Reduced speed of microvascular blood flow in hemodialysis patients versus healthy controls: A coherent hemodynamics spectroscopy (CHS) study

Michele L. Pierro†, Jana M. Kainerstorfer†, Angelo Sassaroli†, Bertan Hallacoglu†, Amanda Civiletto††, Daniel E. Weiner††, and Sergio Fantini†

†Department of Biomedical Engineering, Tufts University, 4 Colby Street, Medford, MA 02155, USA
†† Tufts Medical Center, 800 Washington Street Boston, MA 02111, USA

Introduction

Coherent Hemodynamics spectroscopy (CHS) is a novel technique for the study of cerebral hemodynamics recently proposed by Fantini.[1] CHS is based on frequency-resolved measurements of cerebral hemodynamic oscillations that are induced by periodic physiological maneuvers, to yield measurements of the blood transit time in the microcirculation, relative arterial/venous contributions to cerebral hemodynamics, and autoregulation efficiency. In this study, we have applied for the first time CHS in a clinical setting, the hemodialysis unit.

Methods and results

The experimental set up is shown in Fig. 1. Five hemodialysis patients (HD: nos. 1-5) and six healthy subjects (nos. 6-11) were measured. Oscillations in cerebral deoxy- and oxy-hemoglobin concentrations (*D* and *O*) were induced by cyclic inflation-deflation of a thigh cuff at seven frequencies in the range 0.07-0.17 Hz, and measured with near-infrared spectroscopy (NIRS) on the subject's forehead (Fig. 2). Fig. 2 also shows the instantaneous phase difference between *D* and *O* oscillations (Arg(**D**)-Arg(**O**)). Fantini's model considers *D*, *O* and *T* (total hemoglobin) phasors (**D**(ω), **O**(ω) and **T**(ω)=**O**(ω)+**D**(ω)) as the outputs of a Linear Time Invariant system (Figs. 3-4) where the inputs are the phasors associated with blood volume (**v**) and flow velocity (**f**). By fitting the measured CHS spectra of |**D**|/|**O**|, |**O**|/|**T**|, Arg(**D**)-Arg(**O**), and Arg(**O**)-Arg(**T**) (Fig. 5), the model yields six physiological parameters (Fig. 6): capillary and venous blood transit times, capillary/venous blood volume ratio, arterial/venous ratio of blood volume changes, cut-off frequency for aoutoregulation, and high-frequency flow/volume ratio times the venous/total blood volume ratio.

The major result of this work (Fig. 6) is the longer blood transit time observed in the cerebral microvasculature ($t^{(c)}$ and $t^{(v)}$) for the dialysis patients with respect to the healthy subjects.

Conclusions

This study demonstrates the applicability of the novel CHS technique in a clinical setting. Fantini's hemodynamic model allowed for the quantitative analysis of the measured CHS spectra and revealed a longer blood transit time (slower blood flow) in the prefrontal cortex of hemodialysis patients with respect to healthy controls. This result can be extended to spatially resolved studies of key features of cerebral hemodynamics.

Acknowledgements

This research was supported by the National Institutes of Health (grant nos. R03-MH093846 and R01-CA154770) and by the National Science Foundation (award no. IIS-1065154).

References

[1] Fantini, S.; Neuroimage, doi:10.1016/j.neuroimage.2013.03.065 (2013).

Fig. 1 **Experimental Setup**

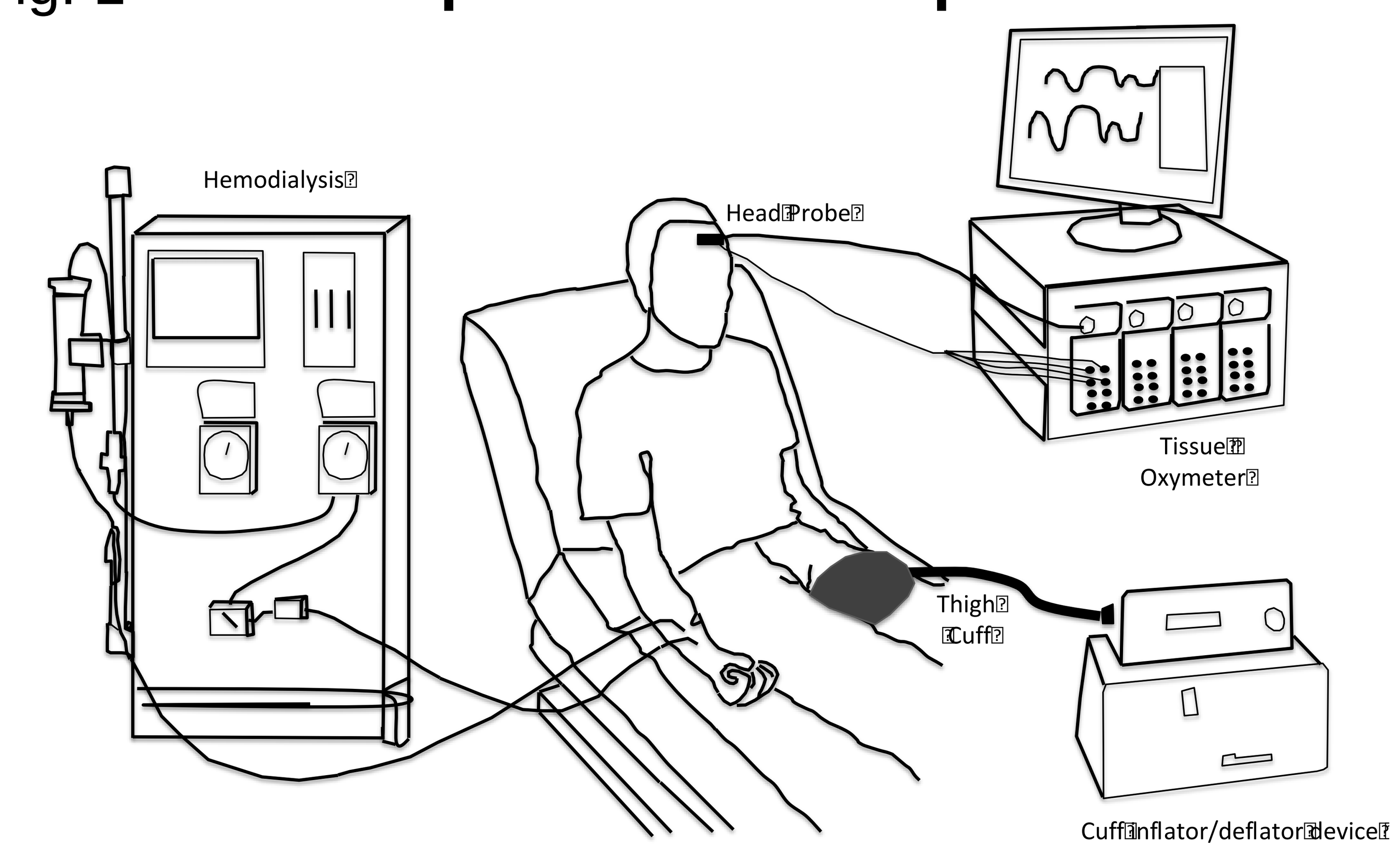


Fig. 2 **Induced Oscillations**

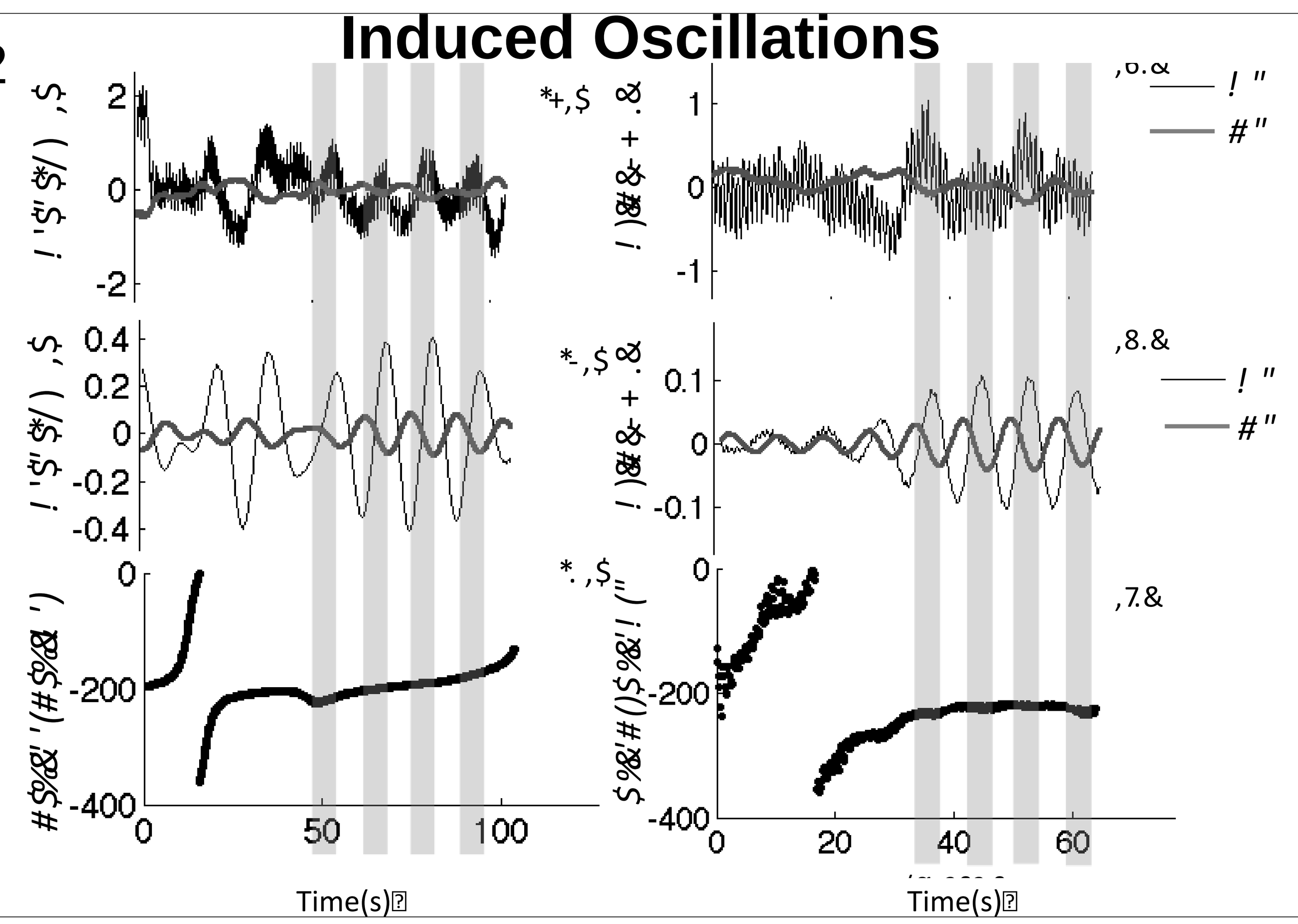
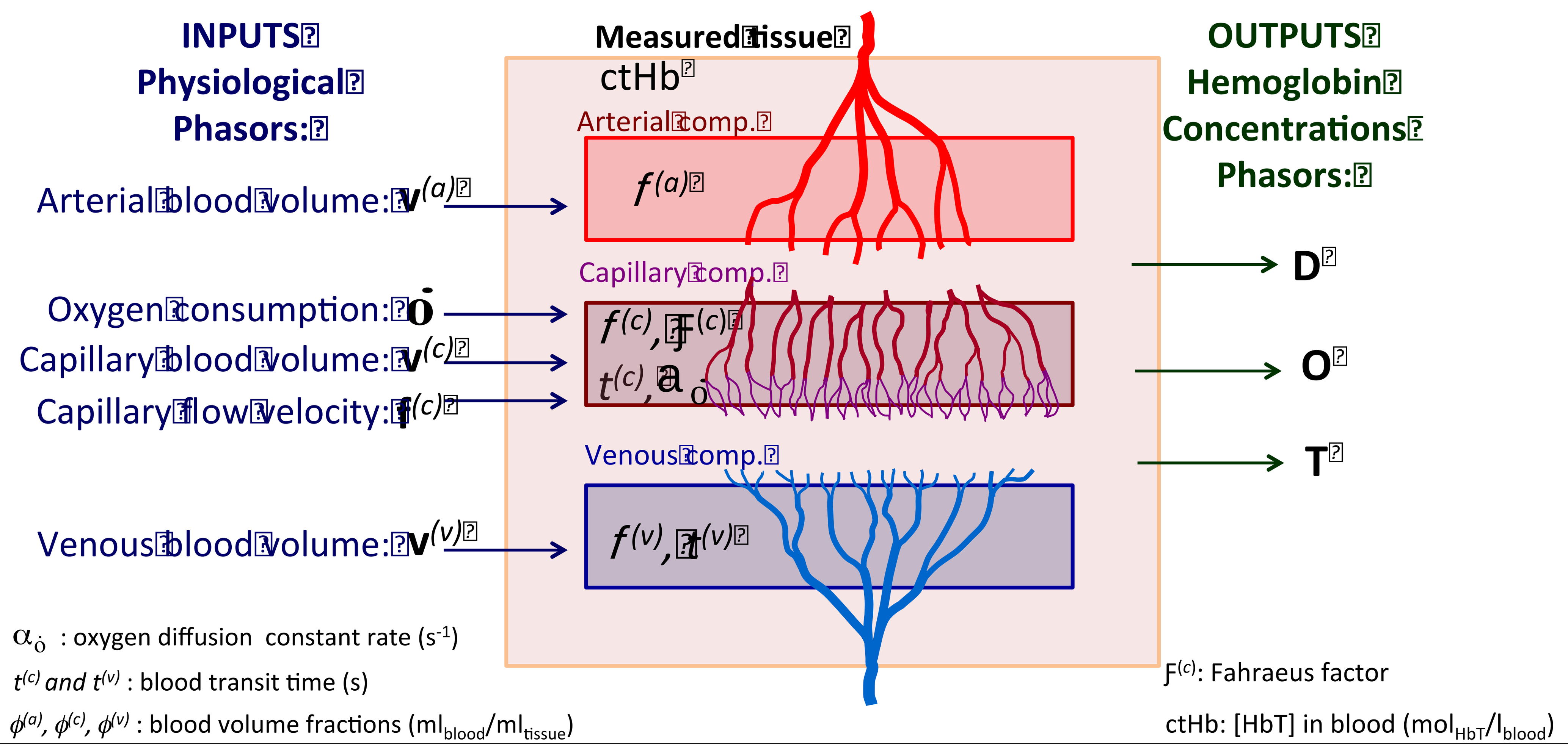


Fig. 3 **HEMODYNAMIC MODEL**



α_δ : oxygen diffusion constant rate (s^{-1})
$t^{(c)}$ and $t^{(v)}$: blood transit time (s)
$\phi^{(a)}$, $\phi^{(c)}$, $\phi^{(v)}$: blood volume fractions (ml$_{blood}$/ml$_{tissue}$)
$F^{(c)}$: Fahraeus factor
ctHb: [HbT] in blood (mol$_{HbT}$/l$_{blood}$)

Fig. 4 **Phasor Representation**

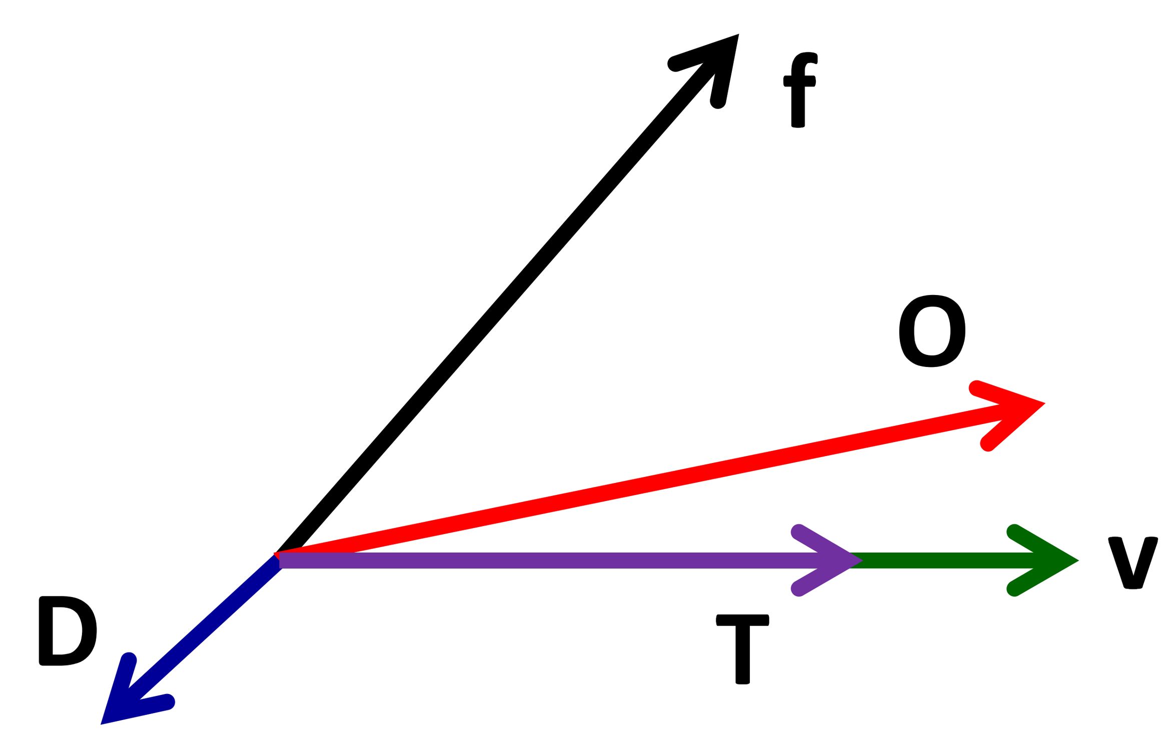


Fig. 5 **CHS Spectra**

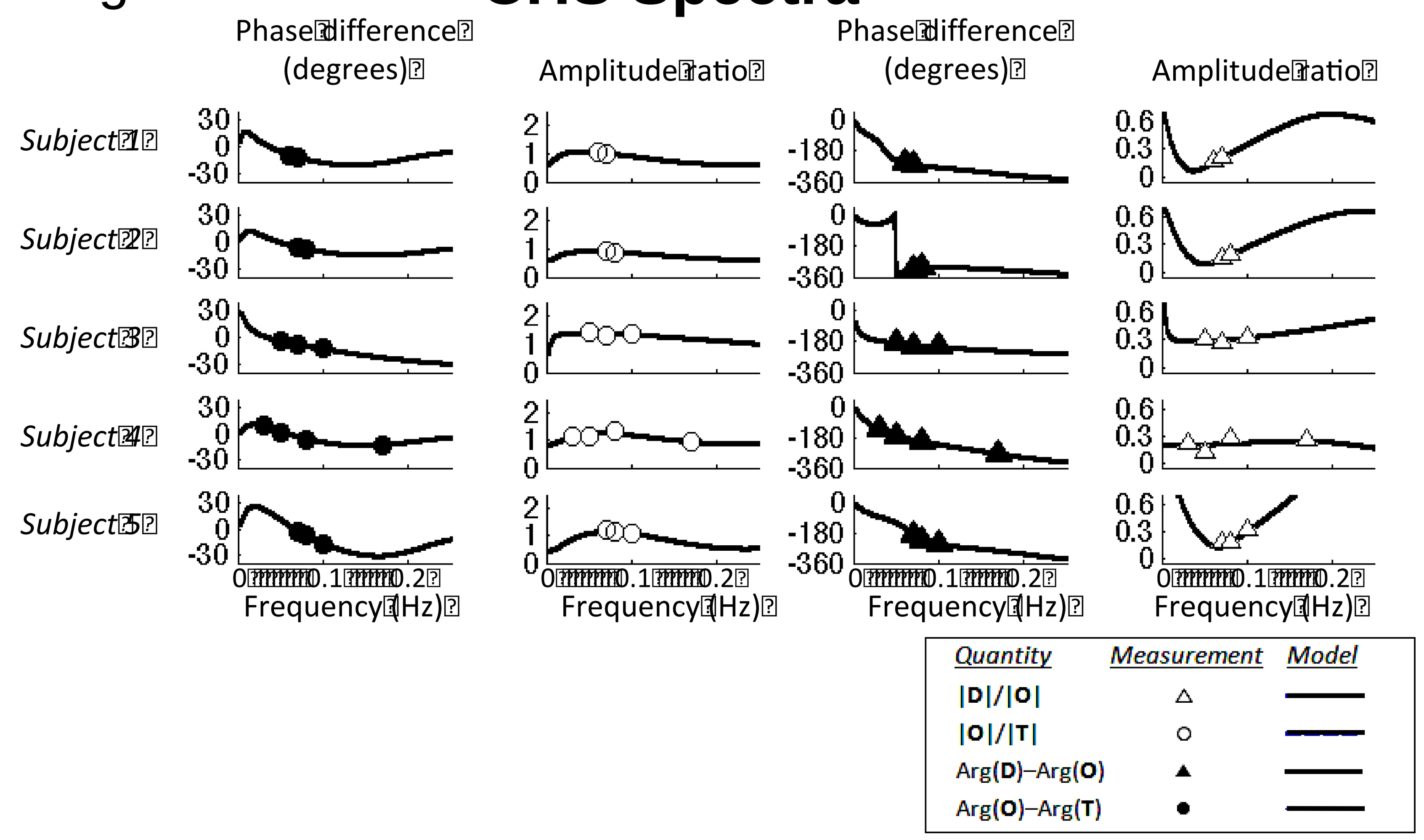


Fig. 6