

The Nonlinear Dynamic Response of Fetal Heart Rate to Intrapartum Uterine Pressure

Johann Vargas-Calixto^{1*}, Yvonne Wu², Michael Kuzniewicz³, Marie-Coralie Cornet², Heather Forquer³, Lawrence Gerstley³, Emily Hamilton^{1,4}, Philip Warrick^{1,4}, Robert Kearney¹

¹McGill University, Montreal, Canada, ²University of California, San Francisco, USA, ³Kaiser Permanente, Northern California, USA, ⁴Peri-Gen Inc., Montreal, Canada,

Aims: Our study aims to characterize the nonlinear dynamic response of fetal heart rate (FHR) to intrapartum uterine pressure (UP). This analysis could aid in the early detection of fetuses at risk of developing fetal acidosis and subsequent hypoxic-ischemic encephalopathy (HIE).

Methods: We analyzed UP and FHR from 200 births with normal outcomes at Kaiser Permanente Northern California. We included available signals up to 12 hours before birth. We extracted continuous segments of 10 to 30 minutes. They were high-pass filtered at 4.5 mHz and decimated to 0.5 Hz using an antialiasing filter. UP-FHR was estimated as the cascade of a delay, a static nonlinearity, and a linear filter. The data fit well to a delay, determined by a grid search, and a Hammerstein structure consisting of a fifth-order Chebyshev polynomial followed by a second-order, state-space linear subsystem. Finally, we carried out a surrogate analysis to remove spurious models.

Results: We analyzed 4,619 segments; 70.62% of them passed the surrogate test. Figure 1 shows an identified system consisting of (1) a static nonlinearity that resembles a half-wave rectifier and (2) low-pass linear dynamics. Figure 2 shows the input UP and the observed vs. predicted FHR. The prediction accounted for 89.8% of the FHR variance.

Conclusions: Our results show that a Hammerstein model can successfully capture the FHR response to UP. In the future, we will expand this analysis to all subjects in our database (25,574 vaginal deliveries) and will explore differences between fetuses with normal outcomes and those with HIE.

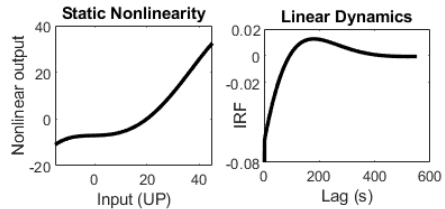


Figure 1: Identified UP-FHR system

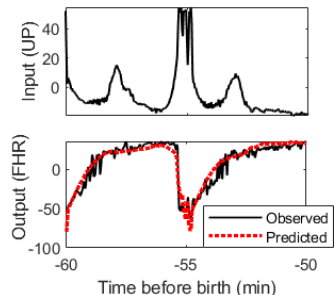


Figure 2: Filtered UP and observed vs predicted FHR