

Mixed Effect Regression Analysis in Distinction of English Words with Final- obstruent Using Preceding Vowel Length

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Schedule

- Background Information
- Experiment and data
- Research question and hypothesis
- Models selection
- Results analysis
- Conclusion

Background information

- In English, there is voiced final-obstruent as well as voiceless final-obstruent. e.g. bed/bet (“d” is voiced while “t” is voiceless.)
- Make distinction of final obstruent:
 - Primary cue: voicing.
 - Secondary cue: preceding vowel length. (more significant)
- Secondary cue: preceding vowel length.
- In English, the preceding vowel length of voiced final obstruents is longer than preceding vowel length of voiceless final obstruents. (Kenyon, 1951)

Background information

- In Dutch, however, there is no voiced final-obstruent. e.g. hard/hart (“d” becomes “t”. So they are homophones.)
- When Dutch speaks English, they should be able to make distinction of final-obstruent. (using primary cue or/and secondary cue)
- Can Dutch use preceding vowel length of final-obstruent to make distinction in English?

Background information

- Whispered speech causes no vocal fold vibration. (no voicing at all)
- It is logical to infer that speakers (native and non-native speakers) rely more secondary cue (vowel length) more heavily in case of whispered speech than in case of phonated speech.

Research questions

- 1. Is there a difference in preceding vowel length between words with voiced final-obstruents and words with voiceless final-obstruents?
 - (H1: The vowel length is longer in voiced final-obstruents.)
- 2. For native and non-native speakers, is there a difference in vowel length between those two groups?
 - (H2: There is difference.)
- 3. Is there a difference in preceding vowel length between whispered speech and phonated speech?
 - (H3: Whispered speech leads to longer preceding vowel length.)

Experiment

- 1. There were 20 non-native speakers and 8 native speakers.
- 2. Monosyllabic English words were given. They could be divided in group of voiced/voiceless final obstruent, and fricative/stop.
- 3. Both native and non-native speakers pronounce words in both whispered speech and phonated speech.
- 4. Measured the vowels length of each words as time duration in unit of millisecond.

Data

- Subject: Native speakers (NS) and Non-native speaker (NNS)

- Item:

	Whisper	Obstruent	Voicing	WhCtV
1	Whispered	Fricative	Voiced	111
2	Whispered	Fricative	Voiceless	110
3	Whispered	Stop	Voiced	101
4	Whispered	Stop	Voiceless	100
5	Phonated	Fricative	Voiced	011
6	Phonated	Fricative	Voiceless	010
7	Phonated	Stop	Voiced	001
8	Phonated	Stop	Voiceless	000

whisper (Wh)	obstruent (Ct)	voicing (V)
whispered: 1	fricative: 1	voice: 1
phonated: 0	Stop: 0	voiceless: 0

- Vowel Length (DV)

Data

	A	B	C	D	E	F	G	H	I	J
1	Participant	Group	+Wh+Ct+V	+Wh+Ct-V	+Wh-Ct+V	+Wh-Ct-V	-Wh+Ct+V	-Wh+Ct-V	-Wh-Ct+V	-Wh-Ct-V
2	F1AH36	NS	257.29	142.5	311	258.47	261.69	125.33	264.03	230.43
3	F1AM27	NS	258.7	165.04	316.68	299.02	232.31	144.24	252.99	268.63
4	F1MG27	NS	225.25	163.43	290.57	248.1	242.16	138.57	255.94	235.19
5	F1NP23	NS	244.53	187.79	284.46	271.79	224.58	149.23	263.78	246.29
6	F1NR28	NS	213.7	148.74	259.34	217.67	178.11	94.34	195.56	159.6
7	M1BC38	NS	275.51	198.35	288.24	256.49	256.68	139.2	239.45	229.95
8	M1JF41	NS	224.91	156.37	272.72	230.82	259.03	146.13	284.34	216.12
9	M1TW30	NS	206.88	126.19	257.27	205.77	190.71	89.25	224.76	180.57
10	F2AD19	NNS	179.16	178.36	257.45	247.48	177.94	153.58	230.38	220.59
11	F2AN24	NNS	198.75	180.75	237.24	240.39	215.81	196.93	240.12	240.46
12	F2BP23	NNS	197.54	193.93	259.18	267.49	225.62	232.69	271.16	275.34
13	F2CG25	NNS	186.83	180.26	261.15	245.16	184.52	177.6	242.08	246.27
14	F2EC22	NNS	253.47	238.22	320.04	322.83	217.46	214.18	288.25	284.03
15	F2MB21	NNS	215.97	212.78	292.03	280.13	218.14	197.27	264.1	271.69
16	F2MK26	NNS	255.01	209.97	292.39	282.53	221.57	188.67	248.45	230.72
17	F2MT20	NNS	243.26	243.24	326.37	332.46	201.48	195.84	278.84	266.45
18	F2MV22	NNS	221.47	195.22	254.8	258.34	195.16	157.05	213.29	196.95
19	F2WH23	NNS	207.89	207.43	300.85	308.63	202.21	286.89	256.09	260.03
20	M2AM21	NNS	193.8	163.07	225.08	233.3	201.58	155.59	207.7	223.78
21	M2JJ25	NNS	209.82	188.75	277.03	271.49	198.71	195.87	212.97	196.65
22	M2JK27	NNS	153.42	137.1	238.41	232.68	162.5	135.55	210.75	180.02
23	M2JM24	NNS	263.09	241.04	369.65	368.94	228.99	198.57	291.4	248.88
24	M2MA25	NNS	173.59	168.21	237.27	215.59	157.5	138.17	193.02	180.43
25	M2ML24	NNS	207.94	188.29	304.64	284.94	170.89	148.68	242.61	233.6
26	M2RJO39	NNS	194.77	153.89	283.82	252.23	168.34	129.21	228.96	201
27	M2RM24	NNS	225.99	227.23	305.12	307.36	204.51	198.1	259.05	252.27
28	M2RR24	NNS	201.97	178.35	248.21	235.18	172.13	149.31	209.61	188.4
29	M2RW29	NNS	199.58	154.06	238.73	215.32	206.32	159.27	215.27	197.31

Data

	A	B	C	D	E	F	G
1	Parts	Group	WhCtV	Wh	Ct	V	VL
2		1 NS	111	whispered	fricative	voiced	257.29
3		1 NS	110	whispered	fricative	voiceless	142.5
4		1 NS	101	whispered	stop	voiced	311
5		1 NS	100	whispered	stop	voiceless	258.47
6		1 NS	011	phonated	fricative	voiced	261.69
7		1 NS	010	phonated	fricative	voiceless	125.33
8		1 NS	001	phonated	stop	voiced	264.03
9		1 NS	000	phonated	stop	voiceless	230.43
10		2 NS	111	whispered	fricative	voiced	258.7
11		2 NS	110	whispered	fricative	voiceless	165.04
12		2 NS	101	whispered	stop	voiced	316.68
13		2 NS	100	whispered	stop	voiceless	299.02
14		2 NS	011	phonated	fricative	voiced	232.31
15		2 NS	010	phonated	fricative	voiceless	144.24
16		2 NS	001	phonated	stop	voiced	252.99
17		2 NS	000	phonated	stop	voiceless	268.63
18		3 NS	111	whispered	fricative	voiced	225.25
19		3 NS	110	whispered	fricative	voiceless	163.43
20		3 NS	101	whispered	stop	voiced	290.57
21		3 NS	100	whispered	stop	voiceless	248.1
22		3 NS	011	phonated	fricative	voiced	242.16
23		3 NS	010	phonated	fricative	voiceless	138.57
24		3 NS	001	phonated	stop	voiced	255.94

Mixed Effect Regression

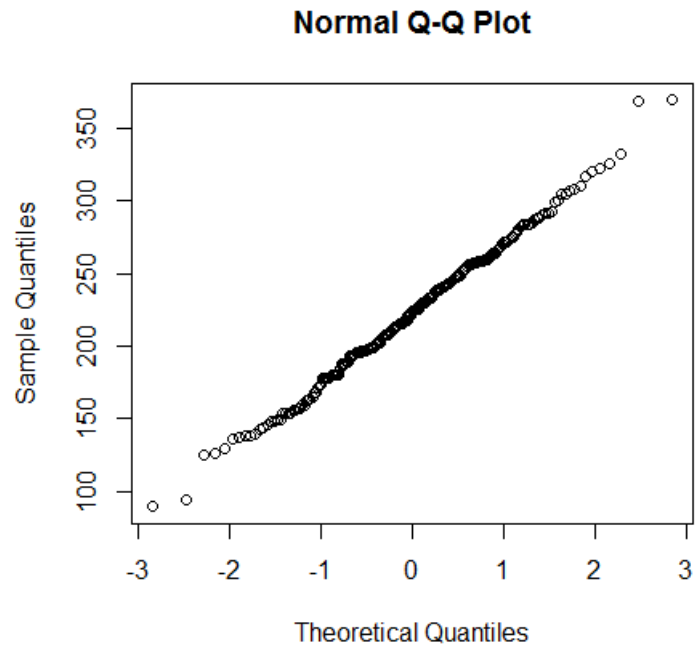
- Suitable for categorical and continuous predictors.
- It contains fixed effect and random effect.
- Results can be generalized across subjects and items.
- Easy to add random effect.

$$y_i = \mu_a + \epsilon_{j[i]} + (\mu_b + \delta_{j[i]}) \times x_i + e_i$$

Mixed Effect Regression

- Fixed effect: Voicing (V), Group, Whisper(wh).
- Random effect:
 - 1. Participants (intercept)
 - 2. Words (intercept)
 - 3. Random slope for participants group (NS/NNS) per words.
 - 4. Random slope for words features (Voicing? Whispering?) per participants.

Normality of ID (vowel length)

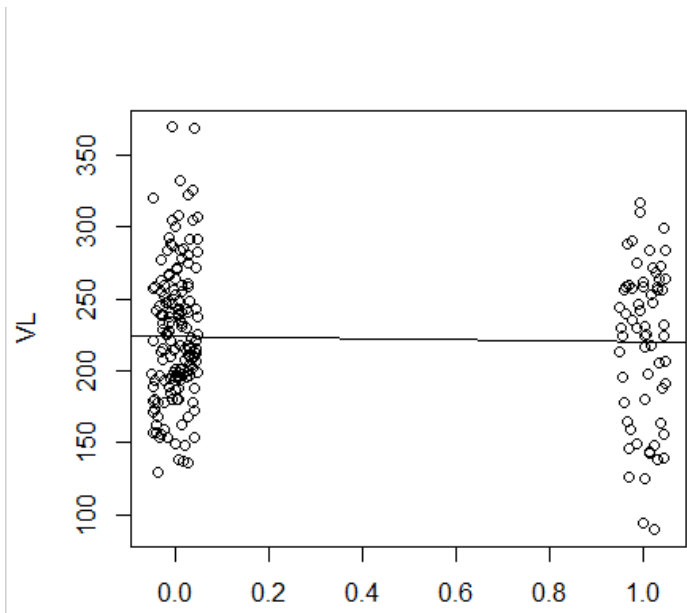


```
> shapiro.test(df$VL)
```

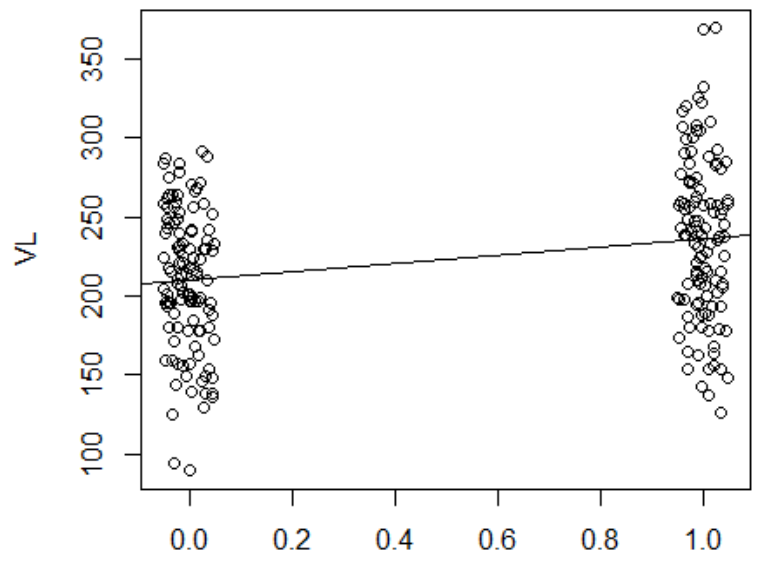
```
shapiro-wilk normality test
```

```
data: df$VL
```

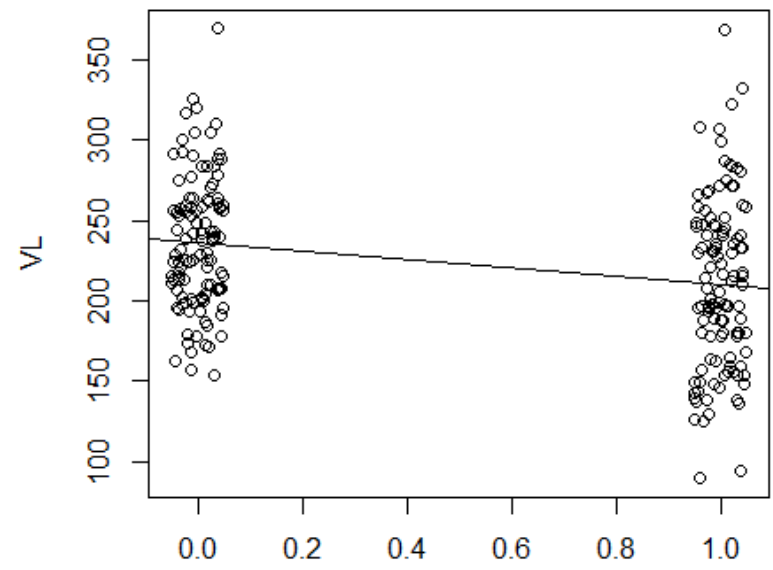
```
W = 0.9962, p-value = 0.8605
```



VL~Group



VL~Wh



VL~V

Library in R

```
> library(lme4)
```

```
> vl.lmer1<-lmer(VL~Group+(1|Group)+(1+V|WhCtV),data=df)
```

Model: H1 (voiced/voiceless)

(No random slope)

```
> AIC(vl.lmerV1,vl.lmerV2,vl.lmerV3)
```

	df	AIC
vl.lmerV1	5	2121.771
vl.lmerV2	4	2339.714
vl.lmerV3	4	2230.095

VL~V+(1 Parts)+(1 WhCtV)	VL~V+(1 WhCtV)	VL~V+(1 Parts)																																																																																								
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Model: H1 (voiced/voiceless)

(With random slope)

> AIC(vl.lmerVS1,vl.lmerVS2,vl.lmerVS3)

	df	AIC
vl.lmerVS1	9	2063.322
vl.lmerVS2	6	2219.355
vl.lmerVS3	6	2342.670

VL~V+(1+V Parts)+(1+Group WhCtV)	VL~V+(1+Group WhCtV)	VL~V+(1+V Parts)
<pre> Random effects: Groups Name Variance Std.Dev. Corr Parts (Intercept) 527.30 22.963 vvoiceless 30.46 5.519 1.00 whctv (Intercept) 1453.96 38.131 GroupNS 757.80 27.528 0.12 Residual 318.78 17.854 Number of obs: 224, groups: Parts, 28; whctv, 8 Fixed effects: Estimate Std. Error t value (Intercept) 226.444 19.751 11.465 vvoiceless -6.101 26.991 -0.226 Correlation of Fixed Effects: (Intr) vvoiceless -0.670 </pre>	<pre> Random effects: Groups Name Variance Std.Dev. Corr whctv (Intercept) 1419.5 37.68 GroupNS 620.9 24.92 0.17 Residual 1000.2 31.63 Number of obs: 224, groups: whctv, 8 Fixed effects: Estimate Std. Error t value (Intercept) 227.828 19.065 11.950 vvoiceless -5.768 26.962 -0.214 Correlation of Fixed Effects: (Intr) vvoiceless -0.707 </pre>	<pre> Random effects: Groups Name Variance Std.Dev. Corr Parts (Intercept) 327.39 18.09 vvoiceless 53.14 7.29 1.00 Residual 1764.42 42.01 Number of obs: 224, groups: Parts, 28 Fixed effects: Estimate Std. Error t value (Intercept) 236.263 5.239 45.10 vvoiceless -26.297 5.780 -4.55 Correlation of Fixed Effects: (Intr) vvoiceless -0.365 </pre>

Model: H2 (NS/NNS)

(No random slope)

```
> AIC(vl.lmerGr1,vl.lmerGr2,vl.lmerGr3)
```

	df	AIC
vl.lmerGr1	5	2124.351
vl.lmerGr2	4	2233.681
vl.lmerGr3	4	2358.928

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Residual		1133	33.66																																																																																							
	Estimate	Std. Error	t value																																																																																							
(Intercept)	224.342	13.696	16.380																																																																																							
GroupNS	-4.299	4.978	-0.864																																																																																							
(Intr)																																																																																										
GroupNS	-0.104																																																																																									
Groups	Name	Variance	Std.Dev.																																																																																							
Parts	(Intercept)	467.6	21.62																																																																																							
Residual		1969.7	44.38																																																																																							
	Estimate	Std. Error	t value																																																																																							
(Intercept)	224.342	5.974	37.55																																																																																							
GroupNS	-4.299	11.176	-0.38																																																																																							
(Intr)																																																																																										
GroupNS	-0.535																																																																																									

Model: H2 (NS/NNS)

(With random slope)

> AIC(v1.lmerGrS1,v1.lmerGrS2,v1.lmerGrS3)

	df	AIC
v1.lmerGrS1	9	2064.443
v1.lmerGrS2	6	2221.049
v1.lmerGrS3	6	2357.928

VL~Group+(1+V Parts)+(1+Group WhCtV)	VL~Group+(1+Group WhCtV)	VL~Group+(1+V Parts)																																																																																																																						
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Model: H3 (Whispered/f

(No random slope)

> AIC(vl.1merwh1, vl.1merwh2, vl.1merwh3)

	df	AIC
vl.1merwh1	5	2121.823
vl.1merwh2	4	2230.147
vl.1merwh3	4	2340.945

VL~Wh+(1 Parts)+(1 WhCtV)	VL~Wh+(1 WhCtV)	VL~Wh+(1 Parts)																																																																																								
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Model: H3 (Whispered/

(With random slope)

> AIC(v1.lmerwhs1,v1.lmerwhs2,v1.lmerwhs3)

	df	AIC
v1.lmerwhs1	9	2062.418
v1.lmerwhs2	6	2218.446
v1.lmerwhs3	6	2339.783

VL~Wh+(1+V Parts)+(1+Group WhCtV)	VL~Wh+(1+Group WhCtV)	VL~Wh+(1+V Parts)
<pre> Random effects: Groups Name Variance Std.Dev. Corr Parts (Intercept) 527.36 22.964 vvoiceless 30.39 5.513 1.00 whctv (Intercept) 1275.91 35.720 GroupNS 757.90 27.530 0.20 Residual 318.78 17.854 Number of obs: 224, groups: Parts, 28; whctv, 8 Fixed effects: Estimate Std. Error t value (Intercept) 211.01 18.71 11.275 whwhispered 24.93 25.01 0.997 Correlation of Fixed Effects: (Intr) whwhispered -0.668 </pre>	<pre> Random effects: Groups Name Variance Std.Dev. Corr whctv (Intercept) 1238.0 35.19 GroupNS 620.9 24.92 0.26 Residual 1000.2 31.63 Number of obs: 224, groups: whctv, 8 Fixed effects: Estimate Std. Error t value (Intercept) 212.82 17.67 12.041 whwhispered 24.94 25.00 0.998 Correlation of Fixed Effects: (Intr) whwhispered -0.707 </pre>	<pre> Random effects: Groups Name Variance Std.Dev. Corr Parts (Intercept) 302.9 17.41 vvoiceless 516.6 22.73 0.26 Residual 1644.1 40.55 Number of obs: 224, groups: Parts, 28 Fixed effects: Estimate Std. Error t value (Intercept) 217.423 5.504 39.50 whwhispered 25.540 5.418 4.71 Correlation of Fixed Effects: (Intr) whwhispered -0.492 </pre>

Result (voiced/voiceless)

- H1: $VL \sim V + (1 + V | \text{Parts}) + (1 + \text{Group} | \text{WhCtV})$

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Parts	(Intercept)	527.30	22.963	
	vvoiceless	30.46	5.519	1.00
whCtV	(Intercept)	1453.96	38.131	
	GroupNS	757.80	27.528	0.12
Residual		318.78	17.854	

Number of obs: 224, groups: Parts, 28; whCtV, 8

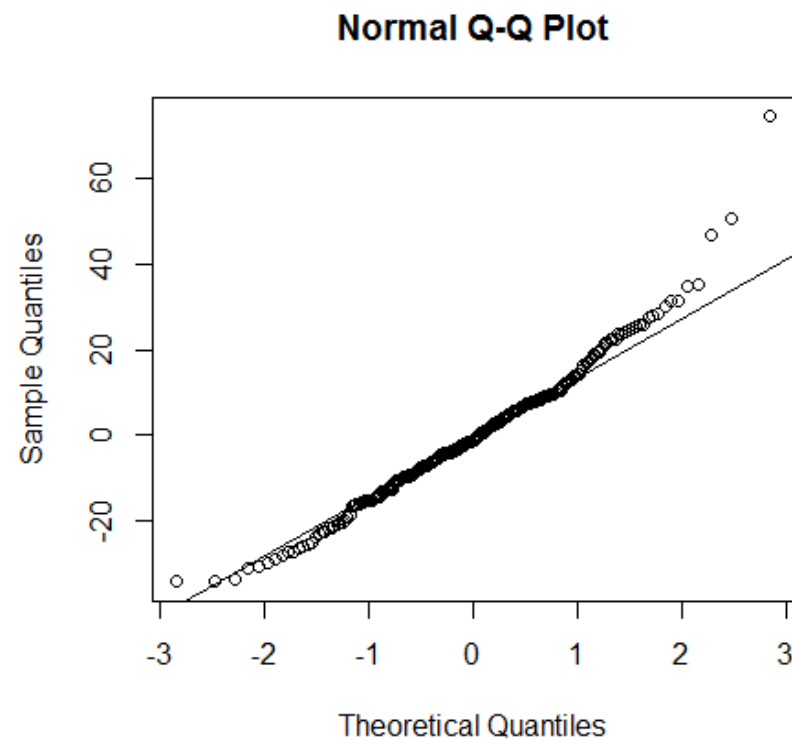
Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	226.444	19.751	11.465
vvoiceless	-6.101	26.991	-0.226

Correlation of Fixed Effects:

	(Intr)
vvoiceless	-0.670

AIC=2063.322



QQ plot of residual

Result (NS/NNS)

- H2: $VL \sim \text{Group} + (1 + V | \text{Parts}) + (1 + \text{Group} | \text{WhCtV})$

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Parts	(Intercept)	539.3	23.222	
	vvoiceless	30.5	5.523	1.00
whCtV	(Intercept)	1281.1	35.792	
	GroupNS	818.5	28.609	0.21
Residual		318.7	17.853	

Number of obs: 224, groups: Parts, 28; whCtV, 8

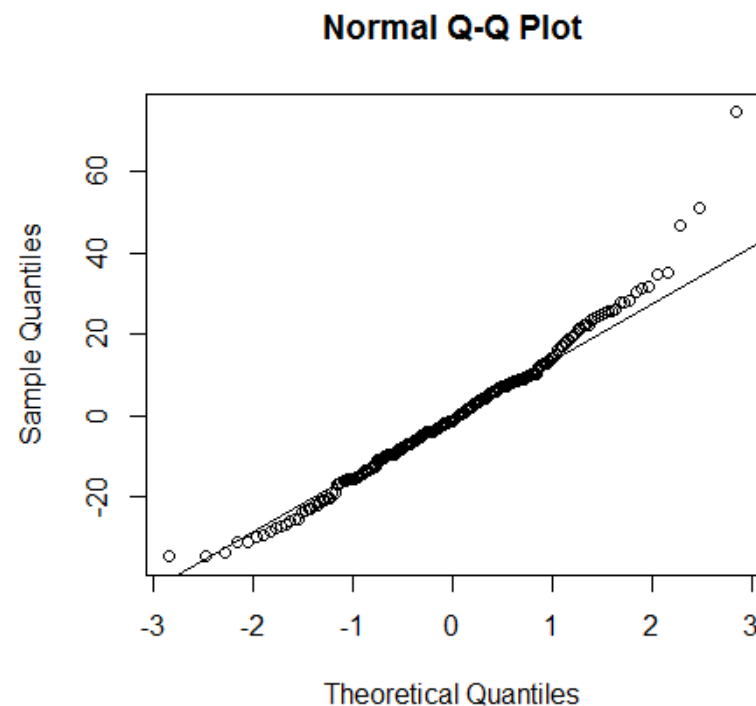
Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	223.583	13.987	15.985
GroupNS	-1.595	15.025	-0.106

Correlation of Fixed Effects:

(Intr)	
GroupNS	-0.037

AIC=2064.443



QQ plot of residual

Result (Whispered/Phonated)

- $VL \sim Wh + (1 + V | Parts) + (1 + Group | WhCtV)$

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Parts	(Intercept)	527.36	22.964	
	vvoiceless	30.39	5.513	1.00
whctv	(Intercept)	1275.91	35.720	
	GroupNS	757.90	27.530	0.20
Residual		318.78	17.854	

Number of obs: 224, groups: Parts, 28; whCtV, 8

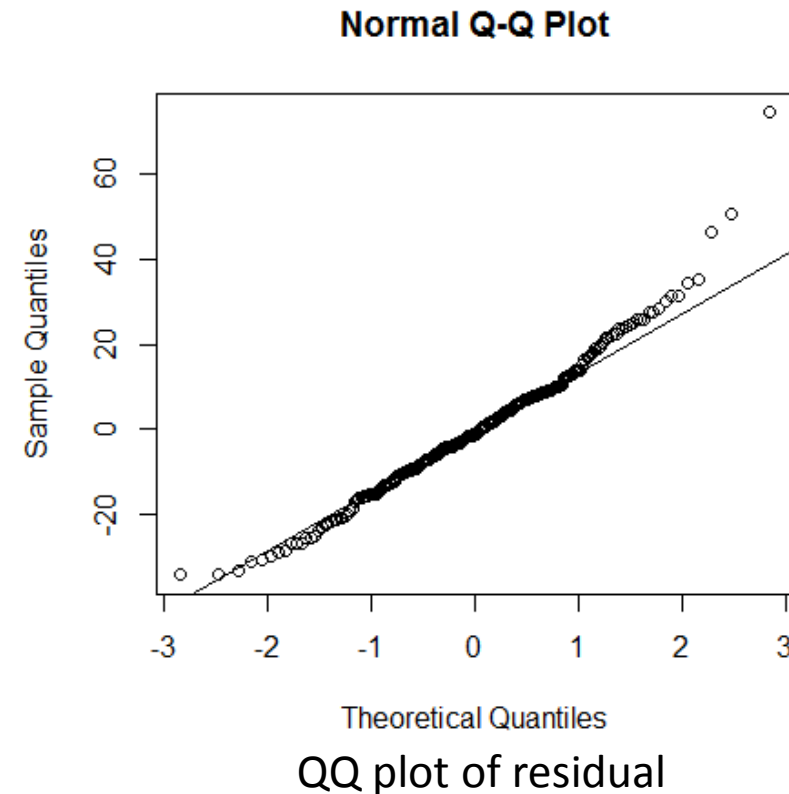
Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	211.01	18.71	11.275
whwhispered	24.93	25.01	0.997

Correlation of Fixed Effects:

	(Intr)
whwhispered	-0.668

AIC=2062.418



Multiple fixed effect

> AIC(vl.lmerM, vl.lmerMS)

	df	AIC
vl.lmerM	7	2109.642
vl.lmerMS	11	2050.785

1	VL~Group+V+Wh+(1 Parts)+(1 WhCtV)	VL~Group+V+Wh+(1+V Parts)+(1+Group WhCtV)
	<pre> Random effects: Groups Name Variance Std.Dev. Parts (Intercept) 650.9 25.51 whCtV (Intercept) 1522.8 39.02 Residual 503.2 22.43 Number of obs: 224, groups: Parts, 28; whCtV, 8 Fixed effects: Estimate Std. Error t value (Intercept) 224.721 24.723 9.090 GroupNS -4.299 11.176 -0.385 Vvoiceless -26.297 27.756 -0.947 whwhispered 25.540 27.756 0.920 Correlation of Fixed Effects: (Intr) GropNS vvc1ss GroupNS -0.129 Vvoiceless -0.561 0.000 whwhispered -0.561 0.000 0.000 </pre>	<pre> Random effects: Groups Name Variance Std.Dev. Corr Parts (Intercept) 539.24 23.22 Vvoiceless 30.58 5.53 1.00 whctv (Intercept) 1486.77 38.56 GroupNS 818.23 28.60 0.10 Residual 318.73 17.85 Number of obs: 224, groups: Parts, 28; whCtV, 8 Fixed effects: Estimate Std. Error t value (Intercept) 214.931 24.238 8.868 GroupNS -1.558 15.033 -0.104 Vvoiceless -7.823 27.362 -0.286 whwhispered 25.079 27.327 0.918 Correlation of Fixed Effects: (Intr) GropNS vvc1ss GroupNS -0.048 Vvoiceless -0.553 -0.023 whwhispered -0.564 0.000 0.000 </pre>

Multiple fixed effect

> AIC(v1.lmerMC, v1.lmerMCS)

	df	AIC
v1.lmerMC	11	2028.113
v1.lmerMCS	15	2017.376

VL~Group*V*Wh+(1 Parts)+(1 WhCtV)	VL~Group*V*Wh+(1+V Parts)+(1+Group WhCtV)																																																																																																																															
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Result

95% confidence interval for the slope estimate:

	H1: Vvoiceless	H1:Vvoiceless (only Parts)	H2: GroupNS	H2: GroupNS (V Parts)	H3: WhWhispered	H3: WhWhispered (only Parts)
Estimate	-6.101	-26.3	-1.595	16.026	24	25.54
Std. Error	26.991	5.64	15.025	10.81	25.01	5.418
CI (UP)	47.881	-15.02	28.455	37.646	74.02	36.376
CI (DOWN)	-60.083	-37.58	-31.645	-5.594	-26.02	14.704

Result

- H1: Words with voiceless final obstruent seem to have smaller vowel length. If we **merely** consider random effect of participants, the result is significant. But when we consider the native/non-native effect per items, the difference is obviously smaller and not significant at all.
- H2: There is no difference in preceding vowel length between native and non-native speakers. But when we consider the voiced/voiceless effect per participants, the difference is relatively obvious.
- H3: Words in whispered speech have longer vowel length. When we merely consider random effect of participants, the result is significant.

Conclusion

- 1. Dutch can use vowel length as secondary cue no matter voiced/voiceless final obstruent.
- 2. Whispered speech can cause longer vowel length, no matter for Dutch or native English speakers.

- Thank you and Question?