RESPONSE AND CONTROL OF HEART RATE VIA POSTURE AND MOVEMENT

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Abstract: After a few days of immobilization, patients need some form of treatment to stabilize their cardiovascular system. It is known that mobilization has a major influence on the cardiovascular system and, therefore, is an important component in neurorehabilitation. In this study a strategy is presented to control the heart rate using two mechanical stimuli: body inclination angle and stepping frequency. First, we could show that the heart rate of healthy subjects, as well as minimally conscious patients, shows a clear and repeatable response to body tilting and stepping. Furthermore, first experiments demonstrated the feasibility to control the heart rate of healthy subjects. Future experiments are required to optimize the control strategy with healthy subjects and to present the feasibility of the controller for use with patients. The long term goal will be to control heart rate, systolic and diastolic blood pressure, as well as respiration frequency, in order to stabilize the patients' cardiovascular system and improve their health state with a reduced amount of pharmaceutical medication.

1 INTRODUCTION

An important therapeutic strategy in an early phase of neurorehabilitation is mobilization by stepping of the legs, and body tilting. Leg mobilization itself 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 (Held, 2004; Hainsworth and Al-Shamma, 1988).

First applications with the dynamic tilt table Erigo showed a positive effect on blood circulation in healthy adults (Czell et al., 2004) as well as in patients (Luther et al., 2008). The Erigo enables two sensory stimulation inputs to be applied. Firstly, the subject can be tilted to different inclination angles and secondly, the legs can be mobilized by a stepping pattern. During tilting the stepping mechanism supports blood circulation, providing a significant reduction in the number of syncopes observed by Czell (2004) and Luther (2008). As a consequence, it was possible to integrate body tilting more intensively into patient therapy and, hence, improve the rehabilitation process.

In this project we investigated the relationship between the two inputs provided by the Erigo, and the cardiovascular output of the human. Many research groups have previously performed classical tilt table experiments to show a steady state response of heart rate (HR) as well as blood pressure and the occurrence of syncopes (Hainsworth and Al-Shamma, 1988; Mukai and Hayano, 1995; Petersen et al., 2000). However, an open question remains as to how well the cardiovascular system reacts to simultaneous leg mobilization and body tilting. Thus, in our study, continuous data were measured in order to observe also the behavior during the transient state in the tilting phase, in addition to a steady state.

The results presented in this paper show the reaction of the HR in healthy subjects and minimally conscious patients. Based on these results we performed a first feasibility study to control the HR of healthy subjects.

Our results form the basis to control the

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cardiovascular output also for patients in order to stabilize their clinical state with a reduced amount of drugs.

2 METHODS

2.1 The Erigo System

The tilt table Erigo (Hocoma AG, Switzerland) combines a continuously adjustable tilt table with an integrated motor-driven stepping device (Figure 1). The tilt angle α_{tilt} can be adjusted between 0° and 76° (velocity: 3.4°/s), whereas, the stepping frequency f_{step} can be continuously adjusted up to 80 steps per minute (one leg: 40 steps per minute; stepping frequency f_{step}=0.67Hz). The duration of extension and flexion phase is identical and the leg elements move with a 180° phase shift to each other at a constant speed.

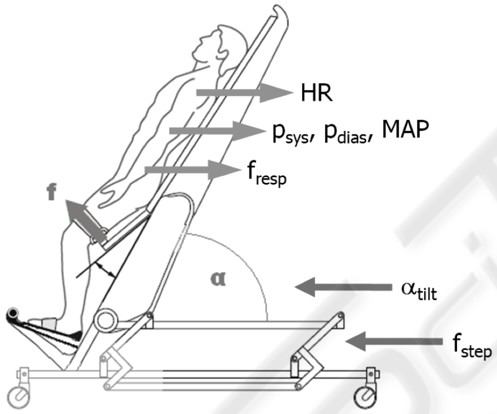

Figure 1: Measurement setup with the tilt table Erigo and the input variables tilt angle α_{tilt} (normalized height $h_{norm}=\sin(\alpha_{tilt})$) and stepping frequency f_{step}. The physiological output signals are: Heart rate HR, systolic, diastolic and mean arterial blood pressure p_{sys}, p_{dias} and MAP, as well as respiration frequency f_{resp}.

The trunk and hip are tightly fixed by a belt system and the head is stabilized with a neck cushion that is shapeable according to the individual needs of the subjects. The feet are attached on two separate mobile footplates and Velcro® strips fasten the legs to an end-effector of the Erigo in order to perform reproducible standardized movements. The Erigo allows a highly synchronized movement of the hip, knee and ankle of the left and right leg. In contrast to real human gait, however, subjects move their legs in only a vertical but not in horizontal direction.

2.2 The Measurement System

HR and respiration frequency f_{resp} were acquired with a g.tec recording system from Guger Technologies (Austria). For the ECG recording lead I and II of the Einthoven's triangle were used. A flow sensor to monitor changes of temperature of breathing (nose and mouth) captures the respiration signal. All electrode and sensor signals are collected via the g.tec system and the continuous blood pressure signal is acquired noninvasively by a CNAP Monitor 500 from CNSystems AG (Austria). The monitor provides beat-to-beat values for systolic, diastolic and mean blood pressure p_{sys}, p_{dias} and MAP that is fed into the g.tec system under conditions of chronological synchronism.

2.3 Control Strategy

In this paper the focus is on a control strategy for the HR signal. A feedforward – feedback structure is used and the desired heart rate HR_{des} is given by the investigator (Figure 2).

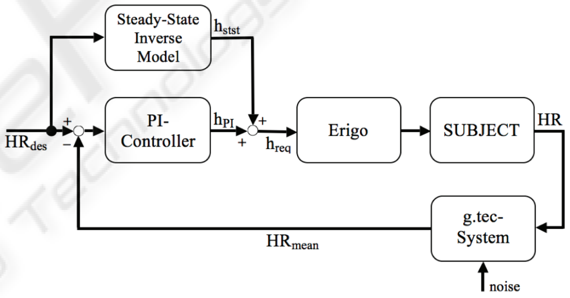

Figure 2: Overview of the control strategy. HR = heart rate; HR_{des}= desired HR; h_{stst}= corresponding normalized height to a desired HR; h_{PI}= output of the controller; h_{req}= required normalized height; HR_{mean} = mean of the measured HR during 20s.

In the feedforward loop a steady state inverse model describes the physiological reaction of the subject to the change of the height of the heart in the steady state. The normalized height h_{norm} in all subjects is determined by $h_{norm}=\sin(\alpha_{tilt})$. To describe the dependence between the change of the normalized height of the subject's heart h_{norm} and the expected HR a 2nd order polynomial function is used. The expected normalized height for a desired steady state h_{stst} is the first input for the plant of the controller.

This height together with the output of the PI-controller h_{PI} determines the required height h_{req} fed to the Erigo. The PI-controller is given by the structure

$$G(s) = K_p + \frac{1}{T_N s} = K_p \left(1 + \frac{K_I}{K_p} \frac{1}{s} \right), \qquad (1)$$

whereas, K_p is the gain and $K_I = T_N^{-1} = K_p = 1.3$.

By means of a control signal to the Erigo the subject is tilted to the required height h_{req} and the resulting HR is acquired by the g.tec system. An adaptive threshold algorithm (Christov, 2004) is applied to detect the actual HR, whereas, every 20s a mean value is identified. To emphasise on the latest detected HR values (during the period of 20s) a linear weighting function is used. This mean value HR_{mean} will be compared with the desired HR value HR_{des} and fed into the PI-controller. The output h_{PI} is only modified when the measured value HR_{mean} differs more than 10% of the desired value HR_{des}.

3 EVALUATION

3.1 Subjects

Eight healthy subjects (5 female and 3 male) with no history of neurological, psychiatric or cardiovascular disorder 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.

Further, 3 minimally conscious patients (1 female and 2 male) with an average age of 52.6 years (SD: ± 8.96 years) were included in the study 42, 4 and 2 months after the incident. Glasgow Coma Scale values of the patients vary between 6 and 10.

3.2 Protocol

A baseline measurement (duration: 10 minutes) was performed before and after the intervention phase. In the intervention phase, subjects were tilted four times to a normalized height of either sin(20°), sin(40°), sin(60°) or sin(76°) and back to 0 for 3 minutes (healthy subjects) or 5 minutes (patients) each time. The procedure was performed for three different stepping frequencies: 0, 24 and 48 steps per minute.

For the control strategy a initial phase of 6 minutes was needed in order to identify the minimal HR during baseline condition (h_{norm}=sin(0°) during the first 3 minutes) and maximum condition (h_{norm}=sin(76°) during the second 3 minutes). In the following experiment the desired HR value HR_{des} was exactly 50% of the evaluated difference between HR at baseline and maximum condition.

The control strategy is shown in figure 2 and after 10 minutes controlling the HR to 50%, the desired HR went back to the value known from the baseline condition.

3.3 Results

The evaluation of the steady state of the HR while tilting a healthy subject and setting the stepping frequency to 48 steps per minute is shown in figure 3. The corresponding HR values to the different normalized heights are clearly distinguishable. In general, the physiological system reacts with an overshoot and turns back to a steady state after the subject is tilted to a defined height (data not shown).

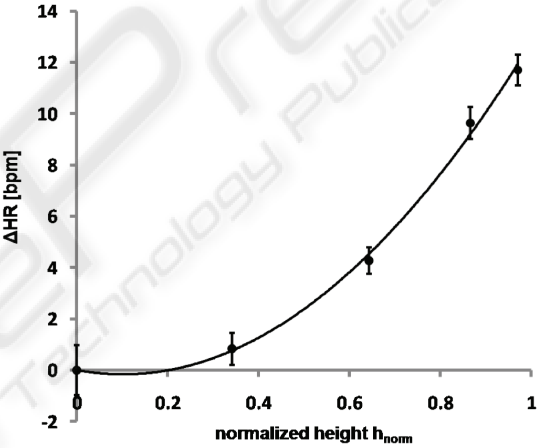

Figure 3: Steady state values (with standard deviation) of the HR during different normalized heights for all subjects (n=8). Stepping frequency was set to 48 steps per minute.

First, with stepping a steady state is reached within the first minute, whereas, without stepping it takes up to 3 minutes till a plateau is reached. Second, without stepping the reached steady state is up to 6 bpm higher.

The results of the feasibility study about controlling HR via posture are shown in figure 4. In the first 6 minutes the baseline and maximum condition is evaluated. In baseline condition the mean value for HR is 53bpm (0%) and after body tilting to h_{norm}=sin(76°) the value rises to 72 bpm (100%). As a consequence, for the following 10 minutes the input for the controller is 62.5 bpm (50%) and after this period the desired value decreases back to 53 bpm (0%). The measured HR shows a natural variability, nevertheless, the mean value of the HR during the controlled period is 61.7

bpm (desired value: 62.5 bpm) and 52.8 bpm (desired value: 53 bpm), respectively.

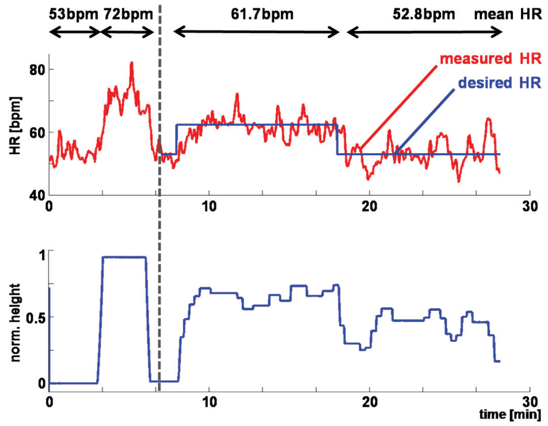

Figure 4: Controlled HR (measured HR) with the desired HR (upper panel) and the corresponding normalized height (lower panel).

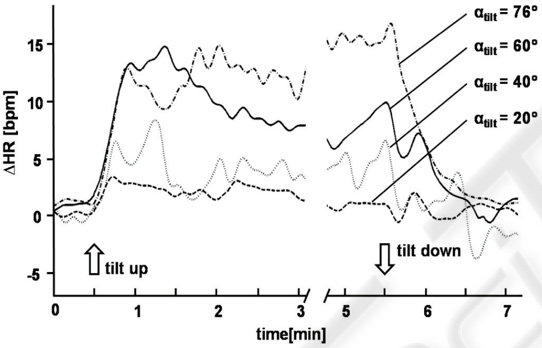

Figure 5: Mean HR during different normalized heights for all patients (n=3) during a stepping frequency of 48 steps per minute. The standard deviation for α_{tilt} = 20°, 40°, 60° and 76° was 2.23 bpm, 3.45 bpm, 3.06 bpm and 5.50 bpm, respectively.

The patients' data show a very similar behaviour to different normalized heights while the stepping frequency was also fixed to 48 steps per minute (Figure 5). Generally, during the tilting phase the variability is higher in patients compared to healthy subjects. No clear steady state can be seen in the data. With this preliminary data set, differences regarding stepping and normalized heights are not statistically significant.

3.4 Discussion

A general issue is the subjects inter- and intra-variability between different measurements. However, a relationship between mean HR and different normalized heights can be clearly demonstrated. Figure 3 shows mean values composed of 8 healthy subjects and consequently, most of the short-term variability is cancelled out in that illustration.

Establishing a control strategy for cardiovascular signals requires working with signals from individual subjects. As shown in figure 4, even with no control of the HR signal in the first 6 minutes the natural short-term variability can be relatively high (±5 bpm). For that reason it was necessary to implement strategies that can cope with this variability. Two issues are implemented to deal with such a high variability: First, the normalized height was only changed in the interval of 20s and, second, the height was only modified when the measured value differed more than 10% of the desired value.

Using such mechanisms it was not possible to eliminate the variability, but during the two control phases (2 times of 10 minutes) it could be shown that the mean values (61.7 bpm and 52.8 bpm) differed less than 1 bpm from the desired values (62.5 bpm and 53 bpm). For a clinical application the control of cardiovascular signals in longer time periods is more important than short term effects. Heart rate variability (HRV) is a sign of healthiness and, therefore, it is worth to sustain it or perhaps to support it. In contrast, in the long term it is important for the cardiovascular system of patients to be maintained within well defined bounds. Thus, short term effects like the variability are not essential for our control strategy and control over longer periods is satisfactory.

The patients' data also show a repeatable response to different normalized heights. Nevertheless, during the tilting phase no clear steady state can be observed in the data (Figure 5). This may be due to the small sample size (3 patients), whereas, the data of healthy subjects is based on 8 persons. On the other hand minimally conscious patients are clinically not stable and, therefore, it could be that these patients don't show a steady state because of the medication or the individual injury. The study is still in progress and more patients will be assessed before drawing clear conclusions based on the acquired data of patients.

4 CONCLUSIONS & OUTLOOK

We conclude that the HR of healthy subjects as well as of patients in minimally conscious state shows a clear response to different normalized heights. With the presented control strategy it is possible to control the HR of healthy subjects.

Future work will be done to arrange more experiments with healthy subjects in order to optimize the control strategy. Additionally, more patients will be included into the study to get refined results about their cardiovascular response. To understand the patients' behaviour in a better way will give us the opportunity to adjust the control strategy for needs in the rehabilitation process.

The long term goal will be to find robust behaviours of cardiovascular signals to investigate control strategies based on HR, systolic and diastolic blood pressure as well as respiration frequency. This would establish a basis to influence the cardiovascular system of patients in order to stabilize their clinical state without additional drugs.

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REFERENCES

Christov, I. I., 2004. *Real time electrocardiogram QRS detection using combined adaptive threshold.* BioMedical Engineering OnLine 3:28

Czell, T., 2004. *Influence of passive leg movements on blood circulation on the tilt table in healthy adults.* J Neuroeng Rehabil, 2004. 1(1): p. 4.

Hainsworth, R. and Al-Shamma, Y. M. H., 1988. *Cardiovascular-Responses to Upright Tilting in Healthy-Subjects.* Clinical Science 74(1): 17-22.

Heldt, T., 2004. *Computational models of cardiovascular response to orthostatic stress.* Division of Health Sciences and Technology. Cambridge, Massachusetts Institute of Technology.

Luther, M. S., Krewer, C. et al., 2008. *Comparison of orthostatic reactions of patients still unconscious within the first three months of brain injury on a tilt table with and without integrated stepping. A prospective, randomized crossover pilot trial.* Clin Rehabil 22(12): 1034-41.

Mukai, S. and Hayano, J., 1995. *Heart rate and blood pressure variabilities during graded head-up tilt.* J Appl Physiol 78(1): 212-216.

Petersen, M. E. V., Williams, T. R., et al., 2000. *The normal response to prolonged passive head up tilt testing.* Heart 84(5): 509-514.