Asymmetries in the perception of Mandarin tones: evidence from mismatch negativity

Stephen Politzer-Ahles
University of Oxford

Kevin Schluter, Kefei Wu, & Diogo Almeida
New York University Abu Dhabi

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Mismatch Negativity (MMN)

- *f f f f s f f s f f f f f f f f s f f f s…*

deviants

standards

- *s s s s f s s f s s s s s s s s f s s s f…*

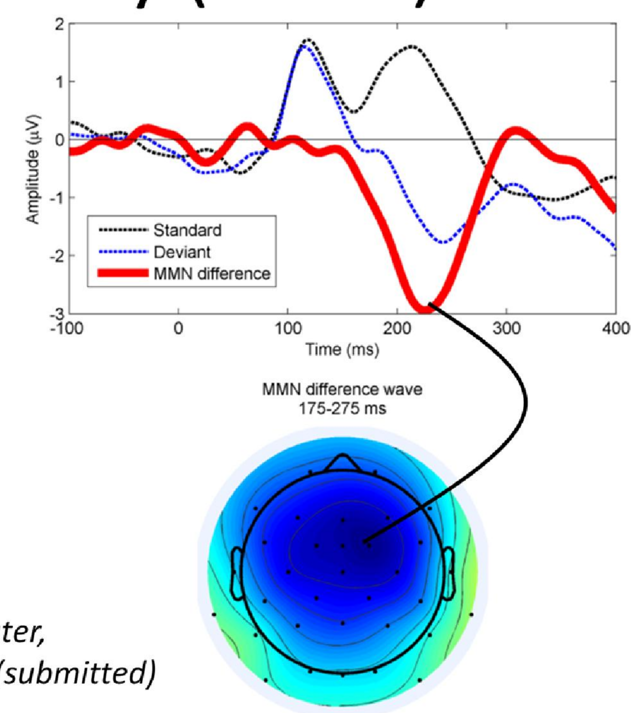

Figure adapted from Schluter, Politzer-Ahles, & Almeida (submitted)

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So we're going to be discussing brain responses to the perception of sounds, specifically a certain brain response called the Mismatch Negativity. Mismatch negativity is a brain response elicited when you notice a change between a frequently presented sound and an infrequently presented sound. For example, in an experiment, a person will hear f f f f f f s f f f f s, and we take the average of all the brain responses to /s/; which gives you this blue line: the voltage of the brain response, measured at this spot on the top of the head, from the moment you hear the sound until about 400 ms later. And then you can play the opposite case, the exact same sounds but this time s is common and f is rare; take the brain response to the exact same physical stimulus (s) when it is the common sound, which gives you this black line, and when you subtract them, what remains is this big negativity, which represents detecting the contrast between the two sounds.

Asymmetric MMNs

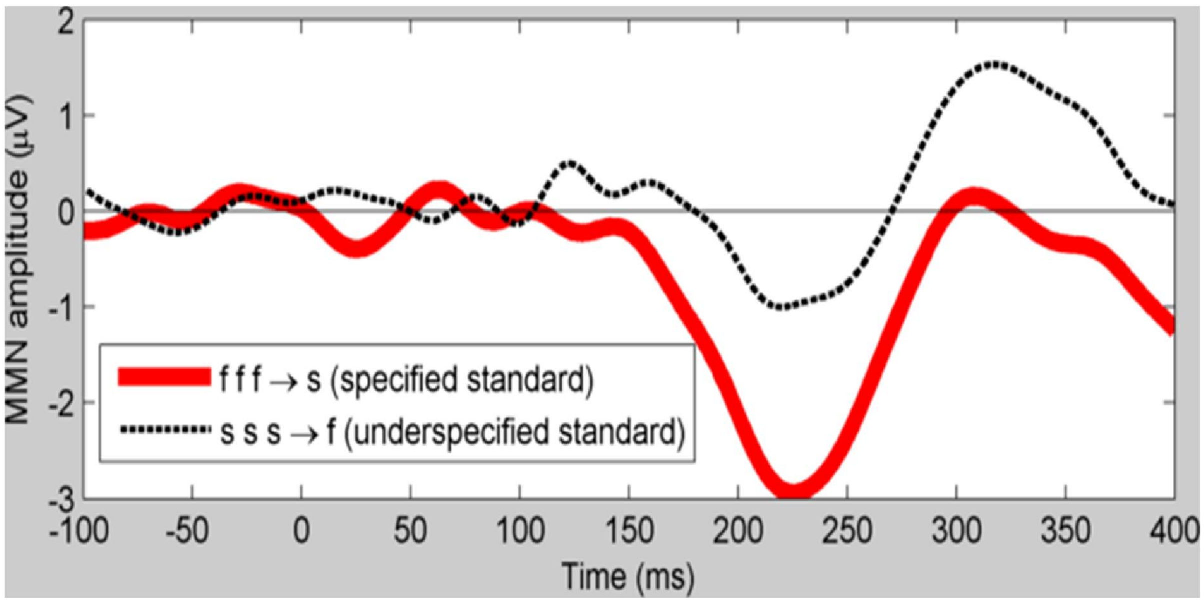

Figure adapted from Schluter, Politzer-Ahles, & Almeida (submitted)

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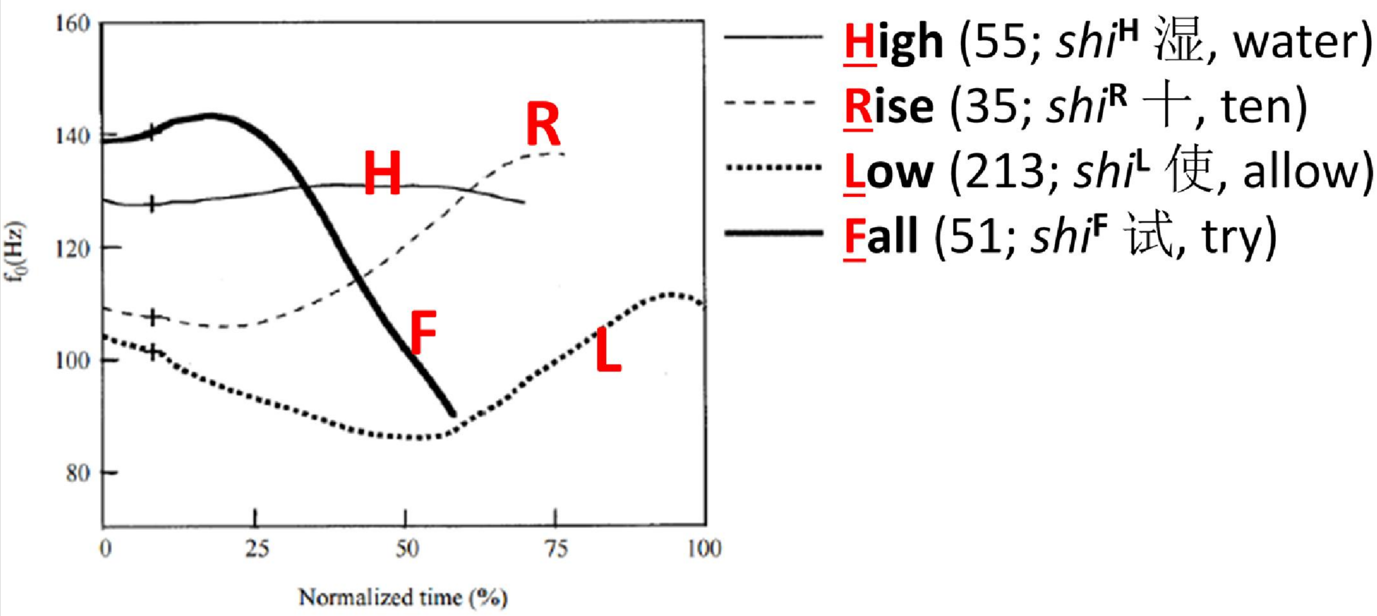
All else being equal you would expect the MMN to be the same regardless of which order you hear the two sounds in---after all, it's the same contrast either way.. But actually there are many instances where you get asymmetrical MMNs, for example, getting a big mmn for f f f s but a small mmn for s s s f even though it's the same contrast.

These asymmetries are interesting because they can tell us about the memory representations of these sounds. i.e., since the MMN relies on comparing a deviant signal you just heard against your short-term memory trace of a sound you heard a few hundred ms ago, these asymmetries can inform us about whether one of those sounds is represented with a weaker or less specific memory trace.

Mandarin tones



Almost all of what we know about these asymmetries in language processing comes from segmental contrasts (with the exception of some work on Cantonese tones, which we can discuss after). So in this study we instead looked at suprasegmental cues, and particularly Mandarin contour tones, which are a complex, multidimensional suprasegmental feature.

Mandarin has four contrastive tones, high, rising, low, falling. In particular, I'll be focusing on this low tone.

Several reasons why L is interesting:

It has multiple allomorphs, because it undergoes context-based alternation (tone sandhi)

Some people argue that low tone is phonologically underspecified; this is something that's known to be relevant for the generation of these asymmetries in mismatch negativity

Low tone also has a more complex contour than the other tones; this is also relevant for mismatch negativity

Conditions

- L~R contrast:
  - *yi*^{R} *yi*^{R} *yi*^{R} → *yi*^{L}
  - *yi*^{L} *yi*^{L} *yi*^{L} → *yi*^{R}
- L~F contrast:
  - *yi*^{L} *yi*^{L} *yi*^{L} → *yi*^{F}
  - *yi*^{F} *yi*^{F} *yi*^{F} → *yi*^{L}
- R~F contrast:
  - *yi*^{R} *yi*^{R} *yi*^{R} → *yi*^{F}
  - *yi*^{F} *yi*^{F} *yi*^{F} → *yi*^{R}

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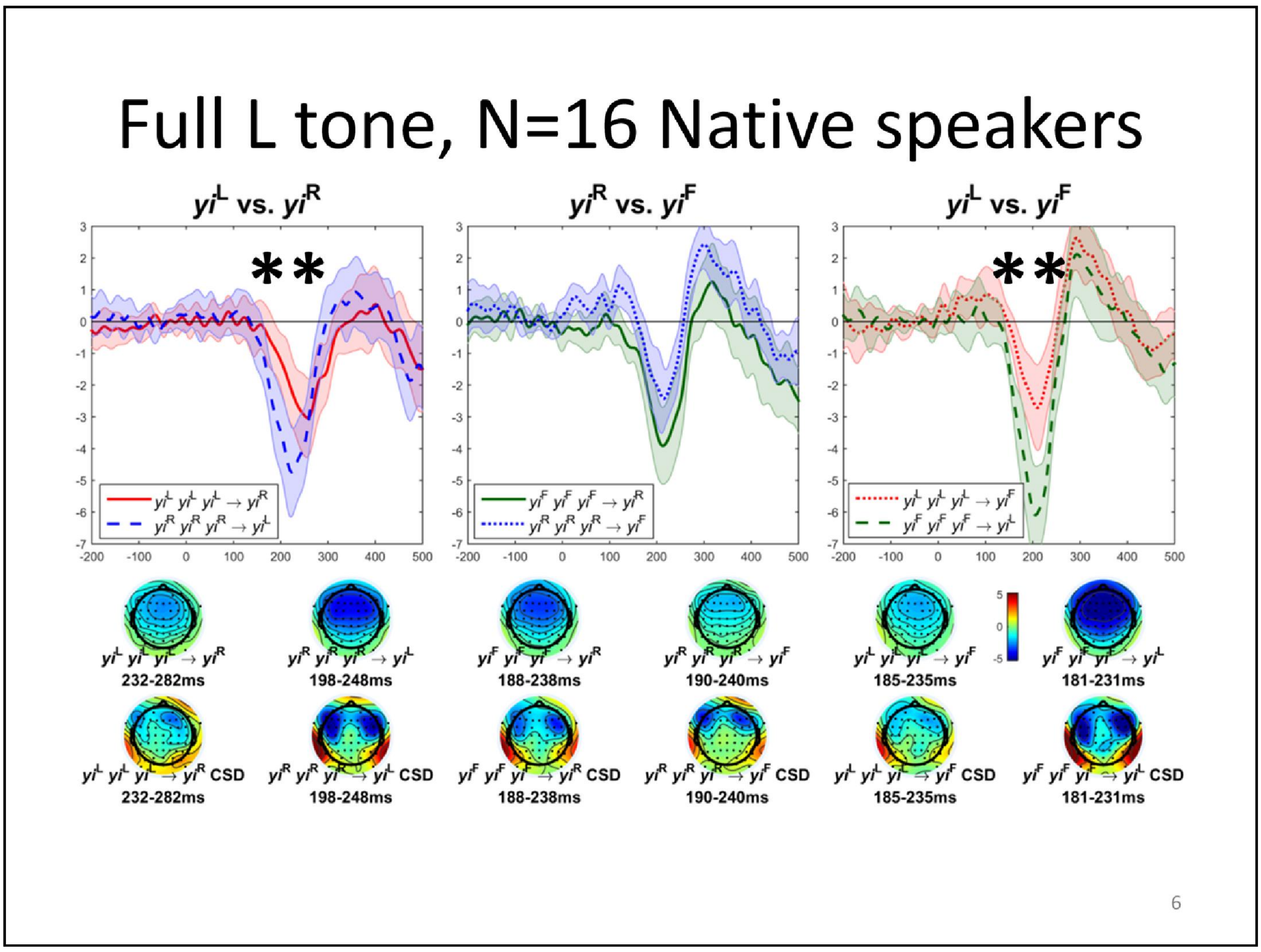
So in these experiments, we'll look at MMNs for the several contrasts. We look at contrast between L and R, which are phonologically related, and also between Low and a phonologically unrelated tone, in this case Falling tone, so that if there are asymmetries in the mismatch negativity, we can see if it's limited to a phonologically alternating pair or if Low tone is just special across the board.

Finally, we have another pair that doesn't involve low tone at all.

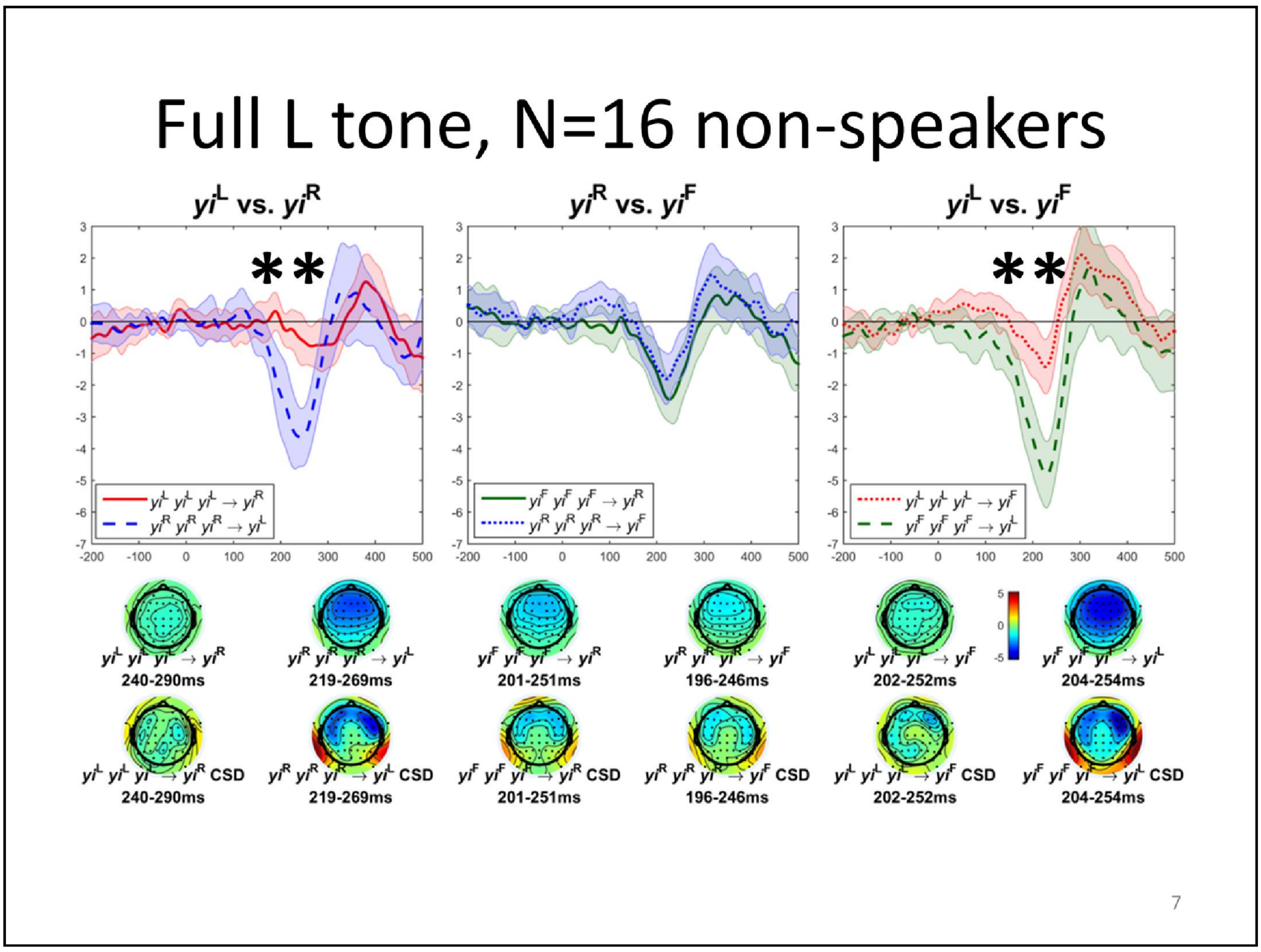
In each of these pairs, we can test the contrast in both directions to see if the mismatch negativity will be bigger going from one tone to the other than it is in the opposite direction.



So here's what that looks like. Within each box I'm showing the MMNs for a given contrast in each direction. For example, this blue line is the MMN for rise rise rise low; and this smaller red line is the MMN for the same pair of tones flipped around, low low low rise. Any time when the two lines separate, that means there was an asymmetrical MMN for that contrast.

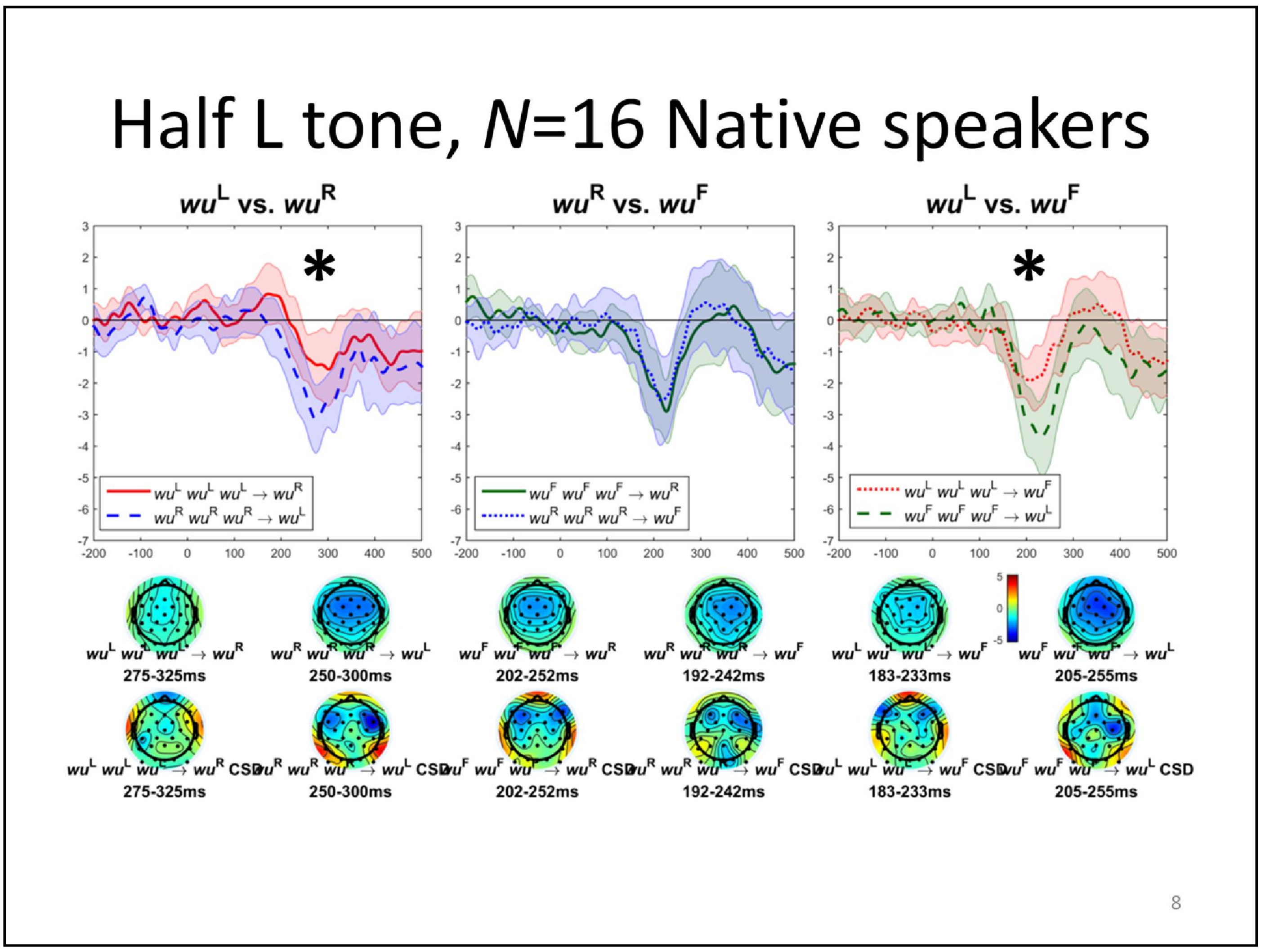
You can see that in both contrasts involving Low, the MMN was asymmetrical. The lines are separating for the Low vs. Rise contrast, and also for the Low vs. Falling contrast. And in both asymmetries, it's because the MMN is smaller when Low is standard and something else is deviant (that's the red lines). Interestingly, you see that the asymmetry is not limited to the Low-Rise contrast where the two tones share a phonological relationship; instead, Low tone is asymmetrical with any other tone, so this suggests that there may be something special about the way low tone is processed acoustically or the way it's represented in memory.

Of course, we don't know if this asymmetry is based on how these tones are phonologically organized in memory, or if it's based on some kind of non-linguistic acoustic factor. If the effect is something about the special phonology of Low tone, we would expect these asymmetries to show up only in people who have a standard Mandarin phonology, and not for naïve speakers, so we also ran speakers with no knowledge of Chinese.



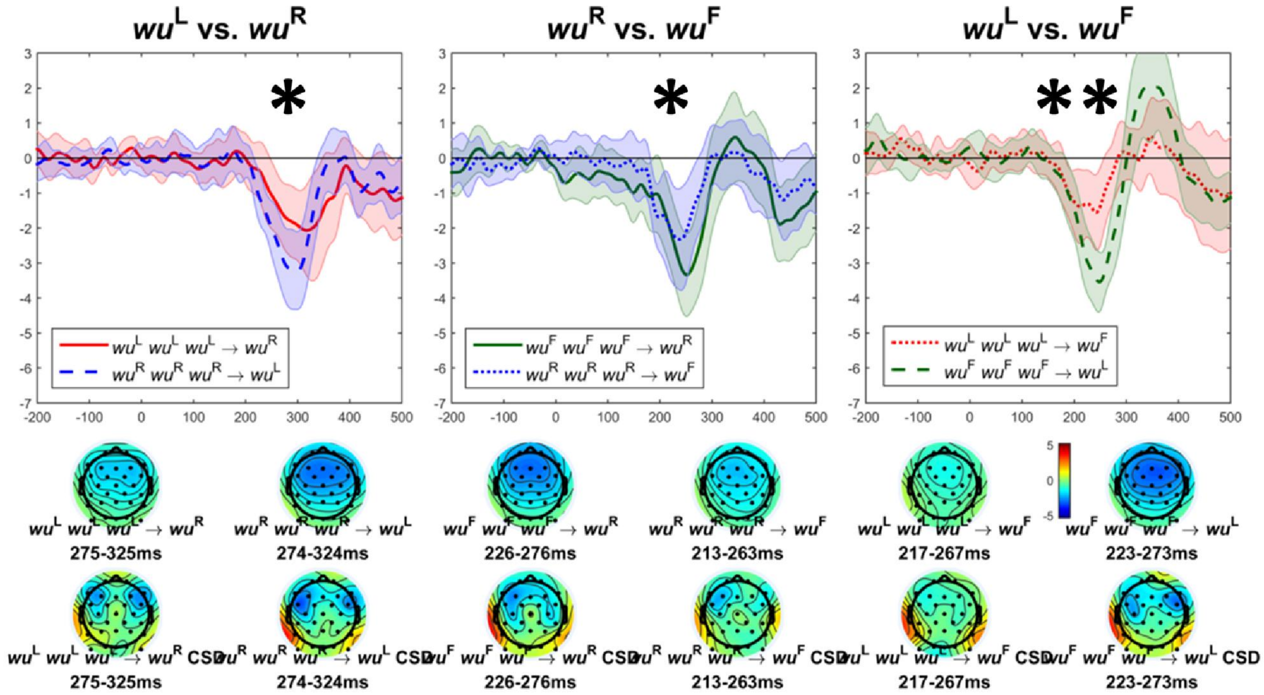
And they got the same asymmetries. So once again, you see the lines separating for Low vs. Rise and also for Low vs. Fall. So it seems like there is something other than phonological representation playing a role here, since these speakers don't have Mandarin tones.

(You could alternatively argue that this is phonological knowledge, and simply Low tone is underspecified universally even if you don't have a tone system in your language. Under that argument, the direction of this asymmetry should reverse, for both speakers and non-speakers, when testing a T3-Tx contrast in a different dialect, e.g. Jinan)



Now, we also replicated this with a different syllabic context and a slightly different tonal contour---if you're familiar with Mandarin, we used a half tone 3 instead of a full tone 3, and we can talk later about why that might matter. But long story short, the new stimuli replicated those results both for the Chinese speakers, and for the non-Chinese speakers.

Half L tone, *N*=16 non-speakers



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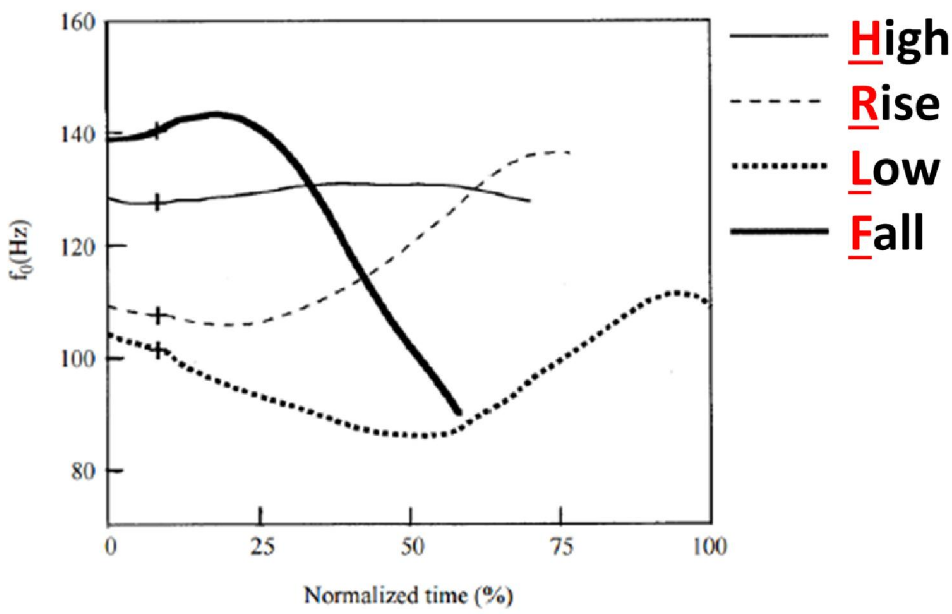
Acoustic complexity (2)



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One possible explanation for the asymmetry for naïve speakers is acoustic complexity: there's lots of evidence from basic psychophysics that you get a big MMN when your deviant is more complex than your standard, and a smaller MMN when your deviant is less complex than your standard. This might explain why naïve listeners with no Mandarin phonology were able to show these asymmetries.

- Earlier experiments: {$yi^{\mathbf{L}}$, $yi^{\mathbf{R}}$, $yi^{\mathbf{F}}$}; {$wu^{\mathbf{L}}$, $wu^{\mathbf{R}}$, $wu^{\mathbf{F}}$}
- Next experiment:
  - $yi^{\mathbf{L}}_{a}$, $yi^{\mathbf{L}}_{b}$, $yi^{\mathbf{L}}_{c}$, $yi^{\mathbf{R}}_{a}$, $yi^{\mathbf{R}}_{b}$, $yi^{\mathbf{R}}_{c}$, $yi^{\mathbf{F}}_{a}$, $yi^{\mathbf{F}}_{b}$, $yi^{\mathbf{F}}_{c}$, $yi^{\mathbf{H}}_{a}$, $yi^{\mathbf{H}}_{b}$, $yi^{\mathbf{H}}_{c}$
  - $wu^{\mathbf{L}}_{a}$, $wu^{\mathbf{L}}_{b}$, $wu^{\mathbf{L}}_{c}$, $wu^{\mathbf{R}}_{a}$, $wu^{\mathbf{R}}_{b}$, $wu^{\mathbf{R}}_{c}$, $wu^{\mathbf{F}}_{a}$, $wu^{\mathbf{F}}_{b}$, $wu^{\mathbf{F}}_{c}$, $wu^{\mathbf{H}}_{a}$, $wu^{\mathbf{H}}_{b}$, $wu^{\mathbf{H}}_{c}$
  - $yu^{\mathbf{L}}_{a}$, $yu^{\mathbf{L}}_{b}$, $yu^{\mathbf{L}}_{c}$, $yu^{\mathbf{R}}_{a}$, $yu^{\mathbf{R}}_{b}$, $yu^{\mathbf{R}}_{c}$, $yu^{\mathbf{F}}_{a}$, $yu^{\mathbf{F}}_{b}$, $yu^{\mathbf{F}}_{c}$, $yu^{\mathbf{H}}_{a}$, $yu^{\mathbf{H}}_{b}$, $yu^{\mathbf{H}}_{c}$
  - $a^{\mathbf{L}}_{a}$, $a^{\mathbf{L}}_{b}$, $a^{\mathbf{L}}_{c}$, $a^{\mathbf{R}}_{a}$, $a^{\mathbf{R}}_{b}$, $a^{\mathbf{R}}_{c}$, $a^{\mathbf{F}}_{a}$, $a^{\mathbf{F}}_{b}$, $a^{\mathbf{F}}_{c}$, $a^{\mathbf{H}}_{a}$, $a^{\mathbf{H}}_{b}$, $a^{\mathbf{H}}_{c}$
  - $e^{\mathbf{L}}_{a}$, $e^{\mathbf{L}}_{b}$, $e^{\mathbf{L}}_{c}$, $e^{\mathbf{R}}_{a}$, $e^{\mathbf{R}}_{b}$, $e^{\mathbf{R}}_{c}$, $e^{\mathbf{F}}_{a}$, $e^{\mathbf{F}}_{b}$, $e^{\mathbf{F}}_{c}$, $e^{\mathbf{H}}_{a}$, $e^{\mathbf{H}}_{b}$, $e^{\mathbf{H}}_{c}$

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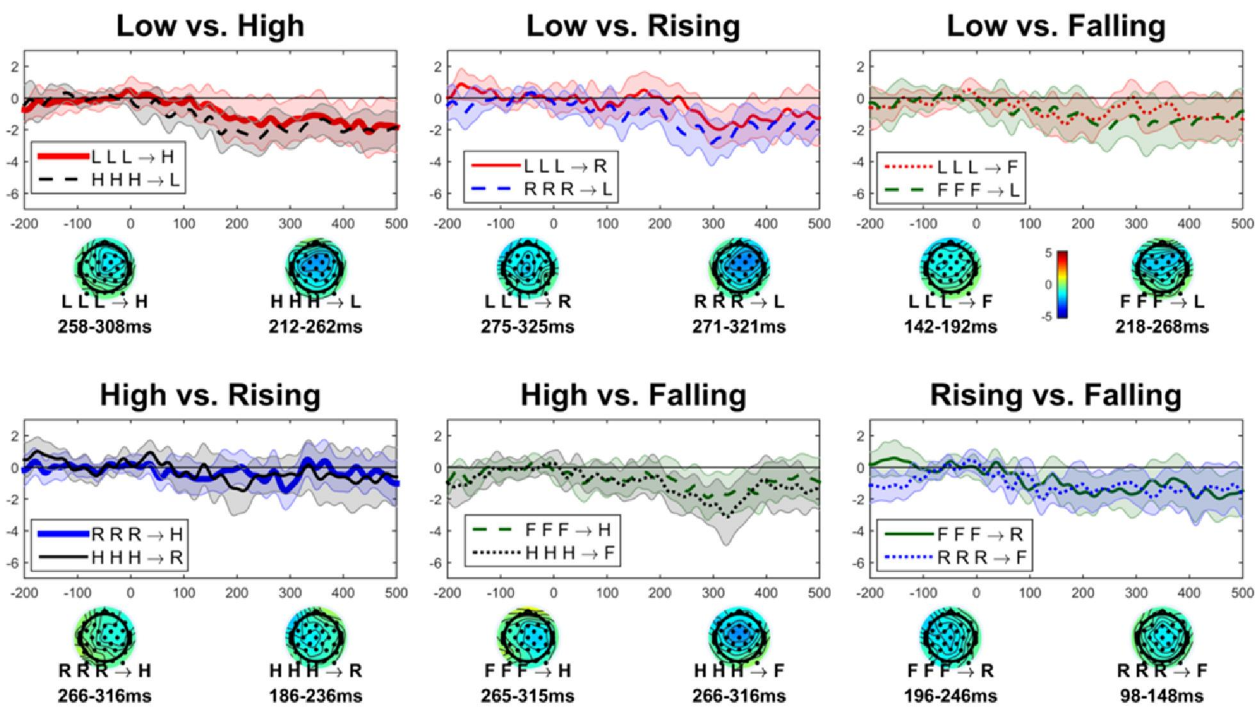
One way to try to detect a phonological effect might be to change the paradigm so that it minimizes acoustic contributions to the MMN and maximizes phonological ones. In the earlier experiments, for each given tone there was only one token, repeated thousands of times; so any tiny difference would be easy to notice—they were identical in all ways except F0, but any small diffrence in the F0 contour could trigger MMN. So what we can do instead is use a lot of different tokens of each tone, with some within-category variability, and also put the tones on lots of different carrier syllables. So instead of hearing e.g. yi2 yi2 yi2 yi3 yi2 yi2 yi3, participants instead hear like yi2 wu2 a2 e3 a2 yu2 wu3. This way participants can't just listen for one little acoustic change; the only way to get that categorical difference, which you need to have to elicit a mismatch negativity, is for them to pull out an abstract tone representation out of all the varied tokens they are hearing. This should make it less likely for low-level acoustic factors to influence the MMN, and leave more room for us to see a phonological effect.

Varied tokens, *N*=15 Native speakers



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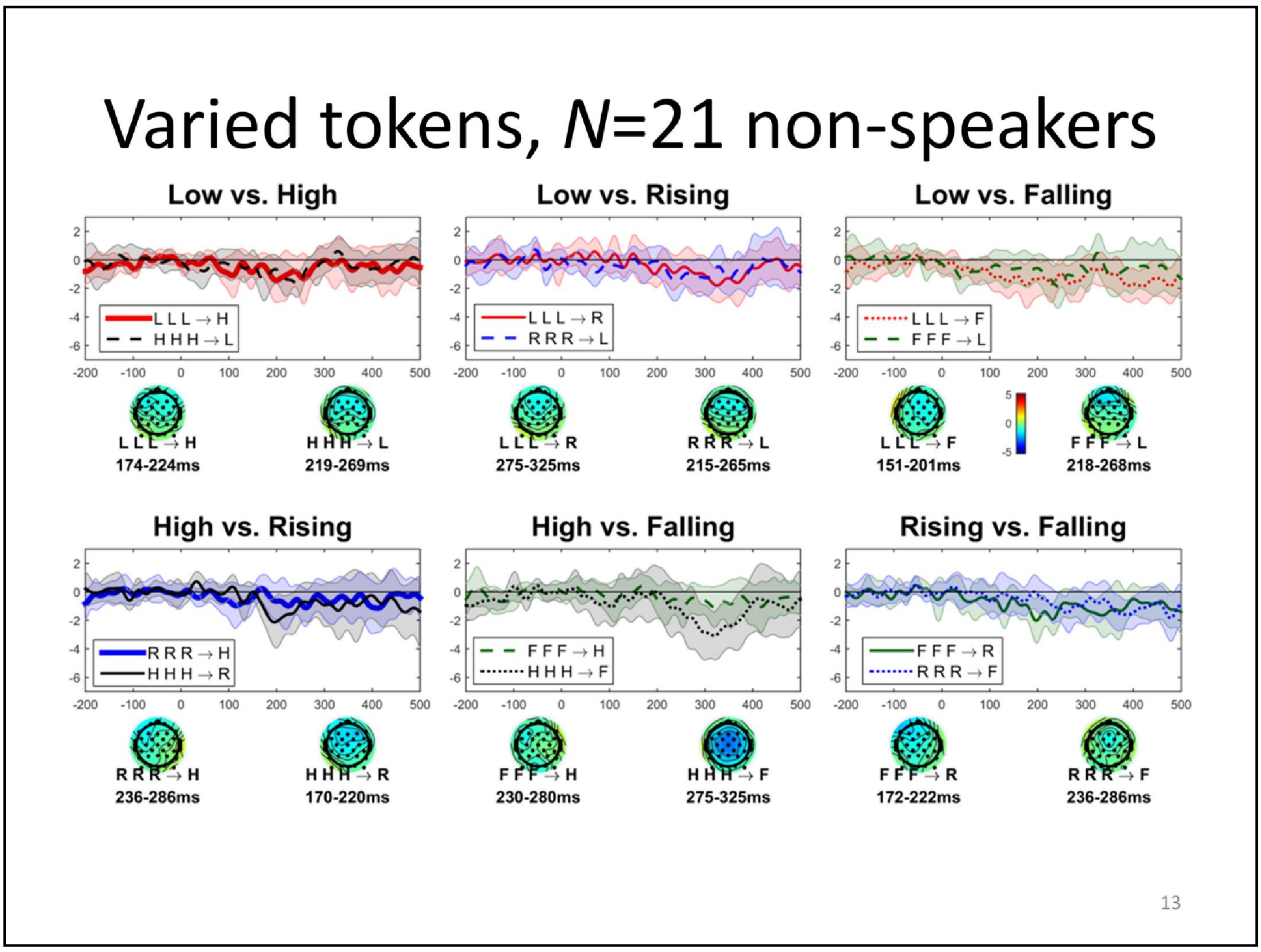
So, data collection for this experiment is still in progress, and of course the MMNs look much weaker than what you've seen before because we've made the experiment much more difficult. Also note that in this one we added high tone, so we're contrasting all four tones rather than just three. But if you look at the red lines, which represent when you have Low tone as the standard, you can see that, across the board, whenever L is contrasted with any other tone, there is a numerical asymmetry in the same direction as what we've seen in the previous experiments.

So even in this much more complicated sound stream, there is still evidence for asymmetrical mismatch negativities between low and other tones in native speakers. Of course the important question is, is this asymmetry also there in the non-speakers?



And finally, it looks like no. If you look at the red line again, there’s not really a systematic trend in either direction. So it seems like we finally have some evidence for a case where there’s an asymmetry that’ conditioned by language background.

(There’s always the problem of how canonical the tokens are---not a problem for the experiments where non-natives get an effect, but for this exp it could be a problem. I think the only good way to answer it is to re-run a version where the base token that everything else is derived from is a [creak-less] T3, so T3 is the most canonical and the others are weird)

Conclusions (1)

- A robust asymmetry in the MMN elicited by Mandarin contour tones
  - All other things being equal, contrasts between Low and other tones elicit bigger MMN when Low is the standard rather than the deviant

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So to the take-home message here is that there is a very robust asymmetry in the brain response to Mandarin tones. In native speakers, across the board, you get smaller mismatch negativities when a Low tone is the standard than when something else is the standard and Low is the deviant.

Conclusions (2)

- Non-linguistic acoustic factors may drive much of the asymmetry
- Preliminary evidence that phonological knowledge also contributes to asymmetry

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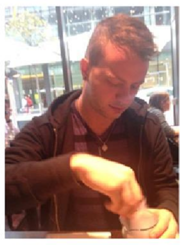
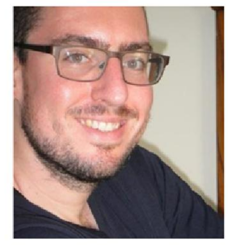
Much of this effect is likely to be driven by non-linguistic factors, since we saw it across speakers of different language backgrounds. But we still have to nail down what specific acoustic factors are driving that.

But importantly, based on the last experiment, there is some evidence that some of the asymmetry we see in native speakers is also driven by phonological knowledge. So this suggests that Mandarin Low tone has a different phonological representation than the other tones and that this difference in representation has cognitive and neural consequences.



Kevin Schluter (NYUAD)

Kefei Wu (NYUAD)



Diogo Almeida (NYUAD)

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