Stress assignment and subsequentiality

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Introduction

- Generative theories of stress traditionally view the component of the grammar that assigns predictable stress describes a *mapping* from unstressed syllables to stressed syllables

  $\sigma\sigma\sigma\sigma\sigma\sigma\sigma \mapsto \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma$

- What is the nature of stress assignment mappings?

Introduction

- Formal language theory (FLT) delineates classes of functions that serve as typological hypotheses for stress assignment
- Some work on stress as a phonotactic (Heinz 2007, 2009; Rogers et al. 2013; Baek 2018), almost nothing on stress as a function (though see Hao & Andersson 2019)
- Appears that majority of patterns are *subsequential* (Mohri 1997)

Results

- All examined *quantity insensitive* (QI) stress is subsequential; not all *quantity sensitive* (QS) stress is[1]
- Within QS, default-to-same (DTS) patterns more complex than default-to-opposite (DTO) [2]
- *Weakly deterministic* (WD) functions (Heinz & Lai 2013; McCollum et al. under review) can capture DTS patterns

[1] See also Hao & Andersson (2019)
[2] Terminology from Prince (1985)

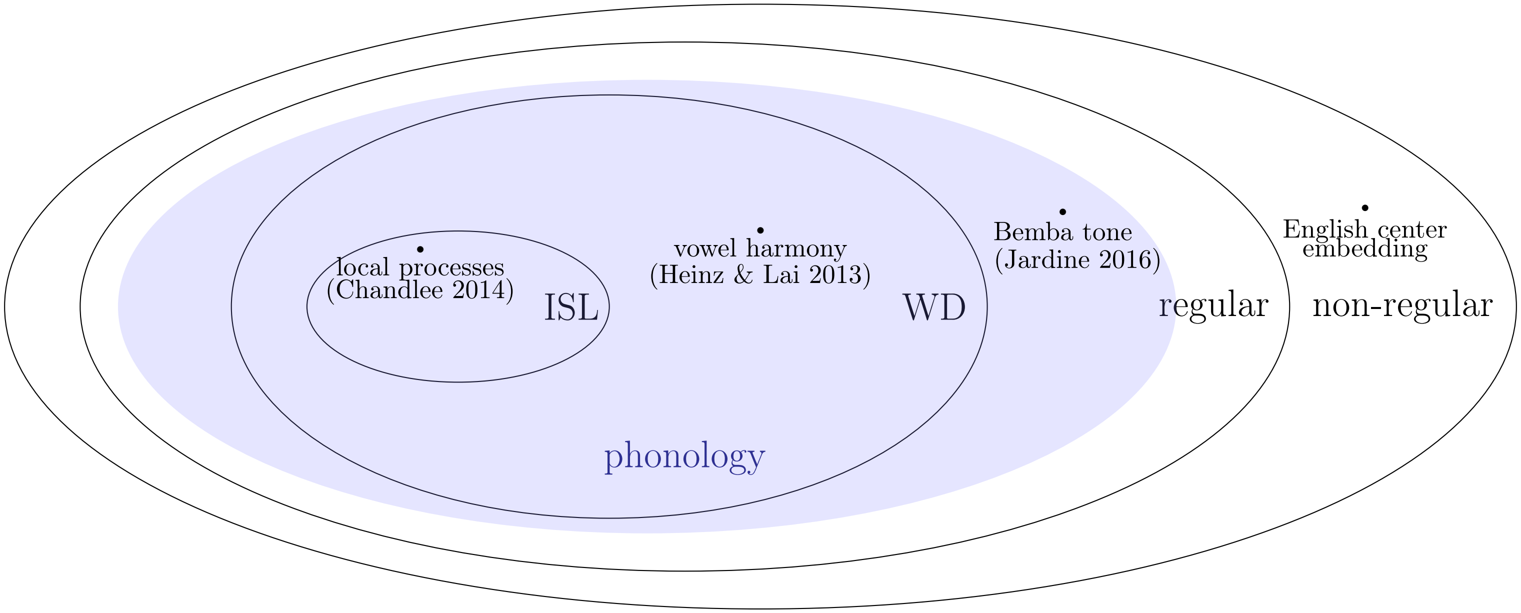
Why this matters

- Most phonological functions are subsequential (Heinz & Lai 2013; Chandlee 2014)
- Taken with Jardine (2016), suggests that suprasegmental processes may have access to more powerful functions
- Raises representational questions
- Raises questions regarding quality of evidence for stress

Plan

- Background
- QI stress
- QS stress
- Implications

Complexity



- FLT complexity classes divide space of possible functions based on expressive power of those functions
- Phonology is *regular* (Johnson 1972; Kaplan & Kay 1994)
- In fact, most is subregular (Rogers et al. 2013; Heinz 2018)

Stress?

- We take the *subsequential* class (Mohri 1997) as an initial hypothesis for stress
- Restrictive (sub-regular); well-understood (logical and FST characterization); includes most phonological processes (Chandlee 2014; Jardine 2016; Chandlee & Jardine 2019)

Stress with logic

- *Logical transductions* (Courcelle 1994) between input structure and output structure
- Connected to function classes, know their expressivity

  quantifier-free (QF) logic = *input strictly local* (ISL) functions[3]

  QF with recursion $\subseteq$ subsequential functions[4]
- Start with QI stress, then QS

[3](Chandlee & Jardine 2019; Chandlee & Lindell forthcoming)
[4]With some restrictions; see Chandlee & Jardine (2019)

Stress with logic

- Output defined in logical terms of input, preserves order and number of elements
- Stress placed where definition of stress predicate satisfied
- **Example:** Initial stress (Nenets; Decsy 1966)

$$\acute{\sigma}(x) \stackrel{d}{=} \#(p(x))$$

$$\begin{array}{lll} \#\sigma\sigma\sigma\# & \mapsto & \#\acute{\sigma}\sigma\sigma\# \\ \#\sigma\sigma\sigma\sigma\# & \mapsto & \#\acute{\sigma}\sigma\sigma\sigma\# \\ \#\sigma\sigma\sigma\sigma\sigma\# & \mapsto & \#\acute{\sigma}\sigma\sigma\sigma\sigma\# \\ \ldots & \mapsto & \ldots \end{array}$$

QI: Non-iterative stress

- Describes an initial stress function for string of any length
- Can write similar QF transductions for any non-iterative pattern in Gordon (2002)'s typology of QI stress[5]

initial :	$\acute{\sigma}(x) \overset{d}{=} \#(p(x))$	$\#\sigma\sigma\sigma\sigma\# \mapsto \#\acute{\sigma}\sigma\sigma\sigma\#$
peninitial :	$\acute{\sigma}(x) \overset{d}{=} \#(p(p(x)))$	$\#\sigma\sigma\sigma\sigma\# \mapsto \#\sigma\acute{\sigma}\sigma\sigma\#$
antepenultimate :	$\acute{\sigma}(x) \overset{d}{=} \#(s(s(s(x))))$	$\#\sigma\sigma\sigma\sigma\# \mapsto \#\sigma\acute{\sigma}\sigma\sigma\#$
penultimate :	$\acute{\sigma}(x) \overset{d}{=} \#(s(s(x)))$	$\#\sigma\sigma\sigma\sigma\# \mapsto \#\sigma\sigma\acute{\sigma}\sigma\#$
final :	$\acute{\sigma}(x) \overset{d}{=} \#(s(x))$	$\#\sigma\sigma\sigma\sigma\# \mapsto \#\sigma\sigma\sigma\acute{\sigma}\#$

[5] Later these are employed as useful user-defined predicates e.g. $\mathit{initial}(x) \overset{d}{=} \#(p(x))$

QI: Iterative stress

- Pintupi (Hansen & Hansen 1969)

  $\acute{\sigma}, \acute{\sigma}\sigma, \acute{\sigma}\sigma\sigma, \acute{\sigma}\sigma\grave{\sigma}\sigma, \acute{\sigma}\sigma\grave{\sigma}\sigma\sigma, \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma...$

- QF won't work – need QF plus recursion

- **Implicit definitions:** (Rogers 1997) definition can refer to its output

$$\grave{\sigma}(x) \stackrel{d}{=} \acute{\sigma}(p(p(x)))$$

- Restriction to predecessor *or* successor function (but not both!) in recursion ensures subsequentiality (Chandlee & Jardine 2019)

QI: Iterative stress

- $\acute{\sigma}(x) \stackrel{d}{=} initial(x)$
  $\grave{\sigma}(x) \stackrel{d}{=} (\acute{\sigma}(p(p(x))) \vee \grave{\sigma}(p(p(x)))) \wedge \neg final(x)$

- 6σ
  $\sigma\sigma\sigma\sigma\sigma\sigma \rightarrow \underline{\acute{\sigma}}\sigma\sigma\sigma\sigma\sigma \rightarrow \acute{\sigma}\sigma\underline{\grave{\sigma}}\sigma\sigma\sigma \rightarrow \acute{\sigma}\sigma\grave{\sigma}\sigma\underline{\grave{\sigma}}\sigma$
  7σ
  $\sigma\sigma\sigma\sigma\sigma\sigma\sigma \rightarrow \underline{\acute{\sigma}}\sigma\sigma\sigma\sigma\sigma\sigma \rightarrow \acute{\sigma}\sigma\underline{\grave{\sigma}}\sigma\sigma\sigma\sigma \rightarrow \acute{\sigma}\sigma\grave{\sigma}\sigma\underline{\grave{\sigma}}\sigma\sigma$

- Pintupi stress function is subsequential

QI: Iterative stress

- Garawa (Furby 1974)

  $\acute{\sigma}, \acute{\sigma}\sigma, \acute{\sigma}\sigma\sigma, \acute{\sigma}\sigma\grave{\sigma}\sigma, \acute{\sigma}\sigma\sigma\grave{\sigma}\sigma, \acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma, \acute{\sigma}\sigma\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma$

- Sometimes called "bidirectional" (Kager 2007)

QI: Iterative stress

- $\acute{\sigma}(x) \overset{d}{=} initial(x)$
  $\grave{\sigma}(x) \overset{d}{=} (penult(x) \vee \grave{\sigma}(s(s(x)))) \wedge \neg peninit(x)$
- 6σ
  $\sigma\sigma\sigma\sigma\sigma\sigma \;\longrightarrow\; \underline{\acute{\sigma}}\sigma\sigma\sigma\underline{\grave{\sigma}}\sigma \;\longrightarrow\; \acute{\sigma}\sigma\underline{\grave{\sigma}}\sigma\grave{\sigma}\sigma$

  7σ
  $\sigma\sigma\sigma\sigma\sigma\sigma\sigma \;\longrightarrow\; \underline{\acute{\sigma}}\sigma\sigma\sigma\sigma\underline{\grave{\sigma}}\sigma \;\longrightarrow\; \acute{\sigma}\sigma\sigma\underline{\grave{\sigma}}\sigma\grave{\sigma}\sigma$
- Garawa stress function is subsequential
- Is not truly bidirectional – we will see one that is!

So far

- All patterns so far subsequential – any potentially unbounded processing of the input only looks in one direction
- All patterns in Gordon (2002)'s typology are subsequential
- This is strong evidence that QI patterns are subsequential
- This is *not* the case for QS stress

QS stress

- Inputs are strings of L, H syllables
- Look at DTO and DTS patterns
- leftmost-heavy or right (LHOR) of Kwakw'ala, leftmost-heavy or left of Lushootseed (Hayes 1995)

LHOR	LHOL
$LLL\acute{L}$	$\acute{L}LLL$
$\acute{H}HHH$	$\acute{H}HHH$
$L\acute{H}LLLL$	$L\acute{H}LLLL$
$L\acute{H}LLHL$	$L\acute{H}LLHL$

- Are these also subsequential?

QS stress

- Placement of stress needs to track presence of H syllables
- *precede-H(x)* $\stackrel{d}{=} H(s(x)) \vee$ *precede-H(s(x))*

$$\overleftarrow{\text{LLLLL}}\text{HLL}$$

- *follow-H(x)* $\stackrel{d}{=} H(p(x)) \vee$ *follow-H(p(x))*

$$\text{LLH}\overrightarrow{\text{LLLLL}}$$

- If both are used, *not* subsequential

QS stress: LHOR

- $\acute{\square}(x) \stackrel{d}{=} (L(x) \wedge final(x) \wedge \neg follow\text{-}H(x)) \vee$
  $$(H(x) \wedge \neg follow\text{-}H(x))$$
- Correctly describes DTO stress function, is subsequential

$$\begin{array}{lll} LLLL & \mapsto & LLL\acute{L} \\ HHHH & \mapsto & \acute{H}HHH \\ LHHLLL & \mapsto & L\acute{H}HLLL \\ LHLLHL & \mapsto & L\acute{H}LLHL \end{array}$$

QS stress: LHOL

- $\acute{\Box}(x) \stackrel{d}{=} (L(x) \wedge initial(x) \wedge \neg precede\text{-}H(x)) \vee$
  $(H(x) \wedge \neg follow\text{-}H(x))$
- $\overleftarrow{\boxed{\mathrm{L}}}\mathrm{LHLHL} \;\rightarrow\; \mathrm{LLHLHL}$

  $\overrightarrow{\mathrm{LL}}\boxed{\mathrm{H}}\mathrm{LHL} \;\rightarrow\; \mathrm{LL\acute{H}LHL}$
- Correctly describes DTS stress function, is *not* subsequential!

Beyond subsequential

- All examined QI subsequential – most even more restricted
- Most QS stress is also subsequential, but some are not
- What is LHOL?

Beyond subsequential

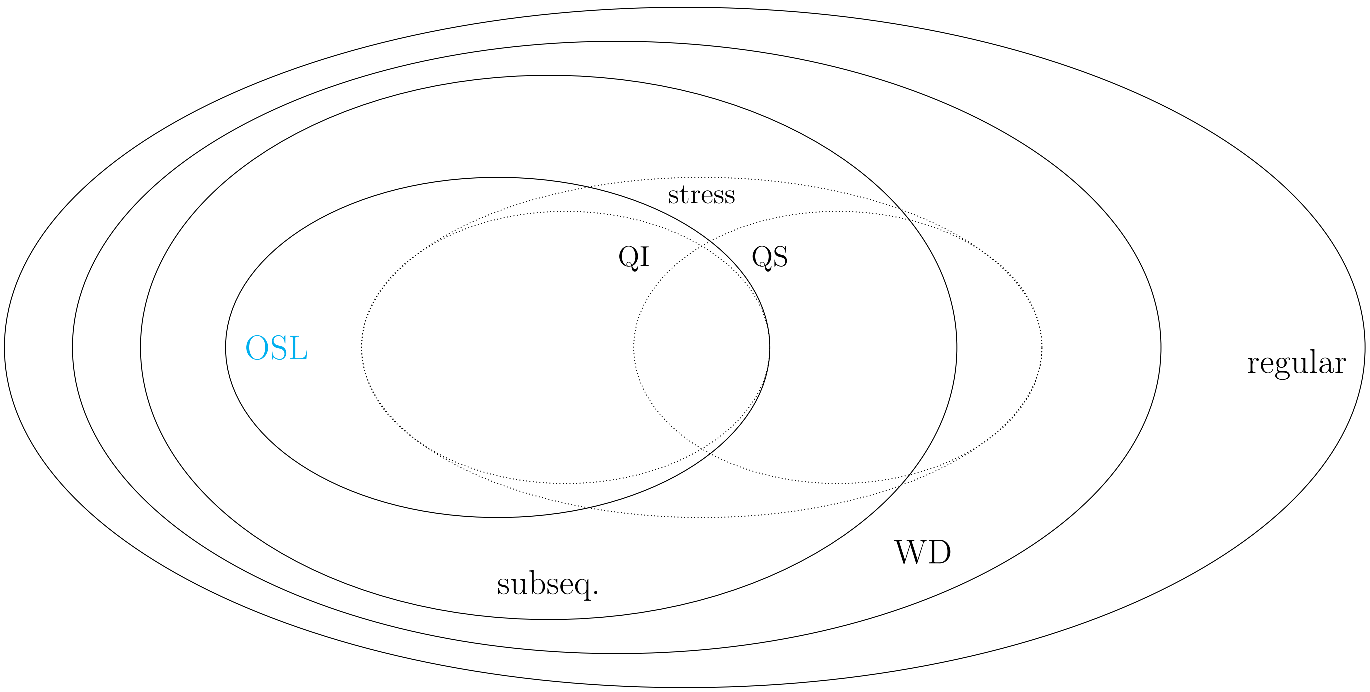
- *Weakly deterministic* (WD) class[6] describes bidirectional phonological processes, more powerful than subsequential
- Composition of two subsequential functions (with some restrictions)
- LHOL[7,8]

input:	/LLHLHL/	/LLLLLL/
left to right	LLH́LHL	LLLLLL
right to left	LLH́LHL	ĹLLLLL

[6] Heinz & Lai (2013); McCollum et al. (under review)
[7] See independent parallel result in Hao & Andersson (2019)
[8] See Appendix for potential issue with WD for stress

Questions

- What is the class of functions corresponding to stress assignment?



- Output-strictly local class (OSL; Chandlee 2014; Chandlee et al. 2015) appropriate for QI stress?

Evidence for stress

- Worrying about relatively high complexity of DTS is taking the descriptions of the patterns at face value
- Should we do that?

Evidence for stress

- For DTO, some concerning results
- Gordon (2000) finds that "many, if not all" (p.2) such patterns are subject to reanalysis in other terms
- Concludes that "the general picture which emerges is one of doubt concerning the existence of default-to-opposite stress" (p.2)
- Evidence that the same might hold for DTS stress too (Mongolian; (Karlsson 2005))
- FLT analysis highlights patterns that call for further empirical study

Summary

- Characterization of stress function in FLT terms
- Examined QI stress patterns subsequential
- Not all QS patterns subsequential
- Class of functions that is a precise fit for stress as of yet undescribed
- Lingering questions of evidence for stress

Thanks

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References

Baek, H. (2018). Computatonal representation of unbounded stress. *Proceedings of CLS 53*, (pp. 13–24).

Chandlee, J. (2014). *Strictly Local Phonological Processes*. PhD thesis, University of Delaware.

Chandlee, J., Eyraud, R., & Heinz, J. (2015). Output strictly local functions. *Mathematics of Language 2015*.

Chandlee, J., & Jardine, A. (2019). Quantifier-free least-fixed point functions for phonology. *Mathematics of Language 16*.

Chandlee, J., & Lindell, S. (forthcoming). A logical characterization of strictly local functions. In J. Heinz (Ed.) *Doing Computational Phonology*. OUP.

Courcelle, B. (1994). Monadic second-order definable graph transductions: a survey. *Theoretical Computer Science*, *126*, 53–75.

Decsy, G. (1966). Yurak chrestomathy. *Uralic and Altaic Series*, *50*.

Furby, C. (1974). *Garawa phonology*, vol. Series A. Australian National University: Pacific Linguistics.

Gordon, M. (2000). Re-examining default-to-opposite stress. *Annual Meeting of the Berkeley Linguistics Society*, *26*.

Gordon, M. (2002). A factorial typology of quantity-insensitive stress. *Natural Language & Linguistic Theory*, *20*(3), 491–552.

Hansen, K., & Hansen, L. E. (1969). Pintupi phonology. *Oceanic Linguistics*, *8*, 153–170.

Hao, S., & Andersson, S. (2019). Unbounded stress in subregular phonology. *Proceedings of SIGMORPHON 16*.

Hayes, B. (1995). *Metrical Stress Theory: Principles and Case Studies*. Chicago: The University of Chicago Press.

Heinz, J. (2007). Learning unbounded stress systems via local inference. In E. Elfner, & M. Walkow (Eds.) *Proceedings of the 37th Meeting of the Northeast Linguistics Society*. University of Illionois, Urbana-Champaign.

Heinz, J. (2009). On the role of locality in learning stress patterns. *Phonology*, *26*(2), 303–351.

Heinz, J. (2018). The computational nature of phonological generalizations. In L. M. H. . F. Plank (Ed.) *Phonological typology*. Berlin & Boston: De Gruyter Mouton.

Heinz, J., & Lai, R. (2013). Vowel harmony and subsequentiality. In A. Kornai, & M. Kuhlmann (Eds.) *Proceedings of the 13th Meeting on Mathematics of Language*. Sofia, Bulgaria.

Jardine, A. (2016). Computationally, tone is different. *Phonology*, *33(2)*, 385–405.

Johnson, D. (1972). Formal aspects of phonological description.

Kager, R. (2007). Feet and metrical stress. In P. de Lacy (Ed.) *The Cambridge Handbook of Phonology*, (pp. 195–227). Cambridge, England: Cambridge University Press.

Kaplan, R., & Kay, M. (1994). Regular models of phonological rule systems. *Computational Linguistics*, *20*, 331–378.

Karlsson, A. (2005). *Rhythm and Intonation in Halh Mongolian*. Ph.D. thesis, Lund University.

Koser, N., & Jardine, A. (to appear). The complexity of optimizing over strictly local constraints. *Proceedings of PLC 43*.

McCollum, A., Bakovic, E., Mai, A., & Meinhardt, E. (under review). The expressivity of segmental phonology and the definition of weak determinism.

Mohri, M. (1997). Finite-state transducers in language and speech processing. *Computational Linguistics*, *23*, 269–311.

Prince, A. (1985). Improving tree theory. *BLS*, *11*, 471–490.

Rogers, J. (1997). Strict LT2 : Regular :: Local : Recognizable. In C. Retoré (Ed.) *Logical Aspects of Computational Linguistics: First International Conference, LACL '96 Nancy, France, September 23–25, 1996 Selected Papers*, (pp. 366–385). Berlin, Heidelberg: Springer Berlin Heidelberg.

Rogers, J., Heinz, J., Fero, M., Hurst, J., Lambert, D., & Wibel, S. (2013). Cognitive and sub-regular complexity. In G. Morrill, & M.-J. Nederhof (Eds.) *Formal Grammar*, (pp. 90–108). Berlin, Heidelberg: Springer Berlin Heidelberg.

Wilson, C. (2003). Analyzing unbounded spreading with constraints: marks, targets, and derivations.

Wilson, C. (2006). Unbounded spreading is myopic.

Appendix: beyond subsequential

- Issue – consider the following pattern:

  $\acute{\sigma}$

  $\acute{\sigma}\sigma$

  $\acute{\sigma}\sigma\sigma$

  $\acute{\sigma}\sigma\acute{\sigma}\sigma$

  $\acute{\sigma}\sigma\sigma\sigma\sigma$

  $\acute{\sigma}\sigma\acute{\sigma}\sigma\acute{\sigma}\sigma$

  $\acute{\sigma}\sigma\sigma\sigma\sigma\sigma\sigma$

- "sour grapes"-like pattern (Wilson 2003, 2006) for stress (Koser & Jardine to appear)

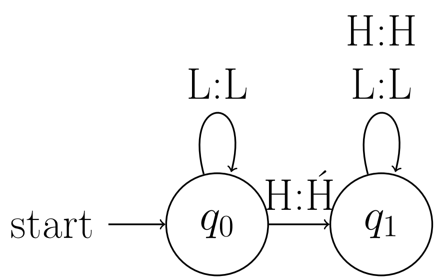
Appendix: beyond subsequential

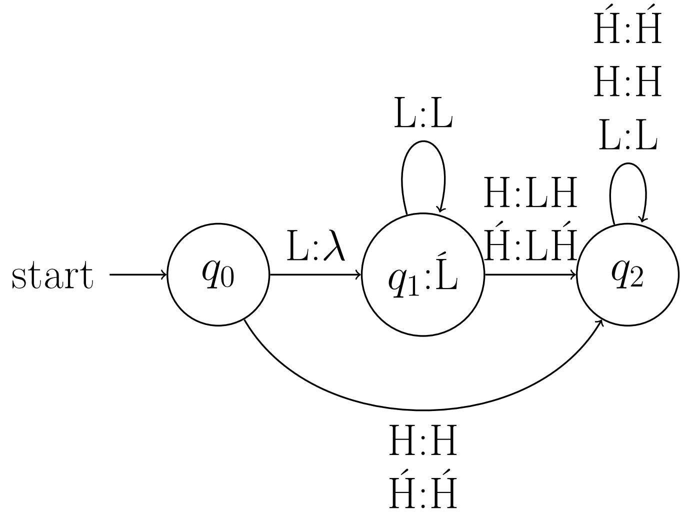
- Whether WD rules this out depends on definition, still being worked out

input:	$/\sigma\sigma\sigma\sigma\sigma\sigma\sigma/$	$/\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma/$
left to right	$\acute{\sigma}\sigma\sigma\sigma\sigma\grave{\sigma}\sigma$	$\acute{\sigma}\sigma\sigma\sigma\sigma\sigma\sigma$
right to left	$\acute{\sigma}\sigma\grave{\sigma}\sigma\grave{\sigma}\sigma$	$\acute{\sigma}\sigma\sigma\sigma\sigma\sigma\sigma$

- Subsequential is too strong a hypothesis for QS, status of WD for QI unclear

LHOL transducer; L-to-R left, R-to-L right





SG stress transducer, L-to-R top, R-to-L bottom