Data cleaning

- H&W removed from the list as well as we could **all compounds, inflected forms, and forms created by highly transparent processes of morphological derivation.**
- H&W syllabified the training data following the Maximal Onset Principle (Selkirk, 1982), so that constraints could refer to onset and coda position.
- We avoided **"exotic" onsets** like [km] (Khmer), since when maximized they result in implausible syllabifications like *acme* [ˈæ.kmi].

4.1 Selecting the relevant constraints

- From the 160 constraints are selected **10 fairly clearly natural constraints** and **10 fairly clearly unnatural ones**.
- The selection was guided by the knowledge of phonological typology and phonetic naturalness,
- Five of the 10 natural constraints were manifestations of the well-known **Sonority Sequencing Principle**

(Sievers 1881; Greenberg 1978; Berent et al. 2007).

Stimuli pairs for the natural constraints

	Constraint	Violating-Control	IPA
1.	*[-son][+son] in CODA	kipl – kilp;	[ˈkɪpl] – [ˈkɪlp]
		canifl –canift	[kəˈnɪfl] – [kəˈnɪft]
2.	*[+cons][-cons] in CODA	tilr - tilse	[ˈtɪlɹ] – [ˈtɪls]
		shapenr - shapent	[ʃəˈpɛntɹ] – [ʃəˈpɛnt]
3.	*[-cons][+cons] in ONSET	hlup - plup	[ˈhlʌp] – [ˈplʌp]
		hmit - smit	[ˈhmɪt] – [ˈsmɪt]
4.	*[-cont][-cont] in ONSET	cping - sping	[ˈkpɪŋ] – [ˈspɪŋ]
		ctice - stice	[ˈktaɪs] – [ˈstaɪs]
5.	*[-cont][+nasal] in ONSET	cnope - clope	[ˈknoʊp] – [ˈkloʊp]
		pneck - sneck	[ˈpnɛk] – [ˈsnɛk]

Sonority-based constraint

Stimuli pairs for the natural constraints

	Constraint	Violating-Control	IPA
6.	*[+lab] [+dor] in CODA	trefk - treft	[ˈtɹɛfk] – [ˈtɹɛft]
	heterorganicity in codas	rufk - ruft	[ˈɹʌfk] – [ˈɹʌft]
7.	*[+dor][+lab] in CODA	bikf - bimf	[ˈbɪkf] – [ˈbɪmf]
	heterorganicity in codas	sadekp - sadect	[səˈdɛkp] – [səˈdɛkt]
8.	*[+lab][+lab] in ONSET	bwell - brell	[ˈbwɛl] – [ˈbɹɛl]
	homorganicity in Onsets	pwickon - twickon	[ˈpwɪkən] – [ˈtwɪkən]
9.	*[-son, -voice] [-son, +voice]	esger - ezger	[ˈɛsgəɹ] – [ˈɛʒgəɹ]
	Voicing assimilation	trocdal - troctal	[ˈtɹɑkdəl] – [ˈtɹɑktəl]
10.	*[glide] in CODA	jouy - jout	[ˈdʒaʊj] – [ˈdʒaʊt]
	Glides in coda, in a diphthongal language	tighw - tibe	[ˈtaɪw] – [ˈtaɪb]

Stimuli pairs for the unnatural constraints

	Constraint	Violating-Control	IPA
1.	*[+round, +high][-cons, -son]	luhallem - laihallem	[luˈhæləm] – [leɪˈhæləm]
	No [u, ʊ, w] before [h]	tuheim – towheim	[tuˈheim] – [toʊˈheim]
2.	*[+cons, -ant][-son]	ishty - ishmy	[ˈɪʃti] – [ˈɪʃmi]
	[ʃ, ʒ, tʃ, dʒ] may not precede obstruents	metchter - metchner	[ˈmɛtʃtəɹ] – [ˈmɛtʃnəɹ]
3.	*[-back][+diphthong]	youse - yoss	[ˈjaʊs] – [ˈjɑs]
	No [j] before [aɪ, aʊ, ɔɪ]	yout - yut	[ˈjaʊt] – [ˈjʌt]
4.	*[$_w$ [-diph, +ronnd, +high]	utrum - otrum	[ˈutɹəm] – [ˈoʊtɹəm]
	No word-initial [u, ʊ]	ooker - ocker	[ˈʊkəɹ] – [ˈɑkəɹ]
5.	*[+diphthong][+cont, -ant]	pyshon - pyson	[ˈpaɪʃən] – [ˈpaɪsən]
	No [aɪ, aʊ, ɔɪ] before [ʃ, ʒ]	foushert - fousert	[ˈfaʊʃəɹt] – [ˈfaʊsəɹt]

Stimuli pairs for the unnatural constraints

	Constraint	Violating-Control	IPA
6.	*[+cont, -strident] [-sonorant]	hethker - hethler	[ˈhɛθkəɹ] – [ˈhɛθləɹ]
	No [θ, ð] before obstruents	muthpy - muspy	[ˈmʌθpi] – [ˈmʌspi]
7.	*[+cont, -strident] [-stress, +rnd]	potho - pothy	[ˈpɑθo] – [ˈpɑθi]
	No [θ, ð] before stressless rounded vowels	taitho - taithy	[ˈteɪθo] – [ˈteɪθi]
8.	*[+diph, +rnd, -back] [-ant]	noiran - nyron	[ˈnɔɪɹən] - [ˈnaɪɹən]
	No [ɔɪ] before [ʃ, ʒ, tʃ, dʒ]	boitcher - boisser	[ˈbɔɪtʃə˞] – [ˈbɔɪsəɹ]
9.	*[+cont, +voice, -ant] [+stress][-son]	zhep - zhem	[ˈʒɛp] – [ˈʒɛm]
	No [ʒ] before stressed vowel + obstruent	zhod - zhar	[ˈʒɑd] – [ˈʒɑɹ]
10.	*[$_{w}$ [+diph, +rnd] [-son, +voice]	ouzie - oussie	[ˈaʊzi] – [ˈaʊsi]
	Initial [aʊ, ɔɪ] may not precede a voiced ostruent	oid - oit	[ˈɔɪd] – [ˈɔɪt]

4.2 Diachronic origin of unnatural constraints

- **Why languages should have any unnatural constraints at all?**
- Some of the constraints have a clear **diachronic basis**
- some may indeed be true entirely **by accident**.
- Constraint (6e): **banning [aɪ, aʊ] before [ʃ]**
  - /ʃ/ originated in English from historical *sk,
  - [aɪ] and [aʊ] from historical *iː, *uː.
  - → Historical descendent of a constraint that originally banned **long vowels before a consonant cluster**, a highly natural pattern.

a blend of diachronic and accidental factors

- Still others may be a blend of diachronically motivated and accidental factors.
- Constraint (6c):
  - the absence of [jaɪ] has a clear diachronic origin
  - → [aɪ] descends from [iː], and bans on [j] before high front vowels are common typologically.
  - The lack of [jaʊ], however, may be accidental.

    (Kawasaki 1982, §2.7.2; for English see Jespersen 1909, §58)

5. Magnitude estimation experiment

- Participants increase or decrease **the magnitude of their response** based on the relative increase or decrease in some property of the stimuli.
- **Response:** Rating of the relative goodness of nonwords as potential words of English .
  - word acceptability experiment
- **Response modality:** (1) number estimation and (2) line drawing
  - these two tasks are easy to implement and their relationship to each other is well understood.
  - Lodge (1981) and Bard, Robertson, and Sorace (1996)

5.1 Methods

- **5.1.1. Participants**
  - Twenty-nine UCLA undergraduate students
- **5.1.2 Materials**
- There were 10 natural and 10 unnatural constraints, and each constraint was tested with two Violating/Control pairs
- There were a total of 80 stimuli:
  - **20 Natural Violating forms**
  - **20 Natural Control forms**
  - **20 Unnatural Violating forms**
  - **20 Unnatural Control forms**

a **Violating word** : violated only the constraint in question,
a **Control word:** violated no other constraints.

5.1.2. Materials (3)
Stimuli pairs for the natural constraints

	Constraint	Violating-Control	IPA
1.	*[-son][+son] in CODA	kipl – kilp;	[ˈkɪpl] – [ˈkɪlp]
		canifl –canift	[kəˈnɪfl] – [kəˈnɪft]
2.	*[+cons][-cons] in CODA	tilr - tilse	[ˈtɪlɹ] – [ˈtɪls]
		shapenr - shapent	[ʃəˈpɛntɹ] – [ʃəˈpɛnt]
3.	*[-cons][+cons] in ONSET	hlup - plup	[ˈhlʌp] – [ˈplʌp]
		hmit - smit	[ˈhmɪt] – [ˈsmɪt]
4.	*[-cont][-cont] in ONSET	cping - sping	[ˈkpɪŋ] – [ˈspɪŋ]
		ctice - stice	[ˈktaɪs] – [ˈstaɪs]
5.	*[-cont][+nasal] in ONSET	cnope - clope	[ˈknoʊp] – [ˈkloʊp]
		pneck - sneck	[ˈpnɛk] – [ˈsnɛk]

Sonority-based constraint

5.1.2. Materials (3)
Stimuli pairs for the natural constraints

	Constraint	Violating-Control	IPA
6.	*[+lab] [+dor] in CODA	trefk - treft	[ˈtɹɛfk] – [ˈtɹɛft]
	heterorganicity in codas	rufk - ruft	[ˈɹʌfk] – [ˈɹʌft]
7.	*[+dor][+lab] in CODA	bikf - bimf	[ˈbɪkf] – [ˈbɪmf]
	heterorganicity in codas	sadekp - sadect	[səˈdɛkp] – [səˈdɛkt]
8.	*[+lab][+lab] in ONSET	bwell - brell	[ˈbwɛl] – [ˈbɹɛl]
	homorganicity in Onsets	pwickon - twickon	[ˈpwɪkən] – [ˈtwɪkən]
9.	*[-son, -voice] [-son, +voice]	esger - ezger	[ˈɛsgəɹ] – [ˈɛʒgəɹ]
	Voicing assimilation	trocdal - troctal	[ˈtɹɑkdəl] – [ˈtɹɑktəl]
10.	*[glide] in CODA	jouy - jout	[ˈdʒaʊj] – [ˈdʒaʊt]
	Glides in coda, in a diphthongal language	tighw - tibe	[ˈtaɪw] – [ˈtaɪb]

5.1.2. Materials (4)
Stimuli pairs for the unnatural constraints

	Constraint	Violating-Control	IPA
1.	*[+round, +high][-cons, -son]	luhallem - laihallem	[luˈhæləm] – [leɪˈhæləm]
	No [u, ʊ, w] before [h]	tuheim – towheim	[tuˈheim] – [toʊˈheim]
2.	*[+cons, -ant][-son]	ishty - ishmy	[ˈɪʃti] – [ˈɪʃmi]
	[ʃ, ʒ, tʃ, dʒ] may not precede obstruents	metchter - metchner	[ˈmɛtʃtəɹ] – [ˈmɛtʃnəɹ]
3.	*[-back][+diphthong]	youse - yoss	[ˈjaʊs] – [ˈjɑs]
	No [j] before [aɪ, aʊ, ɔɪ]	yout - yut	[ˈjaʊt] – [ˈjʌt]
4.	*[$_w$ [-diph, +ronnd, +high]	utrum - otrum	[ˈutɹəm] – [ˈoʊtɹəm]
	No word-initial [u, ʊ]	ooker - ocker	[ˈʊkəɹ] – [ˈɑkəɹ]
5.	*[+diphthong][+cont, -ant]	pyshon - pyson	[ˈpaɪʃən] – [ˈpaɪsən]
	No [aɪ, aʊ, ɔɪ] before [ʃ, ʒ]	foushert - fousert	[ˈfaʊʃəɹt] – [ˈfaʊsəɹt]

5.1.2. Materials (4)
Stimuli pairs for the unnatural constraints

	Constraint	Violating-Control	IPA
6.	*[+cont, -strident] [-sonorant]	hethker - hethler	[ˈhɛθkəɹ] – [ˈhɛθləɹ]
	No [θ, ð] before obstruents	muthpy - muspy	[ˈmʌθpi] – [ˈmʌspi]
7.	*[+cont, -strident] [-stress, +rnd]	potho - pothy	[ˈpɑθo] – [ˈpɑθi]
	No [θ, ð] before stressless rounded vowels	taitho - taithy	[ˈteɪθo] – [ˈteɪθi]
8.	*[+diph, +rnd, -back] [-ant]	noiran - nyron	[ˈnɔɪɹən] - [ˈnaɪɹən]
	No [ɔɪ] before [ʃ, ʒ, tʃ, dʒ]	boitcher - boisser	[ˈbɔɪtʃə˞] – [ˈbɔɪsəɹ]
9.	*[+cont, +voice, -ant] [+stress][-son]	zhep - zhem	[ˈʒɛp] – [ˈʒɛm]
	No [ʒ] before stressed vowel + obstruent	zhod - zhar	[ˈʒɑd] – [ˈʒɑɹ]
10.	*[$_w$ [+diph, +rnd] [-son, +voice]	ouzie - oussie	[ˈaʊzi] – [ˈaʊsi]
	Initial [aʊ, ɔɪ] may not precede a voiced ostruent	oid - oit	[ˈɔɪd] – [ˈɔɪt]

5.1.2. Materials (4): filler words

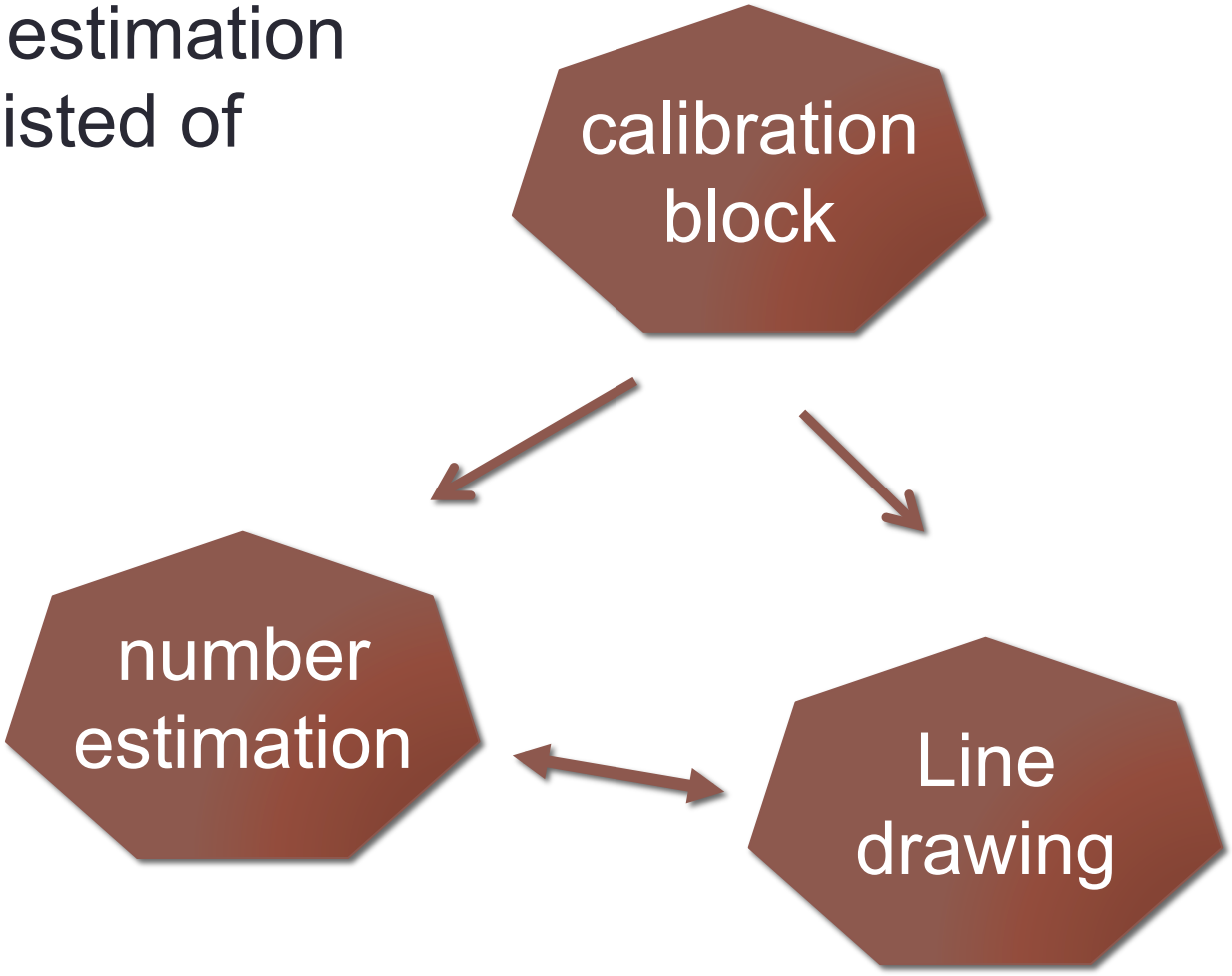
- A set of filler words (40 filler words) are included
  - partly as a way of distracting the participants from the fact that the stimuli were paired, and
  - partly in order to provide an independent check on the method.
- 20 forms each from two earlier phonotactic rating studies
  - Experiment 5 of Scholes (1966) and Albright (2009)

Presentation of the stimuli

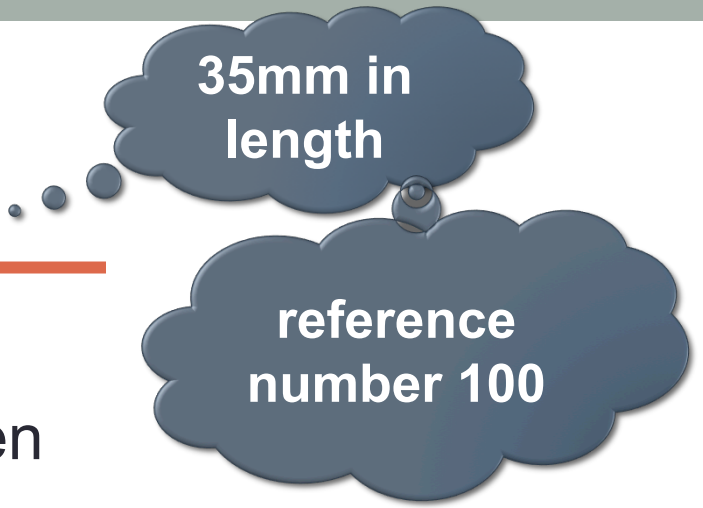
- Stimuli were presented **auditorily** as well as **orthographically**.
  - in order to maximize the chance that participants would internalize the intended phonemic representations of the nonwords represented by the IPA transcriptions.
- The auditory presentation provided the intended pronunciation in cases where orthography may be ambiguous.
- H&W chose to provide orthography as well in order to aid participants in parsing the intended sequence of phonemes.

5.1.3 Procedure

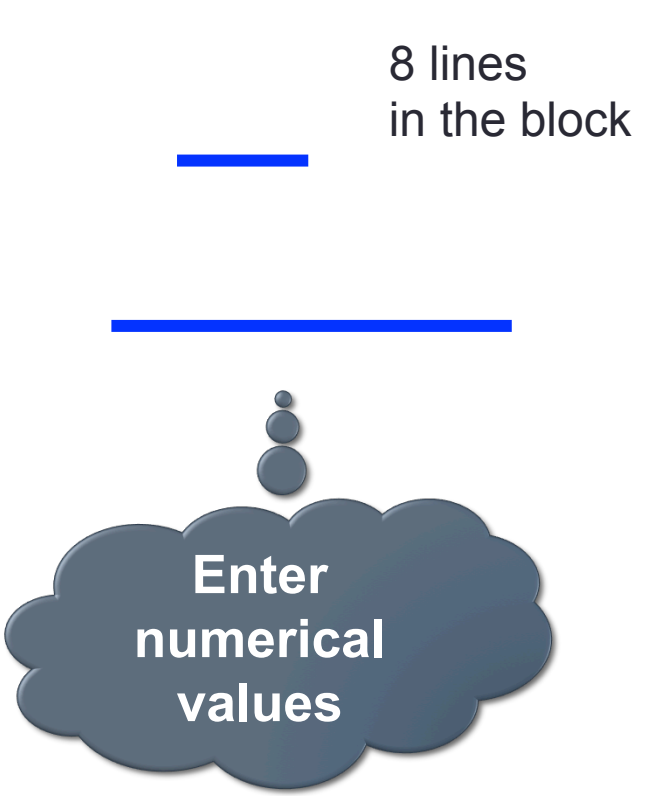
- The magnitude estimation procedure consisted of three blocks



Calibration block: number estimation

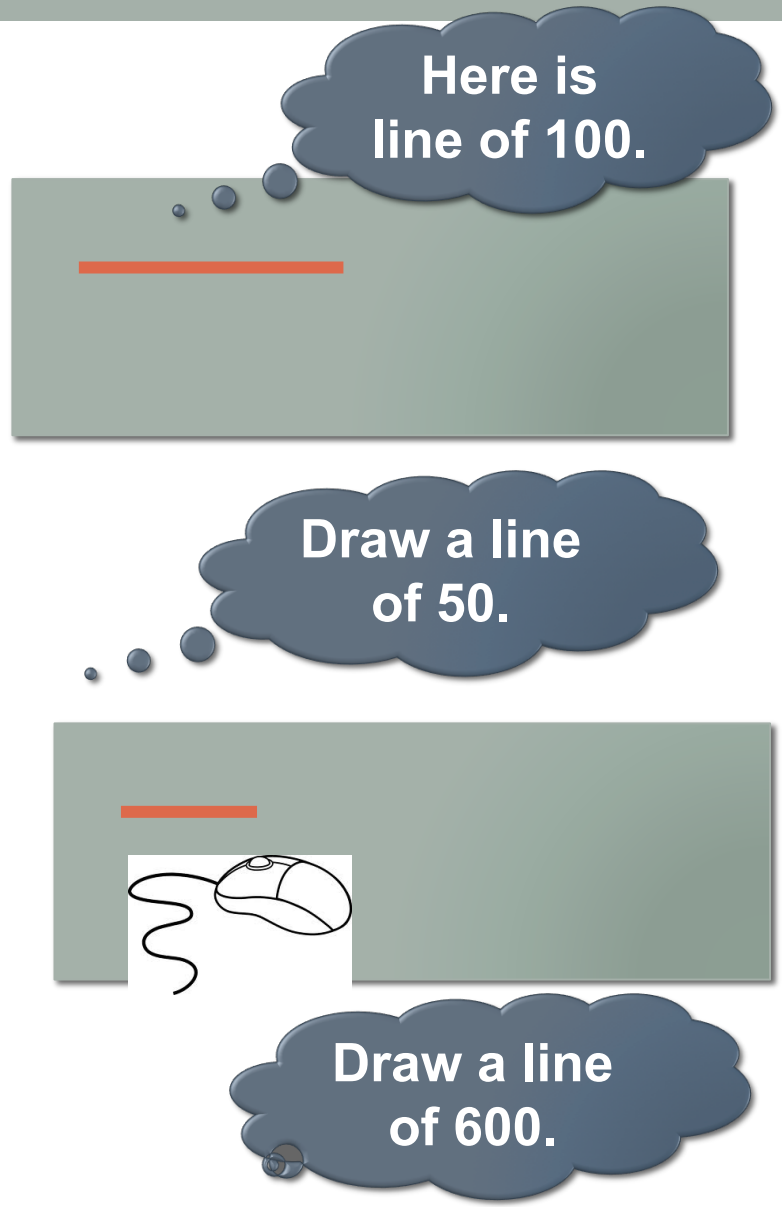


- They were told that they would see multiple lines on the computer screen and that they would **be assigning each one a number based on the length of the line.**
- They were shown a horizontal line approximately **35 mm in physical length**;
  - designated as the reference line and assigned a numerical value of 100.
- Participants were told to enter numerical values for subsequent lines based on their lengths relative to the reference line



Calibration block: Line drawing

- Participants were given eight numbers between 6 and 600 and asked **to draw lines**.
- Participants drew horizontal lines by clicking in a rectangular box on the computer screen, dragging the mouse cursor to another part of the box, then releasing the mouse button.



Rating of made-up words : Line drawing and number estimation

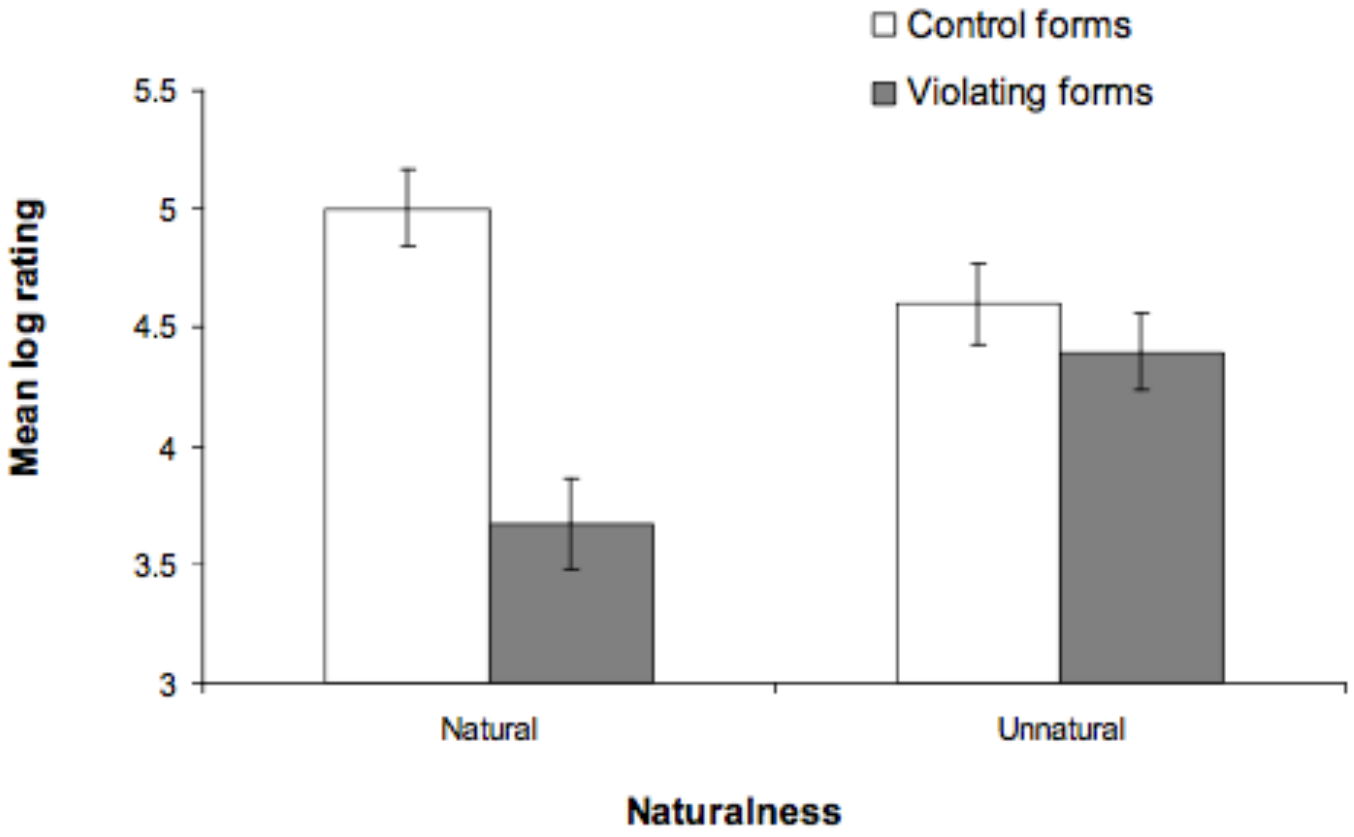
- Entering numbers or drawing lines for made-up words based on **how good the words sounded as new words of English.**
- **Familiarization phase:**
  - *bzarshk* [ˈbzɑɹʃk]
    - examples of strange-sounding
  - *kip* [ˈkɪp]
    - examples of normal-sounding English words.
  - *poik* [ˈpɔɪk]
    - an example of an intermediate word.
    - **reference word** with the number 100 and a line of units 100
- Participants were encouraged to use a proportional scale.
  - e.g., if they thought a word was twice as good a word of English as *poik,* then they would enter a number twice as high as 100 (200).

The rationale for this procedure

1. Participants are **free to extend their scale** upward or downward when they encounter new items that are unprecedentedly good or bad;
2. It makes available essentially **unlimited granularity** for their responses, useful when they encounter new words that seem intermediate between two previous words.

5.2 Main Results and Discussion

- Data from the line drawing task and the number estimation task have been collapsed.



Result

- For the **Natural constraints**, ratings for Violating forms (M = 3.67, *SD* = 1.02) were much lower than those for Control forms (M = 5.00, *SD* = 0.87).
- For the **Unnatural constraints**, the ratings for Violating forms (M = 4.40, *SD* = 0.89) were also lower than those for Control forms (M = 4.60, *SD* = 0.92), but **this difference was much smaller** — less than a sixth of the difference found for the natural constraints.

Linear mixed-effects models

- Fixed effects and an interaction:
  - Naturalness
  - Control/Violating Status
- Random effects:
  - 29 participants & 80 items
- Baayen 2008b

Results of mixed-effects model

Table 1. Results of mixed-effects model for Naturalness and Control/Violating Status.

Fixed effects

	Estimate	*95% CI*		*t-value*	*p-value*
Intercept	5.00	4.79	5.21	42.85	<0.001
Status = Violating form	−1.33	−1.58	−1.09	−9.49	<0.001
Naturalness = Unnatural	−0.40	−0.65	−0.17	−2.87	0.004
Naturalness = Unnatural & Status = Violating	1.13	0.80	1.48	5.70	<0.001

Random effects

	Standard deviation
Subject (intercept)	0.33
Item (intercept)	0.43
Residual	0.76

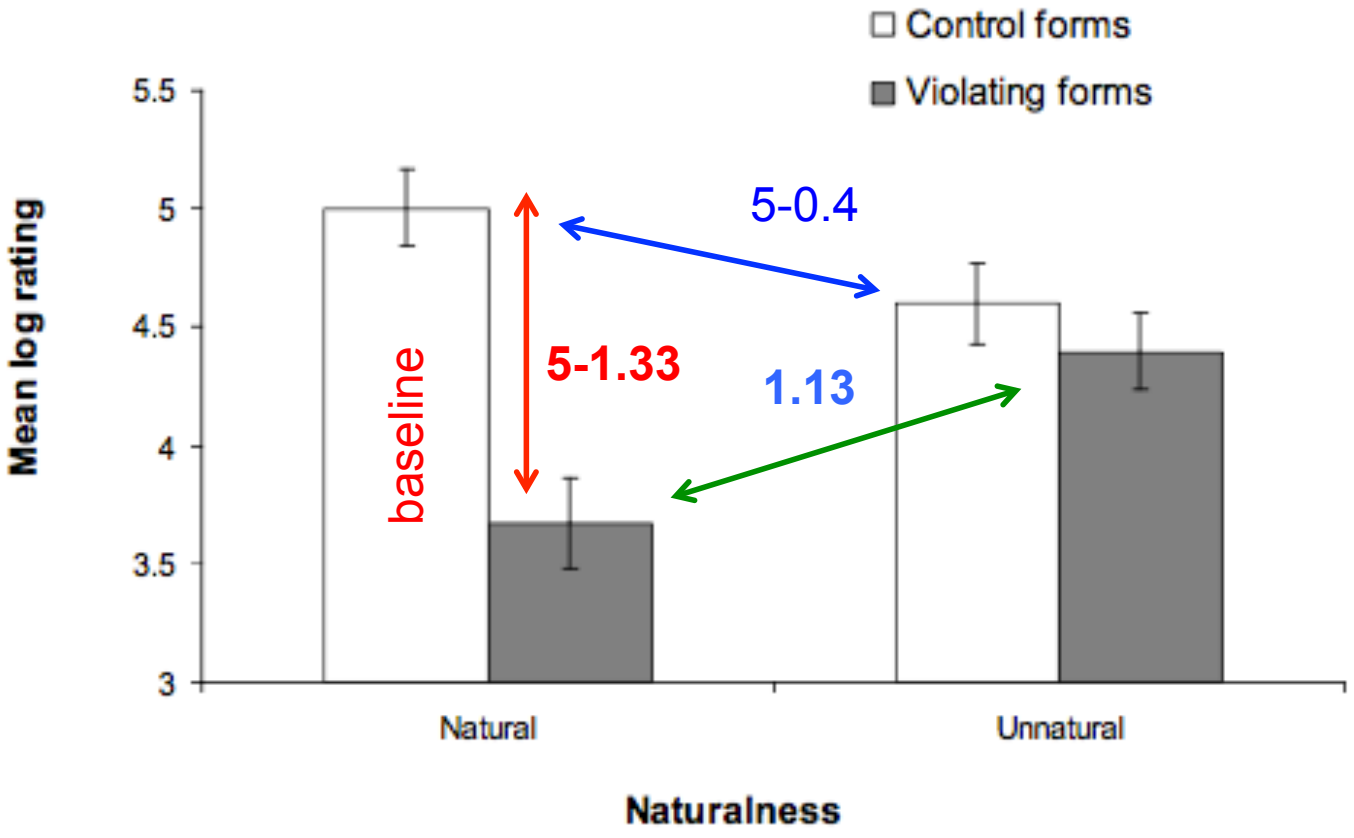
the Natural Control mean rating

Natural Violating

Unnatural Control

1.13 higher than the natural violating

Graphical interpretation of Table 1



5.2.4 Individual constraints

- **The magnitude of the effect of individual constraints**
  - estimated by taking the ratio ***log rating of control form/log rating of violator form***
- With just one exception **every natural constraint had a stronger effect on ratings than every unnatural constraint.**

Table 2. Effects of individual constraints

Constraint	Status	Pairs	Effect size
*[−cont][−cont] IN ONSET	*natural*	*cping/sping, ctice/stice*	1.65
*[glide] IN CODA	*natural*	*jouy/jout, tighw/tibe*	1.56
*[−cons][+cons] IN ONSET	*natural*	*hlup/plup, hmit/smit*	1.51
*[−cont][+nasal] IN ONSET	*natural*	*cnope/clope, pneck/sneck*	1.44
*[+labial][+dorsal] IN CODA	*natural*	*rufk/ruft, trefk/treft*	1.44
*[+dorsal][+labial] IN CODA	*natural*	*bikf/bimf, sadekp/sadect*	1.36
*[+cons][−cons] IN CODA	*natural*	*shapenr/shapent, tilr/tilse*	1.34
*[−sonorant][+sonorant] IN CODA	*natural*	*canifl/canift, kipl/kilp*	1.31
*[+labial][+labial] IN ONSET	*natural*	*bwell/brell, pwickon/twickon*	1.23
*[+cont,−strid][−sonorant]	*unnatural*	*hethker/hethler, muthpy/muspy*	1.14
*[+cont,−strid][−stress,+round]	*unnatural*	*potho/pothy, taitho/taithy*	1.10
*[+diphthong,+round,−back][−ant]	*unnatural*	*boitcher/boisser, noiran/nyron*	1.10
*[+diphthong][+cont,−anterior]	*unnatural*	*foushert/fousert, pyshon/pyson*	1.08
*[$_{\text{word}}$ [−diphthong,+round,+high]	*unnatural*	*ooker/ocker, utrum/otrum*	1.03
*[−back][+diphthong]	*unnatural*	*youse/yoss, yout/yut*	1.02
*[$_{\text{word}}$ [+diphthong,+round][+voice]	*unnatural*	*oid/oit, ouzie/oussie*	1.02
*[+cont,+voice,−ant][+str][−son]	*unnatural*	*zhep/zhem, zhod/zhar*	1.01
*[+cons,−anterior][−sonorant]	*unnatural*	*ishty/ishmy, metchter/metchner*	0.99
*[−son,−voice][−son,+voice]	*natural*	*esger/ezger, trocdal/troctal*	0.98
*[+round,+high][−cons,−sonorant]	*unnatural*	*luhallem/laihallem, tuhaim/towhaim*	0.97

Due to the speaker's failure to make a voiced closure

5.2.5 Did the unnatural constraints have any effect?

- The unnatural constraints did not have as strong an effect as the natural constraints,
- The question remains **whether the unnatural constraints had any effect at all.**
- Another linear mixed-effects model
  - **Data:** a subset of **the data containing only the unnatural constraint forms**
  - **Factors:** Control/Violating Status as a fixed effect and random intercepts for Subject and Item.
  - **Result**: The small difference between Violating and Control forms, though trending in the right direction, did not reach significance, *Estimate* = −0.20, *t-value* = −1.54, $p = 0.12$.
- We conclude that the unnatural constraints had, at best, only a small effect on participant ratings.

6. Possible objections

- **Various alternative interpretations of our results.**
- *6.1 The effect of training data*
- *6.2 Have we correctly classified our constraints for naturalness?*
- *6.3 How do experimental subjects interpret ill-formed stimuli?*
- *6.4 Could the unnatural constraints have been excluded on statistical grounds?*

7. General Discussion

- To review, the original impetus for the study was a point made by Hayes and Wilson (2008)
  - **In the course of learning the system, their model generated a large set of constraints that are evidently phonologically unnatural.**
- Hayes and Wilson suggested that either
  - (1) language learners are actually very adept at learning such generalizations, so that these constraints would turn out to valid if tested against native intuition, or
  - (2) the constraints reveal a defect in the model.
- The findings in this paper point to the latter conclusion.

Bias towards natural constraints

- Original hypothesis:
  - **Natural constraints are learned more easily than unnatural constraints.**
- This hypothesis takes two flavors:
- (1) One is that unnatural constraints are simply inaccessible to language learners → But it is unlikely.
- (2) A more plausible theory is that **learners are *biased* to favor natural generalizations**
  - Wilson 2006, Albright 2007, Berent et al. 2007, Finley 2008, Kawahara 2008, Moreton 2008, Finley and Badecker 2009, Hayes et al. 2009, and others.