# A non-parametric approach to functional ultrasound data: A preliminary evaluation

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In the last decades, functional data analysis (FDA) techniques have been successfully applied to the analysis of biologic data. Some recent examples pertain to the analysis of blood vessel shapes (Sangalli et al., 2014), proteomic data (Koch at al, 2014), human movements data (Ramsay et al., 2014), and neural spike-trains (Wu et al., 2014).
The aim of the present study is to apply FDA techniques to a data set of tongue profiles. In detail, we carry out a comparison of two alternative methods that could be suited for the analysis of tongue shapes, namely smoothing spline ANOVA (SSANOVA) (Gu 2002; Davidson 2006) and the interval-wise testing (IWT) (Pini&Vantini, 2015). The two techniques basically differ in the inferential process leading to the construction of confidence intervals. SSANOVA is indeed a parametric approach based on Bayesian inference. On the contrary, IWT is a non-parametric approach based on permutation tests. In particular, IWT neither assumes data to follow a Gaussian distribution, nor needs to specify any a-priori information about the parameters defining the Gaussian distribution.

The two techniques are applied to a dataset of tongue shapes recorded for a study on Tyrolean, a German dialect spoken in South Tyrol (Vietti&Spreafico 2015). In detail, data are composed of 160 tongue profiles of five variants of uvular /r/ recorded from one native speaker of Tyrolean (F, 33 y.o.). The five groups of curves corresponds to five different manners of articulation: vocalized /r/, approximant, fricative, tap, and trill.
Firstly, SSANOVA is performed following the standard procedure presented in Davidson (2006), using the *gss* R package and the *ssanova* function (Fig 1. on the left). Smoothing spline estimate and Bayesian confidence interval for comparison of the mean curves are obtained as well as the interaction curves with their relative confidence intervals.
Secondly, the IWT is performed. The IWT provides two kinds of outputs:

1) Non-parametric 95% confidence bands for the position of the tongue within the five groups (Fig. 1)
   Non-parametric point-wise (angle-wise) confidence bands are estimated for the mean position of the tongue within each of the five groups. The confidence bands are estimated, for each point of the domain, by means of non-parametric permutation techniques (Pesarin, 2010), with a confidence level of 95% (Fig. 1 on the right).

2) Non-parametric interval-wise tests for group comparisons (Fig. 2)
   We test the equality of the functional distributions of each pair of groups. All tests are based on the IWT proposed in Pini&Vantini (2015) which - differently from the SSANOVA - is able to identify the regions of the domain presenting significant differences between groups, by controlling the probability of wrongly selecting regions with no-difference. The procedure results in the evaluation of an adjusted p-value function that can be thresholded to select the regions of the domain presenting significant differences. Such selection is provided with a control of the interval-wise error rate.

From a preliminary evaluation, the two techniques represent the differences among the five groups of functions in a very similar way when the sample size is sufficiently large, but differently if the sample size is low and the curve distribution is far from being Gaussian. A number of other critical issues emerges from the comparison that deserves further investigation.
In particular the following ones will be discussed.

a) SSANOVA results turn out to be extremely sensitive with respect to the choice of the B-spline basis chosen to model the curves. This is due to the fact that in the SSANOVA the generative probabilistic model is directly built on the coefficients of the basis expansion and not on the curves themselves.
b) SSANOVA results – coherently with the Bayesian perspective – could be strongly dependent on the prior distribution. This fact, for groups with a reduced sample size, leads to confidence bands not centered on the corresponding groups of curves.
c) Within each group the permutation confidence bands seem to better recover the different point-wise variability observed along the tongue profiles.
d) IWT allows group comparisons in terms of adjusted p-value functions, which may result in a more informative and detailed representation of the regions of the tongue where a significant difference is located (especially in the pairwise scatter-matrix representation Fig. 1).

A further speculation may arise from points (a,b): the ITW approach seems to be more stable and more tolerant to unbalanced design or at least to groups (r-variants) characterized by a small number of observations. The computational stability in case of unbalanced design should be more carefully investigated in order to evaluate which technique could be applied to more "naturalistic" data coming for instance from non-experimental settings.

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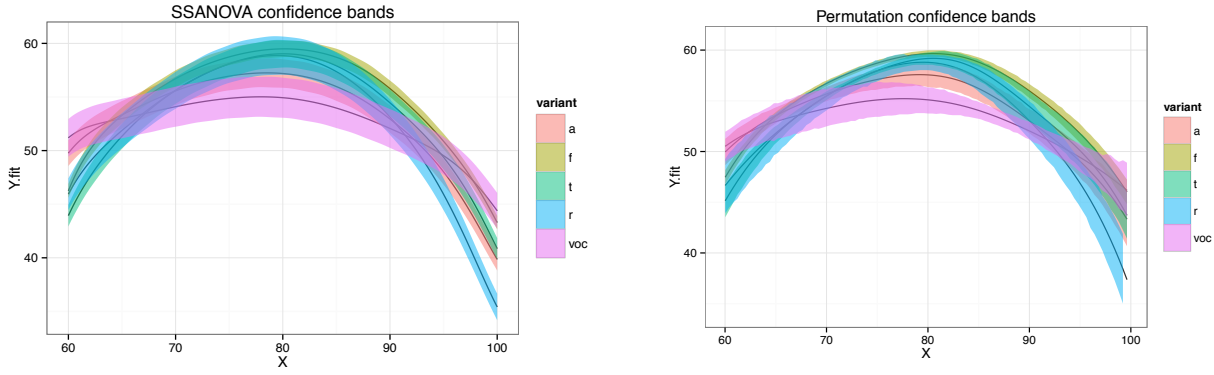


Figure 1.
Confidence bands for the five groups of tongue profiles obtained via SSANOVA (left) and permutation bands (right).

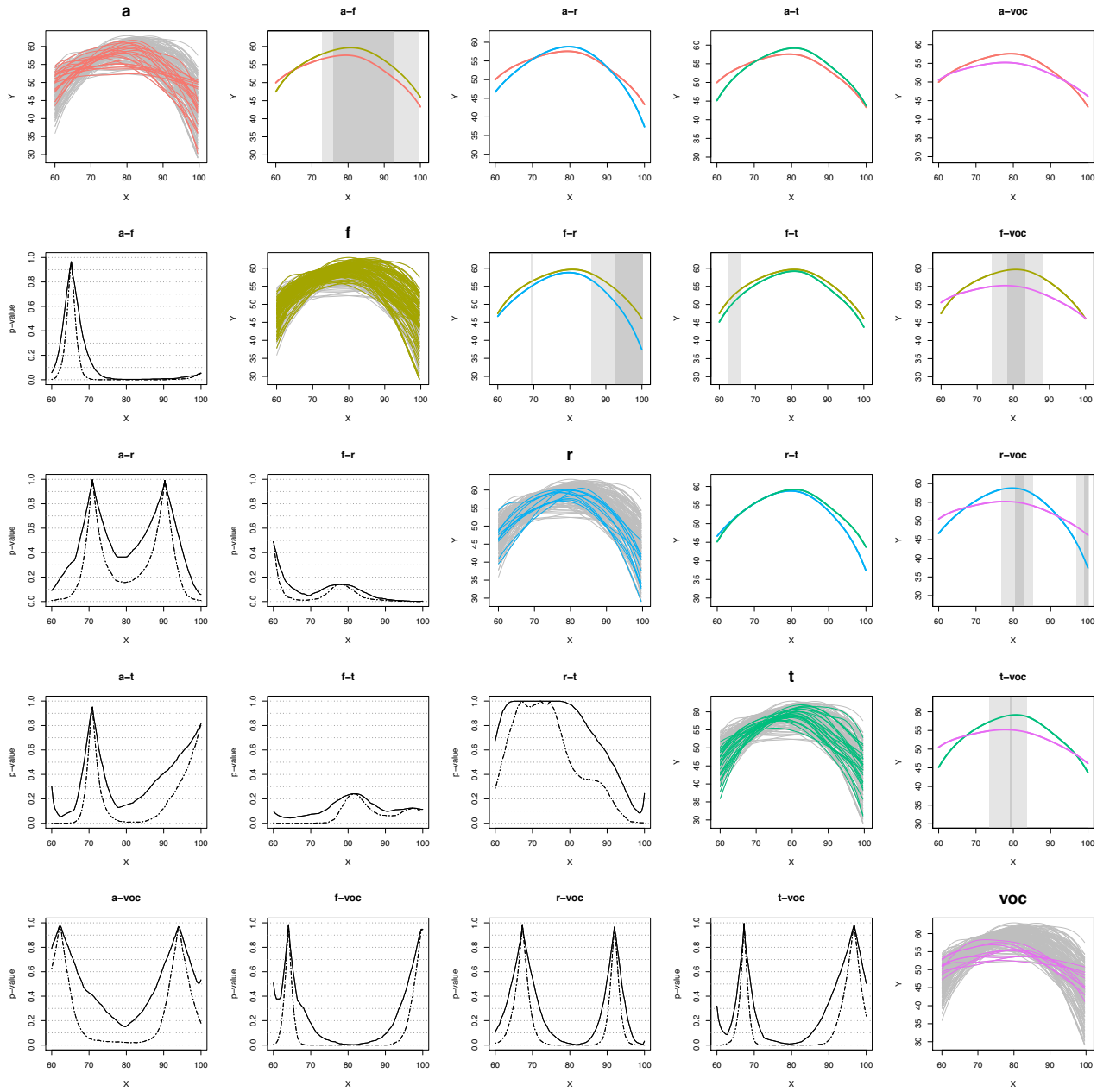


Figure 2.
Pairwise scatter-matrix of two-group comparisons obtained via the IWT procedure. Diagonal panels: tongue profiles of the five groups. Lowed diagonal panels: adjusted (full line) and unadjusted (dashed lines) *p*-value functions. Upper diagonal panels: means of the compared groups and gray areas representing significantly different intervals at 1% (dark gray) and 5% (light gray) significance levels.