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# DOES MOVEMENT PLANNING FOLLOW FITTS' LAW? SCALING ANTICIPATORY POSTURAL ADJUSTMENTS WITH MOVEMENT SPEED AND ACCURACY

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**Abstract—We wanted to determine whether movement planning followed Fitts' law by investigating the relationship between movement planning and movement performance in experienced dancers executing a typical classical ballet step in which the big toe was pointed to targets at different distances and of different widths so as to obtain several indices of difficulty (ID). Movement time, velocity and variability at the target were the variables of movement performance kinematics; movement planning was evaluated by analysis of anticipatory postural adjustments (APAs) to assess their modulation at different IDs. Movement time and peak of velocity were found to scale with the ID only when individual movement distance across target widths was entered into the analysis. APA magnitude and duration both scaled according to movement parameters but not in the same way. APA magnitude scaled with movement velocity, while APA duration was sensitive to the amplitude-to-accuracy ratio following the ID for movements performed in the shortest time interval when on-line feedback control is probably not available. Here we show that timing of muscle activation acts as an independent central command that triggers fine-tuning for speed-accuracy trade-off.** 

**Key words: anticipatory postural adjustments (APAs), movement planning, Fitts' law, ballet.**

The majority of human activities show a trade-off between movement speed and accuracy when, for example, we reach to grasp for an object or point to it. In general, studies on the speed-accuracy trade-off have focused on how movement time (MT) varies as a function of movement amplitude ($D$) and target width ($W$). The most well-known formulation of this relationship was introduced by Fitts (Fitts, 1954; Fitts and Peterson, 1964), who showed that MT increases with $D$ and decreases as target size increases ($W$), such that $\mathrm{MT}=a+b\log_2(2D/W)$, wherein $a$ and $b$ are empirical constants (the intercept and the slope of the regression line, respectively), and $\log_2(2D/W)$ represents the index of difficulty (ID). This relationship predicts that at a constant $2D/W$ ratio, MT will remain unchanged. Hence, MT is directly proportional to the ID, which may have the same value for different combinations of movement parameters $D$ and $W$. The inverse of slope $1/b$ is considered an index of performance, since the higher its value, the less MT is affected by increases in task difficulty. The law has been validated for a variety of movements, experimental conditions, and tested in different subject populations (for a review see Plamondon and Alimi, 1997). Several recent studies, however, have pointed to its limitations (Danion et al., 1999; Cesari and Newell, 2002; Duarte and Freitas, 2005; Freitas et al., 2006; Duarte and Latash, 2007), particularly in situations where the whole body or heavy objects are moved, showing that the model does not account for the influence of relevant biomechanical constraints. It is reasonable to think that the robust nature of Fitts' law likely derives from the need to combine action planning with afferent feedback. But the question is open as to how, in movement planning, biomechanical constraints, as reflected in task parameters, are to be taken into account. One way to investigate the link between action planning and execution is to measure muscle activity before movement initiation, since voluntary actions are always preceded by postural changes (Belen'kii et al., 1967; Bouisset and Zattara, 1987). These changes occur prior to the movement itself and can be conceived of as anticipatory postural adjustments (APAs). APAs are centrally programmed and their putative role is to minimize perturbations to vertical posture that would otherwise be induced by a movement (for a review see Massion, 1992). Starting from early pioneering research, APAs have been studied during lower limb movement (Rogers and Pai, 1990; Brunt et al., 2000; Ito et al., 2003; Duarte and Latash, 2007), trunk movement (Oddsson and Thorstensson, 1986), and arm movement (Bouisset and Zattara, 1981; Aruin and Latash, 1995a,b). APAs have been shown to depend on movement velocity (Horak et al., 1984; Lee et al., 1987; Zattara and Bouisset, 1983; Brunt et al., 1999) and on the inertial load of the forthcoming voluntary action (Bouisset, 1991; Kasai and Taga, 1992; Zattara and Bouisset, 1988). When measured by means of muscle electromyography (EMG), two parameters of APA are usually analyzed: APA magnitude and APA duration (Aruin and Latash, 1995a). Debate has focused on their co-variation with task parameters and whether they are programmed separately or conjointly (Horak et al., 1984; Bouisset et al., 2000).

Despite the wealth of studies on APAs and modulations for executing movement, very few have investigated

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*Abbreviations:* APAs, anticipatory postural adjustments; *D*, movement amplitude; EMG, electromyography; GRF, ground reaction force; ID, index of difficulty; MT, movement time; PV, peak of velocity; SMA, supplementary motor area.

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the distinct role APA magnitude and duration play in actions that include a trade-off between speed and accuracy (Brunt et al., 2000; Bonnetblanc et al., 2004; Berrigan et al., 2006; Nana-Ibrahim et al., 2008) and none to our knowledge have investigated their behaviour on a Fitts' law paradigm considering both different target distances and widths. The beauty of testing APAs in a Fitts' task resides in taking advantage of the model's predictions about task parameters over performance as indicated by the ID. With this study we wanted to analyze the behaviour of APAs in order to reveal how the CNS tunes the timing and the magnitude of anticipatory muscle activity with respect to task parameters for successfully accomplishing an action. Both APA magnitude and duration were considered; our hypothesis was that APA magnitude would be involved in preparing mainly for movement speed, while APA duration would be modulated to the ID, thus including movement accuracy as well. The type of movement we analyzed was substantially the same as that Duarte and Latash applied (2007). But because the action very closely resembles *battement tendu*, a basic ballet move, here we tested experienced/elite professional dancers to ensure optimal performance in the trade-off between movement speed and movement accuracy.

## EXPERIMENTAL PROCEDURES

### Subjects

Twelve adult female dancers (mean [±SD]age 26±8 years; mean [±SD]height 1.64±0.06 m; mean [±SD]body mass 52.4±5.3) took part in the experiment. Eleven subjects were right-side and one was left-side dominant. All subjects were experienced/professional classical ballet dancers (mean [±SD]13±3 years of practice, 6 h of training per week). All subjects gave their written, informed consent to participate in the study. The study protocol was approved by the ethical committee of the Department of Neurological and Visual Sciences, University of Verona, and was performed in accordance with the Declaration of Helsinki.

### Apparatus

The experimental set-up was composed of an optoelectronic motion capture system (MX Ultranet, VICON) equipped with retro-reflective markers (14 mm in diameter). Seven infrared emitting cameras (MX 13, VICON) were placed on a tripod around the volume of movement at a height that permitted optimal detection of the entire movement. The system sampling frequency was 250 Hz. The markers were placed on the following bony landmarks of both body sides: middle of the nail edge of the big toe, lateral malleolus, lateral epicondyle of femur, anterior superior iliac spine, acromion, olecranon, and temple. Because we were interested in analyzing APA behaviour within a Fitts' law experimental design, we focused our attention on the kinematics of the big toe. Analysis of the kinematics of the big toe alone was deemed sufficient for satisfying the experimental requirements.

The electrical muscle activity of the tibialis anterior muscles of the stance limb (TA Stance) and the swing limb (TA Swing) was recorded using a wireless EMG system (ZeroWire, Aurion). Two active surface electrodes were taped approximately 2 cm apart over the muscle belly. The tibialis anterior muscles were specifically selected for analysis because of their dominant and consistent role in gait initiation (Brunt et al., 1991; Elble et al., 1994). Since the electromechanical delay in EMG recording is a constant, it is not believed to affect the final results, as demonstrated by Corcos and colleagues (1992).

A force platform (Kistler, 9281, Amherst, NY, USA) was used to record the horizontal component of the ground reaction force (GRF) in the medio–lateral direction ($F_x$) (Brunt et al., 1991; Elble et al., 1994). The EMG and force plate signals were sampled at a rate of 1000 Hz with 16-bit resolution. The two systems were synchronized with a hardware device (MX Control, VICON) that matched the data acquisition in both systems.

### Procedures

During the experiment, the subjects stood upright with feet parallel set 31 cm apart with arms crossed over the chest; this was defined as the initial position. The subjects were instructed to point with the tip of the big toe of the dominant leg, starting from the initial position, to a round target (width—diameter *W*) at a certain distance (*D*) on the floor. The targets were positioned in front of the subject on a notional line passing perpendicularly to the frontal plane through the middle of the feet position. The task was to execute a single discrete movement. The instructions to the subjects were typical for the Fitts' paradigm: "be as fast and as accurate as possible in your pointing movement." After pointing to the target, the subjects were instructed to hold the final position for about 1.5 s. In all, six target distances ($D$=10, 20, 40, 60, 80, and 100 cm) and five target widths ($W$=2, 4, 6, 8, and 10 cm) were used, yielding 30 different target conditions with different indices of difficulty, ID=$\log_2$ (2$D$/$W$) (Fitts, 1954), varying from 1.00 to 6.64 bits. The distance (*D*) was measured from the initial position of the big toe marker of the swing limb in the sagittal plane to the target centre. The conditions were presented in pseudo-random order, while the trials within a condition were blocked. The subjects performed four to five practice trials prior to each condition. Each trial started with the subject standing in the initial position; at the auditory signal she was free to initiate toe pointing at any moment in a self-paced manner. Only one error (a trial that over- or undershot the target) was accepted per condition (maximum of 5% of error per condition over accepted trials) (Fitts, 1954). Each subject was allowed a total of 20 trials for the final analysis. If an error occurred, the subject immediately repeated the trial. The experiment was performed in a single session and lasted about 3 h per subject. Fatigue was never an issue since resting time was provided throughout the entire experiment session. The subjects were instructed to rest for at least 3 min at the end of each condition but they could always rest as needed. In addition, they were asked to rest for at least 15–20 min at the end of the 15th condition.

### Data analysis

Data analyses were performed using Matlab 7.1 software (Mathworks Inc., Natick, MA, USA). The kinematic data were digitally low-pass filtered at 15 Hz using a sixth-order Butterworth filter. The data were analyzed in the sagittal plane (the main plane of movement), except for the variable error. The peak of velocity (PV) was calculated from the velocity profile in the sagittal plane of the marker on the pointing foot. The starting time of the movement ($t_0$), as defined by the marker on the big toe of the pointing foot, was considered as the instant when the tangential velocity of the marker reached 5% of PV during that particular trial. The end time of the movement ($t_{END}$) was defined as the time when the tangential velocity of the marker reached 5% of PV and remained below that threshold for at least 100 ms (Dounskaia et al., 2005; Wisleder and Dounskaia, 2007; Duarte and Latash, 2007; Fradet et al., 2008). MT was defined as the time between $t_0$ and $t_{END}$, and movement amplitude as the distance between the position of the big toe marker in the anterioposterior direction at $t_0$ and $t_{END}$. The marker on the big toe of the standing foot (the foot that did not move) was monitored to ensure that no motion had taken place.