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# Balance control adjustment when load impact perturbation – A transfer function model-based analysis

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## 1. Introduction

Balance stability mainly depends on the central integration of the sensory signals to compute corrective motor commands and maintain the standing equilibrium. Whatever the postural perturbation, self-generated or externally triggered, the on-line sensorimotor integration determines the predictive or reactive adaptive responses to maintain the whole-body stability during perturbation. This study focuses on (1) the effects of an external load perturbation on the reactive postural control, triggered in different disturbance conditions, and (2) the comparison of the real balance data to the simulated data, obtained from the data set using a system identification method. The goal of this study is to relate a balance control dataset obtained with several subjects to a linear (after some transformations) dynamical system parameterized as an autoregressive model with exogenous input (ARX). A similar approach was proposed for vestibular patients (Voda et al., 2019). In order to estimate the level of similarity between the real and modeled data and estimate the reliability of the modeling approach to varied or altered balance condition, as met in everyday life, sports, or therapy, different conditions of postural stability (variable stance), vision (available or not), and balance control expertise (Tai-Chi skill or not) (Gatts & Woollacott, 2007) was experienced.

## 2. Methods

The experimental conditions and data acquisition were obtained in 2019 and are briefly described here (see N'Yo, 2019, Master's theses, for more details).

### 2.1 Participants.

Four males and one female, aged 25 to 56 y.o., participated in the experiment and gave their informed consent according to the ethics research standards. Two subjects were Tai-Chi expert, three had no prior experience.

### 2.2 Postural task

Participants had to stand upright on a force plate, with a Tai-Chi posture with a protective-like attitude, i.e., arm-hand segment placed forward, at waist level. The postural task consisted to control, as well as possible, the disturbed whole-body equilibrium, due to a load

perturbation applied at hand level by a passive inertial pendulum device (Fig.1). It produces a sudden load impact on the hand-arm of the subject. The load was instantaneously discharge after impact. Subjects had to stabilize their balance, as quickly as possible, despite the charge disturbance.

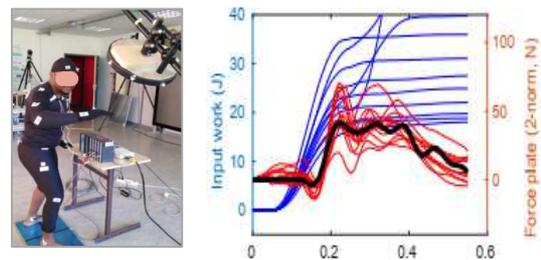
### 2.2 Protocol

The standardized postural tasks sequence consists in a STANCE x VISION x CHARGE crossed-protocol: two STANCE conditions (Normal or Tai-Chi stance), repeated in two VISION conditions (Open- or Closed-Eyes), repeated with two CHARGE ("No load" on the pendulum, or "with load", i.e., with an additional 5kg on). This generates a trial-dependant kinetic energy (work) when the load-perturbation is applied on the subject's hand-arm segment. The tasks sequence is ordered as follow, with 10 trials per task:

1. Normal Stance, Closed Eyes, No load (NSCENL),
2. Normal Stance, Opened Eyes, No load (NSOENL),
3. Tai-Chi Stance, Closed Eyes, No load (TSCENL),
4. Tai-Chi Stance, Closed Eyes, Load (TSCEWL),
5. Tai-Chi Stance, Opened Eyes, No load (TSOENL),
6. Tai-Chi Stance, Opened Eyes, Load (TSOEWL).

### 2.3 Data acquisition

A MOCAP Qualysis system tracks both (1) the load-pendulum trajectory to calculate the perturbation force value in terms of kinetic energy (J), its trajectory and the impact time, and (2) the hand-arm and whole-body anatomical landmark (fig.1). A Kistler force plate records the postural reaction at feet level to compute the resultant force from the 6 DoF components (Fig.1). The electromyograms (EMGs) activities for elbow and ankle flexor and extensor muscles are recorded but not presented in this paper. All data acquisitions are time-synchronized.



**Figure 1.** Left frame: subject standing on the force plate, facing the load-perturbation device during the control postural task. Right frame: comparison plot of the input (work, blue left scale) and output data (postural response, red right scale). In black, the simulated curve from the transfer function.

### 2.4 Data analysis

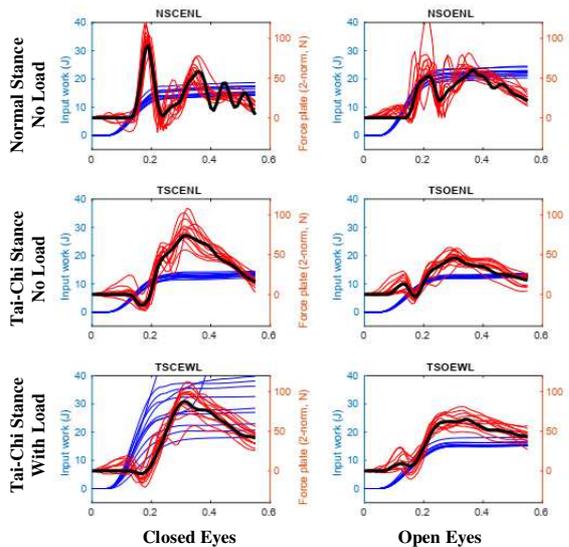
The relation between the perturbation characteristics and the postural behaviour is characterized by an ARX transfer function model (Fig.1, large black line). The input parameters are the values of the perturbation characterized by the kinetic energy of the charge

applied on the hand-arm complex at the impact time (see fig.1, impact work at time 0). The output parameters correspond to the postural reaction force values recorded at the platform level (see Fig.1, force plate values). The transfer function is determined for each specific postural task (condition of perturbation).

### 3. Results and discussion

#### 3.1 Results

**Behavioural analysis.** The comparative analysis of the work vs. force plate time-series data for all the postural conditions (Fig. 2) shows that the postural reaction force is functionally correlated to the intensity of the balance perturbation. The increasing of kinetic energy applied during the standing posture increases significantly the reaction force at feet level. More specifically, time-series data show both a main and an interdependent effect of the STANCE, VISION and CHARGE conditions on the postural reaction force: the disequilibrium compensatory are specifically correlated to the stance, the ‘Tai-Chi stance’ leading to a consistent regularity of the feet reaction force, favoured by either the ‘Open Eye’ or the ‘No load’ condition.



**Figure 2.** Comparison plot between the input work (perturbation values; blue right scale), the output force plate data (postural reaction; left red scale), and the transfer function model (black large line), for different Stance, Vision, and charge conditions: Tai-Chi Stance (With Vs. No load; four frames below) Vs. Normal Stance (No load; two upper frames), with Closed Eyes (left column) vs. Open Eyes (right column). Data for a Tai-Chi expert.

**Transfer function analysis.** The result obtained from the transfer function model (TF) shows that the TF parameters fits well with the behavioral data (Fig. 2), as a representative mean estimation of the overall trials effect for each condition of stance, vision, and charge. Reasonable fits for each position and for each subject are obtained with ARX models of order 10 and by

choosing the optimal fit (minimizing the least squares error) for a time-delay varied between 10 and 200 ms. Results show that the input work fits accurately either in amplitude or temporally with the output force. They also show that the complexity of the body dynamics, for a given subject and for a given posture, can be captured by a simple linear model with a reasonable number of degrees of freedom.

#### 3.2 Discussion

This study demonstrates that the corrective processing of disequilibrium can be modeled by the input-output identification. The TF from ARX-model is able to characterize the effectiveness of the reactive postural adjustments. At a neuro-biomechanical level, results show that the postural adjustments are correlated to the level of the control balance constraints and perturbation, which trig instantaneous dynamic neuro-motor reaction correlated to the postural characteristics of the stance, vision, and load. These on-line control strategies counteract the charge impact to correct the disturbed upright standing. The TF model is able to characterize the context-dependent evolution of the reactive postural adjustments. Hence, the identification parameters use in the TF model allows to clearly characterize the impact of all the postural conditions on postural motor commands.

### 4. Conclusions

The use of TF for a deeper analysis of the inner signs of the postural control processes is of great interest for study on balance impairment, restoration, or optimization. Exploring more efficiently the identification parameters could give us additional knowledge to make further assumption regarding the adaptive processes of balance control.

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### References

- Gatts SK, Woollacott MH. 2007. How Tai Chi improves balance: Biomechanics of recovery to a walking slip in impaired seniors. *Gait & Posture*, 25-2:205-214.
- N-Yo S. 2019. Adaptation to a Push-like Perturbation in a Tai-Chi Posture. Master thesis, Université Grenoble Alpes. <https://hal.science/hal-04061769>
- Voda A, Martin O, Neto PR, Gascuel JD, Schmerber S. 2019. Visual-vestibular compensation in balance recovery: A transfer function model-based analysis. 8th IFAC Conference on Systems Biology in Engineering, Papers Online 52-26:88–93.

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