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„Cardiovascular Modeling and Control via Posture and Motion“

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Cardiovascular Modeling and Control via Posture and Motion

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Introduction

An important therapy strategy in an early phase of rehabilitation for patients in a vegetative state or after acute stroke is mobilization by stepping and body tilting. Mobilization has a major influence on the cardiovascular system. Cardiovascular adaptation to an upright posture depends on the proper interplay of the hemodynamic system and the reflex mechanism that maintain blood pressure homeostasis [1, 2].

First applications with the dynamic tilt table Erigo showed that there is a positive effect on blood circulation [3]. Via the Erigo two sensory stimulation inputs can be applied. Firstly, the subject is tilted to different inclination angles and secondly, the legs are mobilized by a stepping pattern.

In this project we investigate the relationship between cardiovascular quantities and the two inputs provided by the Erigo. Based on these results a physiological model is derived. The final goal is to control the physiological state of the body by varying these sensory stimulation inputs.

Methods

Erigo & Measurement System

The tilt table Erigo (Hocoma AG, Switzerland) combines a continuously adjustable tilt table with an integrated motor-driven stepping device (Fig.1). The tilt angle α_{tilt} can be adjusted between 0° and 76° (velocity: 3.4°/s) and the stepping frequency f_{step} can be regulated between 0 and 80 steps per minute.

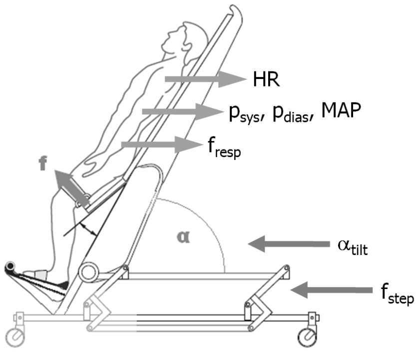

Fig. 1: Measurement setup with the tilt table Erigo and the input variables tilt angle α_{tilt} and stepping frequency f_{step}. The physiological output signals are: Heart rate HR, systolic, diastolic and mean arterial blood pressure p_{sys}, p_{dias} and MAP, as well as respiration frequency f_{resp}.

Heart rate (HR) and respiration frequency f_{resp} are acquired with a g.tec-System from Guger Technologies. The continuous systolic, diastolic and mean arterial blood pressure p_{sys}, p_{dias} and MAP are recorded with a CNAP Monitor 500 from CNSystems.

Model

In a first step, the behavior of the cardiovascular system in response to inclination angles and stepping frequencies is modeled. As output variables, heart rate HR and mean arterial blood pressure MAP are chosen.

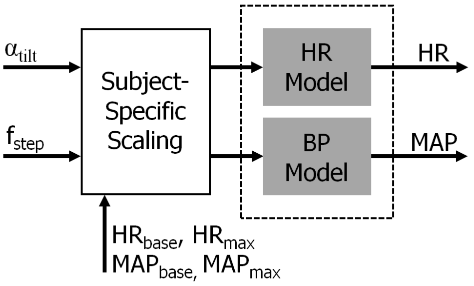

Fig. 2: Model with 2 inputs (α_{tilt} and f_{step}) and 2 outputs (HR and MAP). Baseline and maximal values of HR and MAP are used for subject-specific scaling.

A non-linear Multi Input Multi Output dynamic model is designed, with two inputs α_{tilt} and f_{step} and two outputs HR and MAP (Fig. 2). Heart rate HR and blood pressure BP are modeled separately, each with a weighted sum of static nonlinear functions of the two input variables, followed by linear dynamics. The parameterized nonlinearities are of sigmoidal shape, and the dynamics are described by 2nd order differential equations with unknown coefficients. The global optimum of parameter for nonlinearities and dynamics is found in a one-step identification using Least Squares. Steady-state values for HR and MAP are used for subject-specific scaling to reduce the effects of inter-subject variability.

Evaluation

Subjects

Eight healthy subjects (5 female and 3 male) with no cardiovascular history and an average age of 24.9 years (SD: ±2.23 years), weight of 60.9 kg (SD: ±6.85 kg) and height of 174.9 cm (SD: ±7.61 cm) participated in this study.

Protocol

A baseline measurement (duration: 10 minutes) is performed before and after the intervention phase. In the intervention phase, subjects are tilted four times to an angle of either 20°, 40°, 60° or 76° and back to 0° for three minutes each time. The procedure is performed for three different stepping frequencies: 0, 24 and 42 steps per minute.

Results

The HR during tilting to different angles is shown in Fig. 3. A distinct correlation between tilt angle and resulting steady-state HR can be seen. In reaction to an increasing tilt angle, the physiological system reacts with an overshoot, settles down to a steady state and drops to the original value after the tilt angle decreases back to 0°. Whereas the system shows an overshoot after increasing the tilt angle, there is no negative overshoot in the decreasing phase.

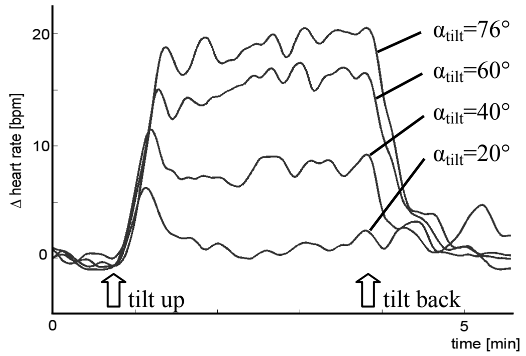

Fig. 3: Mean HR during different tilt angles for all subjects (n=8).

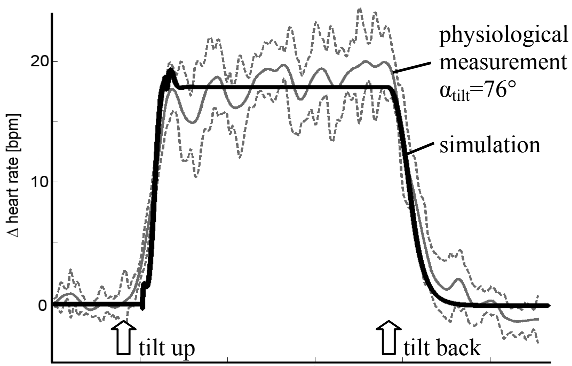

Fig. 4: Average of the physiological reaction of all subjects (n=8) with the plotted standard error (dashed line). Measurements are compared with the predicted data of the model during tilt.

A comparison of the experimental and simulated results of the HR (during α_{tilt} = 76°) is demonstrated in Fig. 4. The predicted data of the model generally stays within the range of the standard error (average value of the standard error: ±3 bpm). Only results for the maximal tilt angle are shown in Fig. 4, but the model fits for α_{tilt}= 60°, 40° and 20° are just as good.

A similarly clear correlation can be seen between MAP and different angles α_{tilt} (data not shown). The experimental data show a sigmoidal behavior. While the tilt angle increases to a maximum of 76°, the MAP rises by about 6 mmHg (SD: ± 3 mmHg).

The reaction of HR to stepping frequency can be well described by a linear relationship, yet this parameter shows only a minor influence.

Discussion

A general issue in modeling is inter-subject variability, even if the group of subjects is homogeneous in terms of age and body mass index. Nevertheless, the experimental results depict a small standard error of the HR and MAP between subjects, showing that subject-specific scaling of the input variables is an efficient means to cope with the variability.

The model is based on experimental data and cannot predict syncopes. The presented model also does not account for natural variability of heart rate and blood pressure. However, the global cardiovascular behavior, including overshoots, is predicted within the range of standard error. This information will probably suffice for simple control of physiological quantities. However, it remains to be investigated whether the results can be reproduced with patients.

Conclusion & Outlook

We conclude that HR and MAP show a reproducible response to different tilt angles in healthy subjects. Future work will investigate the influence on the systolic and diastolic blood pressure as well. Furthermore, the model will be extended to allow predictions of the respiration frequency and further physiological quantities.

The long term goal will be to robustly model cardiovascular and respiratory states and to investigate control strategies that manipulate these states by means of posture and motion. Control of blood pressure for patients in the intensive care unit is one of the possible applications.

Literature

[1] HELD, T.: *Computational models of cardiovascular response to orthostatic stress.* 2004.
[2] HAINSWORTH, R., AL-SHAMMA, Y. M. H.: *Cardiovascular responses to upright tilting in healthy subjects.* Clinical Science, 74:17 22, 1988.
[3] CZELL, D. et al.: *Influence of passive leg movements on blood circulation on the tilt table in healthy adults.* J Neuroeng Rehabil, 2004. **1**(1): p. 4.

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