Experimental Data Analysis

in ©MATLAB

Lecture 7:

Factorial ANOVA, ANCOVA, MANOVA
Example of research project solution

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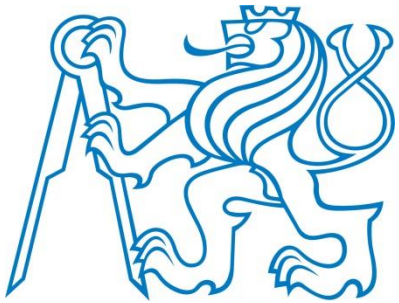


Why Factorial ANOVA?

- In an One-way ANOVA, we selected a random sample for each column/treatment group

Example

The measure of maximum phonation time through sustained vowel phonation well reflects subjects' aerodynamic efficiency of the vocal tract. Normal speaker should be able to perform sustained vowel phonation for more than 15 second. The aim of the research was to verify if there is some impairment of respiratory control across patients with Huntington's disease and Parkinson's disease as compared to healthy control subjects.

Maximum phonation time

Groups ← Single factor „group“

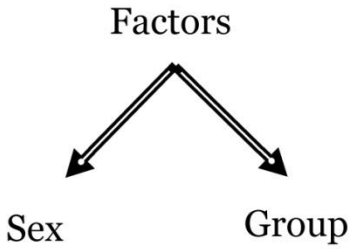
Random sample within each group.

Huntington's disease	Parkinson's disease	Healthy controls
5	8	29
7	17	22
8	11	18
5	10	18
5	15	13
4	10	11

Why Factorial ANOVA?

- In a One-way ANOVA, we selected a random sample for each column/treatment group
- A factorial ANOVA compare means across two or more independent variables
- A two-way ANOVA allows us to “account for variation” at the ROW level due to some other factor or grouping

Maximum phonation time



Sex	Group		
	Huntington's disease	Parkinson's disease	Healthy controls
F	5	8	29
F	7	17	22
F	8	11	18
M	5	10	18
M	5	15	13
M	4	10	11

Why Factorial ANOVA?

- In a One-way ANOVA, we selected a random sample for each column/treatment group
- A factorial ANOVA compare means across two or more independent variables
- A two-way ANOVA allows us to "account for variation" at the ROW level due to some other factor or grouping
- This allows greater focus on COLUMN or GROUP differences making it easier to detect group differences
- We are attempting to minimize the ERROR variance due to the additional variance in the ROWS
- We will now have 5 types of Sum of Squares
  - Total Sum of Squares (SST)
  - Column (Between) Sum of Squares (SSC)
  - Error (Within) Sum of Squares (SSE)
  - Rows (Blocks) Sum of Squares (SSB)
  - Column × Blocks Sum of Squares (SSCB)

ANOVA

One-way vs. Two-way

Group

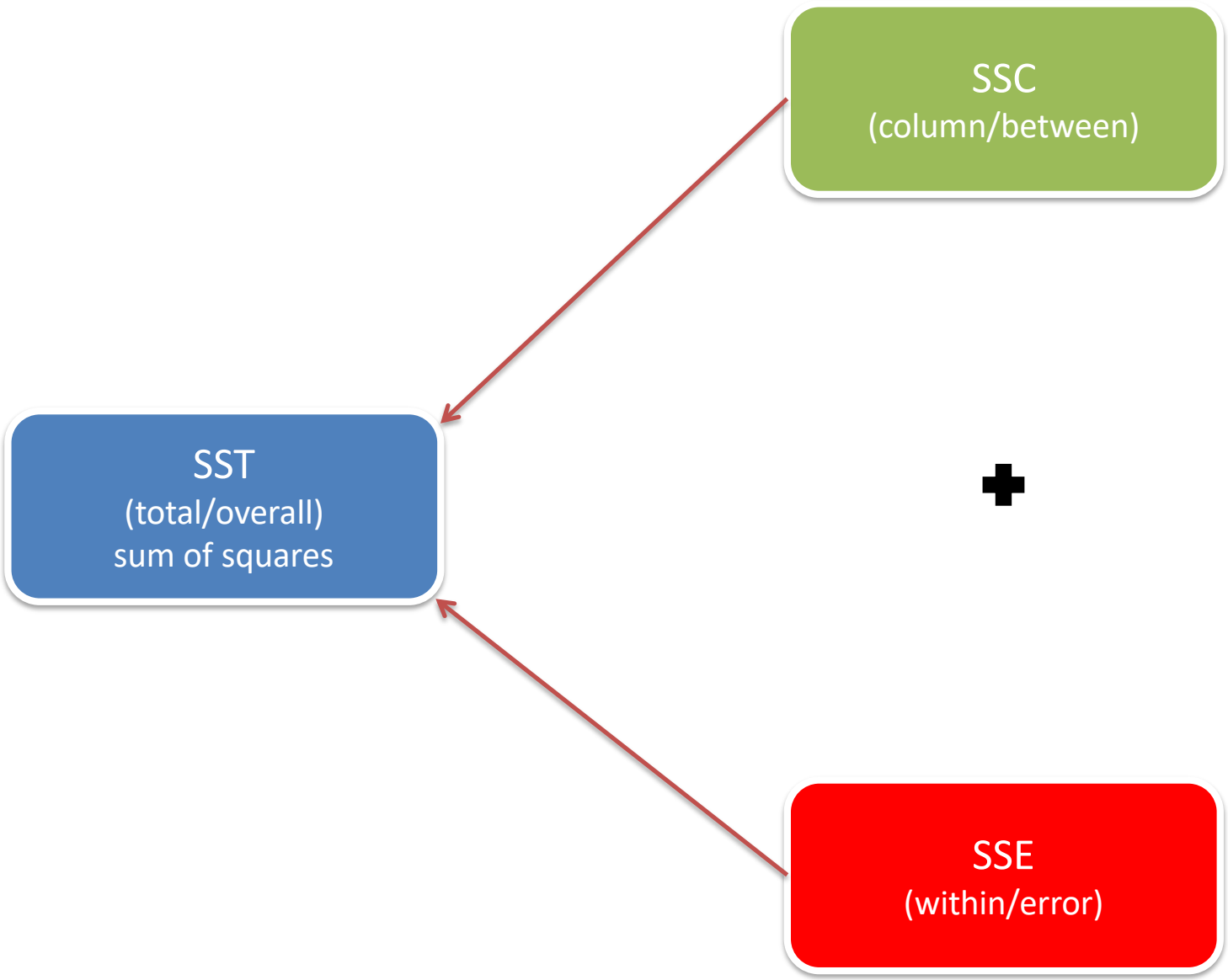
Huntington's disease	Parkinson's disease	Healthy controls
5	8	29
7	17	22
8	11	18
5	10	18
5	15	13
4	10	11
$\bar{x}_1 = 5.7$	$\bar{x}_2 = 11.8$	$\bar{x}_3 = 18.5$

Total average $\bar{\bar{x}} = 12$

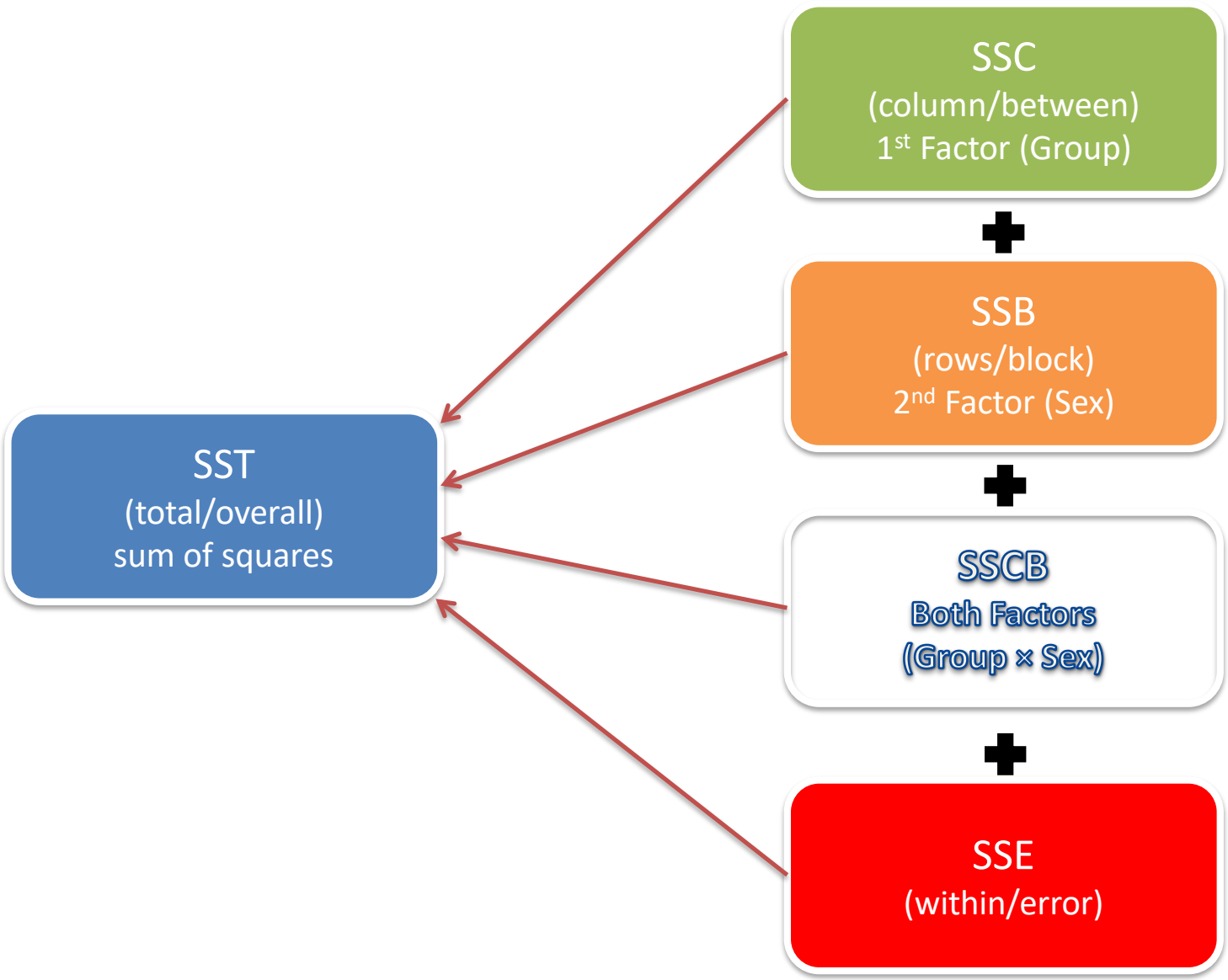
ANOVA
One-way vs. **Two-way**
Group & Sex

	Huntington's disease	Parkinson's disease	Healthy controls	
Female	5	8	29	
	7	17	22	
	8	11	18	
	6.7	8.7	23	$\bar{x}_{R1} = 13.9$
Male	5	10	18	
	5	15	13	
	4	10	11	
	4.7	11.7	14	$\bar{x}_{R2} = 10.1$
	$\bar{x}_{C1} = 5.7$	$\bar{x}_{C2} = 11.8$	$\bar{x}_{C3} = 18.5$	$\bar{\bar{x}} = 12$

Partitioning Sum of Squares: One-way ANOVA



Partitioning Sum of Squares: Two-way ANOVA



Established hypothesis?

1) H_0: Type of disease will have no significant effect on maximum phonation time;

2) H_0: Gender will have no significant effect on maximum phonation time;

3) H_0: Interaction of type of disease and gender will have no significant effect on maximum phonation time; in other words, maximum phonation time is not gender-dependent across different types of neurological diseases.

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	SSC	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	SSB	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	$SSCB$	$(C\text{-}1)(B\text{-}1)$	$\frac{SSCB}{df_{interaction}}$	$\frac{MSI}{MSE}$
Within (Error)	SSE	N-C*B	$\frac{SSE}{df_{error}}$	
Total	SST	N-1		

N = total observations; C = number of columns; B = number of rows

Sum of Squares 1st Factor (Group)

Sex	Huntington's disease	Parkinson's disease	Healthy controls	Average
Female	6.7	12.0	23.0	13.9
Male	4.7	11.7	14.0	10.1
Average	5.7	11.8	18.5	12.0

Huntington Parkinson Healthy

$$SSC = \sum r(\bar{x} - \bar{\bar{x}})^2 + \sum r(\bar{x} - \bar{\bar{x}})^2 + \sum r(\bar{x} - \bar{\bar{x}})^2$$

r = number of data in each column

Female	Squared Group mean - Grand mean	
5	$(5.7 - 12)^2$	40.1
7	$(5.7 - 12)^2$	40.1
8	$(5.7 - 12)^2$	40.1
8	$(11.8 - 12)^2$	0.03
17	$(11.8 - 12)^2$	0.03
11	$(11.8 - 12)^2$	0.03
29	$(18.5 - 12)^2$	42.3
22	$(18.5 - 12)^2$	42.3
18	$(18.5 - 12)^2$	42.3
	Sum	**247.2**

Male	Squared Group mean - Grand mean	
5	$(5.7 - 12)^2$	40.1
5	$(5.7 - 12)^2$	40.1
4	$(5.7 - 12)^2$	40.1
10	$(11.8 - 12)^2$	0.03
15	$(11.8 - 12)^2$	0.03
10	$(11.8 - 12)^2$	0.03
18	$(18.5 - 12)^2$	42.3
13	$(18.5 - 12)^2$	42.3
11	$(18.5 - 12)^2$	42.3
	Sum	**247.2**

***SSC* = 247.2 + 247.2 = 494.4**

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	SSB	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	$SSCB$	(C-1)(B-1)	$\frac{SSCB}{df_{interaction}}$	$\frac{SSI}{MSE}$
Within (Error)	SSE	N-C*B	$\frac{SSE}{df_{error}}$	
Total	SST	N-1		

N = total observations; C = number of columns; B = number of rows

Sum of Squares 2nd Factor (Sex)

Sex	Huntington's disease	Parkinson's disease	Healthy controls	Average
Female	6.7	12.0	23.0	13.9
Male	4.7	11.7	14.0	10.1
Average	5.7	11.8	18.5	12.0

$$SSB = \sum^{\text{Female}} r(\bar{x} - \bar{\bar{x}})^2 + \sum^{\text{Male}} r(\bar{x} - \bar{\bar{x}})^2$$

r = number of data in each column

Female	Squared Female mean - Grand mean	
5	$(13.9 - 12)^2$	3.6
7	$(13.9 - 12)^2$	3.6
8	$(13.9 - 12)^2$	3.6
8	$(13.9 - 12)^2$	3.6
17	$(13.9 - 12)^2$	3.6
11	$(13.9 - 12)^2$	3.6
29	$(13.9 - 12)^2$	3.6
22	$(13.9 - 12)^2$	3.6
18	$(13.9 - 12)^2$	3.6
	Sum	**32.1**

Male	Squared Male mean - Grand mean	
5	$(10.1 - 12)^2$	3.6
5	$(10.1 - 12)^2$	3.6
4	$(10.1 - 12)^2$	3.6
10	$(10.1 - 12)^2$	3.6
15	$(10.1 - 12)^2$	3.6
10	$(10.1 - 12)^2$	3.6
18	$(10.1 - 12)^2$	3.6
13	$(10.1 - 12)^2$	3.6
11	$(10.1 - 12)^2$	3.6
	Sum	**32.1**

***SSB* = 32.1 + 32.1 = 64.2**

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	64.2	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	$SSCB$	$(C\text{-}1)(B\text{-}1)$	$\frac{SSCB}{df_{interaction}}$	$\frac{MSI}{MSE}$
Within (Error)	SSE	$N\text{-}C^{*}B$	$\frac{SSE}{df_{error}}$	
Total	SST	N-1		

N = total observations; C = number of columns; B = number of rows

Sum of Squares Within (Error)

Sex	Huntington's disease	Parkinson's disease	Healthy controls	Average
Female	6.7	12.0	23.0	13.9
Male	4.7	11.7	14.0	10.1
Average	5.7	11.8	18.5	12.0

$$SSE = \sum (x - \bar{x})^2$$

Female	Squared Female score - Female mean	
5	$(5 - 6.7)^2$	2.8
7	$(7 - 6.7)^2$	0.1
8	$(8 - 6.7)^2$	1.8
8	$(8 - 12)^2$	16.0
17	$(17 - 12)^2$	25.0
11	$(11 - 12)^2$	1.0
29	$(29 - 23)^2$	36.0
22	$(22 - 23)^2$	1.0
18	$(18 - 23)^2$	25.0
	Sum	**108.7**

Male	Squared Male score - Male mean	
5	$(5 - 4.7)^2$	0.1
5	$(5 - 4.7)^2$	0.1
4	$(4 - 4.7)^2$	0.4
10	$(10 - 11.7)^2$	2.8
15	$(15 - 11.7)^2$	11.1
10	$(10 - 11.7)^2$	2.8
18	$(18 - 14)^2$	16.0
13	$(13 - 14)^2$	1.0
11	$(11 - 14)^2$	9.0
	Sum	**43.3**

***SSE* = 108.7 + 43.3 = 152.0**

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	64.2	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	$SSCB$	(C-1)(B-1)	$\frac{SSCB}{df_{interaction}}$	$\frac{MSI}{MSE}$
Within (Error)	*152.0*	N-C*B	$\frac{SSE}{df_{error}}$	
Total	SST	N-1		

N = total observations; C = number of columns; B = number of rows

Sum of Squares Total

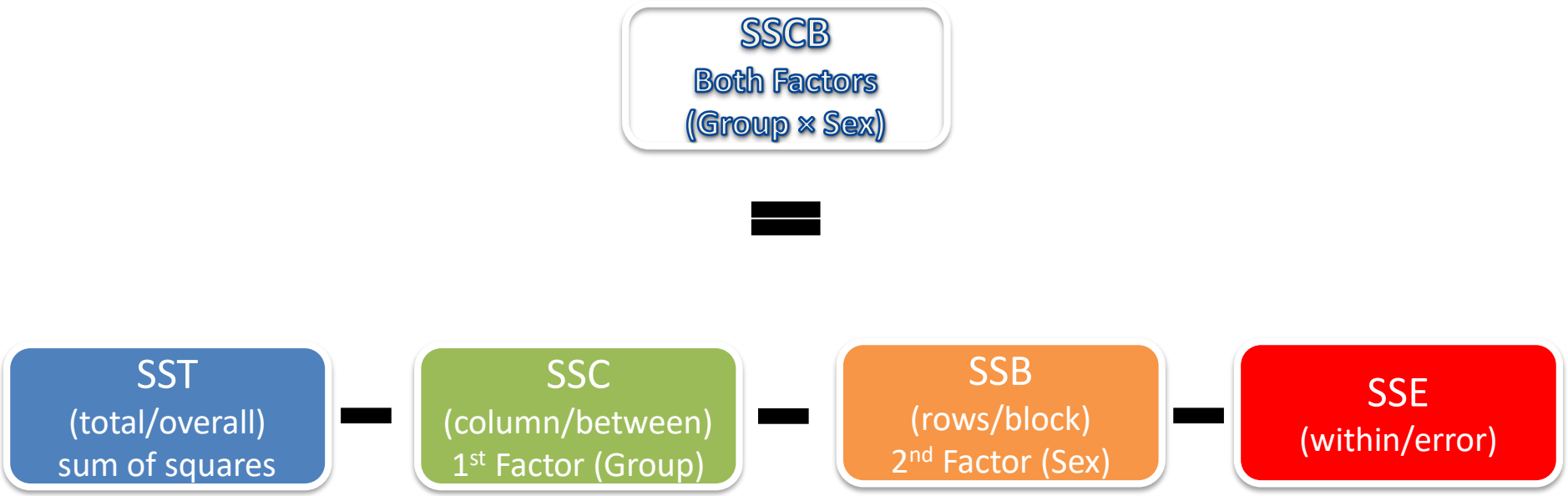
$$SST = \sum (x - \bar{\bar{x}})^2$$

***SST* = 774**

	Squared Each score - Grand mean	
5	$(5 - 12)^2$	49.0
7	$(7 - 12)^2$	25.0
8	$(8 - 12)^2$	16.0
5	$(5 - 12)^2$	49.0
5	$(5 - 12)^2$	49.0
4	$(4 - 12)^2$	64.0
8	$(8 - 12)^2$	16.0
17	$(17 - 12)^2$	25.0
11	$(11 - 12)^2$	1.0
10	$(10 - 12)^2$	4.0
15	$(15 - 12)^2$	9.0
10	$(10 - 12)^2$	4.0
29	$(29 - 12)^2$	289.0
22	$(22 - 12)^2$	100.0
18	$(18 - 12)^2$	36.0
18	$(18 - 12)^2$	36.0
13	$(13 - 12)^2$	1.0
11	$(11 - 12)^2$	1.0
	Sum	**774.0**

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	64.2	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	$SSCB$	(C-1)(B-1)	$\frac{SSCB}{df_{interaction}}$	$\frac{MSI}{MSE}$
Within (Error)	152.0	N-C*B	$\frac{SSE}{df_{error}}$	
Total	774.0	N-1		

N = total observations; C = number of columns; B = number of rows



SSCB = 774.0 – 494.4 – 64.2 – 152.0 = **63.4**

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	C-1	$\frac{SSC}{df_{columns}}$	$\frac{MSC}{MSE}$
2nd Factor (Sex) Row	64.2	B-1	$\frac{SSB}{df_{blocks}}$	$\frac{MSB}{MSE}$
Both Factors (Group*Sex)	63.4	$(C\text{-}1)(B\text{-}1)$	$\frac{SSCB}{df_{interaction}}$	$\frac{MSI}{MSE}$
Within (Error)	152.0	N-C*B	$\frac{SSE}{df_{error}}$	
Total	774.0	N-1		

N = total observations; C = number of columns; B = number of rows

	Sum of Squares	d.f.	Mean Square	F score
1st Factor (Group) Column	494.4	2	247.2	19.5
2nd Factor (Sex) Row	64.2	1	64.2	5.1
Both Factors (Group*Sex)	63.4	2	31.7	2.5
Within (Error)	152.0	12	12.7	
Total	774.0	17		

N = total observations; C = number of columns; B = number of rows

Matlab output to replicate

p = 1 – fcdf(F, df_factor, df_error);

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
group	494.333	2	247.167	19.51	0.0002
sex	64.222	1	64.222	5.07	0.0439
group*sex	63.444	2	31.722	2.5	0.1233
Error	152	12	12.667		
Total	774	17			

Matlab example 1

```
[p table stats terms] =
anovan(sample, {group, sex},'varnames',{'group','sex'},'model','interaction');

[c,m,h,nms] =
multcompare(stats,'dimension',1,'ctype','bonferroni','alpha',0.05)
```

Group	Sex	Sample
1	1	5
1	1	7
1	1	8
1	2	5
1	2	5
1	2	4
2	1	8
2	1	17
2	1	11
2	2	10
2	2	15
2	2	10
3	1	29
3	1	22
3	1	18
3	2	18
3	2	13
3	2	11

Answers to established hypotheses

1) H_0: Type of disease will have no significant effect on maximum phonation time;

$F(2,12) = 19.5$, $p < 0.001$
REJECT

2) H_0: Gender will have no significant effect on maximum phonation time;

$F(1,12) = 5.1$, $p = 0.04$
REJECT

3) H_0: Interaction of type of disease and gender will have no significant effect on maximum phonation time; in other words, maximum phonation time is not gender-dependent across different types of neurological diseases.

$F(2,12) = 2.5$, $p = 0.12$
FAIL TO REJECT

Analysis of covariance (ANCOVA)

- Extension of ANOVA, in which main effects and interactions are assessed on scores of dependent variables (DV) **after DV has been adjusted for the relationship of DV with one or more covariates (CV)**
- CV is a variable that is related to the DV, which you can't manipulate, but you want to account for it's relationship with DV
- CV should be collected before analysis is started

Applications of ANCOVA

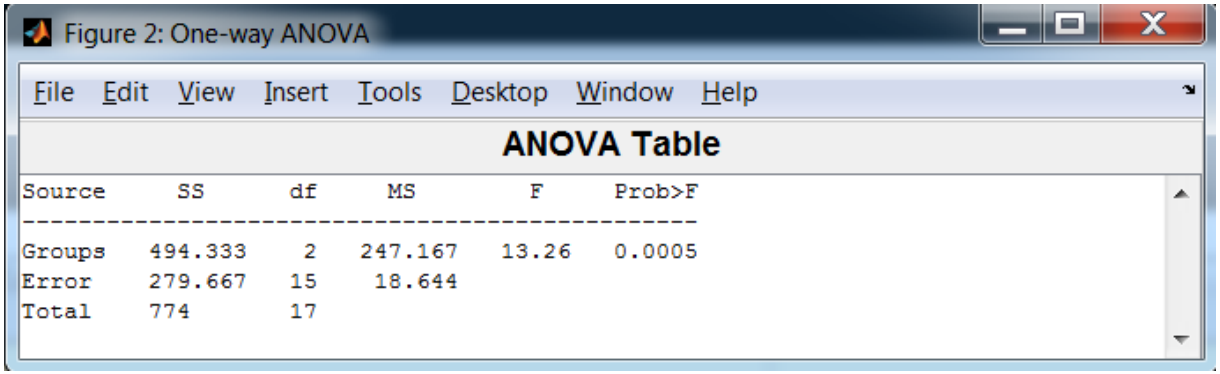
- Increase test sensitivity (main effects and interactions) by using the CV to account for more of the error variance and therefore making the error term smaller
- In other words, using **CV** we **can show a larger effect** or **CV can eliminate the effect**

Assumptions using ANCOVA

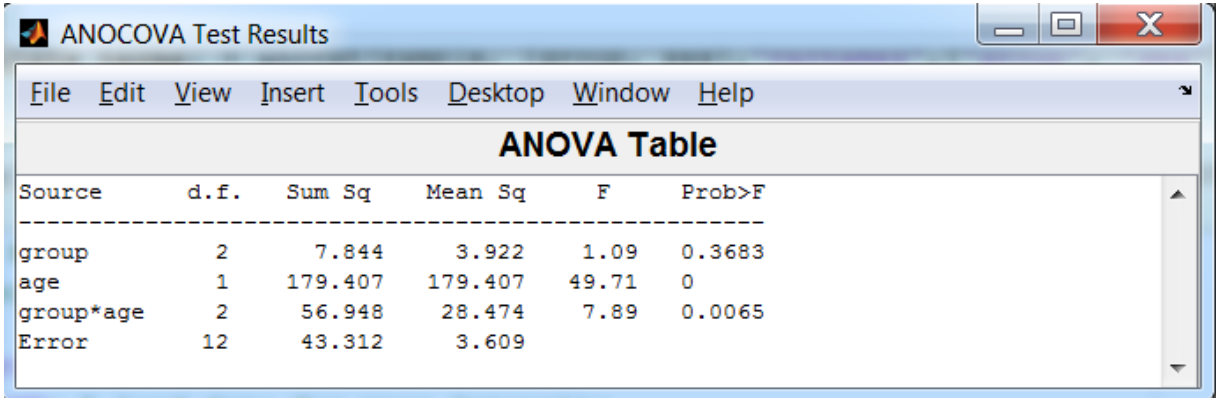
- Normality of sampling distributions of the DV and each CV
- Absence of outliers
- Homogeneity of variance
- Linearity – we have to consider a linear relationship between each CV and DV as well as each pair of CV

Matlab output to replicate

[p,a,s] = anova1(Sample,Group)



[p,a,s] = aoctool(Age,Sample,Group)



Covariate

Group	Age	Sample
1	80	5
1	75	7
1	75	8
1	72	5
1	68	5
1	71	4
2	69	8
2	55	17
2	60	11
2	61	10
2	58	15
2	62	10
3	41	29
3	50	22
3	48	18
3	52	18
3	60	13
3	61	11

Multivariate analysis of variance (MANOVA)

- Extension of ANOVA with the key difference that we are dealing with **many dependent variables** (not a single DV as in the case of ANOVA)
- Combination of DV is called “joint distribution”
- MANOVA gives us answer to question if joint distribution of 2 or more DV is significantly related to one or more factors
- The results of MANOVA simply tell us that a difference exists (or not) across groups

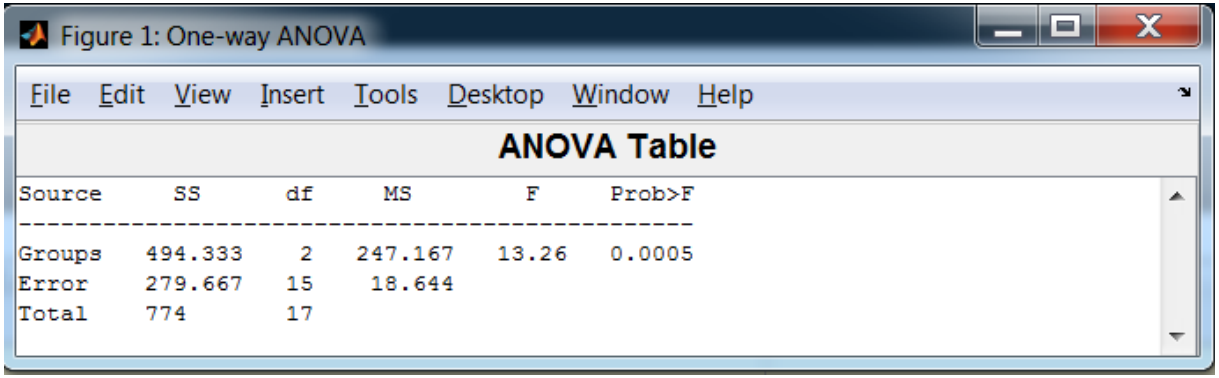
Assumptions using MANOVA

- At least 2 DV
- Multivariate normality of sampling distributions of the DV
- Multivariate homogeneity of variance
- May be correlated, **DV should be related**

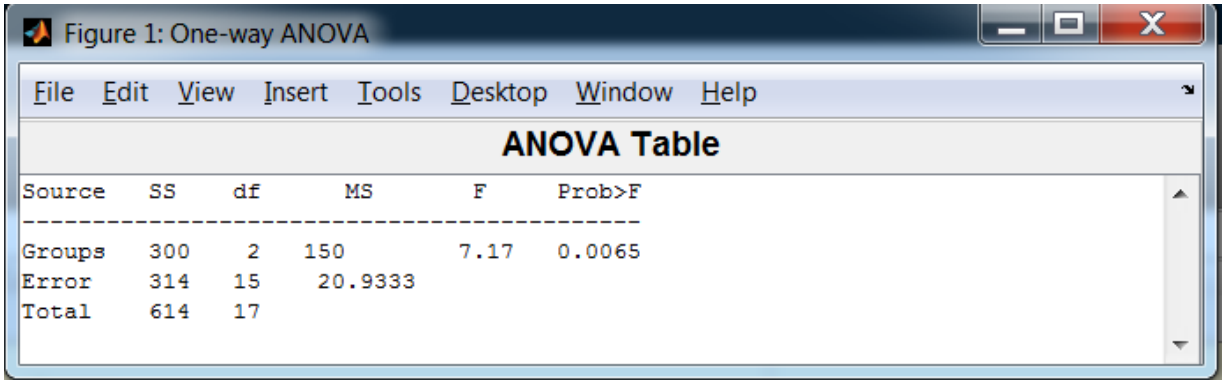
Matlab output to replicate

($r = 0.89$, $p < 0.001$)

[p,a,s] = anova1(Sample1,Group)



[p,a,s] = anova1(Sample2,Group)



[d,p] = manova1([Sample1 Sample2],Group)

d = 1 … estimate of dimension of space containing group means

p = [**0.0051** 0.8946] … we choose **p(d)**

Group	Sample1	Sample2
1	5	3
1	7	7
1	8	8
1	5	3
1	5	5
1	4	4
2	8	8
2	17	14
2	11	10
2	10	10
2	15	10
2	10	8
3	29	29
3	22	10
3	18	12
3	18	17
3	13	12
3	11	10

Research project

ACOUSTIC ANALYSIS OF WORD STRESS PATTERNS IN PARKINSON'S DISEASE

Why to conduct such research?

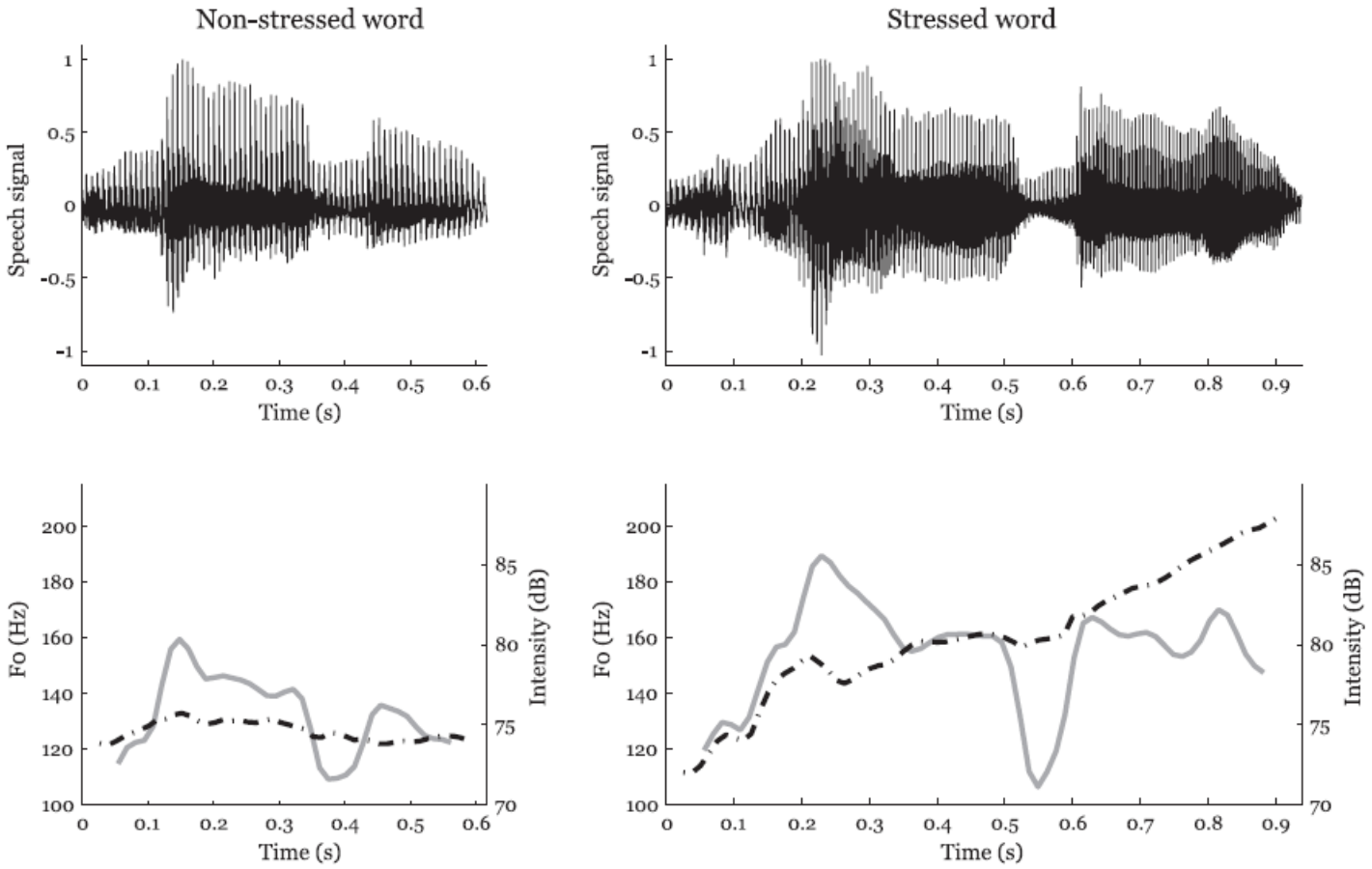
- Patients with PD have limited ability to express contrastive stress
- Impaired stress production is one the most common affected dimensions of speech in PD
- Very limited research regarding stress production in PD

General motivation

- Early and accurate diagnosis
- Monitoring progression of disease
- Monitoring treatment efficacy
- Feedback for speech therapy

Principle of stress expression

- Word prolongation (Time)
- Increase of pitch (Fo)
- Increase of loudness (Intensity)



Hypothesis: what happen during stress expression?

Parameter	Helthy controls	Parkinson's disease
Word length	↑↑↑	↑
Pitch	↑↑↑	↑
Loudness	↑↑↑	↑

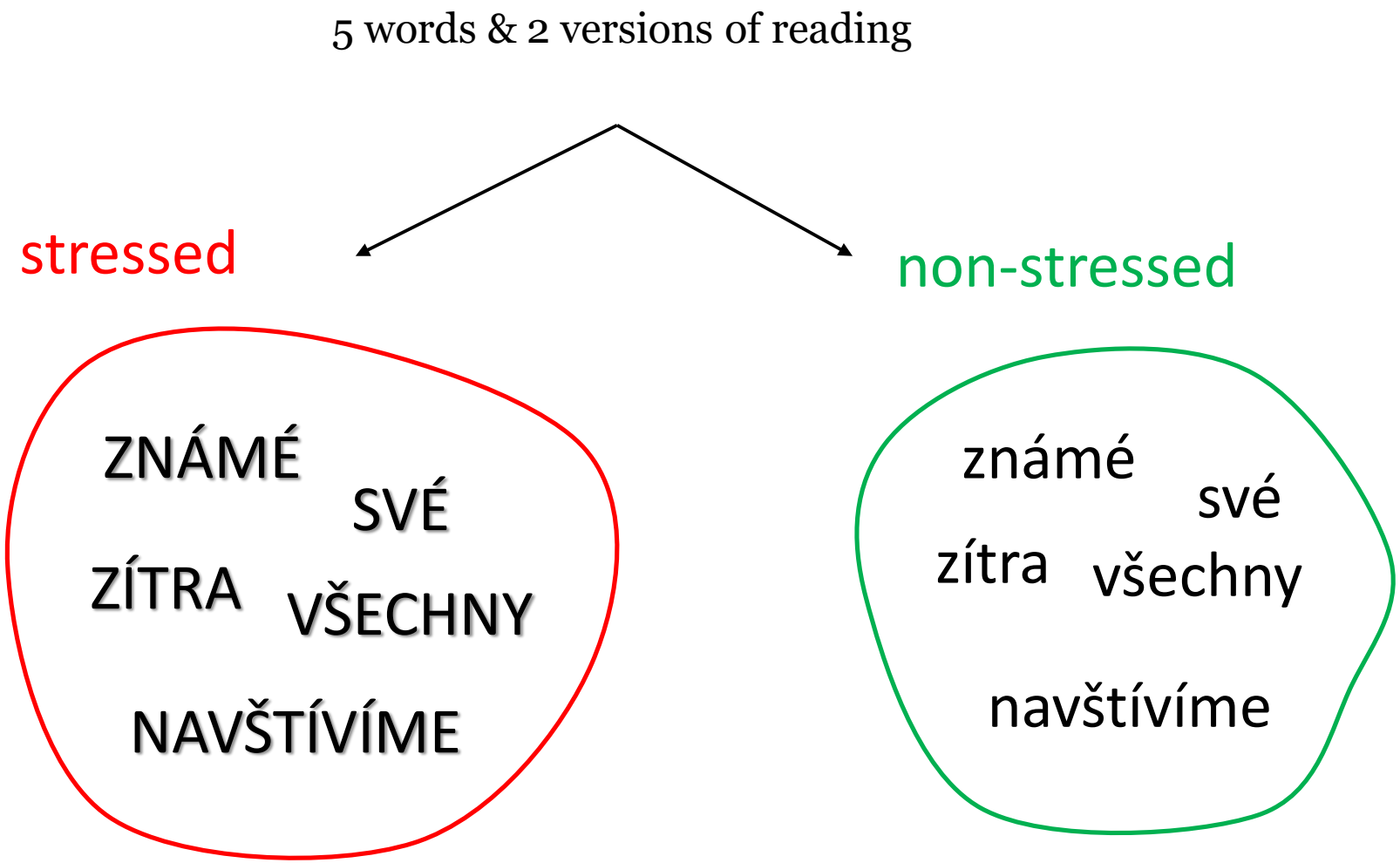
Methods: speech data

- The aim was to unnaturally emphasize certain keyword marked in the text

Dnes jsme to již nestihli,
možná ZÍTRA navštívíme všechny své známé.

Příbuzné jsme již navštívili,
možná zítra navštívíme všechny své ZNÁMÉ.

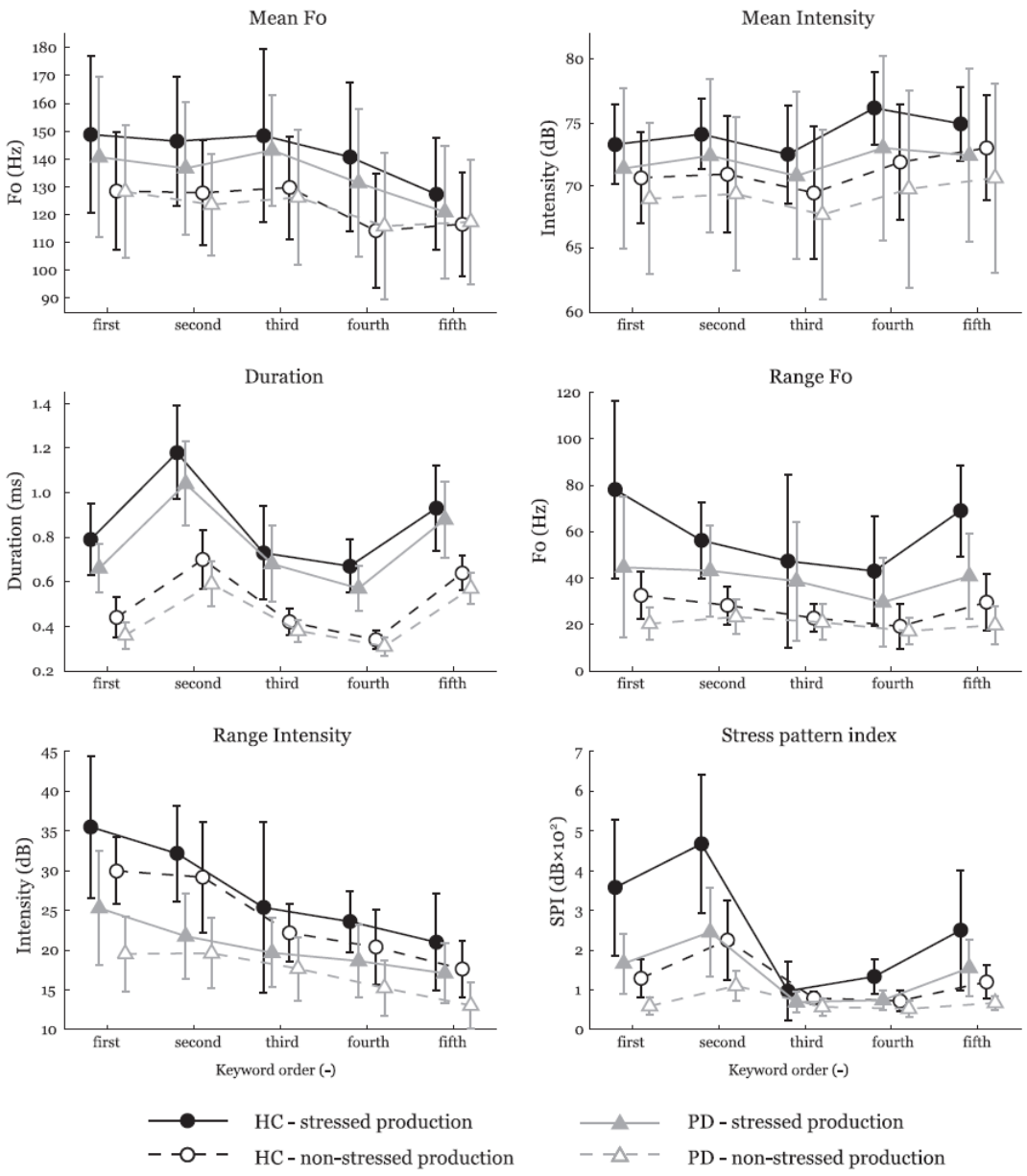
Methods: speech task



Methods: variables

- Mean value of Fo
- Range of Fo (min-max)
- Mean value of intensity of loudness
- Range of intensity of loudness
- Length of word
- Stress pattern index (combining effects of all three fundamental aspects including pitch, loudness, and length)

Results



- 2 groups (PD, HC)
- 6 variables
- 5 words
- 2 conditions (stressed, non-stressed)
  +1 condition (difference between stressed and non-stressed)

For each PD vs. HC comparison:
$6 \times 5 \times 3 =$ **90 tests**

PD = Parkinson's disease
HC = Healthy controls

Results

MEAN F0		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	NS	NS	NS
NAVSTIVIME	PN x HC	NS	NS	NS
SVE	PN x HC	NS	NS	NS
VSECHNY	PN x HC	NS	NS	NS
ZITRA	PN x HC	NS	NS	NS

MEAN INTENSITY		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	NS	NS	NS
NAVSTIVIME	PN x HC	NS	NS	NS
SVE	PN x HC	NS	NS	NS
VSECHNY	PN x HC	NS	NS	NS
ZITRA	PN x HC	NS	NS	NS

DURATION		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	NS	p < 0.01	NS
NAVSTIVIME	PN x HC	p < 0.05	p < 0.01	NS
SVE	PN x HC	p < 0.05	p < 0.05	p < 0.05
VSECHNY	PN x HC	NS	p < 0.05	NS
ZITRA	PN x HC	p < 0.01	p < 0.01	NS

RANGE INTENSITY		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	p < 0.05	p < 0.001	NS
NAVSTIVIME	PN x HC	p < 0.001	p < 0.001	NS
SVE	PN x HC	p < 0.001	p < 0.01	NS
VSECHNY	PN x HC	p < 0.05	p < 0.01	NS
ZITRA	PN x HC	p < 0.001	p < 0.001	NS

RANGE F0		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	p < 0.001	p < 0.01	p < 0.01
NAVSTIVIME	PN x HC	p < 0.05	NS	NS
SVE	PN x HC	NS	NS	NS
VSECHNY	PN x HC	NS	NS	NS
ZITRA	PN x HC	p < 0.01	p < 0.001	NS

STRESS PATTERN INDEX		STRESSED	NORMAL	ABS. STRESS
ZNAME	PN x HC	p < 0.05	p < 0.001	NS
NAVSTIVIME	PN x HC	p < 0.001	p < 0.001	p < 0.05
SVE	PN x HC	p < 0.001	p < 0.05	p < 0.01
VSECHNY	PN x HC	NS	p < 0.01	NS
ZITRA	PN x HC	p < 0.001	p < 0.001	p < 0.01

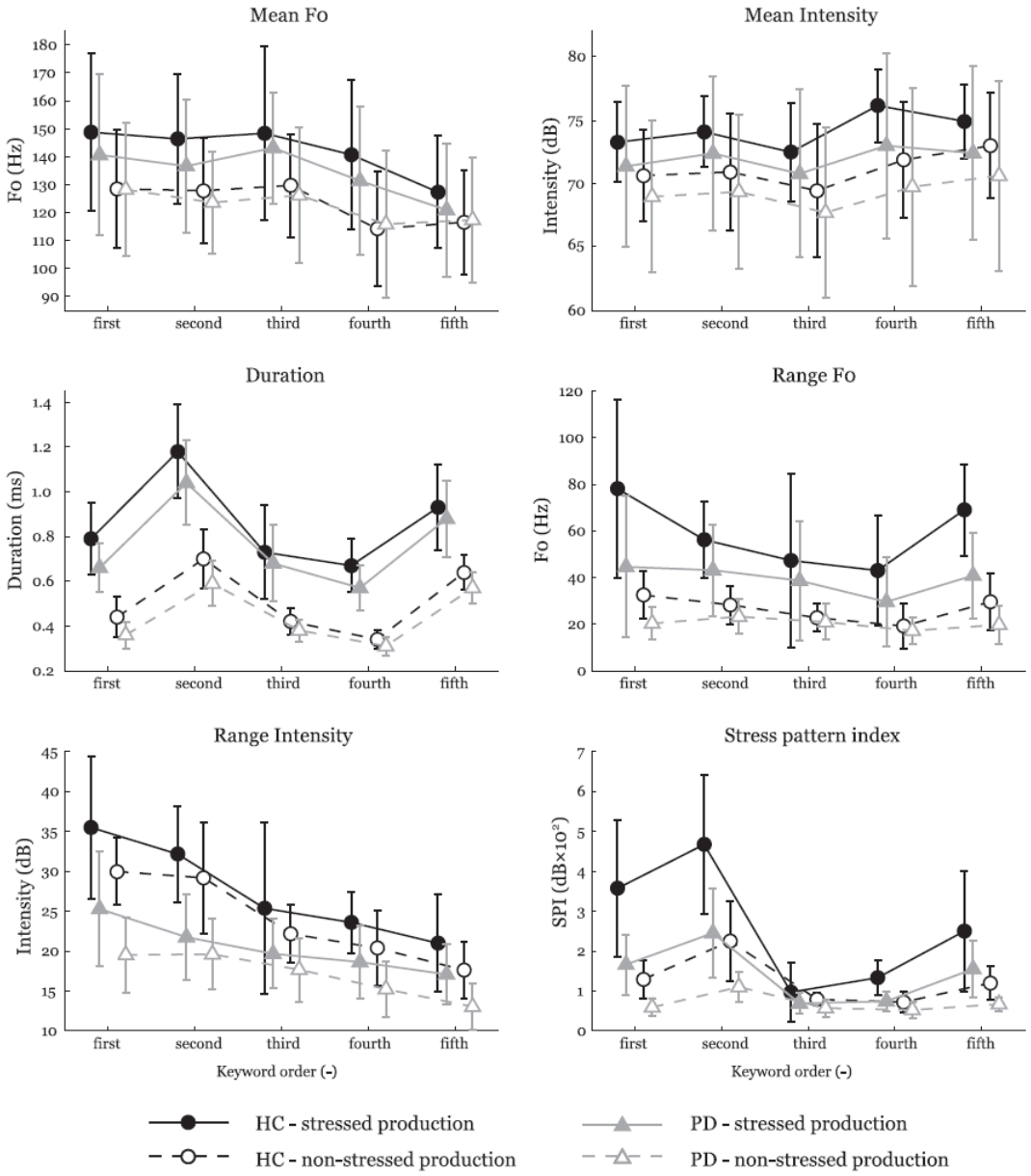
- Very hard to interpret the results
- Type I Error
- Corrected: $p = 0.05/90 \Rightarrow p < 0.00056$
- => no result is significant

NS = not significant

Solution: Three-way RM-ANOVA

- 2 × 2 × 5 RM-ANOVA
- 3 factors
  - SPEAKERS GROUP (PD, HC)
  - STRESS CONDITION (stressed, non-stressed)
  - KEYWORD ORDER (first, second, third, fourth, fifth)

Three-way RM-ANOVA: Interpretation



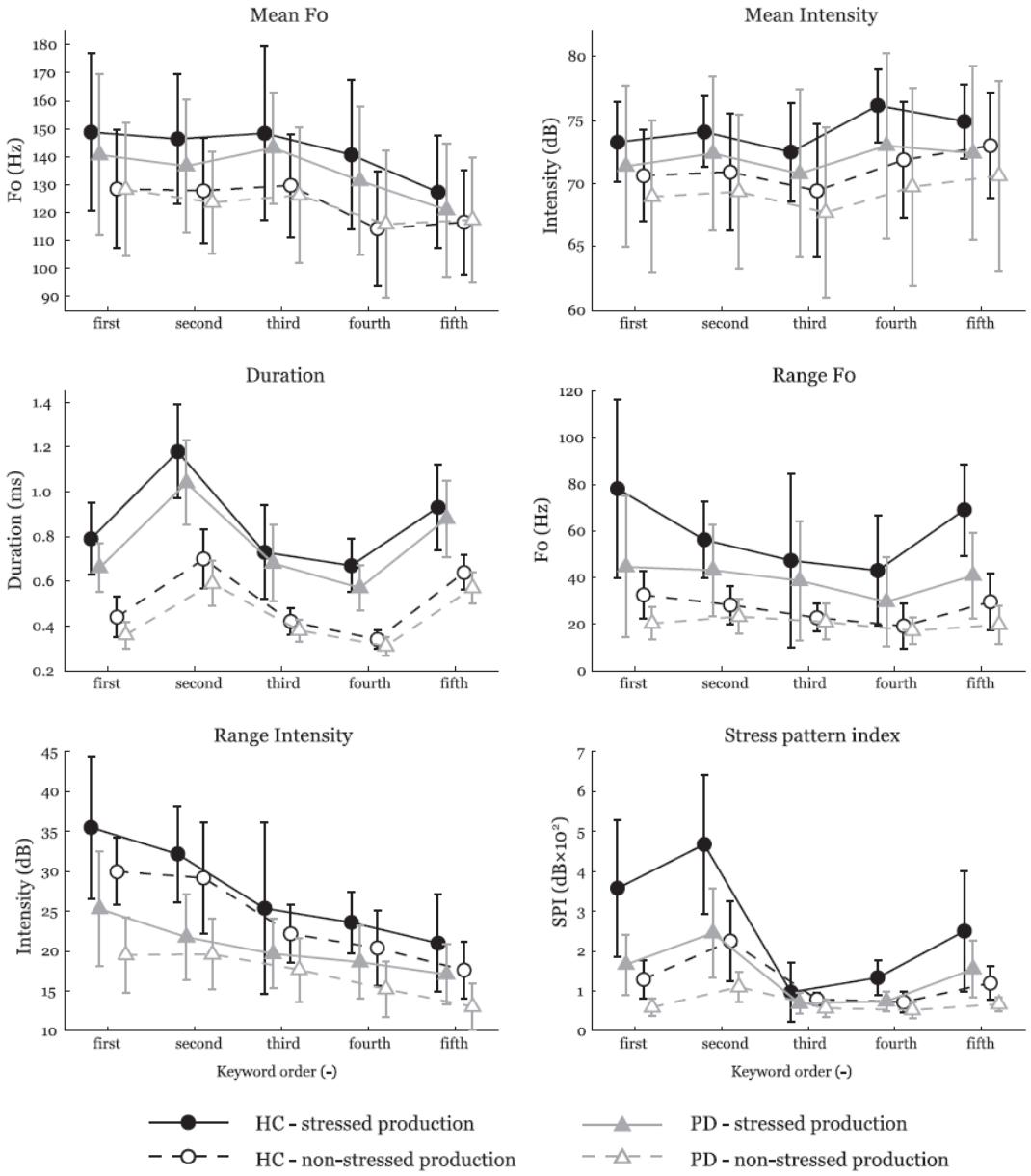
SPEAKERS GROUP

H_A: PD patients will manifest affected speech

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	**n.s.**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Stress condition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Keyword order	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Speakers group x Stress condition	n.s.	n.s.	n.s.	0.0014	n.s.	<0.001
Keyword order x Speakers group	n.s.	n.s.	n.s.	n.s.	<0.001	<0.001
Keyword order x Stress condition	n.s.	n.s.	<0.001	n.s.	n.s.	<0.001

Three-way RM-ANOVA: Interpretation



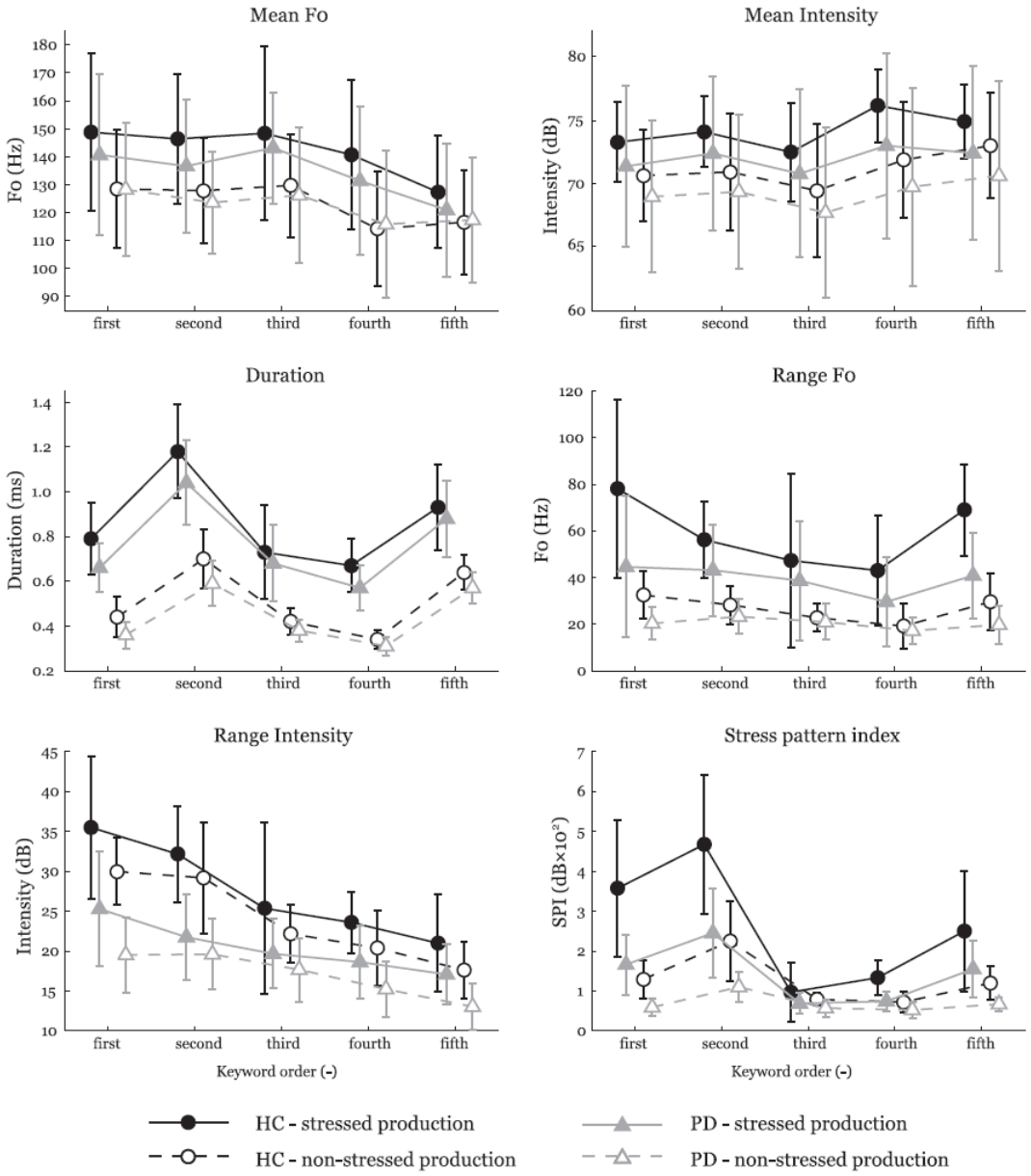
STRESS CONDITION

H_A: Variable reflects effect of the stress condition

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Stress condition	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Keyword order	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Speakers group x Stress condition	n.s.	n.s.	n.s.	0.0014	n.s.	<0.001
Keyword order x Speakers group	n.s.	n.s.	n.s.	n.s.	<0.001	<0.001
Keyword order x Stress condition	n.s.	n.s.	<0.001	n.s.	n.s.	<0.001

Three-way RM-ANOVA: Interpretation



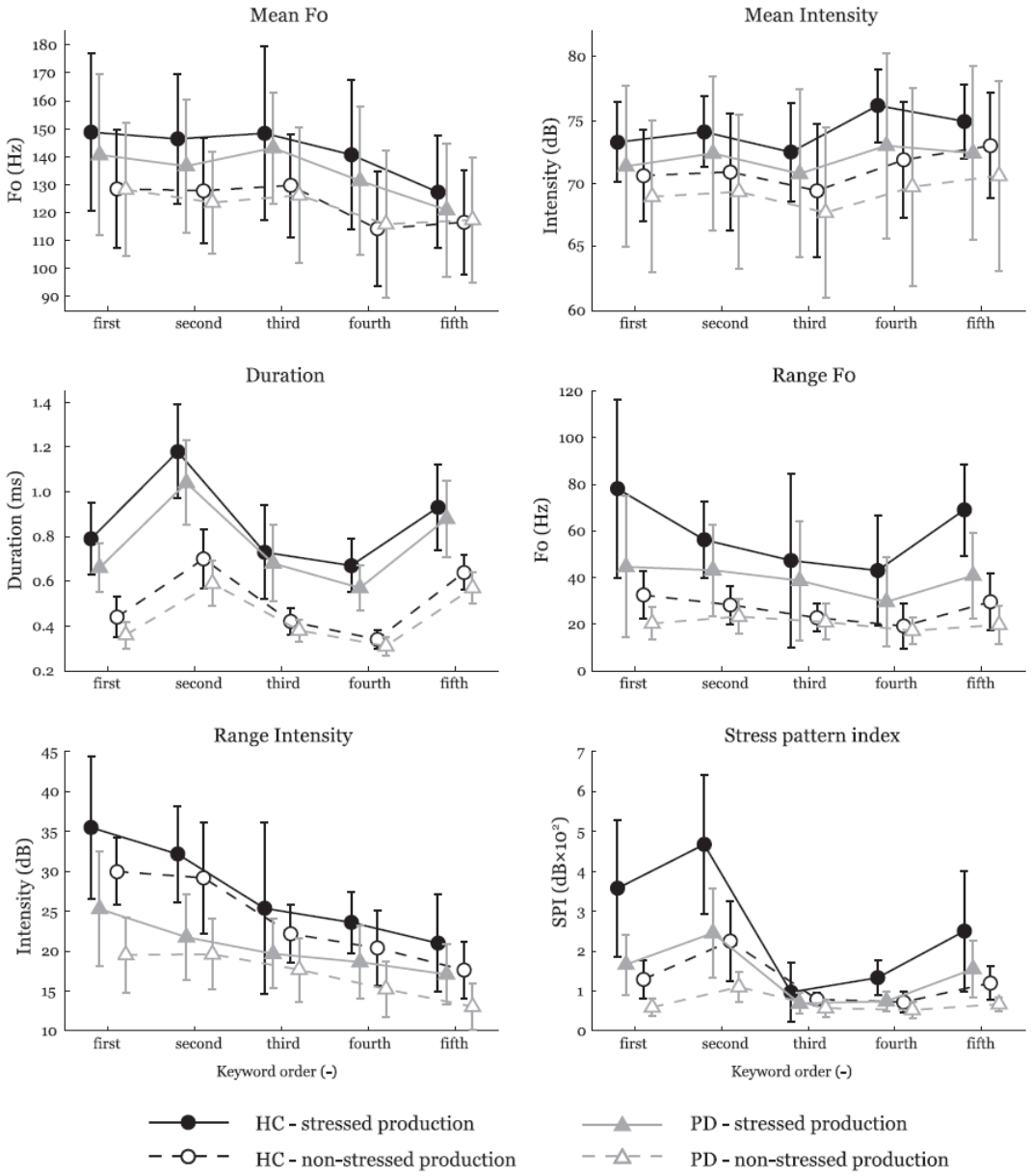
KEYWORD ORDER

H_A: Variable reflects the keyword order

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Stress condition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Keyword order	**<0.001**	**n.s.**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Speakers group x Stress condition	n.s.	n.s.	n.s.	0.0014	n.s.	<0.001
Keyword order x Speakers group	n.s.	n.s.	n.s.	n.s.	<0.001	<0.001
Keyword order x Stress condition	n.s.	n.s.	<0.001	n.s.	n.s.	<0.001

Three-way RM-ANOVA: Interpretation



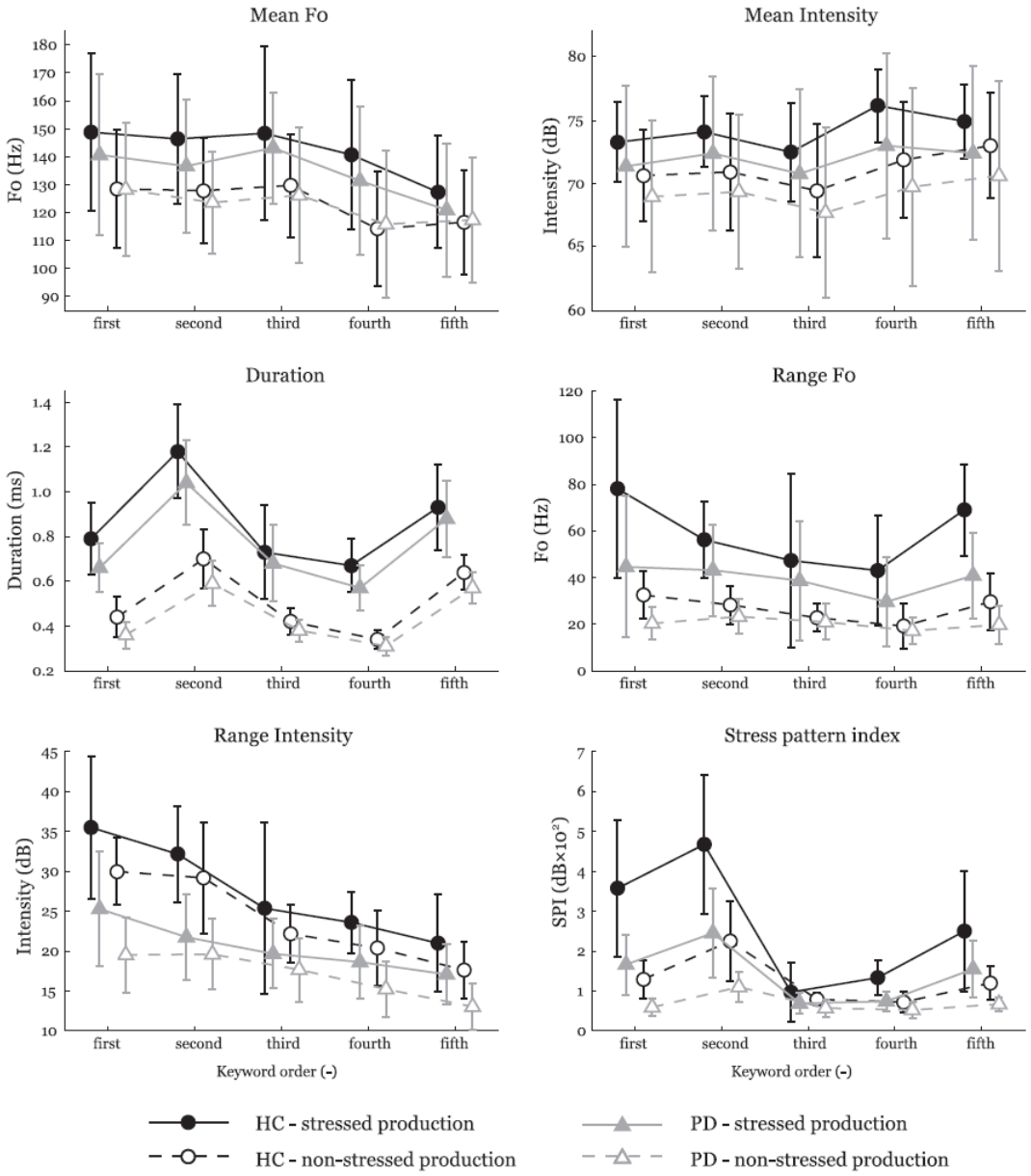
SPEAKERS GROUP × STRESS CONDITION

H_A: PD patients are not able to express stress as effectively as HC

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Stress condition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Keyword order	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Speakers group x Stress condition	**n.s.**	**n.s.**	**n.s.**	**0.0014**	**n.s.**	**<0.001**
Keyword order x Speakers group	n.s.	n.s.	n.s.	n.s.	<0.001	<0.001
Keyword order x Stress condition	n.s.	n.s.	<0.001	n.s.	n.s.	<0.001

Three-way RM-ANOVA: Interpretation



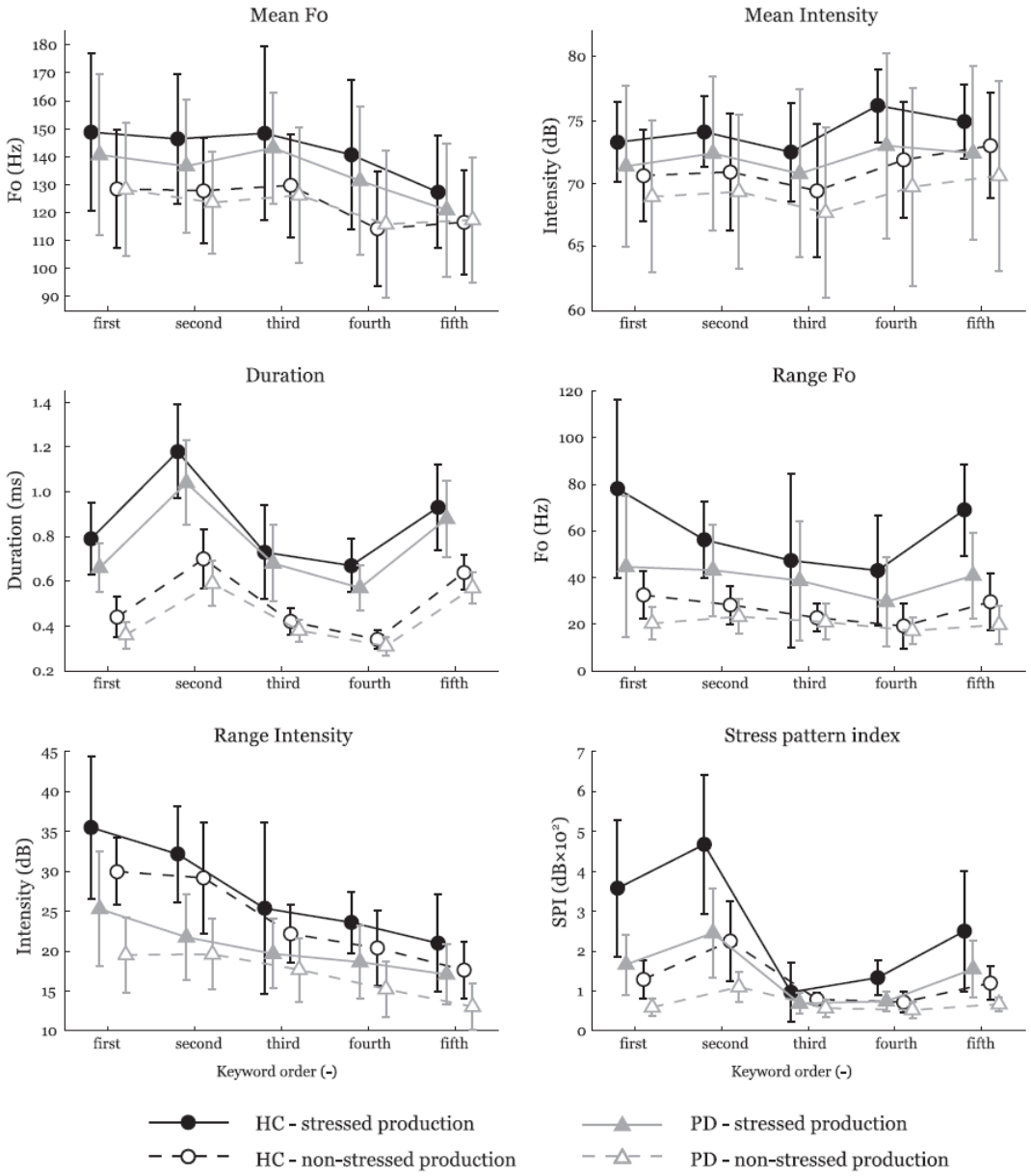
KEYWORD ORDER× SPEAKERS GROUP

H_A: Certain word is more effective in the separation of groups

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Stress condition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Keyword order	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Speakers group x Stress condition	n.s.	n.s.	n.s.	0.0014	n.s.	<0.001
Keyword order x Speakers group	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**<0.001**	**<0.001**
Keyword order x Stress condition	n.s.	n.s.	<0.001	n.s.	n.s.	<0.001

Three-way RM-ANOVA: Interpretation



KEYWORD ORDER× STRESS CONDITION

H_A: Certain word is more suitable for expression of stress condition

Three-way RM-ANOVA: Results

	mean F0	mean Intensity	duration	range F0	range Intensity	SPI
Speakers group	n.s.	<0.001	<0.001	<0.001	<0.001	<0.001
Stress condition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Keyword order	<0.001	n.s.	<0.001	<0.001	<0.001	<0.001
Speakers group x Stress condition	n.s.	n.s.	n.s.	0.0014	n.s.	<0.001
Keyword order x Speakers group	n.s.	n.s.	n.s.	n.s.	<0.001	<0.001
Keyword order x Stress condition	**n.s.**	**n.s.**	**<0.001**	**n.s.**	**n.s.**	**<0.001**

Three-way RM-ANOVA: Interpretation

SPEAKERS GROUP – PD patients will manifest affected speech

STRESS CONDITION – variable reflects effect of the stress condition

KEYWORD ORDER – variable reflects the keyword order

SPEAKERS GROUP × STRESS CONDITION – PD patients are not able to express stress as effectively as HC

KEYWORD ORDER× SPEAKERS GROUP – certain word is more effective in the separation of groups

KEYWORD ORDER× STRESS CONDITION – certain word is more suitable for expression of stress condition

Main conclusions regarding our findings

- PD patients have decreased ability to express stress (SPEAKERS GROUP × STRESS CONDITION)
- PD patients are able to consciously improve their speech performance (MAIN EFFECTS)

Some notes regarding interactions

- Always look for significant interaction first
- If it is significant, you do not analyze main effects
- Variables are interconnected to allows look at them individually