Heart Rate Asymmetry and Emotional Response to Robot-assist Task Challenges in Post-stroke Patients

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Abstract

The level of motivation or stress influences learning the use of a robot-assist device for walking. Heart rate asymmetry (HRA) indicates the level of parasympathetic (HRA<0.5) and sympathetic (HRA>0.5) involvement in heart rate regulation. Three patients and seven controls were presented increasing levels of task difficulty. During training patients showed an increase in stress as indicated by the HRA index (0.524±0.02) in contrast to control participants (0.485±0.03). As the task complexity increased, the HRA in the patient group was atypical and falling below 0.5, compared to control (HRA>0.5). The latter result reflects an increased cognitive involvement and a higher sympathetic predominance in accordance with an increased task difficulty. Thus stroke affected the response to the task challenges in that the patient response to increasing task challenge leads to an inversion of HRA associated with a decreased mental engagement and higher risk of sudden cardiac death

1. Introduction

Treadmill training is an established treatment for gait rehabilitation [1]. To improve rehabilitation outcome robot-assist devices are becoming increasingly available for automated gait training [2]. Active mental engagement [3] and responsiveness is important for successful training outcomes. Motor learning rate is maximal at a task difficulty level that positively challenges and excites subjects whilst not being too stressful or boring [4]. In addition stroke patients are more susceptible to heart attack and HRV in addition to providing cognitive indicators also provides an indication of risk of heart attack. The goal of this research was to determine the beat-to-beat adaptation to task difficulty by a group of stroke patients compared to controls with respect to the level of mental and physical challenge. Measuring cognitive function or mental engagement whilst strapped into a robot-assist device is difficult and therefore we used heart rate variability (HRV), which has been shown to be an indicator of cognitive engagement [5]. Heart rate variability (HRV) has also been shown to correlate well with EEG measures of cognitive involvement as well as to motivation and risk of sudden cardiac death [6].

1.1. Heart rate variability

Heart rate variability (HRV) is thought to reflect the heart's adaptability to changing physiological conditions and HRV is a net effect of extrinsic regulation by the sympathetic (SNS) and parasympathetic nervous system (PNS) and intrinsic heart rhythm. The SNS is responsible for increasing the heart rate while the parasympathetic tone lowers the heart rate. In practice there is always some variability in the heart rate, due to imbalances in the activity levels of the SNS and PNS. Hence, any heart rate cannot increase or decrease indefinitely but instead will be followed by an opposite trend. The speed at which the heart rate increases or decreases is variable, which implies that the periods of increasing or decreasing inter-beat intervals are also not equal. As a result, heart rate asymmetry (HRA) should be a common phenomenon present in the healthy heart [7,8].

1.2. Heart rate asymmetry index

The asymmetry in consecutive beat-to-beat intervals is easily observed in the Poincaré plot of a normal sinus rhythm ECG and can be represented by three different asymmetry indices, namely Guzik's, Porta's and Ehlers' index [7].

In this paper heart rate asymmetry is calculated from the Percentage Index (PI) of the normalized probability of the accelerations and decelerations within the time series.

Heart periods (inverse of heart rate) are either shorter or longer on a beat-by-beat basis following acceleration associated with sympathetic activation and inhibition due to vagal activation.

2. Methods

Data was obtained at the Spinal Cord Injury Center Balgrist, Zurich, Switzerland following the ethics approval from the local ethics committee.

2.1. Robot-assist training environment

The driven gait orthosis (DGO) Lokomat (Hocoma, Switzerland) was used for the locomotion training. Subjects are fixed within the DGO exoskeleton and connected to a body weight support system set at 30%. The device allows assisted locomotion on a treadmill by guiding the subject's legs along a predefined trajectory. The virtual environment with the task conditions is viewed on a back projection screen and included a simultaneous biomechanical task and a cognitive task of varying difficulty level.

The mechanical task was to pick up items by walking to them and the cognitive task was to jump over barrels, which rolled towards the participants by clicking a computer mouse button. Following the training session, subjects completed five experimental conditions of standing, walking and three levels of difficulty/challenge whilst walking. These were related to the distance between barrels and the speed they were moving at [9]. The difficulty levels were: (i) under-challenged where all objects were easily collected; (ii) challenged led to a maximum of 80-90% of objects to be collected; and (iii) over-challenged condition with the possible score less than 10% of the possible maximal score. These three challenge levels correlated with three levels of mental engagement equal to boring, exciting and over-stressed respectively.

2.2. Entropy related asymmetry

The resulting heart rate asymmetry associated with different levels of task difficulty was estimated from the recorded ECG traces. The ECG was recorded using a Lead II configuration at 512 samples/second. R wave peaks were determined using the algorithm first suggested by Tomkins [10]. Inter-beat variation and complexity was determined from the ECG by the heart rate asymmetry index (HRA).

The heart rate asymmetry is determined from the RR intervals as the probability index of accelerations and deceleration of the heart rate and derived from the calculation of tone and entropy [11]. Heart period data or RR intervals are first transformed into the percentage index (PI) time series by:

$$PI(n) = [H(n) - H(n+1)] \times 100 / H(n) \quad (1)$$

where [H(n)] is a heart period time series, and n a serial number of heart beats. The tone is defined as a first order moment (arithmetic average) of this PI time series as:

$$\sum_{n} PI(n) / N \quad \text{(non-dimensional)} \quad (2)$$

where N is a total number of PI terms. The tone represents the balance between accelerations ($PI > 0$) and inhibitions ($PI < 0$) of the heart rhythm and represents the sympatho-vagal balance [12]. The entropy is defined from the PI probability distribution by using Shannon's formula:

$$-\sum_{n} p(i) \log_2 p(i) \quad \text{(bit)} \quad (3)$$

where [p(i)] is a probability that PI(n) has a value in the range, $i<PI(n)< i+1$, i is an integer. The entropy evaluates total acceleration–inhibition activities, or total heart period variations [13]. Acceleration of the heart rate is, therefore, expressed as a plus difference, inhibition as a minus difference (Fig 2).

From the PI series the positive and negative difference periods were separated. The calculation $PI(n) = 0$ was omitted because it is neither acceleration nor inhibition. Then the entropy of the positive and negative differences of the PI time series was calculated. The heart rate asymmetry is given by the following formula:

$$\text{HRA} = \frac{\text{Entropy of the positive differece part of the PI time series}}{\text{Total entropy of PI time series}}$$

2.3. Statistical analysis

The Wilcoxon test for paired comparison was used to determine whether any differences existed between stroke patients and controls with respect to HRA. The significance level was set at $p < 0.05$.

3. Results

Seven healthy subjects (mean age 24.1±2.0 years) with no neurological and physiological impairment and three stroke patients (mean age 60.33±8.62) participated in the study. All stroke patients had a left middle cerebral artery occlusion. Two patients were on beta-blocker medication. Time post infarct was less than six months.

3.1. Comparison of HRA in patients and controls

Fig 1 indicates the response of one typical patient and one control subject for the total test period including the five conditions from standing to the over-challenged task condition.

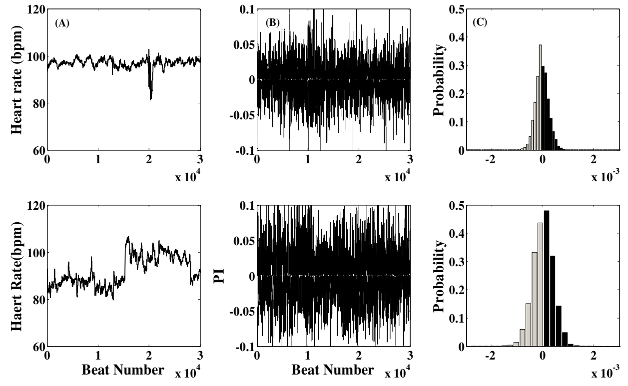

Figure 1. RR interval changes with change in test condition.

Fig 1 shows a typical heart period (RR intervals) time series (A) with the PI time series in (B) and (C) indicating the probability distribution histogram. In the histograms, black bars represent accelerations (PI > 0), and grey bars, inhibitions of the heart rate (PI < 0), respectively.

In stroke patients a flatter RR period trace is found with the probability of deceleration (parasympathetic influence) dominating (Fig 1 top), whereas in the control group the probability of acceleration synonymous with sympathetic drive is more pronounced (Fig.1 bottom).

3.2. HRA response

Results for heart rate asymmetry (HRA) indicated that at rest stroke patients are anxious with slight sympathetic predominance. HRA inverts in patients when the tasks increase in complexity and leading to a maximal parasympathetic predominance during the challenged condition. This high probability of deceleration (0.45 ± 0.07) returns towards a balanced autonomic response during the over-challenged condition (0.47 ± 0.04). The control group showed a steady increase in sympathetic drive, peaking at the challenged condition (0.62 ± 0.17), returning towards baseline during the over-challenged condition as well (Table 1).

Table 1. Heart Rate asymmetry at different stages.

Stages	Patients mean±sd	Controls mean±sd
Standing	0.52 ± 0.02	0.48 ± 0.04
Walking	0.49 ± 0.11	0.52 ± 0.04
Under challenged	0.48 ± 0.02	0.51 ± 0.03
Challenged	0.45 ± 0.07	0.62 ± 0.17
over challenged	0.47 ± 0.04	0.57 ± 0.14

No significant difference between the control and stroke patients was observed for any of the conditions. However the data clearly indicates the difference in autonomic nervous system modulation between the stroke and control participants with respect to task condition (Fig. 2).

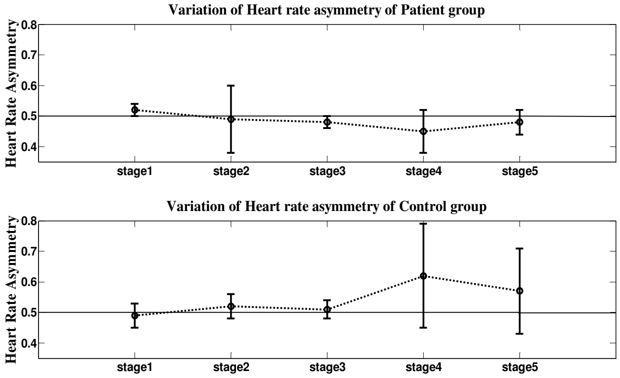

Figure 2. Change in the pattern of HRA.

In Fig 2, the 0.5 line indicator is the reference value of HRA. Values greater than 0.5 indicate sympathetic influence, whereas values below 0.5 indicate parasympathetic influence and slowing of the heart rate.

4. Discussion

Robot-assisted training is an important component of neural rehabilitation and requires appropriate motivation and mental engagement for optimal task execution. Increased task difficulty is reflected in increased stress levels experienced by patients that can be measured using HRV as a proxy for cognitive involvement [14]. However heart rate variability is an important component in its own right as it can indicate the stage of neural rehabilitation and prognosis as well as risk of sudden cardiac death due to arrhythmia. Recovery from stroke is gradual and normal HRV in post-stroke patients is usually not reached even at six months [15,16]. In addition arrhythmia is more common in post-stroke patients and therefore HRA is an important measure in establishing appropriate task difficulty. This study focused on establishing the HRA response to the level of task engagement.

HRV is a function of the level of sympathetic and parasympathetic input, which changes when physical exercise is undertaken or an external or internal stressor is present [17,18]. We found that at the resting stage stroke patients had higher sympathetic tone indicating a higher sympathetic response. Sympathetic activity is increased with increased stress, which may be due to inappropriate anticipation of the robot-assist tasks ahead. Control subjects had a slightly greater parasympathetic output as would be expected at rest [19]. The change in task condition from standing to challenged led to a steady increase in parasympathetic predominance in the stroke patients suggesting decreased motivation (Fig 2). The augmentation of parasympathetic activity in the post-stroke patients can also lead to bradycardia or asystole and sudden cardiac death [20].

5. Conclusion

Heart rate variability has been shown to be a good indicator of the extent of motivation and mental engagement during stroke rehabilitation. Our results indicate that using the HRA index in a cohort of stroke patients with less than six months recovery there is a pronounced heart rate asymmetry in favor of parasympathetic dominance. This could further increase the already increased risk of an arrhythmic event in this patient group during rehabilitation.

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