Accelerometer Rate Adaptive Pacing

Elaboration of Requirements

Rev. 2

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1 Introduction

The purpose of this document is to elaborate on the Boston Scientific *PACEMAKER System Specification* rate-adaptive pacing requirements, and to serve as a resource for designing a programmable, open loop rate-adaptive pacemaker algorithm.

2 Open Loop Rate Adaptive Pacemaker System

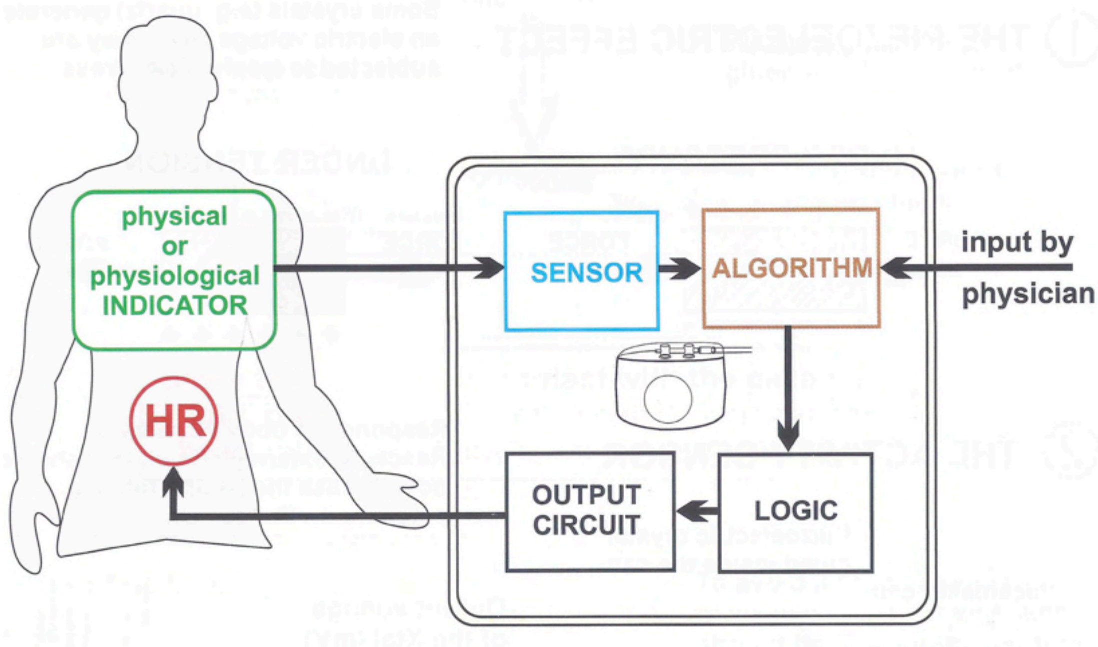


Figure 1: Open Loop Rate Adaptive Pacemaker System [1]

2.1 Indicator

A physical or physiological parameter that changes according the needs of the body.

2.2 Sensor

A 3-axis accelerometer on the pacemaker pulse generator is used to measure a patient's acceleration and generate an electrical signal proportional to physical activity.

2.3 Algorithm

The algorithm is the software function of the pacemaker that converts the electrical signals from the sensor into an appropriate pacing response by the device.

2.4 Logic

The program running on the microcontroller performs the logic to drive the output circuit.

2.5 Output Circuit

The pacemaker shield and leads interface with the heart, and control the patient's heart rate to appropriately adapt to the needs of the body.

3 Algorithm

Refer to section 5.7 of PACEMAKER SRS document for description of programmable parameters used in rate adaptive pacing [2].

3.1 Signal Processing

An appropriate signal processing technique may be applied on the raw activity accelerometer data to reduce the effects of noise and obtain useful information for determining the steady-state patient activity.

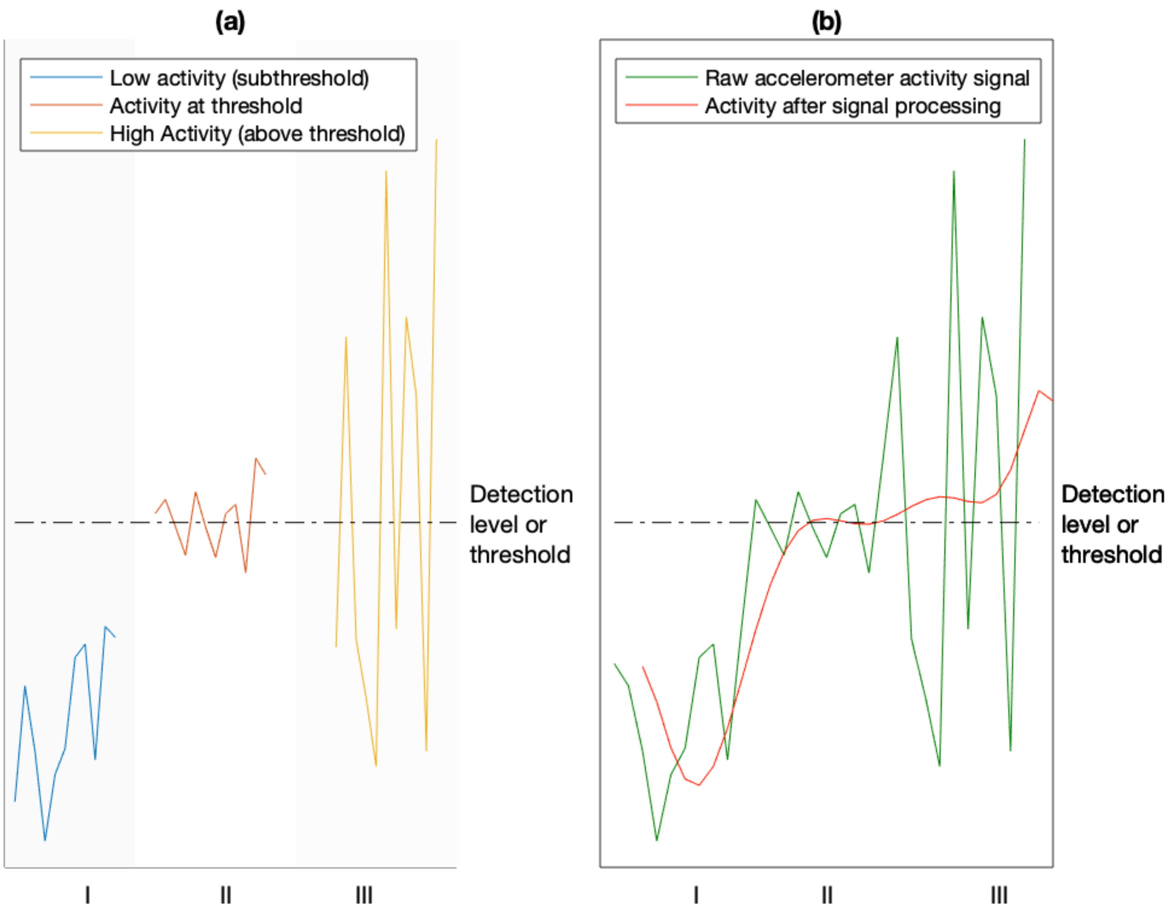


Figure 2: Describing activity detection about an activity threshold [1]. **(a)** Raw accelerometer signal levels: *I* – low activity (patient at rest), *II* – activity at threshold, and *III* – high activity above threshold (patient during exercise). **(b)** A model of activity information obtained during real-time signal processing is superimposed on the raw accelerometer signal plot.

3.2 Rate Adaptive Response Curves

The rate response and the time response characteristics specify the pacing rate at any given time and activity level.

3.2.1 Rate Response Curve

The rate response is used to determine the sensor-indicated rate r_s, or desired pacing rate, at various levels of steady state patient activity.

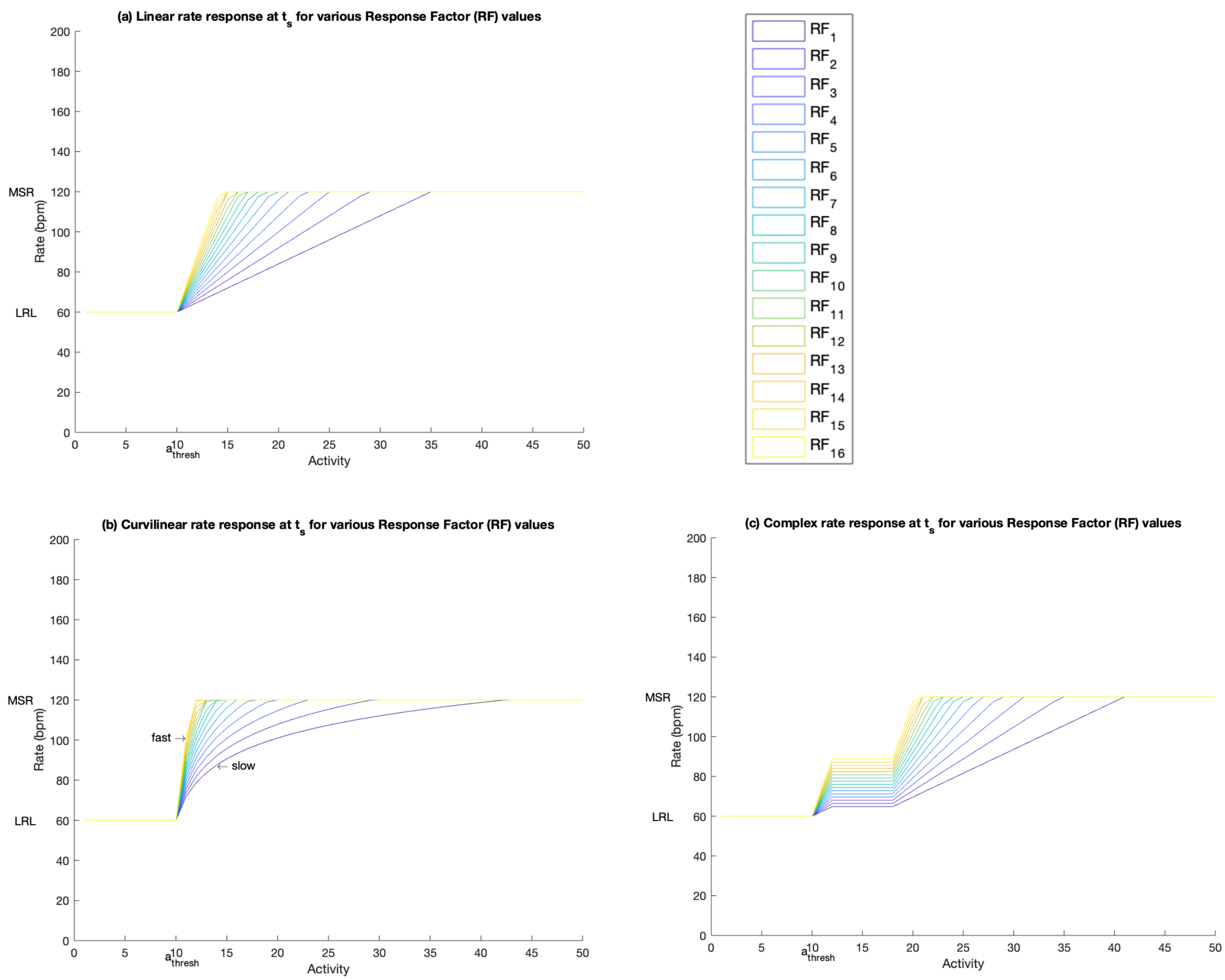


Figure 5: Example models of the desired pacing rate with respect to patient activity at various response factor settings: **(a)** linear rate response **(b)** curvilinear rate response **(c)** piecewise rate response.

3.2.2 Time Response Curve

The time response is used to determine the rate of increase of the current pacing rate towards the desired pacing rate. Various sets of time response curves and shapes can be used in rate-adaptive pacing, as indicated in Figure 6. The operator may program the slope of the acceleration and deceleration curves by configuring the reaction time and recovery time parameters through the DCM.

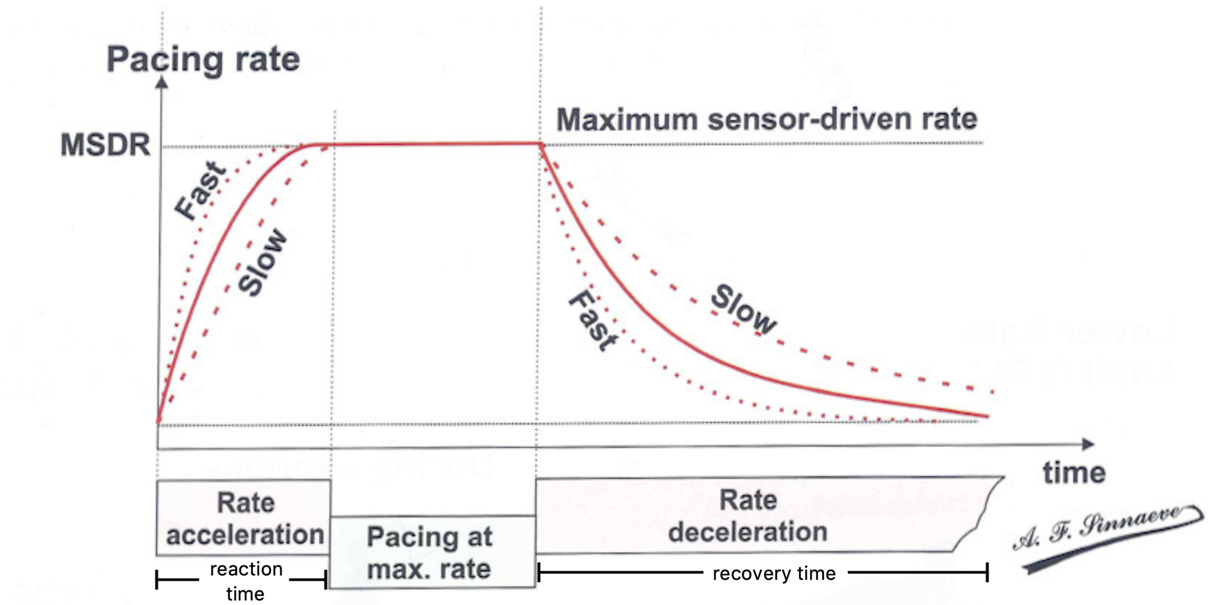


Figure 6: A model of the pacing rate with respect to time for an activity with a sensor-indicated rate at the MSR. Three stages are represented: rate acceleration, constant sensor-controlled pacing at the MSR, and rate deceleration [1].

3.3 Relationship Between Rate Response and Time Response

Suppose a patient has severe chronotropic incompetence and the clinician has programmed their pacemaker with a response factor setting of 16, a MSR of 120 ppm, and a reaction time (r_t) of 10-sec. The pacemaker pulse rate over time can be specified for the patient at various levels of activity as shown in the figure below.

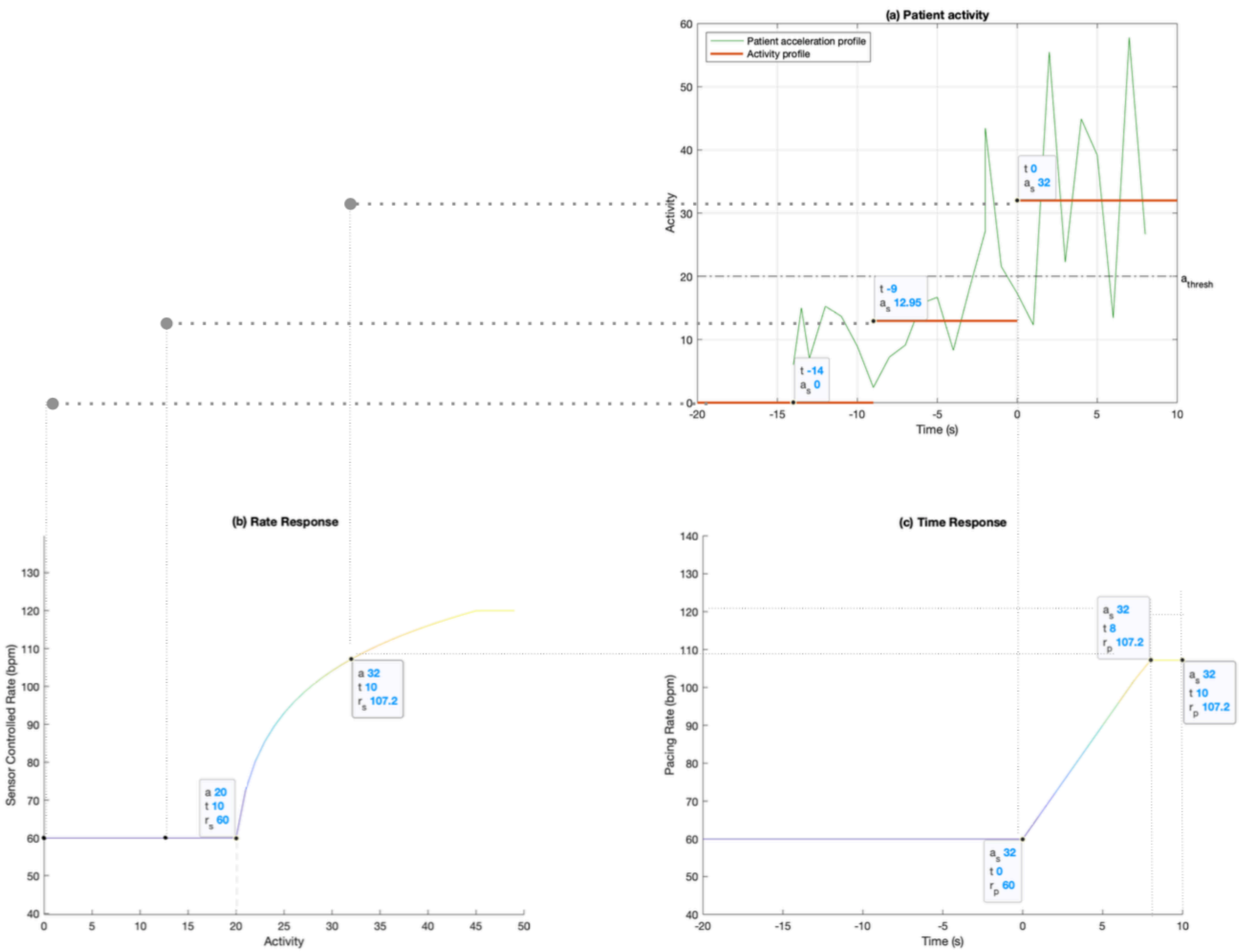
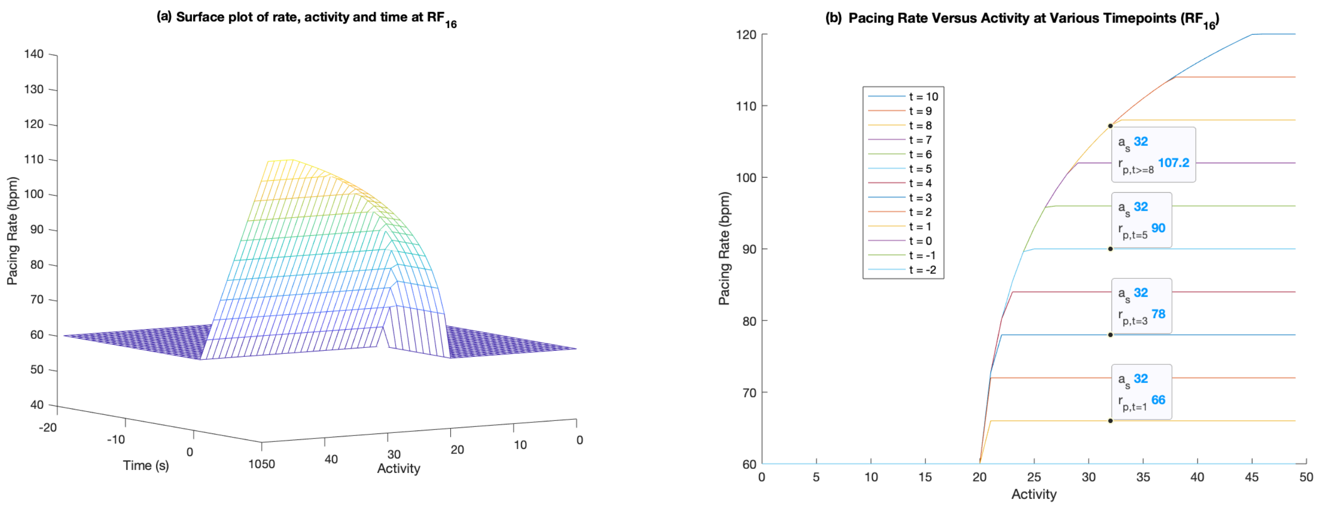


Figure 8: (a) Steady-state activity information (a_s) is collected from the patient's acceleration profile. At t=0, the activity level exceeds the threshold (a_{thresh}). An activity level of 32 is held from t=0s to t=9s. **(b)** From the rate response, we obtain sensor-controlled rate r_s of 107.2 ppm. **(c)** At t=0s, the current pacing rate (r_p) begins to increase from the LRL to r_s at a rate proportional r_t = 10-sec, indicating the onset of sensor-controlled pacing. The pacing rate is equal to r_s=107.2 ppm after t_s=7.87s, under a sustained activity level of 32.



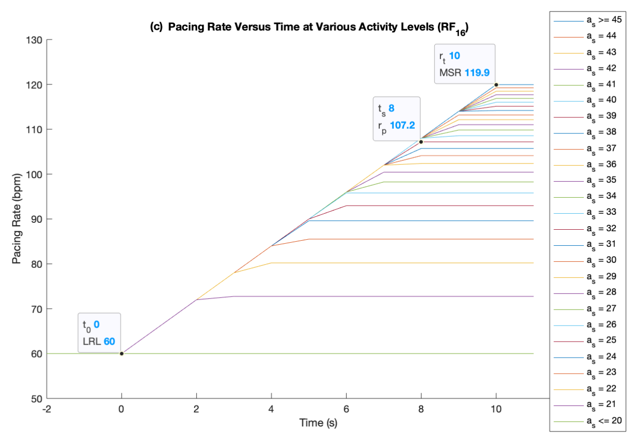


Figure 9: Different views of the rate-activity-time model for a pacemaker in both *rate acceleration* and *constant sensor-controlled pacing*.
(a) Surface plot modeling the relationship between activity, rate and time. **(b)** If a fixed activity level (a_s) is initiated at t_0 (i.e. a step input activity at t_0 with magnitude a_s), r_p can be thought of as moving up along a vertical line from (a_s, LRL) to (a_s, r_s). **(c)** Given the same step input, r_p can be thought of as moving rightward along the rate response curve until it reaches (t_s,r_s), where t_s is the minimum time required until $r_p = r_s$, and r_s is the sensor-indicated rate for the activity. At this point, r_p begins to move along the line $y = r_s$ for as long as the activity is sustained.

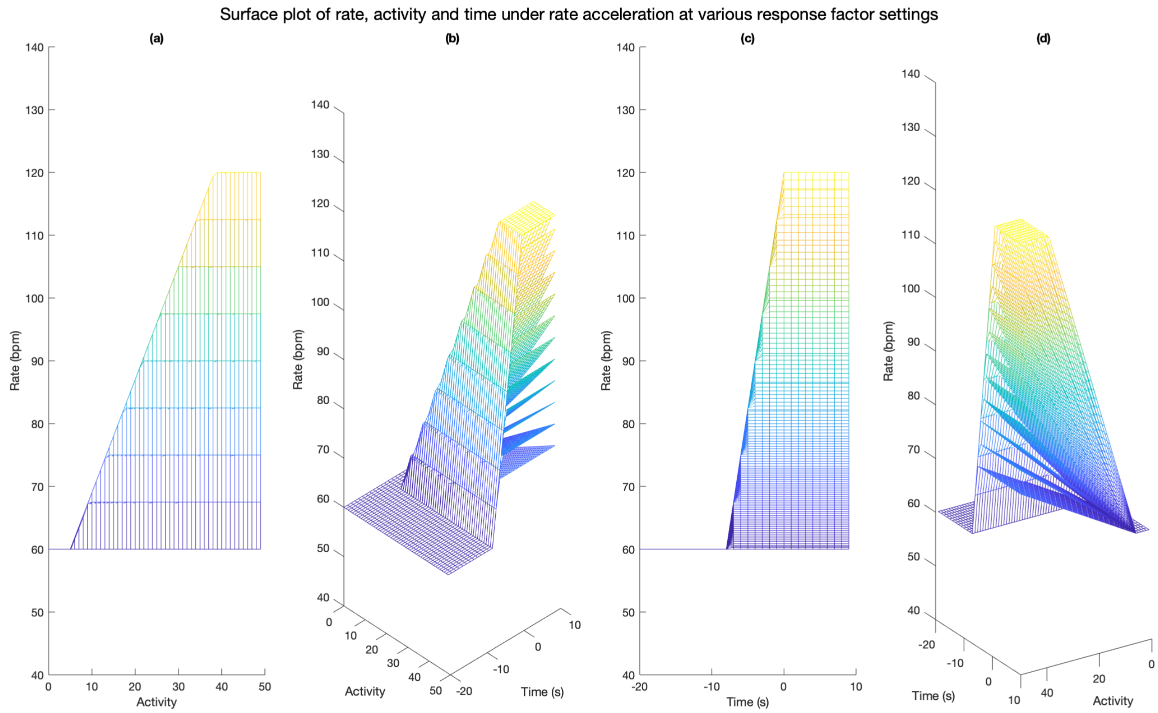


Figure 10: A 3-D model illustrating the relationship between rate, activity and time at various response factors of a pacemaker during rate acceleration.

4 Resources

[1] S.S. Barold et al, “Sensing – Advanced Concepts” in *Cardiac Pacemakers Step by Step,* 1st ed. Leander: Futura, 2004,7, 2, pp. 205, 212-214.

[2] *PACEMAKER System Specification*, *1* ed., Boston Scientific, Marlborough, Massachusetts, 2007, pp. *32-33.*