Smoothing spline ANOVA for tongue curve comparison

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Special Thanks

- To Kyung Sin of UCSB, who introduced, developed and implemented this procedure for our lab.
Comparing tongue curve shapes

- Fundamental question: Are the groups of red and blue curves the same?

/d/: jazz dancer vs. NASDAQ

- Subj AR
- Stops measured just before burst
- Axes: pixels on 740x480 jpg image of ultrasound frame
Data collection at NYU

- Sonosite Titan ultrasound, C-11 probe, 90° FOV, depth of 8.2cm
- Head and transducer stabilization
  - Recently validated, to be presented at ASA in Vancouver (Davidson and De Decker, 2005)
Head and transducer stabilization

- Moldable head stabilizer is attached to the wall with velcro.
- Head is further stabilized with velcro.
- Transducer held rigid with microphone stand
- Synchronized ultrasound output and audio captured directly to computer with Canopus ADVC-1394 capture card and Adobe Premiere.
Analyzing the data

- Points defining the curve are obtained using EdgeTrak (Li, Kambhamettu & Stone 2003)

- The raw data points from Edgetrak (the .ts file) are then imported into S-PLUS.

- Best to get as many points as possible
  - Edgetrak seems to have trouble optimizing more than 64 points
Estimating the data with smoothing splines

- Natural cubic splines

\[
\frac{1}{n} \sum_{all \, i} (y_i - f(x_i))^2 + \lambda \int_a^b (f^{(m)}(u))^2 \, du
\]

- The first term measures closeness to the data while the second term penalizes curvature in the function.

- The unique minimizer is a natural cubic spline with knots at the unique values of \( x_i \) (splines are piecewise polynomials joined at the knots).

- We do not have to know the shape of the function \( f \) a priori. We let the data show us the appropriate functional form.
The choice of the smoothing parameter $\lambda$ is critical to the performance of the spline estimate. Large values of $\lambda$ produce smoother curves while smaller values produce more wiggly curves. At one extreme, as $\lambda \to \infty$, the penalty term dominates, forcing $f$ to be a line. At the other extreme, as $\lambda \to 0$, the penalty term becomes unimportant.
/d/: jazz dancer vs. NASDAQ

/y/: sub divided vs. subdivided
Smoothing Spline ANOVA

- Previous research using SS ANOVAs

![Graphs showing smooth spline fits for normal patients and patients with major depression.](image)
SS ANOVA Model

- The model is of the form

\[ f = \mu + \beta x + \text{main group effect} + \text{smooth}(x) + \text{smooth}(x;\text{group}) \]

- Differences between the curves are determined by examining the interaction term \( \text{smooth}(x;\text{group}) \).

- If \( \text{smooth}(x;\text{group}) \) contributes significantly to the equation, some region(s) of the curves have different shapes.
Checking for significance

- Compare the smoothing parameter value for `smooth(x;group)` with the smoothing parameter value for `smooth(x)`.
- Theoretically, if `smooth(x)` and `smooth(x;group)` are in the same order of magnitude, then the two curves are significantly different.
  - (But according to statisticians, this is subjective and only a guideline)
S-PLUS output

Coefficients (d):
(Intercept) word X word:X
243.2804 2.095481 -58.76313 -1.995127

GCV estimate(s) of smoothing
parameter(s) : 0.7596199 4.8945817

Equivalent Degrees of Freedom (DF): 20.52217

smooth(x) smooth(x;group)

/d/: jazz dancer vs. NASDAQ

Coefficients (d):
(Intercept) word X word:X
241.9666 -1.717282 -63.73833 2.530379

GCV estimate(s) of smoothing
parameter(s) : 0.5951136 14.7699681

Equivalent Degrees of Freedom (DF): 19.32334
Note about curve shapes

- This method is sensitive to any kind of differences among the curves:
  - Shape differences
  - Translation
  - Rotation

- Related statistical techniques can compare curve shapes without taking into account translation or rotation.
  - Accounting for all differences seems best suited to tongue shapes
Bayesian confidence intervals

BCIs of mean curves

/d/: jazz dancer vs. NASDAQ
BCIs of interaction effects

- If the smoothing parameters are of the same order of magnitude (or close), examine the BCIs of the interaction effects to see where there are significant differences.
- If the intervals encompass 0 at all points, then the interaction is not statistically significant.
Interaction effects w/ BCI for jazz dancer

Interaction effects w/ BCI for NASDAQ
Interaction effects w/ BCI for subdivided
Advantages of the BCI

- Tells us *where* along the tongue there are differences.
- First pass: Division into 3 sections
  - Blade
  - Body
  - Root
This method is robust: it does not require that the tongue curves be exactly the same length.

As always, we are not tracking points.
- Just because curves may cross at some spot does not mean they’re the same at that spot.

/d/: jazz dancer vs. NASDAQ
Linguistically relevant differences

- Sometimes, statistical differences seem relevant:
  - Significantly more constriction
  - Significantly more retraction
  - Etc…

/t/: Miss Tina vs. mysterious
Irrelevant differences?

- Sometimes, statistical differences may not be linguistically relevant.

- Do we want to say the tongue root is advanced for sub divided?
Conclusion

- SS ANOVAs are a good method for comparing single shapes.
- Analyzing changes over time requires a different procedure, but there are statistics for that too!
- By examining the Bayesian confidence intervals of the interaction curve, we can determine which part(s) of the tongue are statistically different.
  - Assessment of linguistic relevance