## a - Observed CVP The model is fitted on a 60 second recording. The first 20 seconds are shown here. CVP [mmHg] 15 10 0 5 10 15 20 Time [s] P wave (ECG) Inspiration start - Position in cardiac cycle d - Trend over time b c - Position in respiratory cycle 5.0 5.0 Partial CVP [mmHg] Partial CVP [mmHg] Partial CVP [mmHg] 14 2.5 2.5 13 0.0 0.0 12 11 -2.5 -2.5 0.0 0.3 0.6 0.9 25% 50% 75% 100% 20 40 60 Time since P wave [seconds] Time since inspiration start / cycle length Time [s] e.1 - Interaction between cycles e.2 - Two samples from the interaction smooth Contour height represent partial CVP [mmHg] The samples correspond to the horizontal lines in e.1 5.0 Position in respiratory cycle 100% Partial CVP [mmHg] 2.5 75% End inspiration 50% 0.0 End expiration 25% -2.5 0% 0.0 0.3 0.6 0.9 0.0 0.3 0.6 0.9 Time since P wave [seconds] Time since P wave [seconds] f - Residuals (observed CVP - predicted CVP) 15 CVP [mmHg] 10 5 0 0 5 10 15 20 Time [s]

Observed

Predicted

**Fig. 5** How a generalized additive model (GAM) can be fitted to a CVP waveform. **a** Each sample from a 125 Hz CVP waveform is represented with three predictor variables: position in cardiac cycle, position in respiratory cycle and time (seconds since sample start). A GAM is fitted giving the smooth functions **b** to **e** (the model con-

stant ( $\alpha$ ) is added to the smooth function in **d. f** Model fit including residuals that are markedly reduced compared to the model without an interaction term, visualised in Fig. 4. Grey shades in panel b, c and e represent 95% confidence intervals (often too narrow to be visible)

Residual

