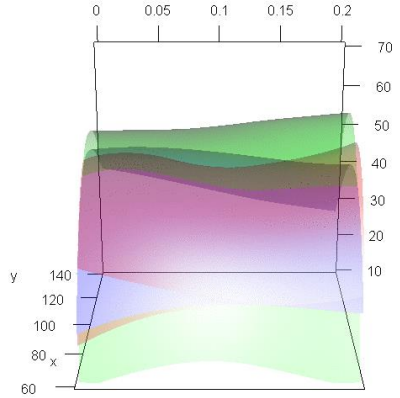
Tongue movements in space and time:
Exploring a dynamic view on speech articulation



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in collaboration with A. Pini, S. Vantini & L. Spreafico

Speech dynamics, social meaning, and phonological categories | LabPhon15 @ Cornell University

Summary

1. Partial Differential Interval-Wise Testing (PD-IWT): spatio-temporal analysis of tongue articulation
2. Study 1: PD-IWT for the phonetic analysis
3. Study 2: PD-IWT for the sociophonetic analysis

PD-IWT technique

- Aim
  - Develop a method to quantify differences among groups of tongue curves from ultrasound imaging (Davidson 2006, Dawson et al. 2016, Zharkova 2016)
- Questions
  a) Are the *n* groups of tongue curves statistically different?
  b) Which regions of the tongue are different?
  c) What is the probability that these differences are occurring by chance?
  d) Is it possible to test for differences in shape (rather than position)?

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+

the temporal dimension

PD-IWT algorithm

1) Raw data
2) Smoothing
3) (Time alignment)
4) Interval-wise testing
5) Adjusted p-value function

PD-IWT algorithm

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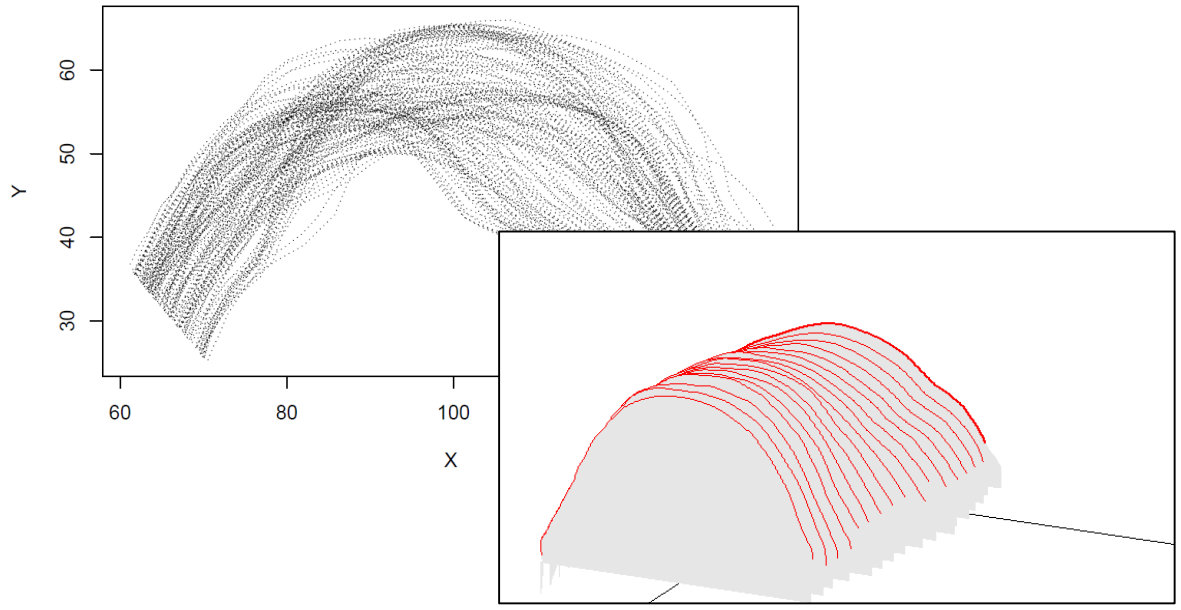
- 1 observation (CCV): 42 coordinates for each t_i (≈ 20 frames per item)



AAA – Spline workspace

PD-IWT algorithm

1) Raw data
2) Smoothing
3) (Time alignment)
4) Interval-wise testing
5) Adjusted p-value function

- From data points to functions
- Fitting method
  - local linear regression of degree 3 with a Gaussian kernel as a smoother

PD-IWT algorithm

1) Raw data
2) Smoothing
3) (Time alignment)
4) Interval-wise testing
5) Adjusted p-value function

- Minimal registration without warping
- Cutting and extrapolating
- Time length ≈ 200ms

PD-IWT algorithm

1) Raw data
2) Smoothing
3) (Time alignment)
4) Interval-wise testing
5) Adjusted p-value function

- Repeated tests on rectangular regions (intervals) of the function
- Non-parametric permutation tests

PD-IWT algorithm

1) Raw data
2) Smoothing
3) (Time alignment)
4) Interval-wise testing
5) Adjusted p-value function

- Correction for functional multiple tests
- Control of the probability of false discoveries
- Continuous p-value function

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Dataset

Research project on articulatory sociophonetics of bilinguals (TUTIP)

- Subject: 1 late bilingual speaker of Tyrolean & Italian (M, 31)
- Stimuli: Tyrolean and Italian word list
- Study 1: focus on CCV syllables in Tyrolean (velar plosive+uvular rhotic+vowel)
  - [kra, kri, kro] X 6 repetition each in Tyrolean

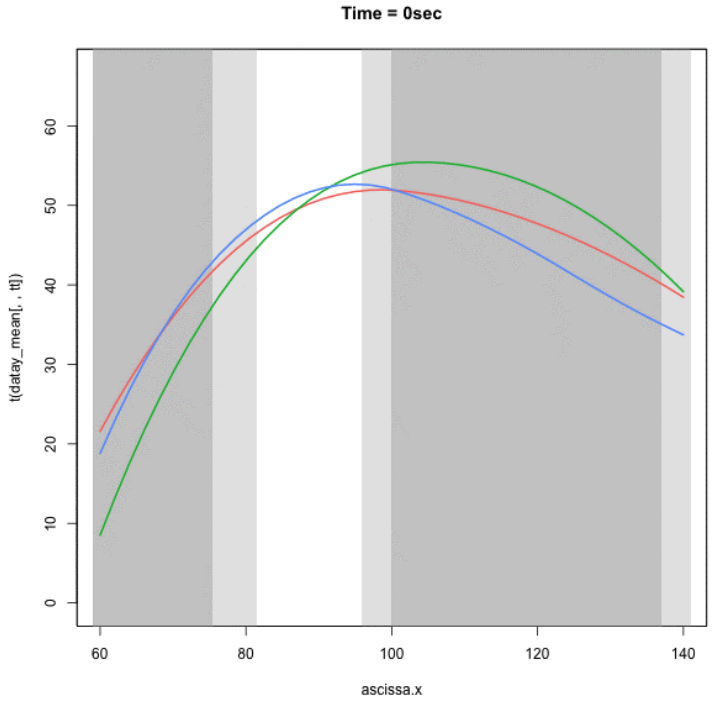
- Equipment: Ultrasonix SonicTablet system, Ultrasonix C9-5/10 transducer
- Technical data: Scanrate 93 Hz; FoV ~ 120°

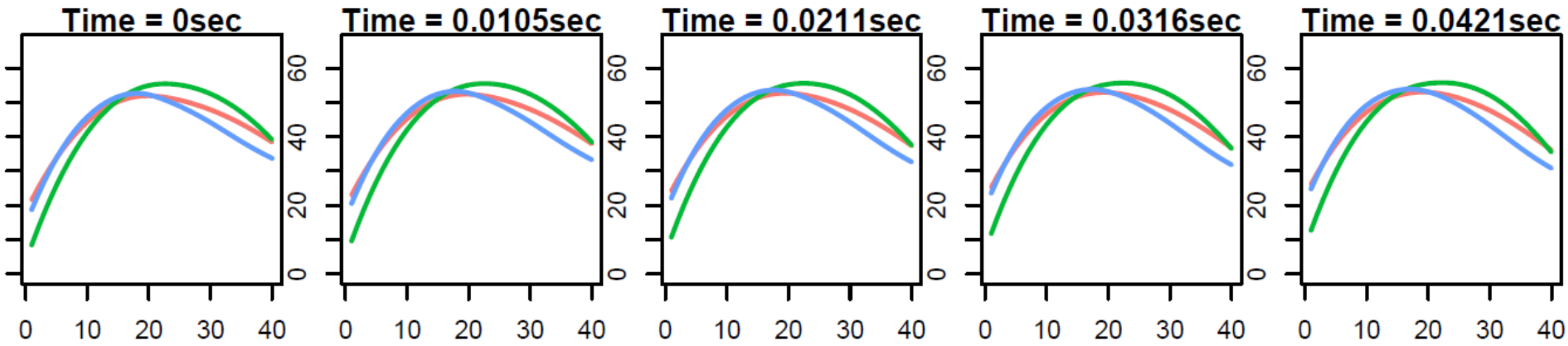
PD-IWT output

- Descriptive plots
- ANOVA test
    1. Position
    2. Slope (Partial Derivative 1)
    3. Velocity PD2
    4. Summary (combined thresholded map with $p < 0.05$, $p < 0.01$)
- Pairwise tests
    1. Position D0 (kra - kri, kra - kro, kri - kro)
    2. Slope PD1
    3. Velocity PD2
    4. Summary

Curves in time

- 3 groups of mean curves plotted in time
- kra = rose
- kri = green
- kro = blue

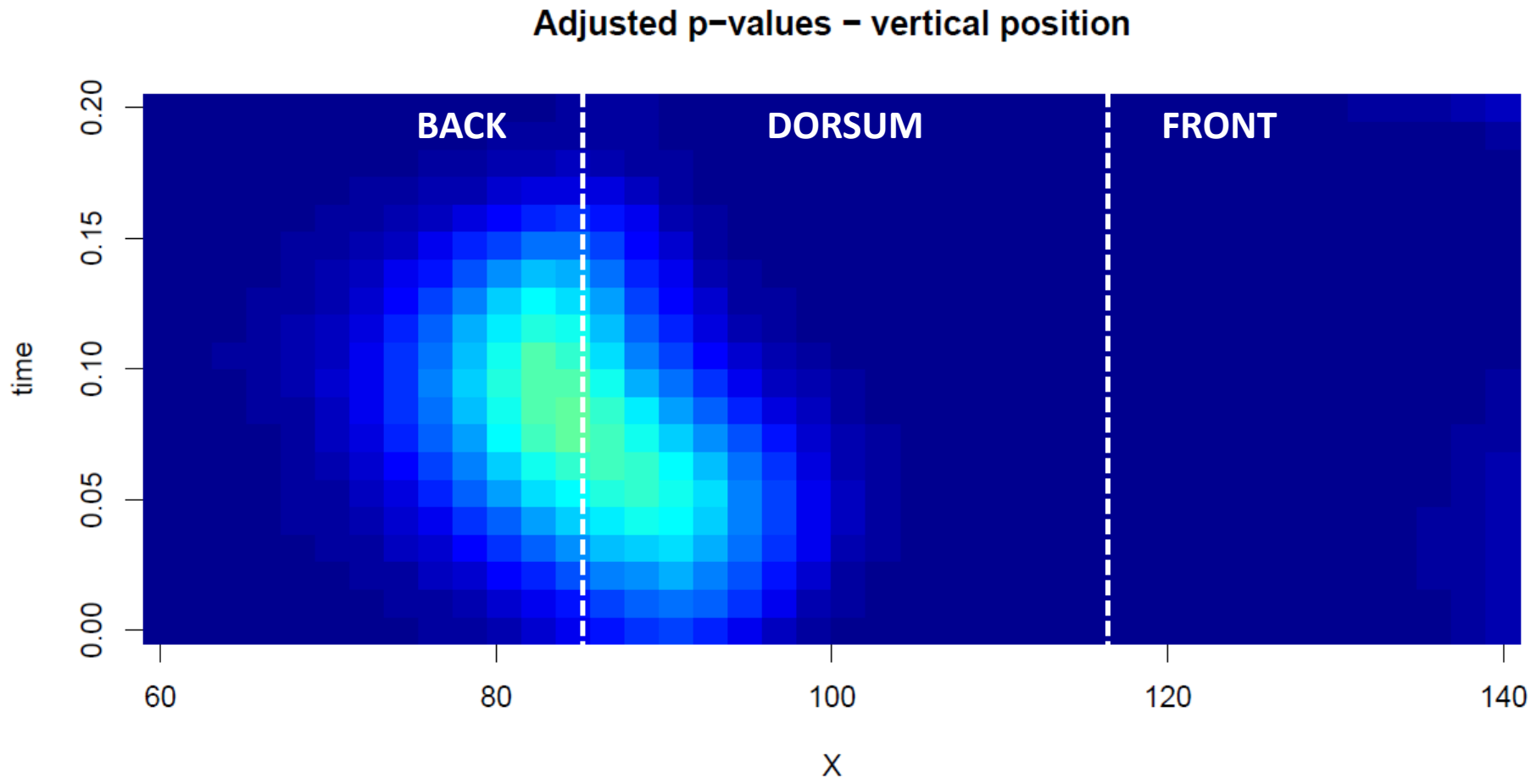




F-ANOVA / questions

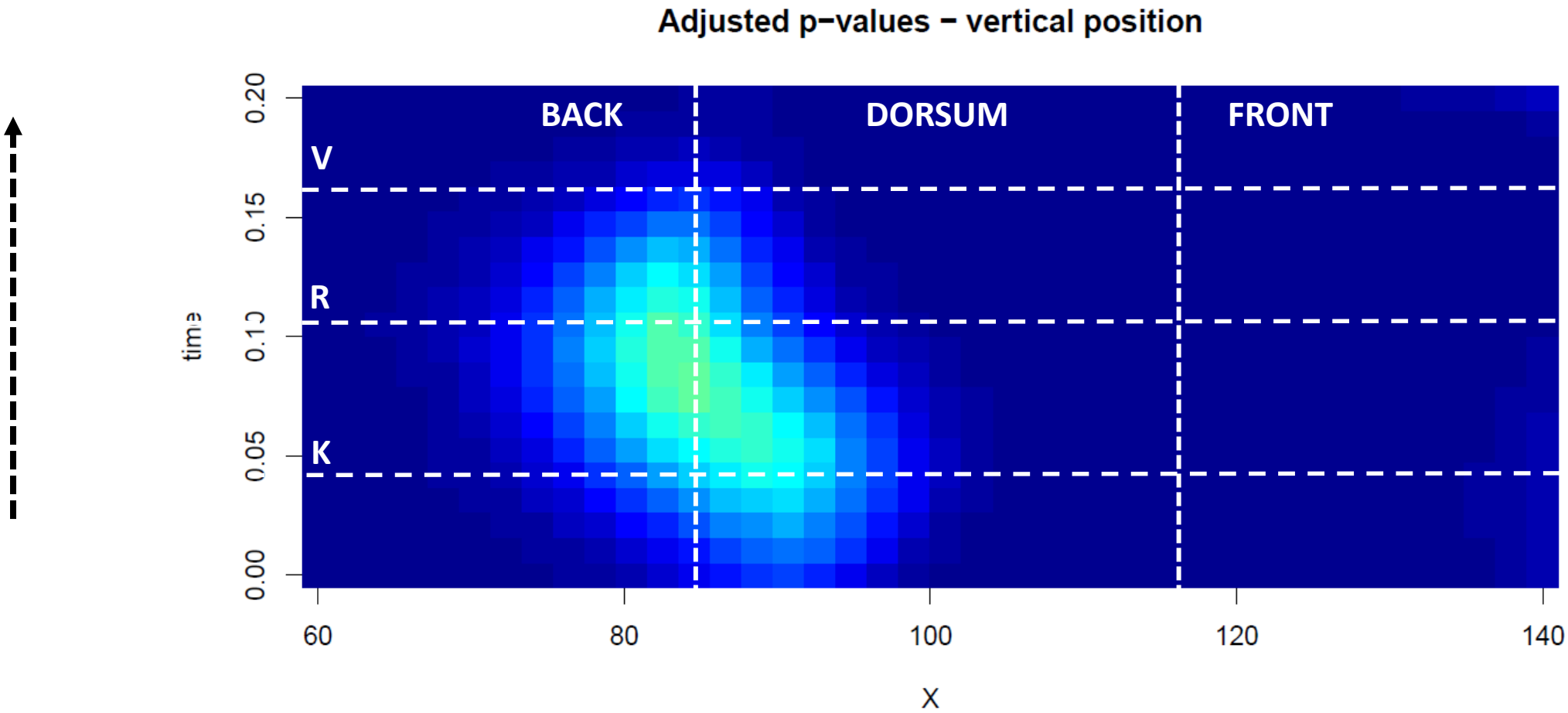
- Compare kra-kri-kro > statistical differences among groups surfaces
  - Are they significantly different?
  - If yes, where and when are they differing?
- Core output: p-value function

F-ANOVA / vertical position in time



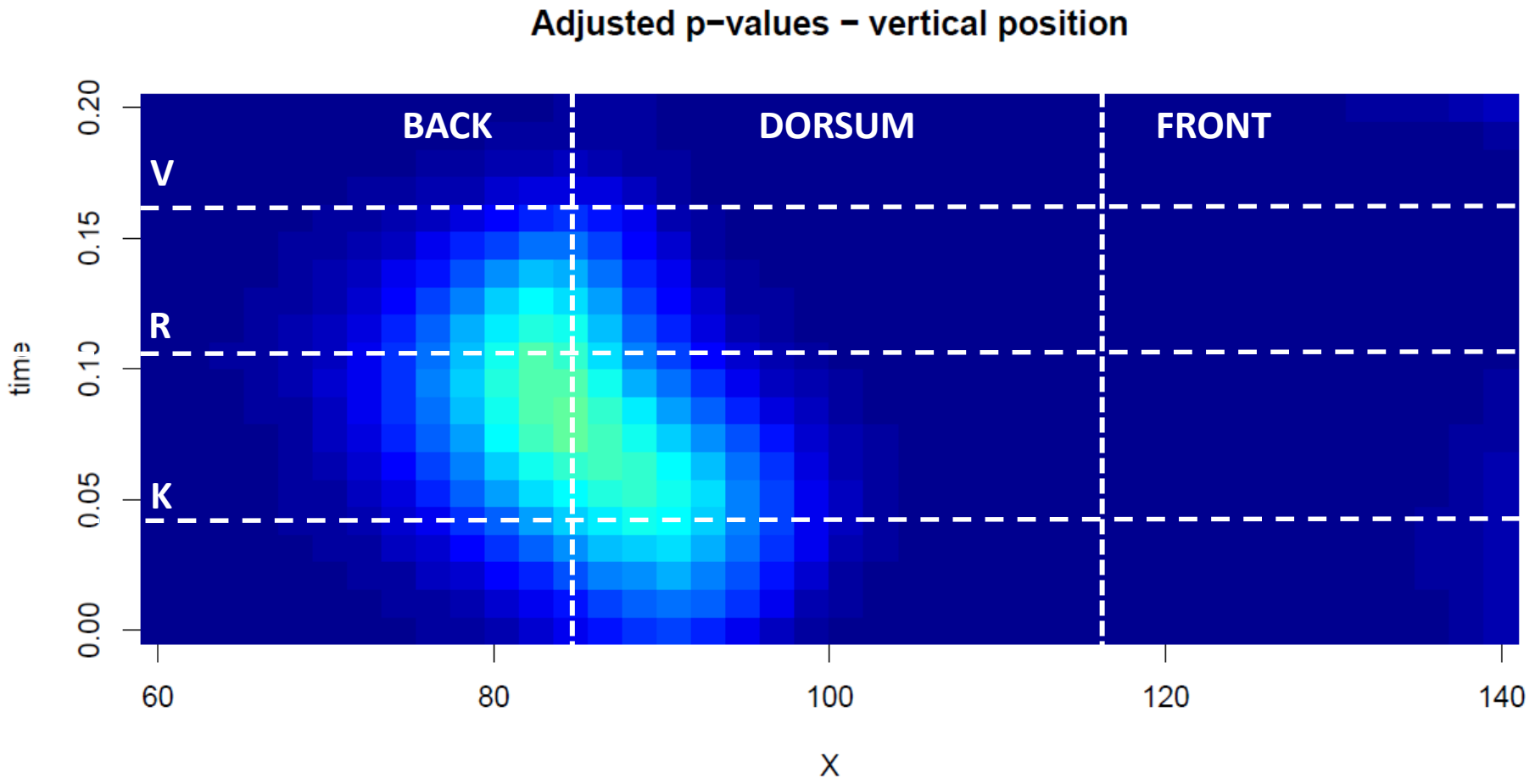
LEFT TO RIGHT
Portions of the tongue

F-ANOVA / vertical position in time



BOTTOM TO TOP
Time

F-ANOVA / vertical position in time



HIGHLY SIMILAR

p-value

1.0

0.8

0.6

0.4

0.2

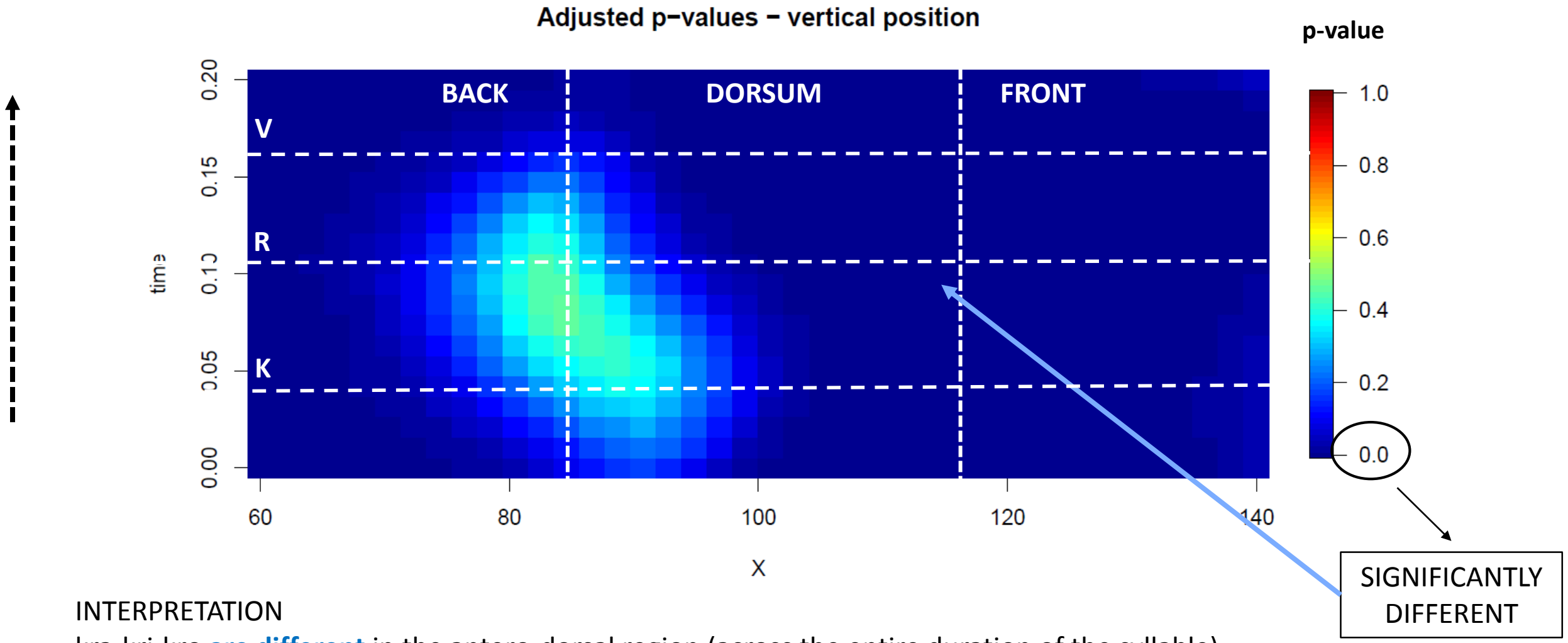
0.0

SIGNIFICANTLY DIFFERENT

COLORS

Significance of the difference

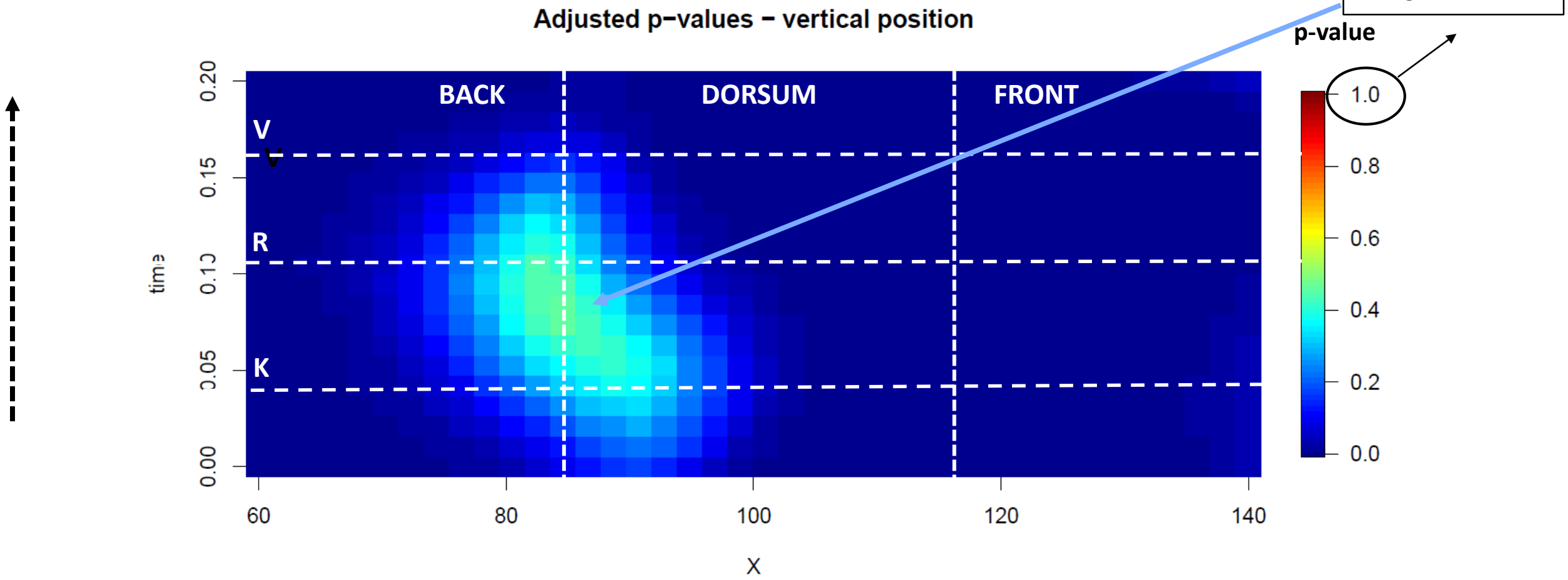
F-ANOVA / vertical position in time



INTERPRETATION

kra-kri-kro **are different** in the antero-dorsal region (across the entire duration of the syllable)

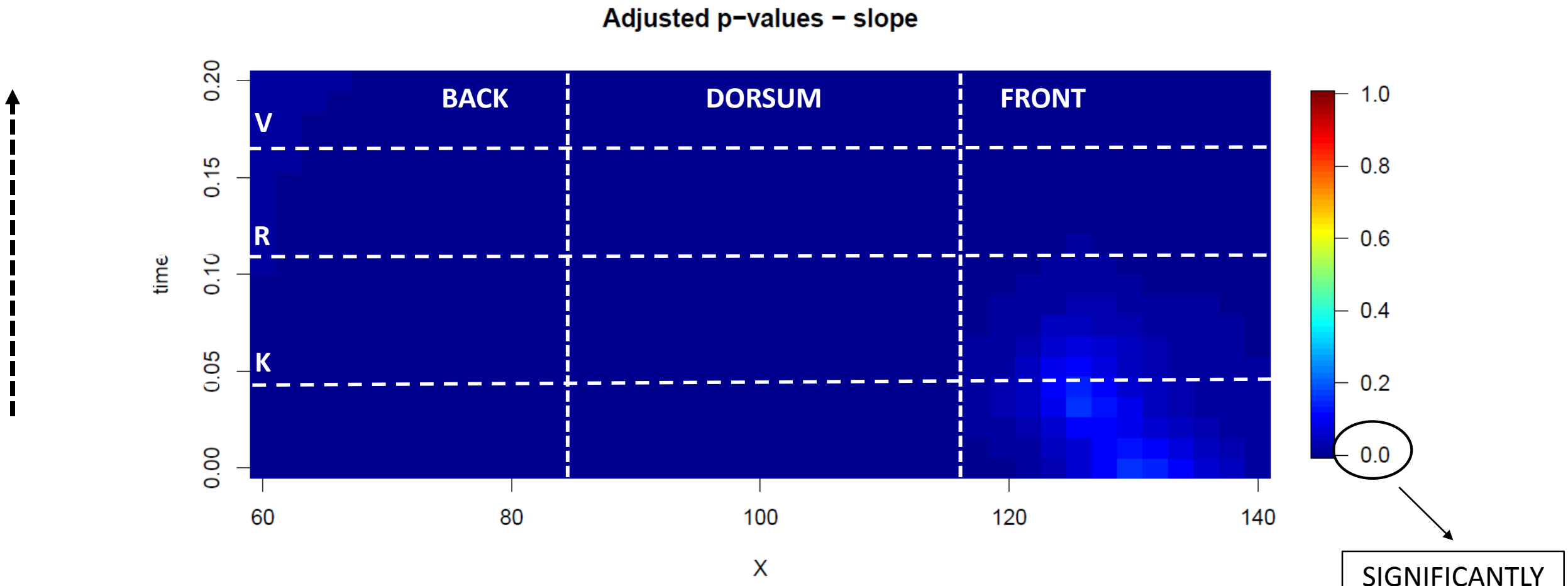
F-ANOVA / vertical position in time



INTERPRETATION

kra-kri-kro **are similar** in the dorsal and in the post-dorsal region

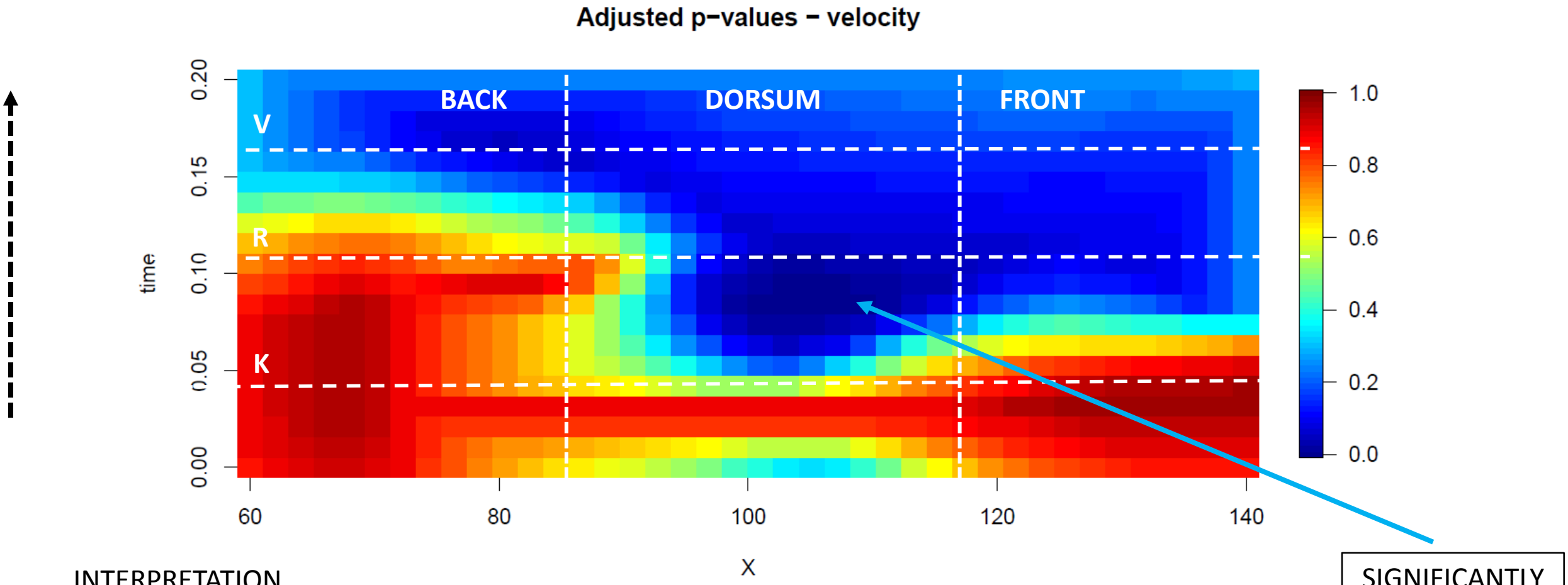
F-ANOVA / slope in time



INTERPRETATION

kra-kri-kro are **totally different** with respect to their slope in every point in time, even if they largely share the same segmental makeup (onset cluster)

F-ANOVA / velocity

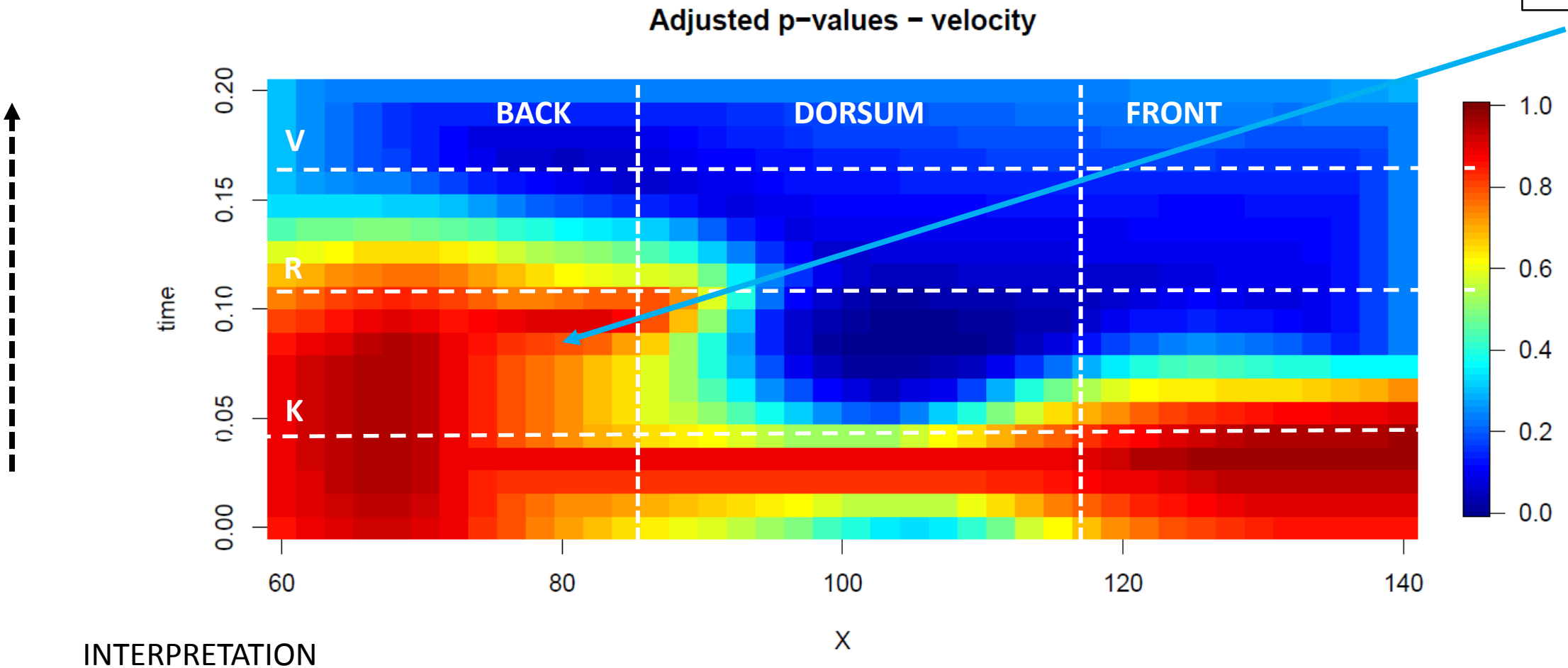


INTERPRETATION

kra-kri-kro **DIFFER** in the frontal and dorsal regions **BEGINNING** from the onset of uvular /r/; in the R-to-V transition phase the tongue back shows a different velocity.

F-ANOVA / velocity

HIGHLY SIMILAR



INTERPRETATION

During the production of the velar stop there are **no differences in velocity** among kra-kri-kro (identical velocity is maintained longer in the back of the tongue)

PD-IWT output

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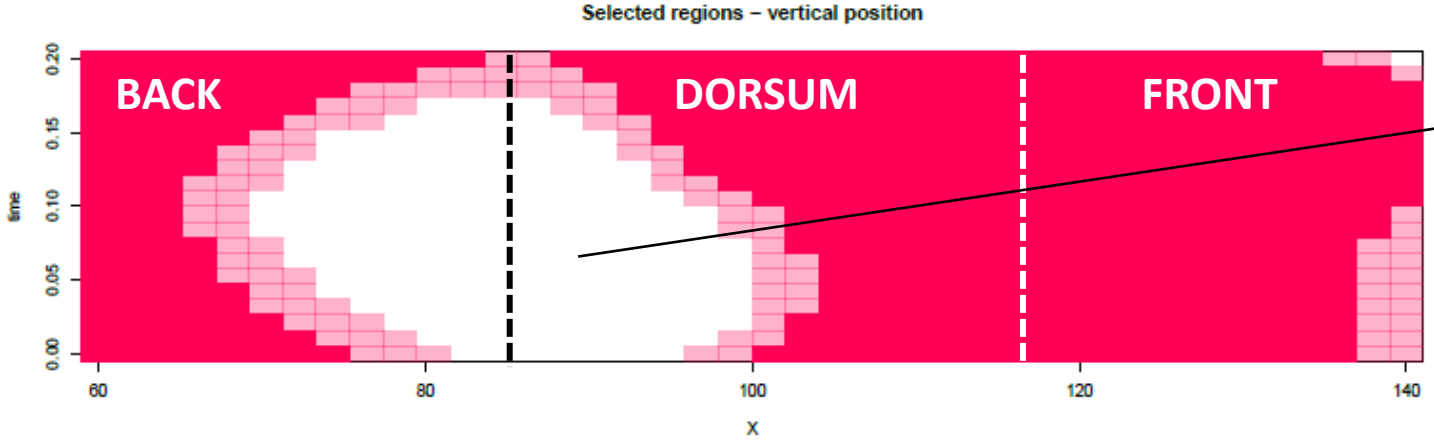
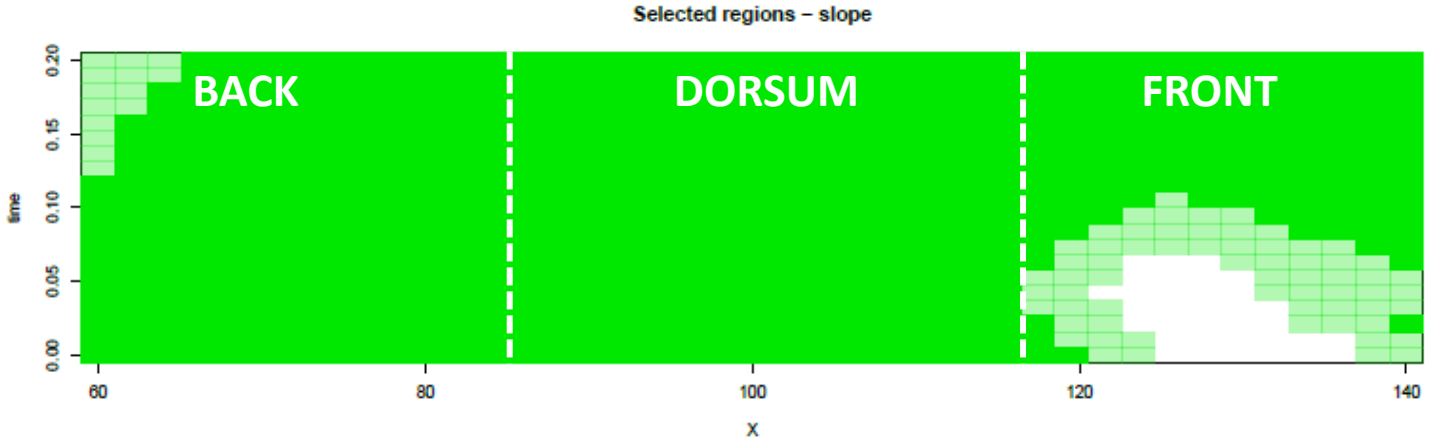
F-ANOVA / summary

VERTICAL POSITION



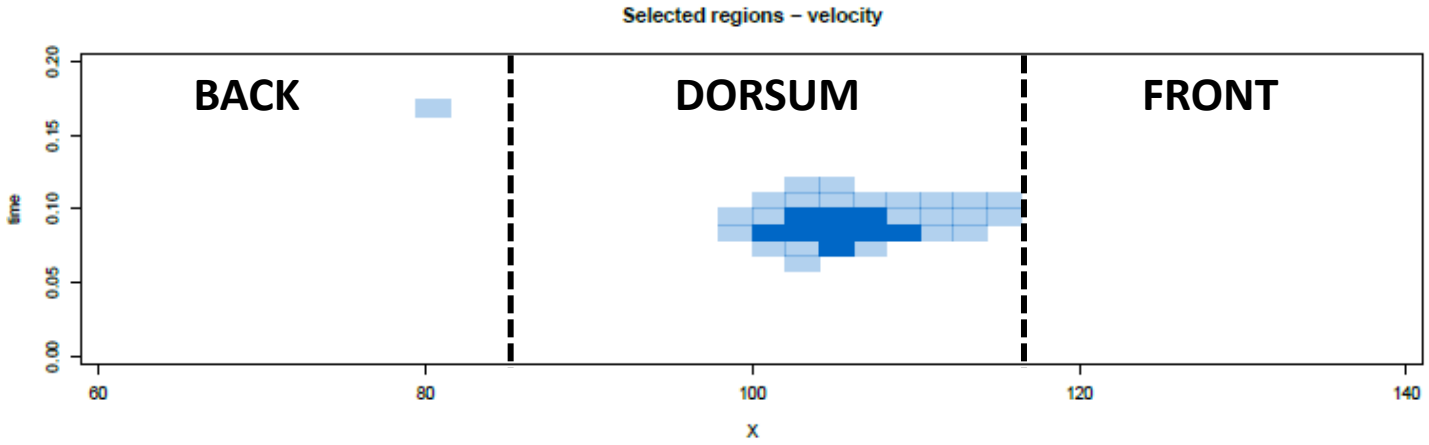
BLANKS REPRESENT SIMILAR REGIONS

SLOPE



light color = p < .05
dark color = p < .01

VELOCITY



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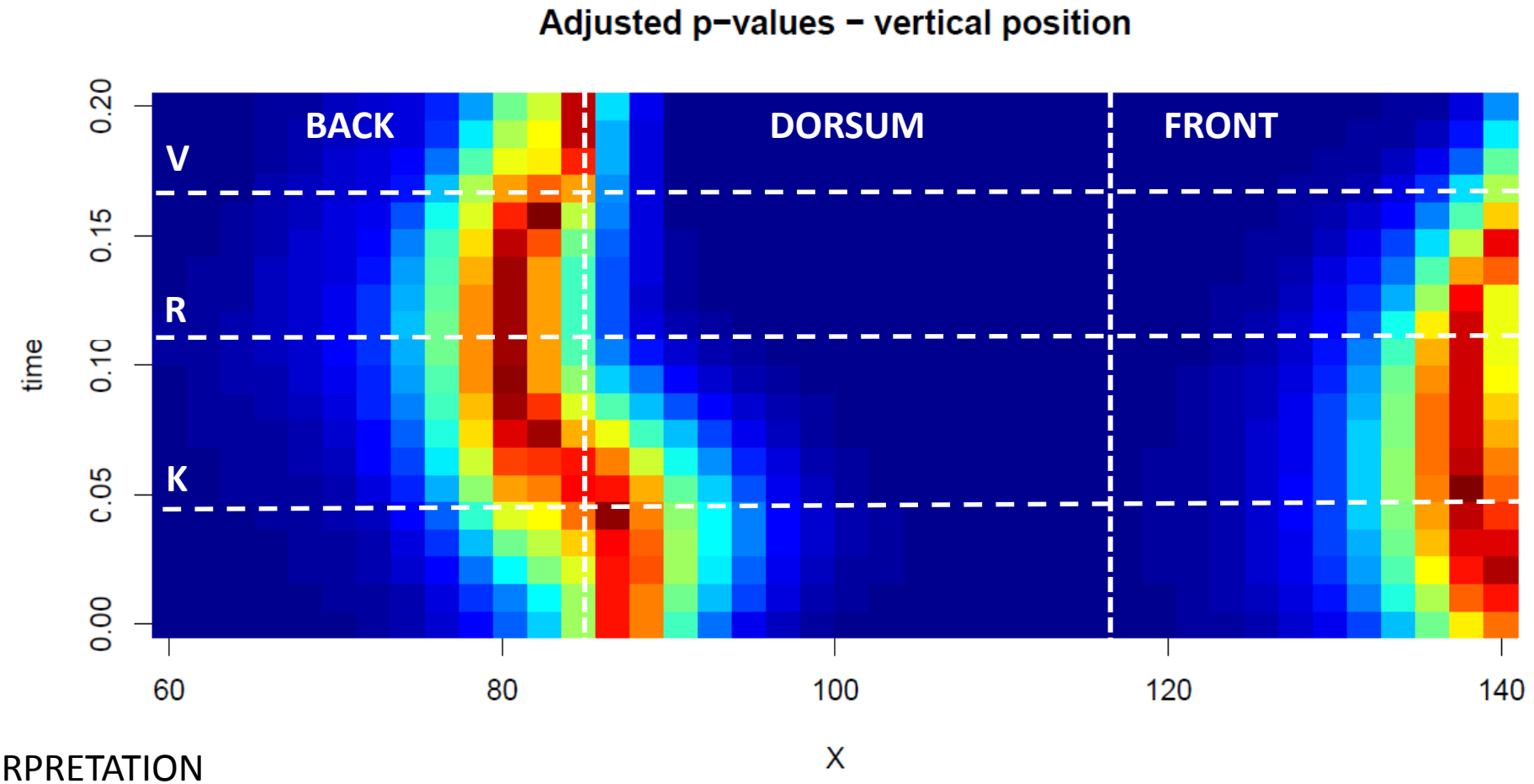
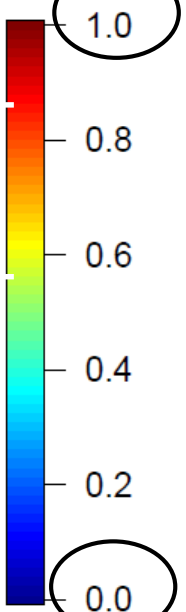
Pairwise comparison / kra - kri





HIGHLY SIMILAR

SIGNIFICANTLY DIFFERENT

INTERPRETATION

As in ANOVA-like post-hoc test, pairwise comparison reveals which levels of the variable are more relevant to account for the variability in the dataset

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- Study 2: focus on CCV syllables in Tyrolean and Italian
  - [kra] X 6 repetition X 2 languages

- Equipment: Ultrasonix SonicTablet system, Ultrasonix C9-5/10 transducer
- Technical data: Scanrate 93 Hz; FoV ~ 120°

Social meaning of tongue movements

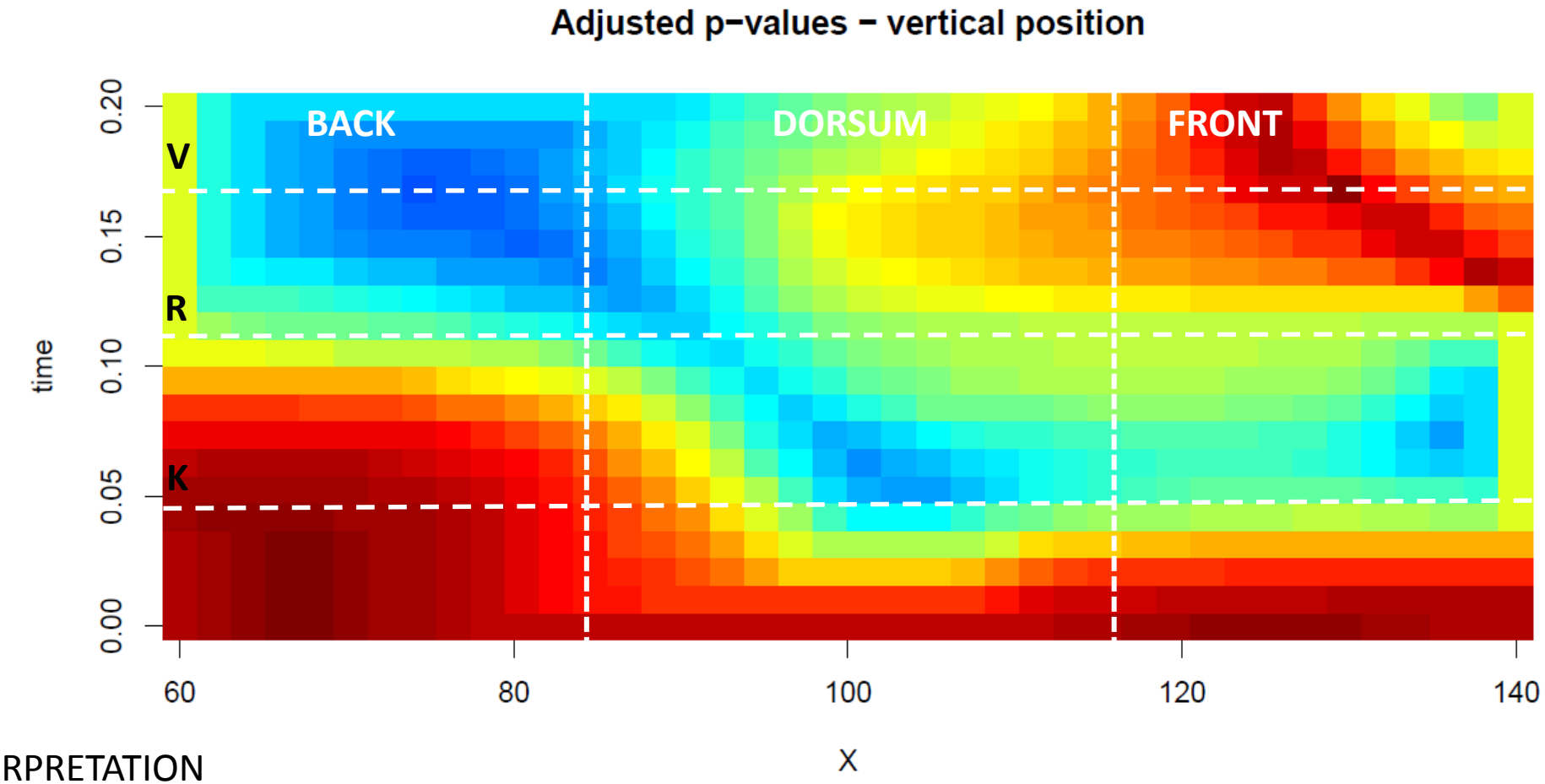
RQ: does the variable sociolinguistic experience of bilingual speakers affect their speech production?

- Sociolinguistic experience
  a) degree of bilingualism (simultaneous/sequential)
  b) social network structure and language use (at the time of the experiment)
- Speech production
  a) articulation of /r/
  b) CRV dynamic information

Social meaning of tongue movements

- Subject characteristics
  - Degree of bilingualism: 1 (late) sequential bilingual speaker, Tyrolean dominant
  - Social network and language use: monolingual speaker, close-knit and centralized network
- Expectation
  - Very similar patterning in both languages due to interaction from Tyrolean to Italian (*Speech Learning Model* Flege 1995, 2007; Barlow 2014)

Bilingual speech: Tyrolean vs. Italian [kra]



HIGHLY SIMILAR

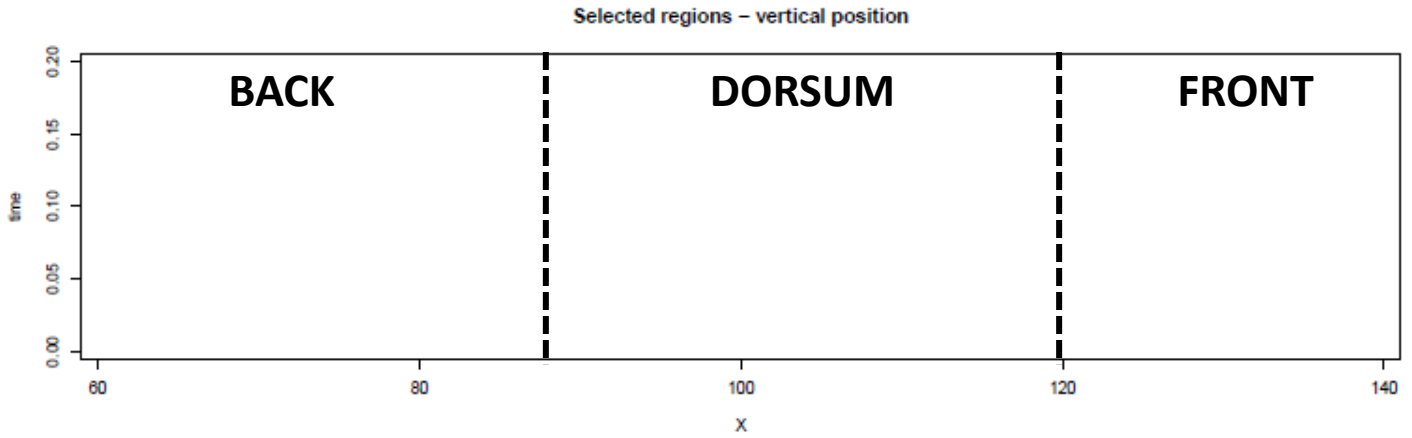
1.0
0.8
0.6
0.4
0.2
0.0

SIGNIFICANTLY DIFFERENT

INTERPRETATION

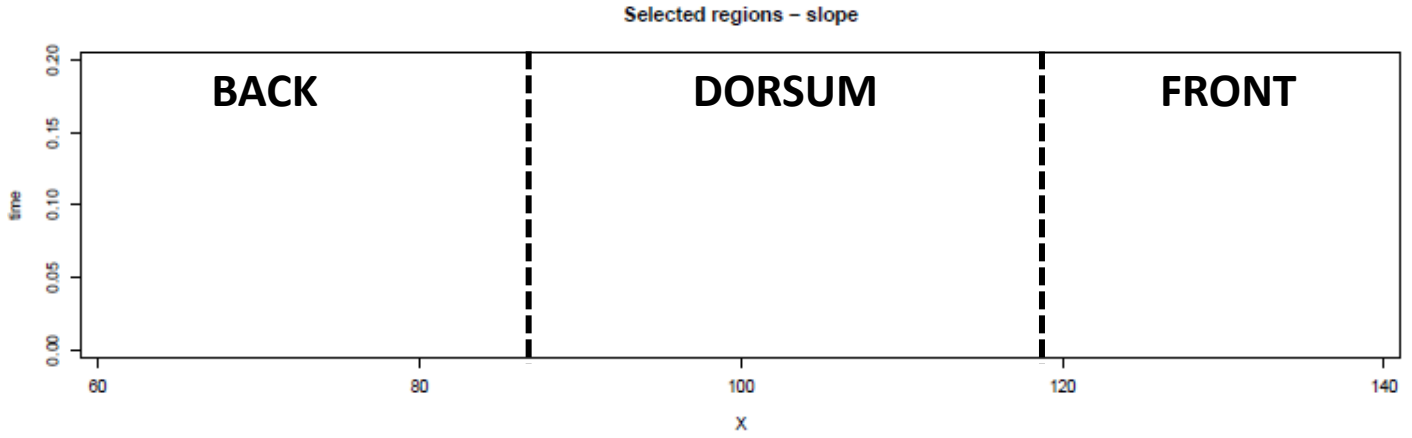
Largely identical (especially velar configuration and dorso-frontal ending phase); mild differences dorsum-front in the k-to-r transition and in the root position while producing the vowel (Ita higher than Tyr)

VERTICAL POSITION



NO DIFFERENCES!

SLOPE



light color = p < .05
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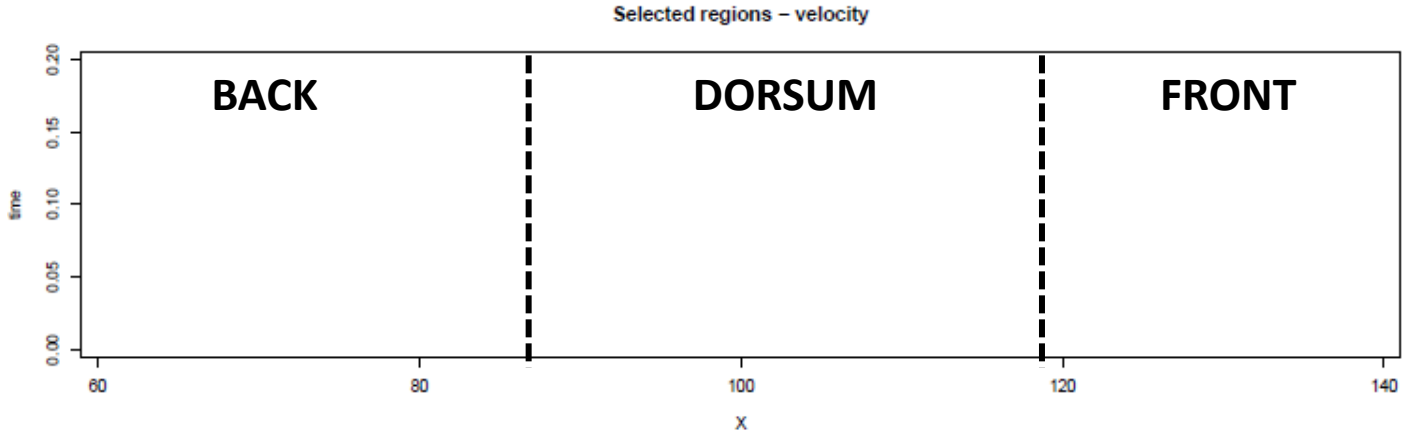
VELOCITY



PD-IWT for the phonetic analysis

- Different metrics of analysis (position, slope, velocity) > evaluation of the overall tongue information (change of position and shape in time)
- Analytic representation of the differences between groups of objects > where and when the objects are different

- Sample problems
  - Coarticulation patterns (target and trajectories): e.g. long temporal domain of coarticulation effects
  - Lexical representation of articulatory information
  - Inter-speaker variation in speech prodution

PD-IWT for the sociophonetic analysis

Discreteness of sociophonetic categories and the relation between social meaning and speech signal

- Speech understanding: the role of discrete units as vehicles for linguistic meaning is questionable (Hawkins 2003, 2010)

  > […] is it defensible to persist in assuming that particular discrete units at different linguistic levels form the basis of human language processes, when we cannot satisfactorily identify or define those units? (Hawkins 2010: 65)

- A fortiori, if we adopt a dynamic articulatory approach, it is not necessary to confine the encoding of social meaning within the boundaries of discrete categories

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