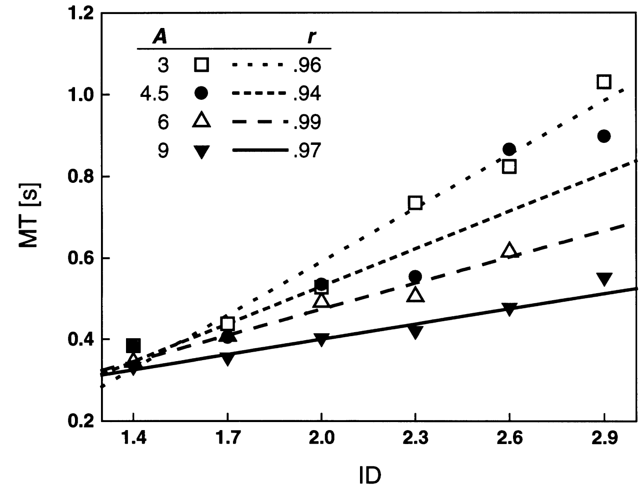

Fig. 1. Mean movement time (*MT*) as a function of index of difficulty (*ID*) for different movement amplitudes (*A*s): 3, 4.5, 6 and 9 cm. Linear regression lines and their corresponding correlation coefficients are presented for each *A*.

The goal of this study was to investigate whether Fitts' law can account for whole body movements. The present findings demonstrated that for each *A*, *MT* was a linear function of *ID*. However, the slopes of the linear-regression lines increased with decreases in *A*. This implies that *A*/*W* was not the only determinant of performance and constitutes a violation of Fitts' law [4] as well as of many of its derivatives [2,8,12,16]. A possible explanation for this scaling effect is related to the amount of *COP* variability present during quiet standing. This variability was estimated by asking the subjects to minimize the deviations of their *COP* from a stationary target placed on the preferred *COP* location. The mean 95% confidence interval of the *COP* location was 0.84 ± 0.17 cm. This value was very close to the *W* (0.80 cm) under $A = 3$ cm and $ID = 2.9$, where *MT* was the longest. This finding is consistent with the view that the inherent variability of the postural control system was a limiting factor of performance under small scales (*A*s and *W*s) and high *ID*s. However, it remains to be determined whether this explanation can account for systematic changes in *MT*/*ID* slopes with changes in scale.

Despite the presence of the scaling effect, it is worth comparing our findings to those reported in the literature. In particular, under our largest *A*, the results showed that people can achieve indices of performance that approached the one's observed in manual tasks ($1/b \approx 10$ *ID*/s for Fitts [4]). However, under the smallest *A*, the results revealed that, at comparable *ID*, people are much slower at displacing their whole body than their upper [4,7,10] and lower [3,7] limbs. This was further corroborated in a pilot study where subjects reported difficulties for *ID*s over 3. These limitations are most likely a reflection of biomechanical constraints, such as inertial and musculo-skeletal properties.

In conclusion, Fitts' Law does not hold for whole body movements, as assessed with *COP* displacements. Future work should focus on determining whether the scaling effect we observed is directly related to the amount of *COP* variability present during quiet standing.

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