Introduction

Localization of the sound in the horizontal plane is mainly based on two physical parameters, the interaural time difference (ITD) and interaural level difference (ILD), expressing, respectively, the difference in the arrival time and level with which a sound reaches one vs. the other ear. Previous experiments showed that changing the weighting of ITD and ILD to determine the location of a sound source in virtual environment is possible while not always successful. Here, we examined whether it is possible to change the spectral weighing of high vs. low components of sound in real environment, and whether that reweighting would generalize to a change in binaural cue weighing.

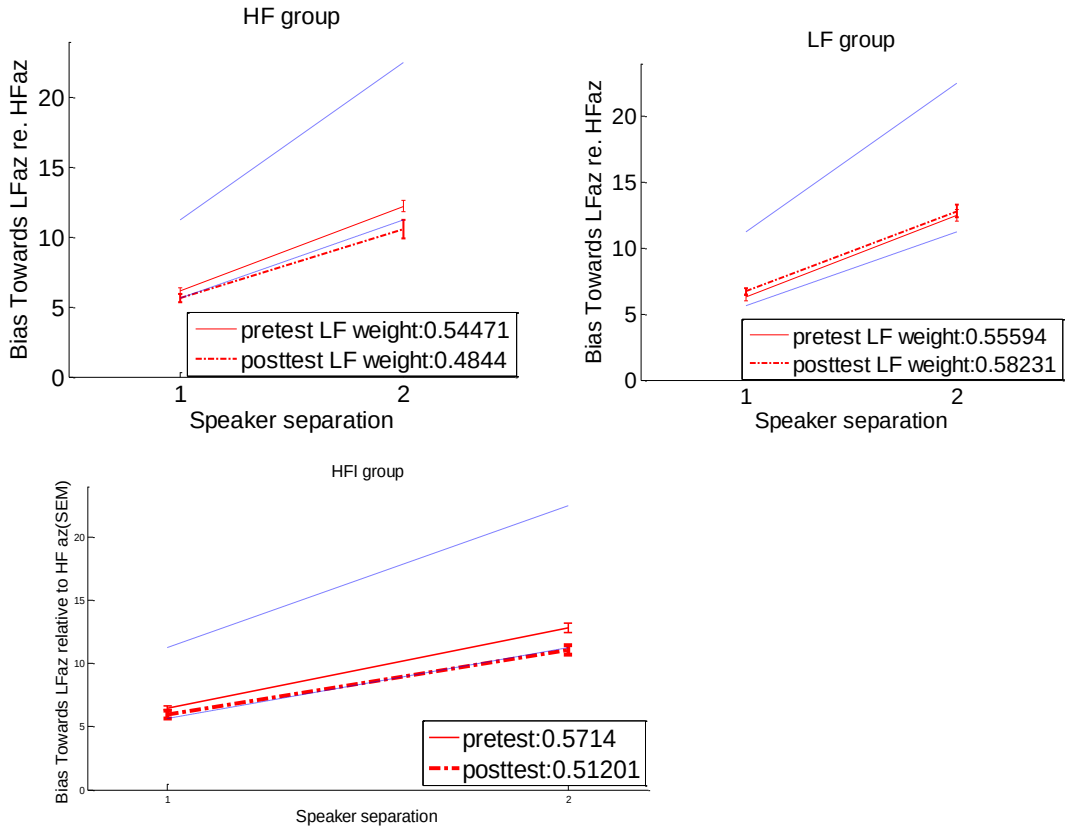
Analysis

2channel bias responses, real environment :

The results were analyzed by computing the bias in responses, where 2 loudspeakers was playing with separation 1 or 2, towards LF-components (re. HF-components), and a weight defined as

$$LFweight = (response - HFaz)/(LFaz - HFaz)$$

where HFaz and LFaz represent the location of the two frequency components (in degrees).

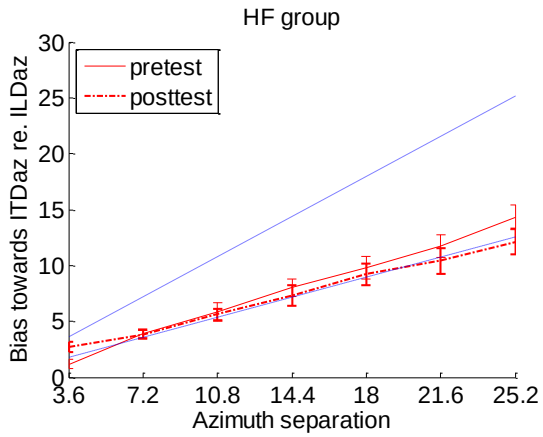


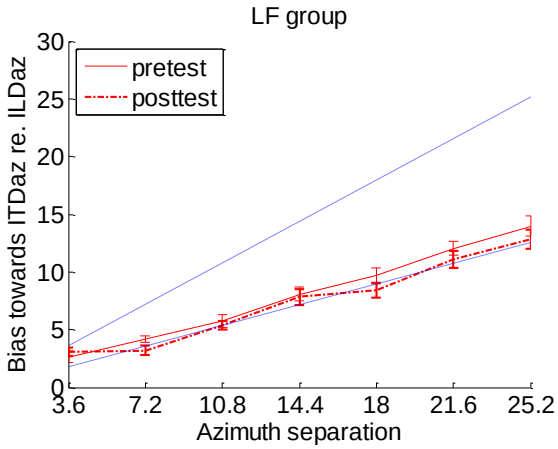
Figures for each subject are in folder : /nfs/data1/lab/Ondrej/Spaci/2channel_bias_group_figures

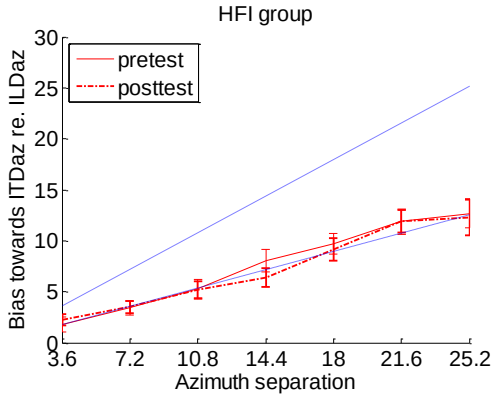
ANOVAs : anova_2channel_speakers_LF_ondrej.txt anova_2channel_speakers_LF_HF_ondrej.txt anova_2channel_speakers_HF_ondrej.tx

Oculus bias :

Figures show biases towards the ITD location as a function of the separation of the ITD and ILD components, separately for the two training groups, and for the pretest and posttest.







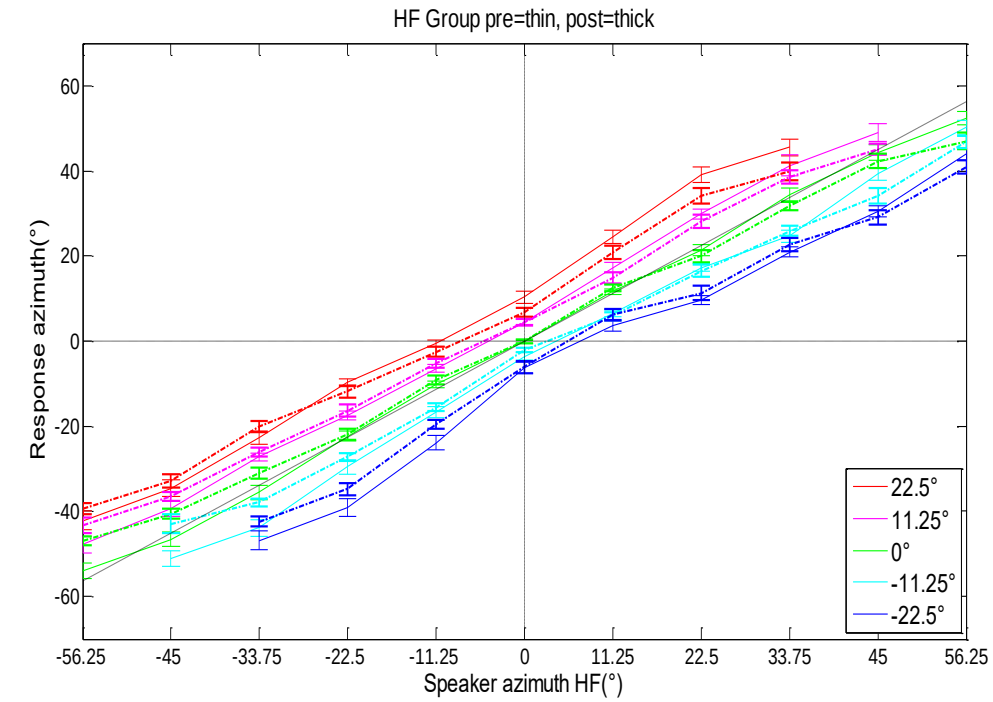
Figures for each subject are in folder : /nfs/data1/lab/Ondrej/Spaci/Oculus_bias_group_figures

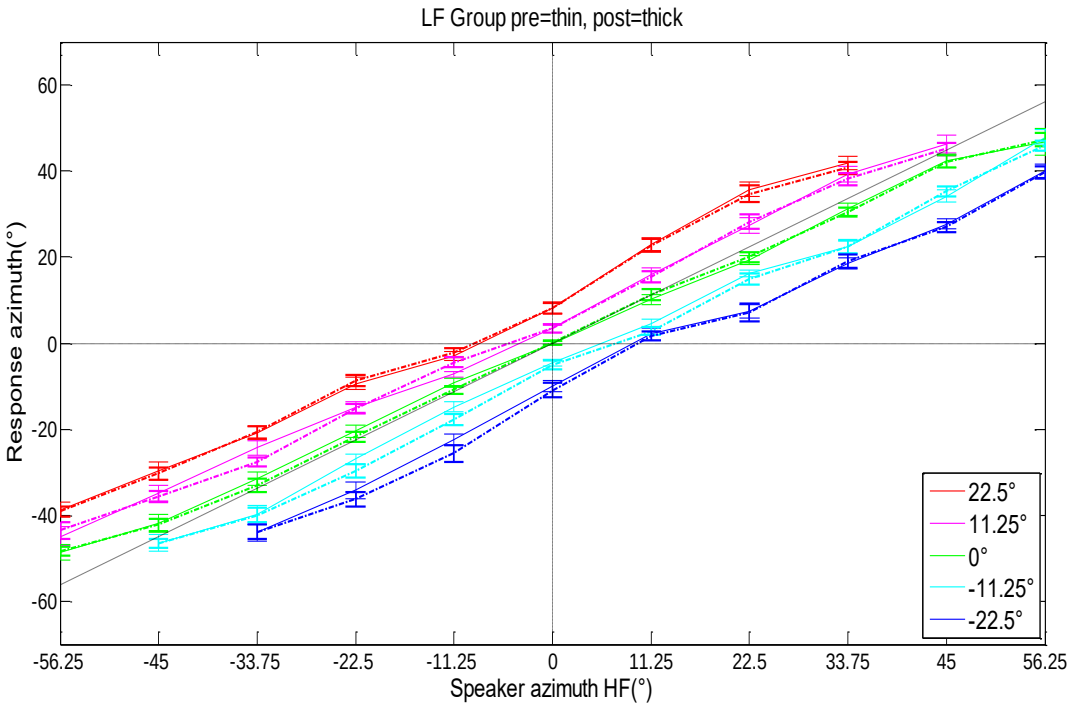
ANOVAs : anova_oculus_bias_LF_ondrej.txt anova_oculus_bias_LF_HF_ondrej.txt anova_oculus_bias_HF_ondrej.txt

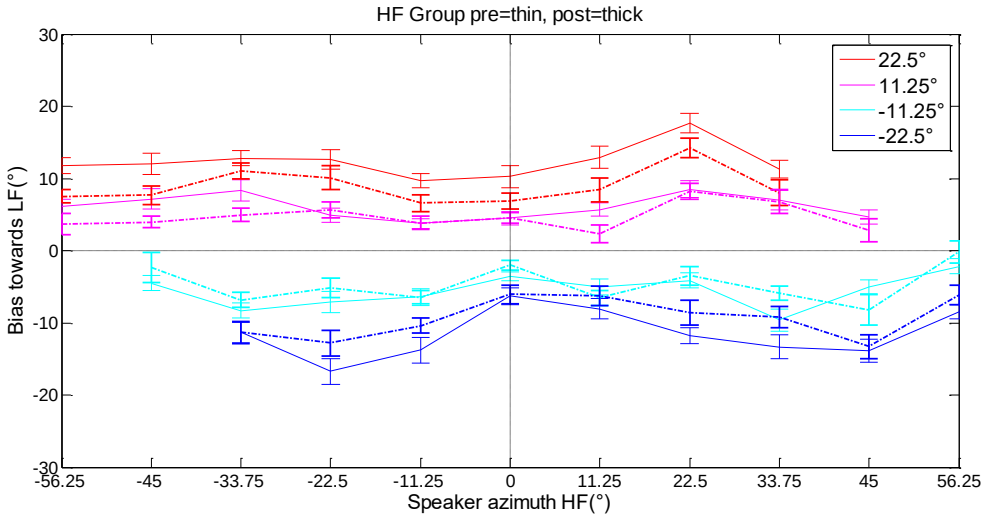
4channel bias responses, real environment :

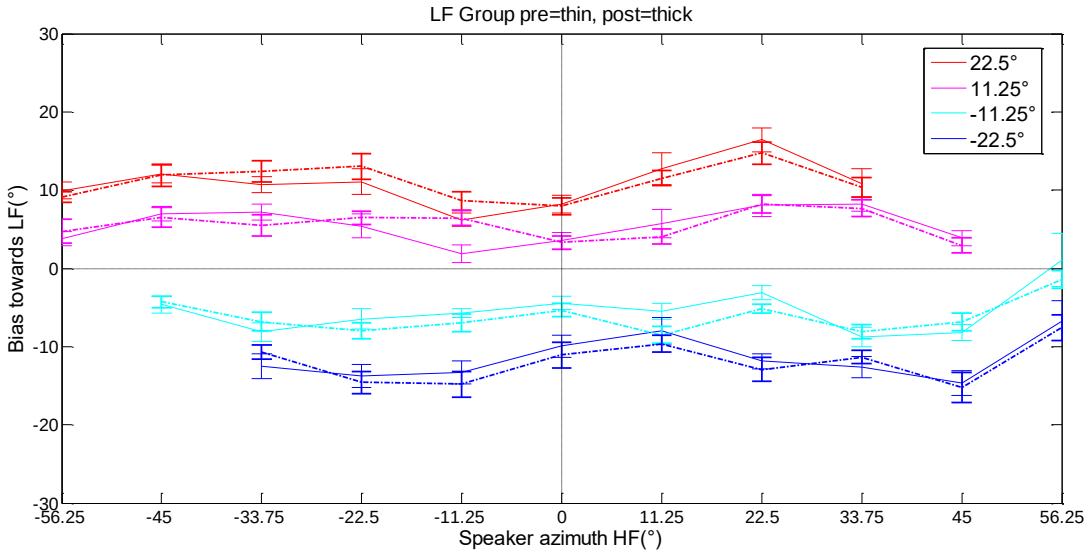
4 loudspeakers were playing

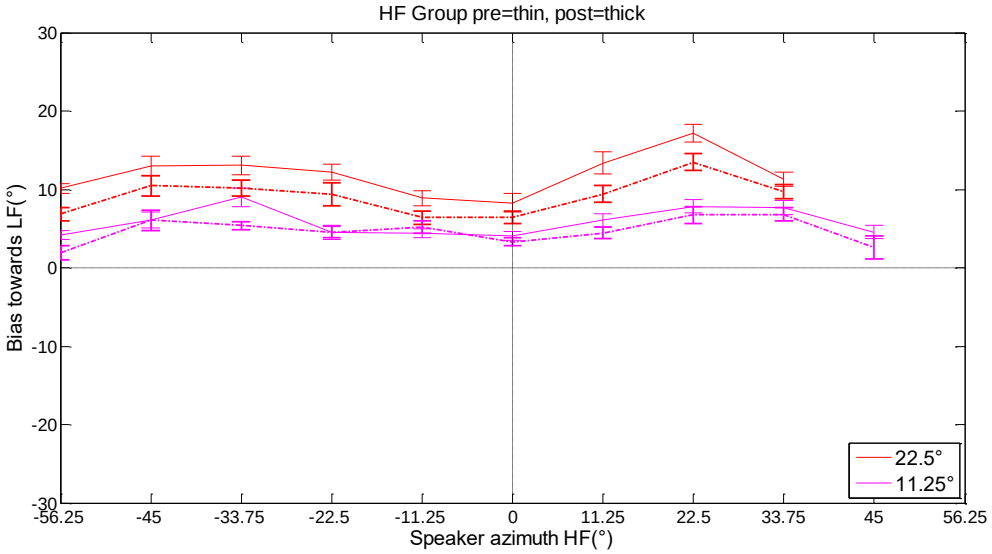
Raw data analysis, 2channel real environment

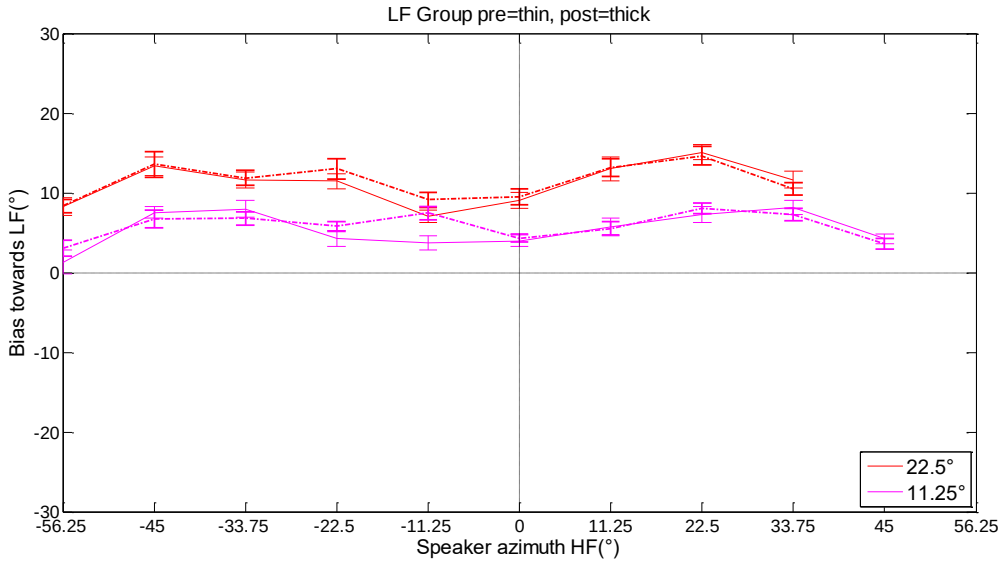

HF Group pre=thin, post=thick
Response azimuth(°)
Speaker azimuth HF(°)
60
40
20
0
-20
-40
-60
-56.25
-45
-33.75
-22.5
-11.25
0
11.25
22.5
33.75
45
56.25
22.5°
11.25°
0°
-11.25°
-22.5°

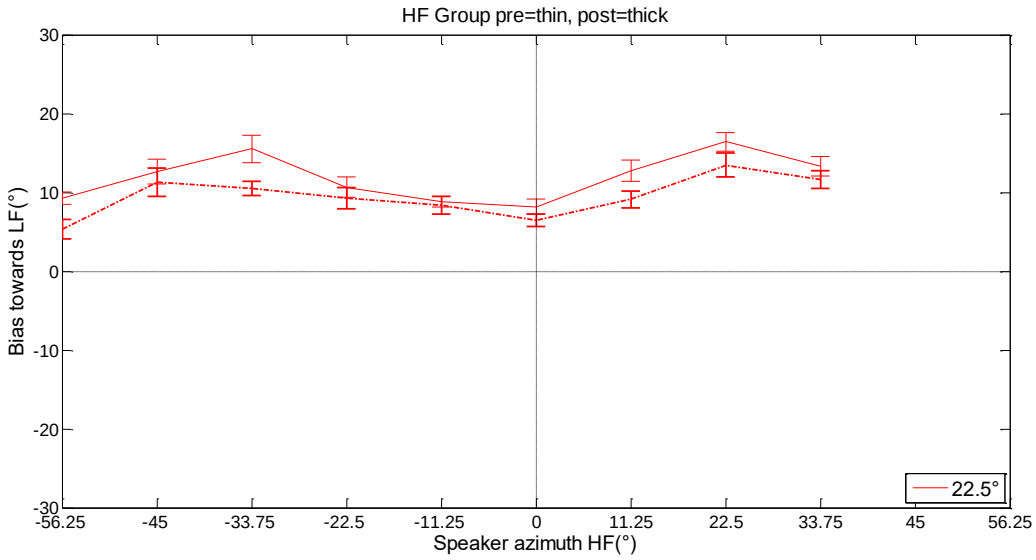

LF Group pre=thin, post=thick
Response azimuth(°)
Speaker azimuth HF(°)
60
40
20
0
-20
-40
-60
-56.25
-45
-33.75
-22.5
-11.25
0
11.25
22.5
33.75
45
56.25
22.5°
11.25°
0°
-11.25°
-22.5°

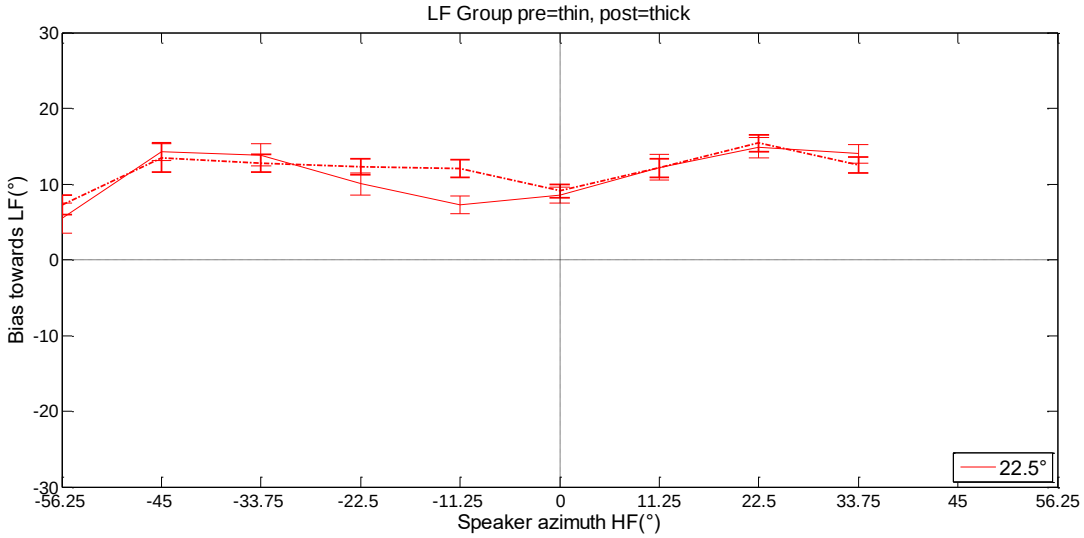

HF Group pre=thin, post=thick
22.5°
11.25°
-11.25°
-22.5°
Bias towards LF(°)
Speaker azimuth HF(°)
30
20
10
0
-10
-20
-30
-56.25
-45
-33.75
-22.5
-11.25
0
11.25
22.5
33.75
45
56.25


LF Group pre=thin, post=thick
22.5°
11.25°
-11.25°
-22.5°
Bias towards LF(°)
Speaker azimuth HF(°)
30
20
10
0
-10
-20
-30
-56.25
-45
-33.75
-22.5
-11.25
0
11.25
22.5
33.75
45
56.25


HF Group pre=thin, post=thick
22.5°
11.25°
Bias towards LF(°)
Speaker azimuth HF(°)
30
20
10
0
-10
-20
-30
-56.25
-45
-33.75
-22.5
-11.25
0
11.25
22.5
33.75
45
56.25





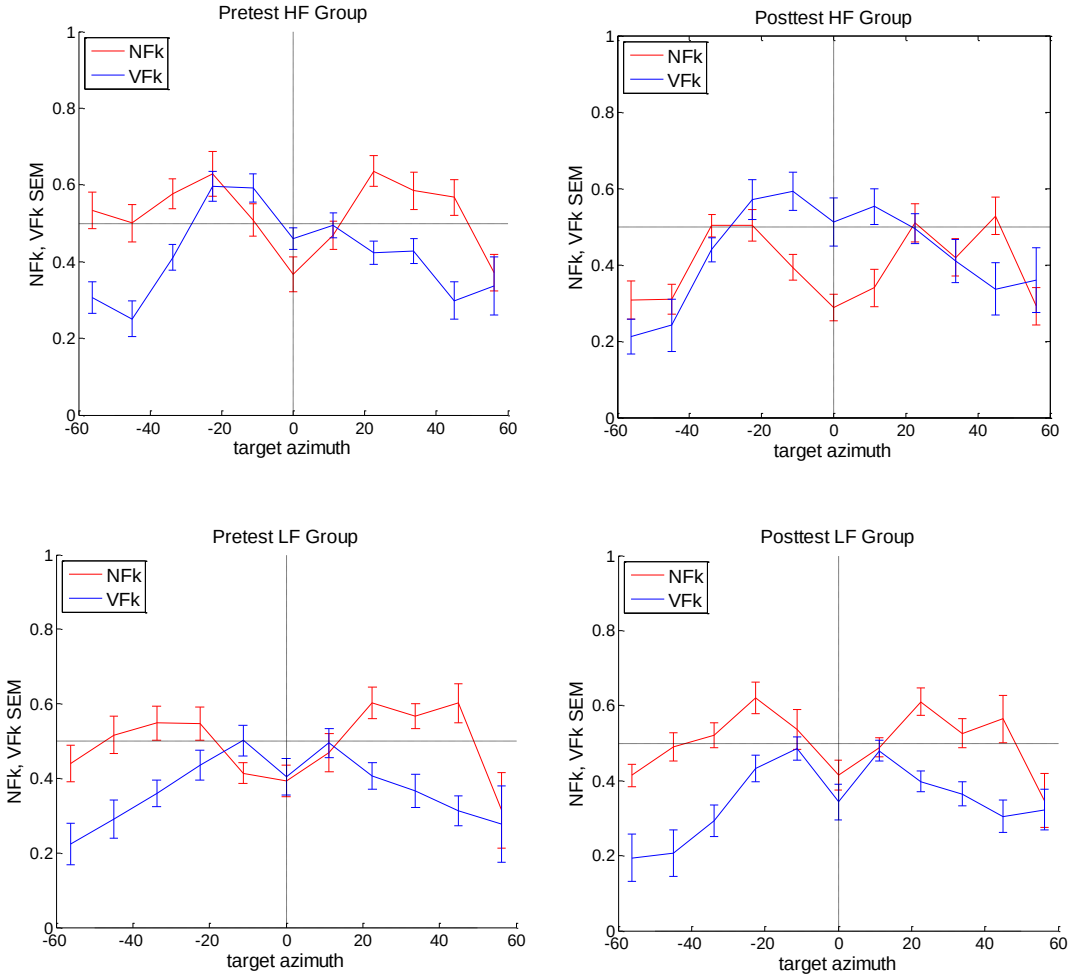


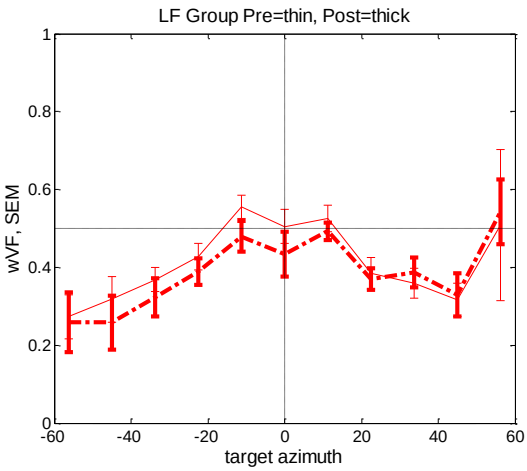
Figures for subjects : /nfs/data1/lab/Ondrej/Spaci/raw_analysis_RE_group_figures

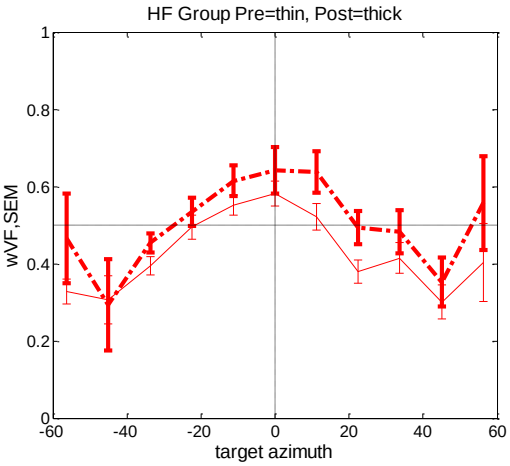
Regression analysis RE:

$$R(\alpha, \Delta_{LF}, \Delta_{HF}) = k_{LF}(\alpha) * \Delta_{LF} + k_{HF}(\alpha) * \Delta_{HF} + Q(\alpha); w_{HF} = \frac{atan\left(\frac{k_{HF}(\alpha)}{k_{LF}(\alpha)}\right)}{90}$$

R is a subject's response azimuth in a trial with LF and HF components at positions $\alpha + \Delta_{LF}$ and $\alpha + \Delta_{HF}$, respectively (α is between -56.25° and 56.25° with 11.25° steps). k_{LF}, k_{HF} and Q are approximated parameters of a regression model, where k_{LF} and k_{HF} are regression slopes (determining the weights of the frequency components) and Q is the overall bias for azimuth α.







anova_regression_2channel_LF_ondrej.t

anova_regression_2channel_HF_ondrej.

ANOVAs:

Figures for subjects :
/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/HF_Group_2channel_ITDk_ILDk

/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/LF_Group_2channel_ITDk_ILDk

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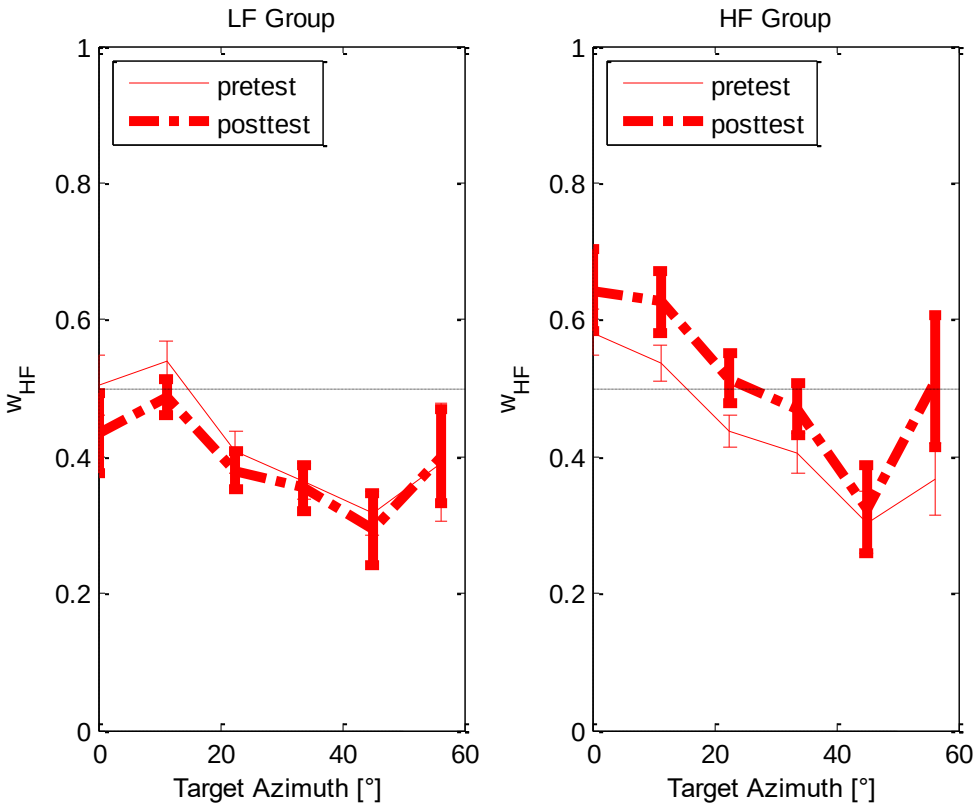
Collapsed weights :



anova_regression_2ch_collapsed_weigh anova_regression_2ch_collapsed_weigh anova_regression_2ch_collapsed_weigh

ANOVAs:

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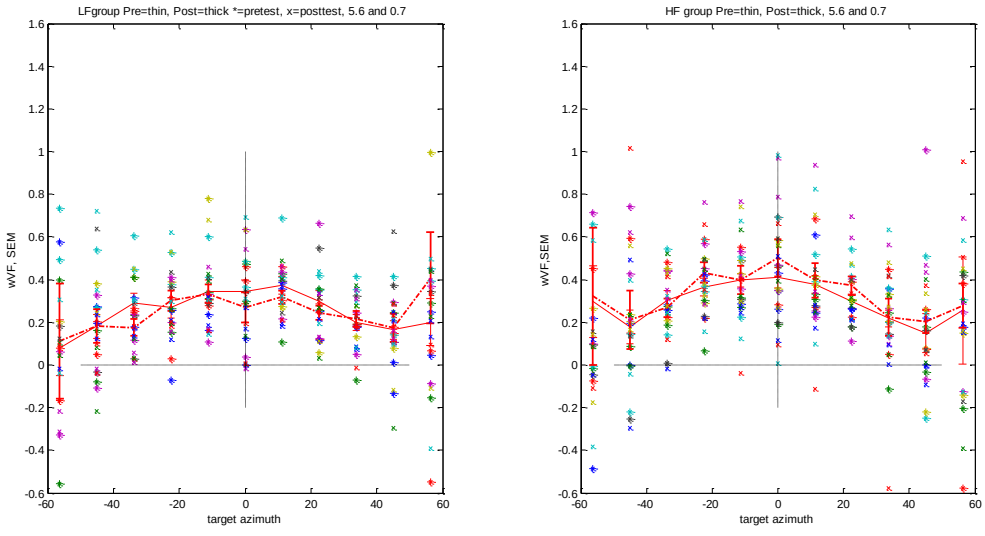
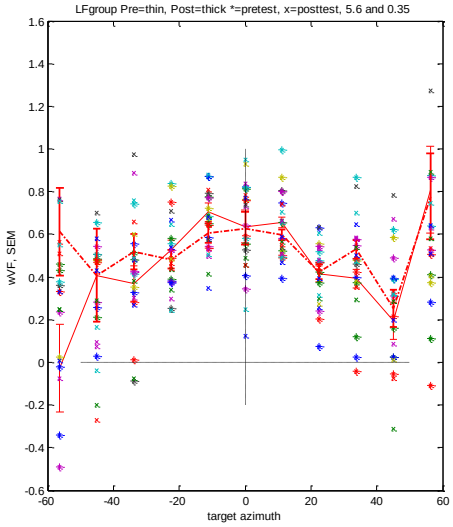
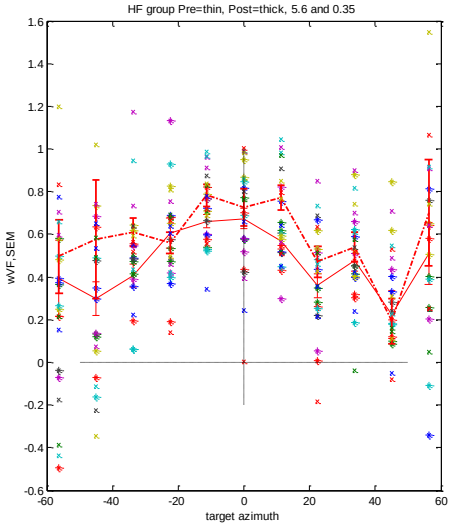
separate weights for combinations of frequencies :

5.6kHz and 0.7kHz

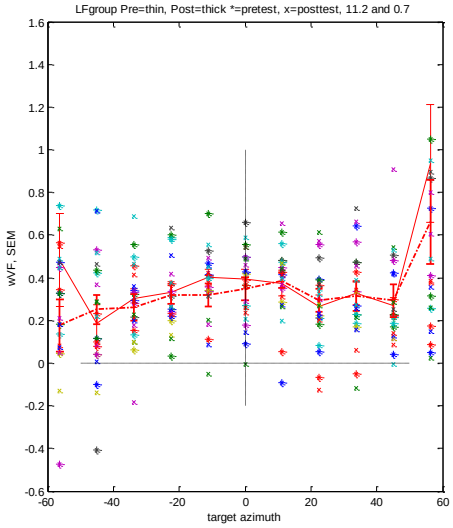


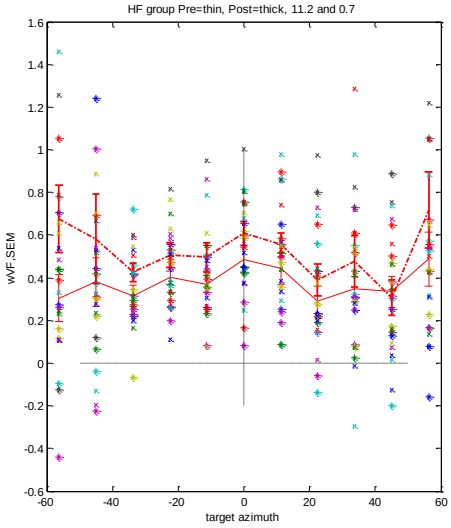
5.6kHz and 0.35kHz



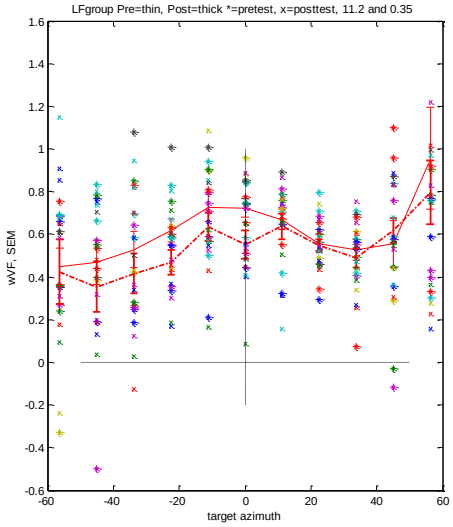


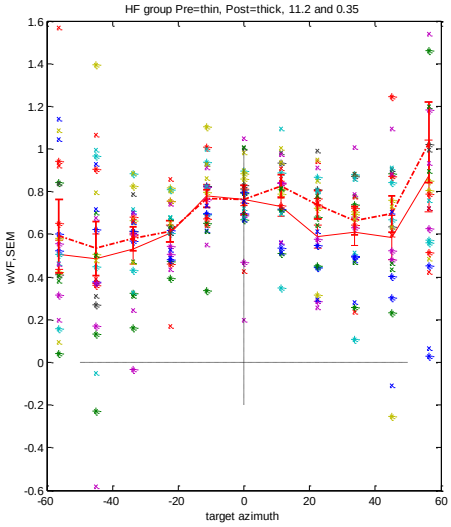
11.2kHz a 0.7kHz





11.2kHz and 0.35kHz





Figures(also with collapsed data) : /nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/separate_weights

ANOVAs(with and without 1 and 11 azimuth and also collapsed):

anova_regression_2ch_weights_allComb anova_regression_2ch_weights_allComb anova_regression_2ch_weights_allComb anova_regression_2ch_weights_allComb anova_regression_2ch_weights_allComb

anova_regression_2ch_weights_allComb anova_regression_LFgrHFgr_allComb_cc anova_regression_LFgrHFgr_allComb_cc anova_regression_LFgr_allComb_collaps anova_regression_LFgr_allComb_collaps

anova_regression_HFgr_allComb_colla anova_regression_HFgr_allComb_colla

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Figures of different combinations of weights, normal and collapsed(5.6,0.35 & 5.6,0.7 ; 11.2,0.35 & 5.6,0.35 ; etc.)

/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/two_combinations_weights

ANOVAs for collapsed data(comb 1 – 5.6 and 0.7 kHz ; comb 2 – 5.6 and 0.35 kHz, comb 3 – 11.2 and 0.7 kHz, comb4 – 11.2 and 0.35 kHz)

anova_regression_LF_HF_allComb_ondr anova_regression_LF_allComb_ondrej_c anova_regression_HF_allComb_ondrej_

ANOVAs for collapsed data with LF and HF factor(LF1 = 0.35, LF2 = 0.7, HF1 = 5.6 , HF2 = 11.2):


anova_regression_2
ch_weights_HFavg_‹


anova_regression_2
ch_weights_HFavg_‹


anova_regression_2
ch_weights_HFavg_‹

ANOVAs for Collapsed weights with only 0.7kHz frequency or only with 0.35kHz frequency


anova_regression_L
FgrHFgr_LF700_ond


anova_regression_L
FgrHFgr_LF350_ond


anova_regression_L
F_LF700_ondrej_coll


anova_regression_L
F_LF350_ondrej_coll


anova_regression_
HF_LF700_ondrej_co


anova_regression_
HF_LF350_ondrej_co

ANOVAs for Collapsed weights with only 0.7kHz frequency or only with 0.35kHz frequency without most lateral position :


anova_regression_2
ch_weights_HFavg_‹


anova_regression_2
ch_weights_HFavg_‹


anova_regression_2
ch_weights_HFavg_‹

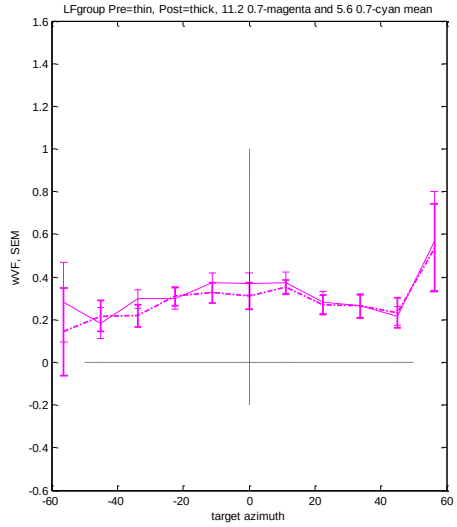

anova_regression_2
ch_weights_HFavg_‹

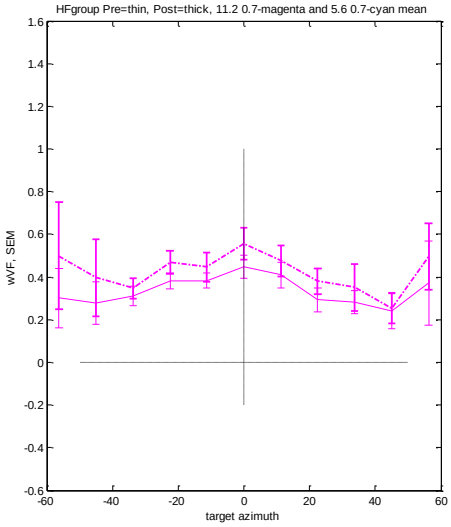

anova_regression_2
ch_weights_HFavg_‹


anova_regression_2
ch_weights_HFavg_‹

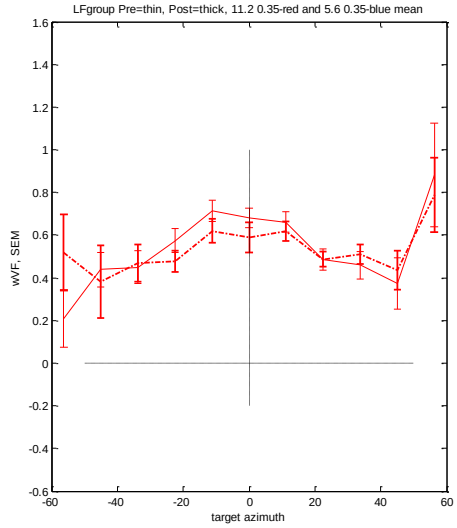
Weights with averaged high frequency:

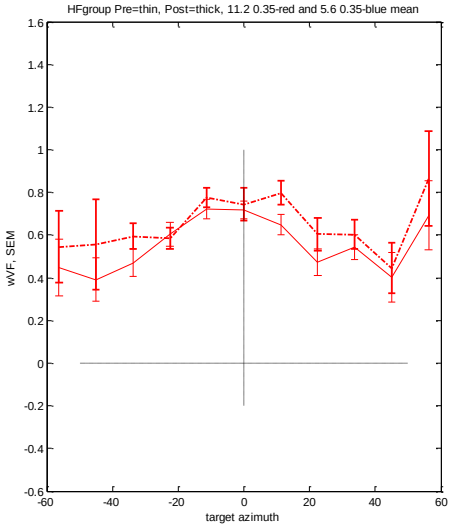
11.2 , 0.7 && 5.6 ,0.7





11.2, 0.35 && 5.6, 0.35





Figures :
/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/two_combinations_weights

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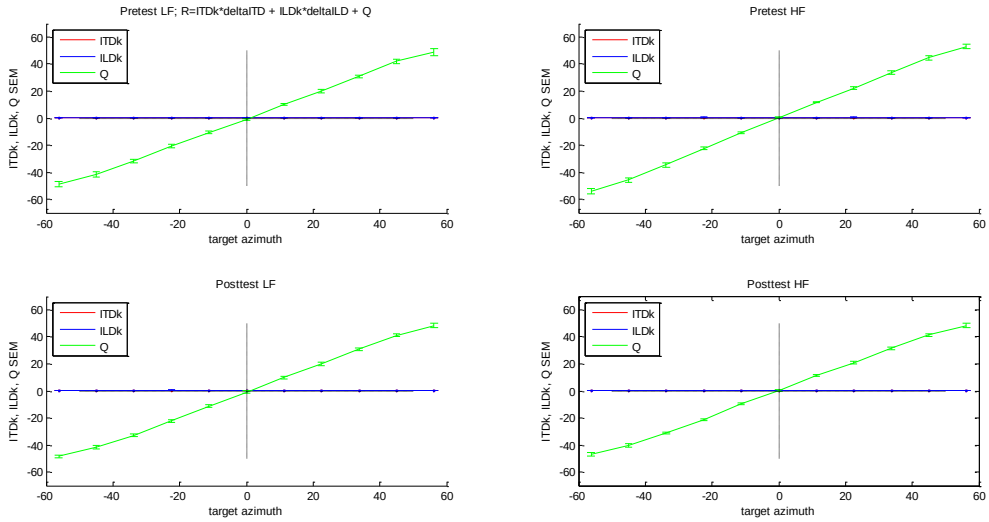
Q parameter analysis:

ITDk_ILDk_subjects_2channel_Q



Figures for subjects :

/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/HF_Group_2channel_Q_ITDk_ILDk

/nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/LF_Group_2channel_Q_ITDk_ILDk

Q-parameter for separate combinations of frequencies:

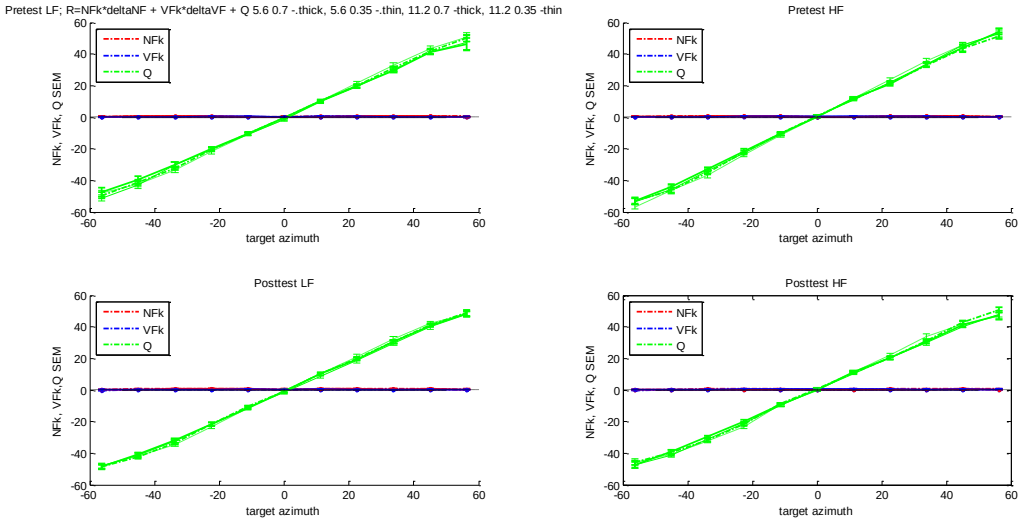


Figure : /nfs/data1/lab/Ondrej/Spaci/regression_analysis/group_figures_2ch_VFk_NF_weights/regression_2channel_allComb_Q

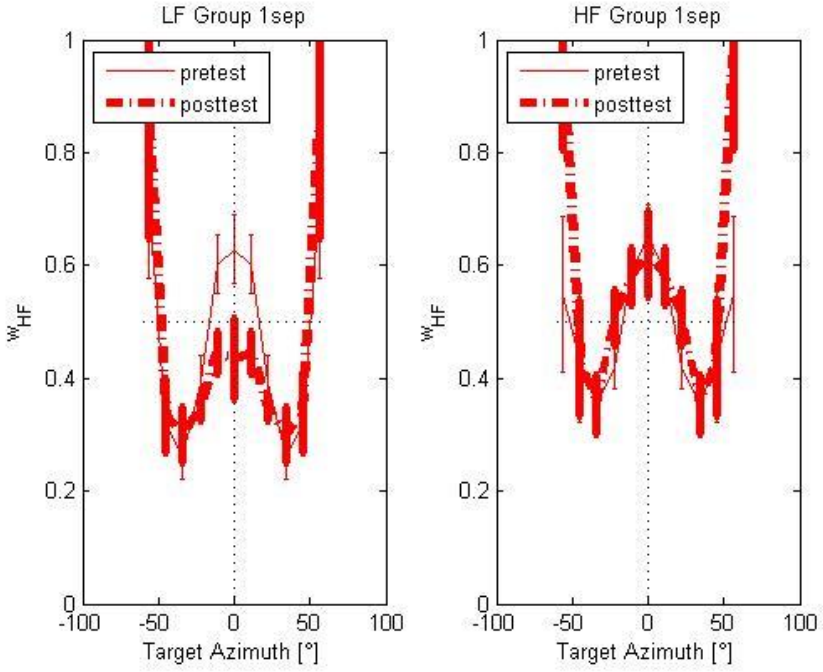
ANOVAs(with and wthout 1 and 11 azimuth):

anova_regression_2ch_allComb_Q_LFgr

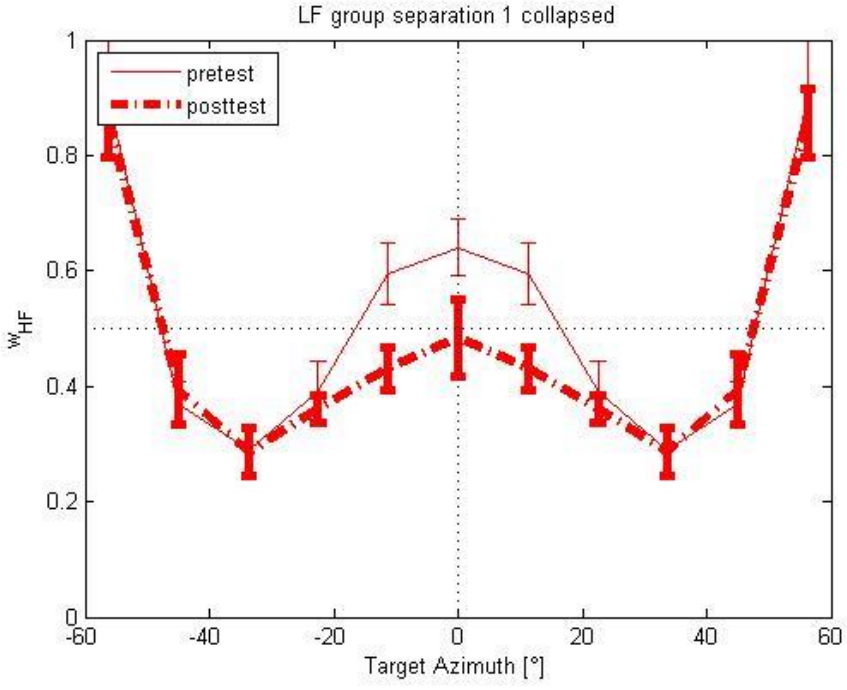
anova_regression_2ch_allComb_Q_LFgr_

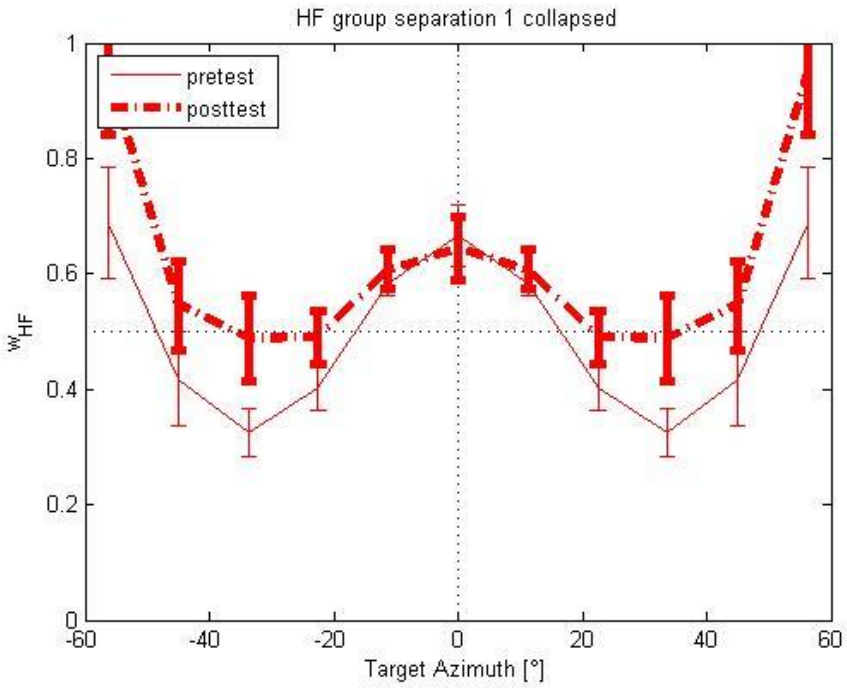
Analysis of model : $R(\alpha,\ \Delta_{LF},\ \Delta_{HF}) = k_{LF}(\alpha) * \Delta_{LF} + k_{HF}(\alpha) * \Delta_{HF} + Q(\alpha)$; $w_{HF} = \frac{atan\left(\frac{k_{HF}(\alpha)}{k_{LF}(\alpha)}\right)}{90}$

With data where separation of speakers was 0 or 1 (fitting done together at all data):



Version2 (fitting done separatly at each combination of frequencies(4) and then averaged):





Figures : /nfs/data1/lab/Ondrej/Spaci/regression_analysis/separation1

ANOVAs for weights :

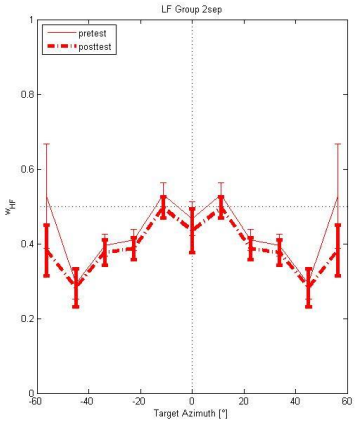
anova_regression_2ch_weights_1sep_9a anova_regression_2ch_weights_1sep_9a anova_regression_2ch_weights_1sep_9a

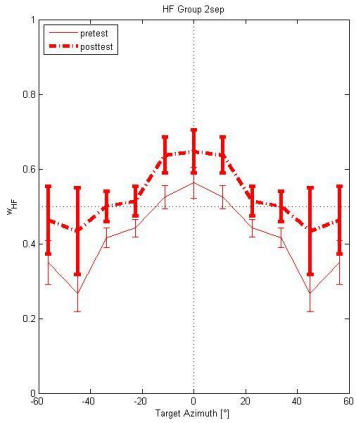
anova_regression_weights_1sep_HFgr anova_regression_weights_1sep_HFgr anova_regression_weights_1sep_HFgr. anova_regression_weights_1sep_LFgr anova_regression_weights_1sep_LFgr

anova_regression_weights_1sep_LFgr anova_regression_weights_1sep_LFgr_ anova_regression_weights_1sep_LFgr_ anova_regression_weights_1sep_LFgr.1

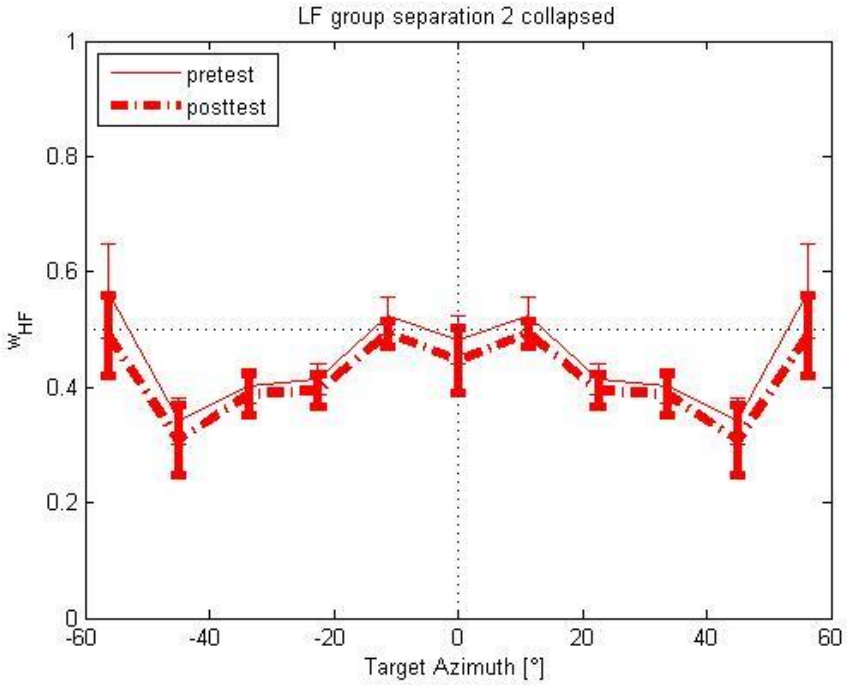
Analysis of model : $R(\alpha,\ \Delta_{LF},\ \Delta_{HF}) = k_{LF}(\alpha) * \Delta_{LF} + k_{HF}(\alpha) * \Delta_{HF} + Q(\alpha); w_{HF} = \frac{atan\left(\frac{k_{HF}(\alpha)}{k_{LF}(\alpha)}\right)}{90}$

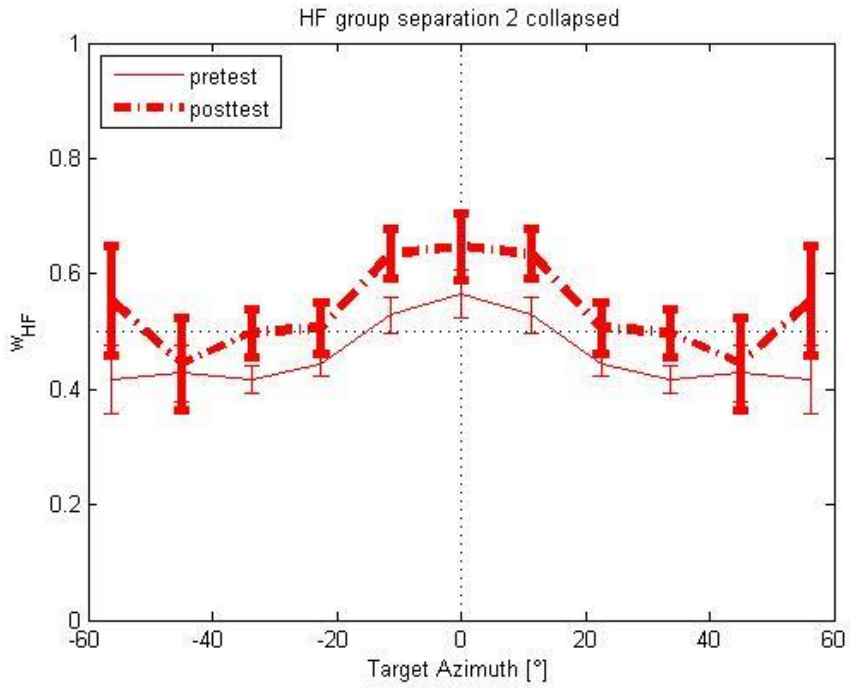
With data where separation of speakers was 0 or 2(fitting done together at all data):





Version2(fitting done separatly at each combination of frequencies(4) and then averaged):





Figures : /nfs/data1/lab/Ondrej/Spaci/regression_analysis/separation2

ANOVAs for weights :

anova_regression_weights_2sep_LFgr1

anova_regression_weights_2sep_LFgr1

anova_regression_weights_2sep_LFgr1

anova_regression_weights_2sep_LFgr_

anova_regression_weights_2sep_LFgr_

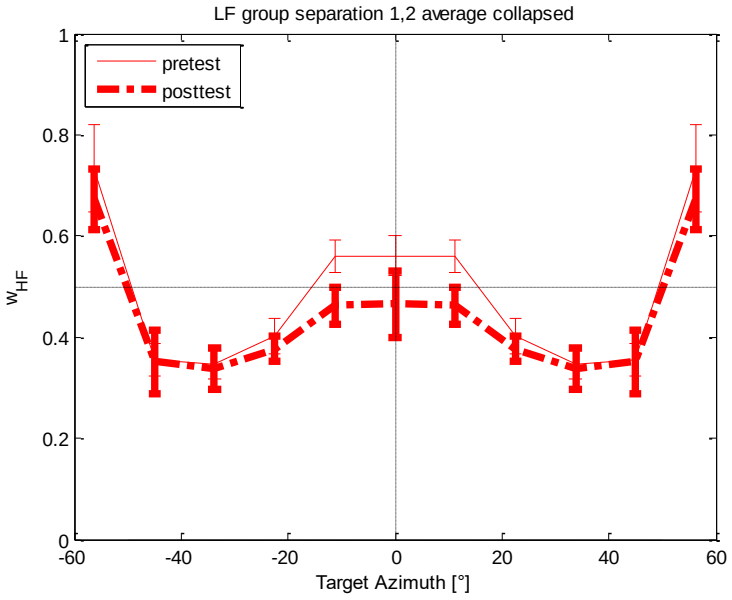
anova_regression_weights_2sep_LFgr_

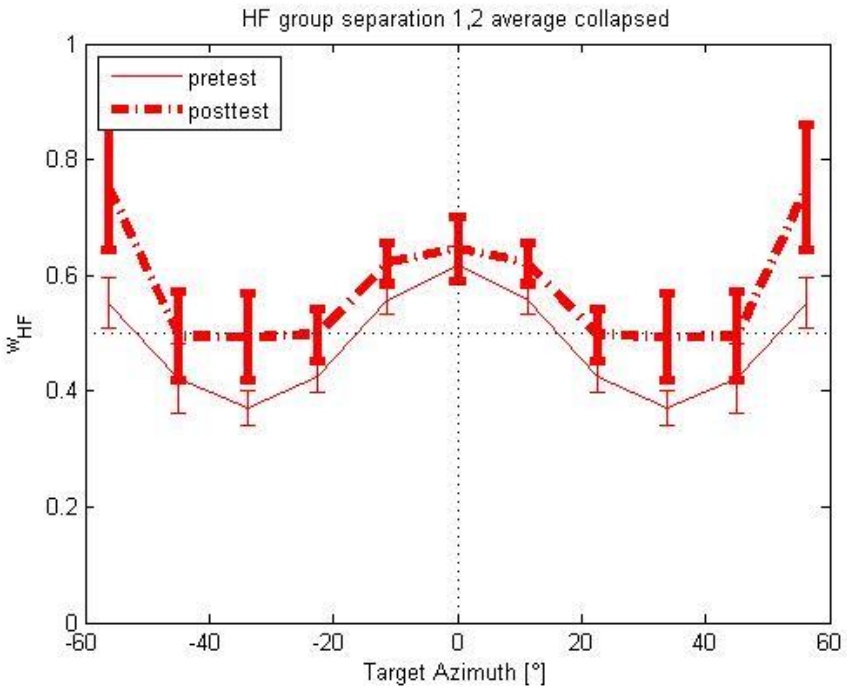
anova_regression_weights_2sep_HFgr_

anova_regression_weights_2sep_HFgr_

anova_regression_weights_2sep_HFgr_

Average of sep1 and sep2 (version2(fitting done separatly at each combination of frequencies(4) and then averaged))



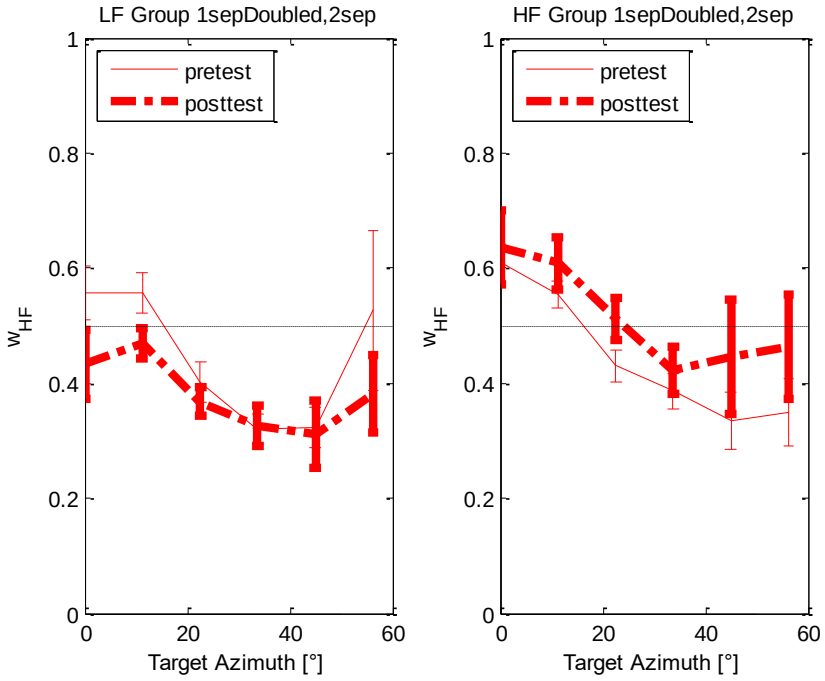


anova_regression_collapsed_1sep2sep_ anova_regression_collapsed_1sep2sep_ anova_regression_collapsed_1sep2sep_ anova_regression_collapsed_1sep2sep_ anova_regression_collapsed_1sep2sep_

ANOVAS:

anova_regression_collapsed_1sep2sep_

Averaged 1sepDoubled and 2sep (fitted after they were averaged, no freq dependant)



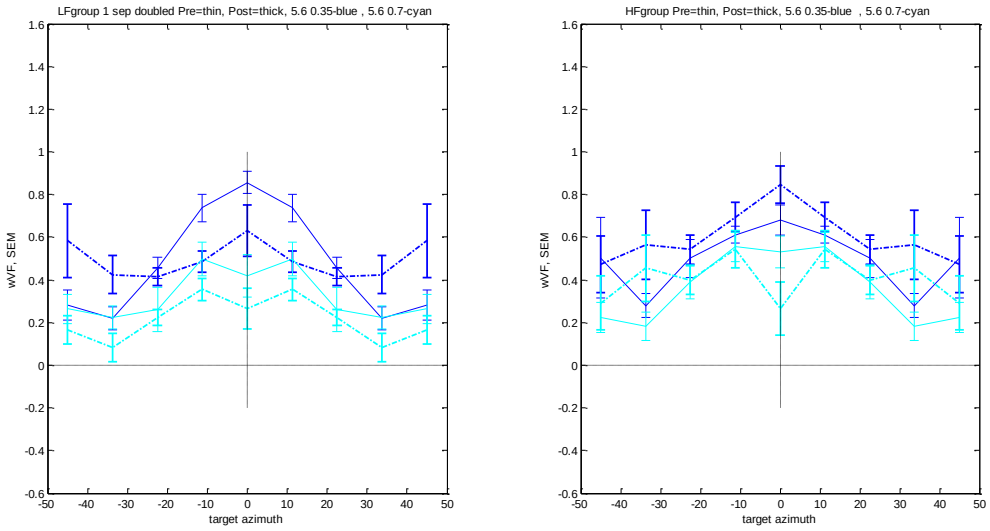
anova_regression_collapsed_1sepDoub

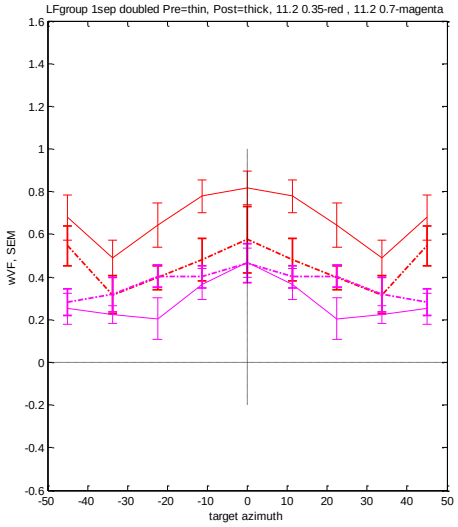
anova_regression_collapsed_1sepDoub

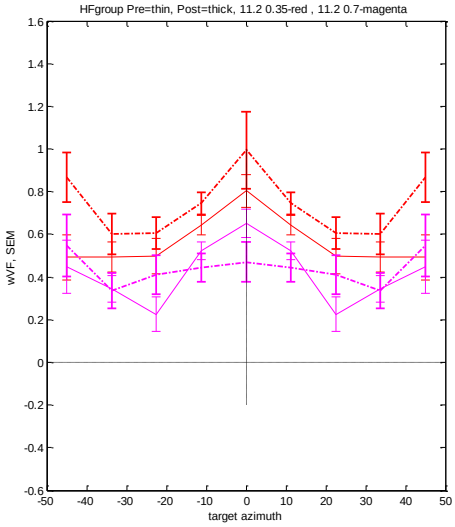
anova_regression_collapsed_1sepDoub

ANOVAS:

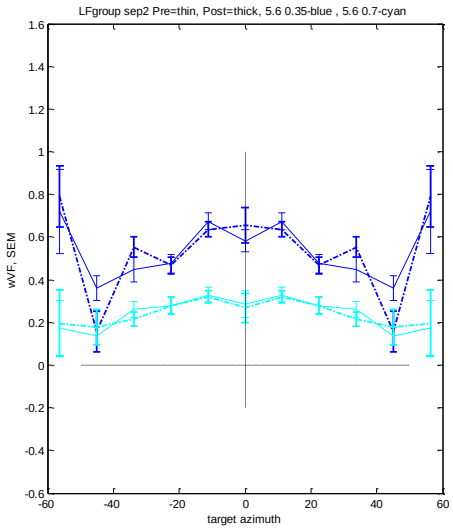
Sep1Doubled collapsed:

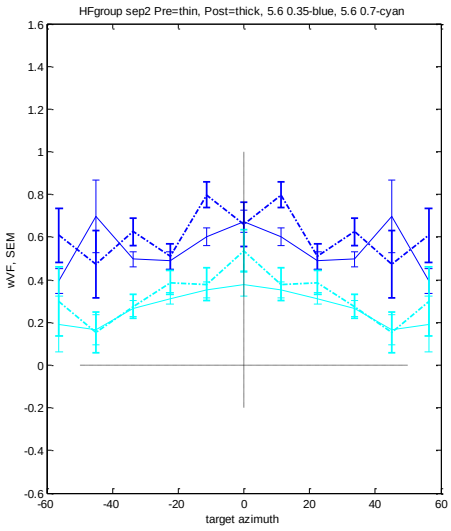


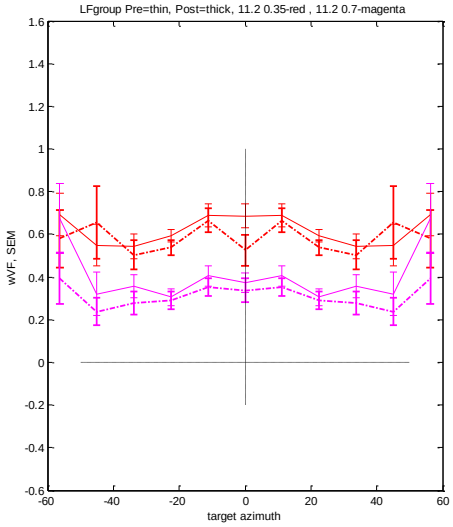


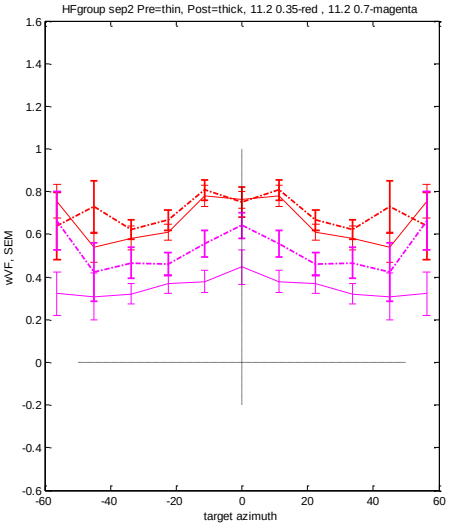


Sep2 collapsed all frequencies

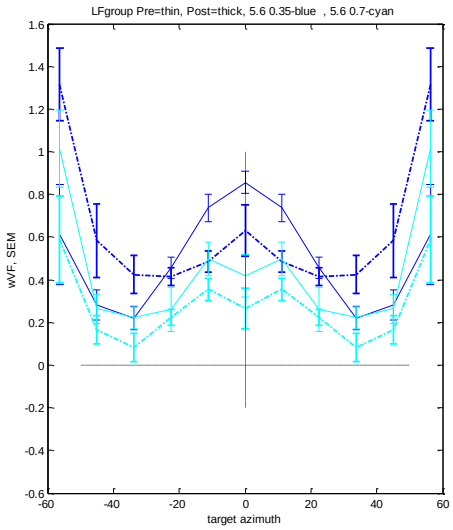


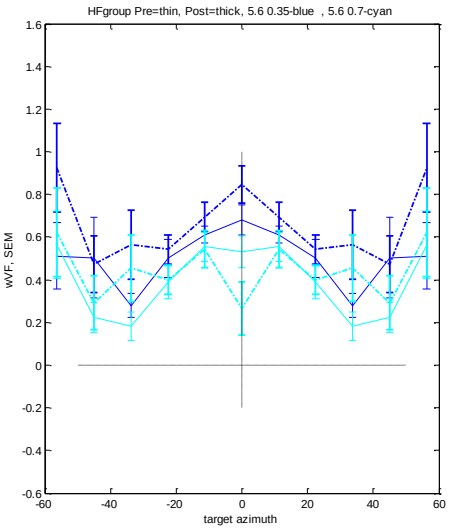


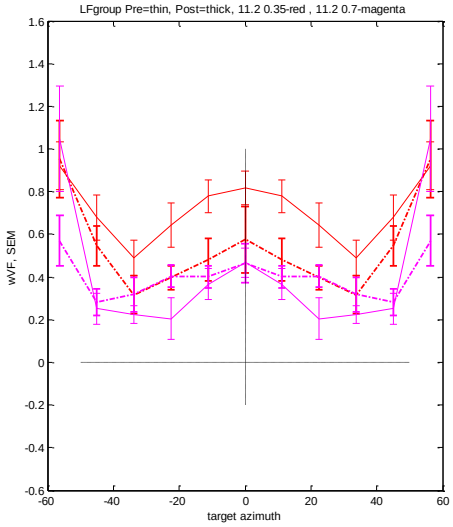


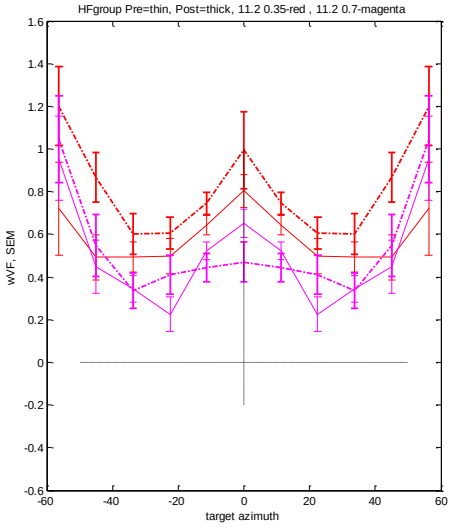


Sep 1 collapsed all freq

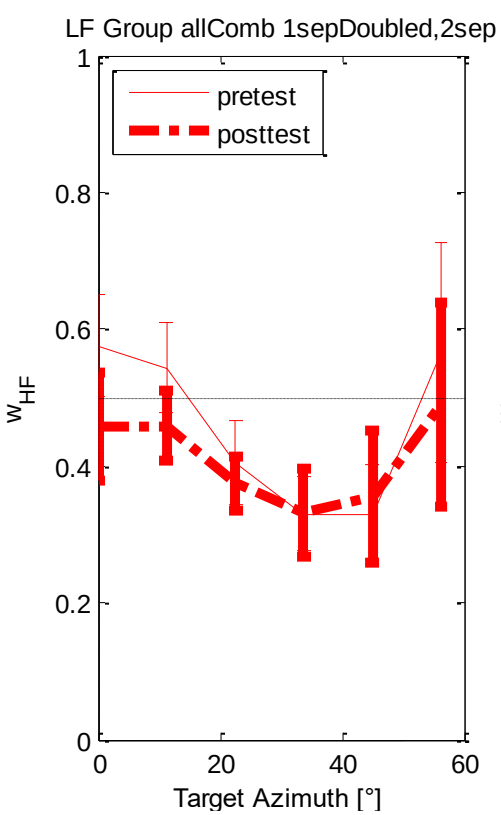


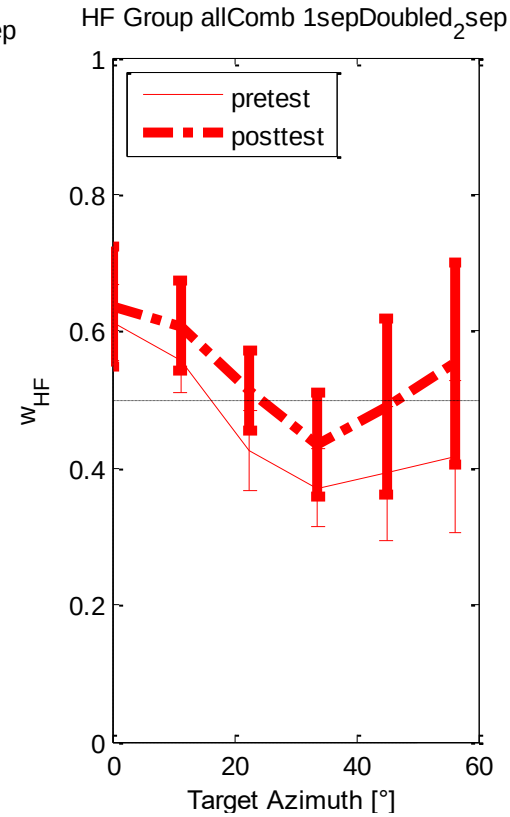






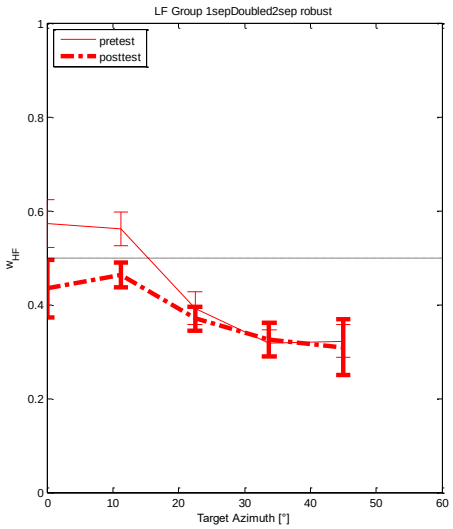
1sepDoubled and 2sep version2 (different combination of doubled stimuli for 1sep fitted with 2sep data):

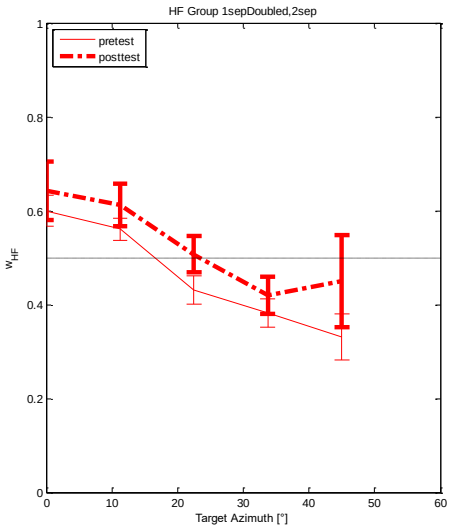




ANOVAS:

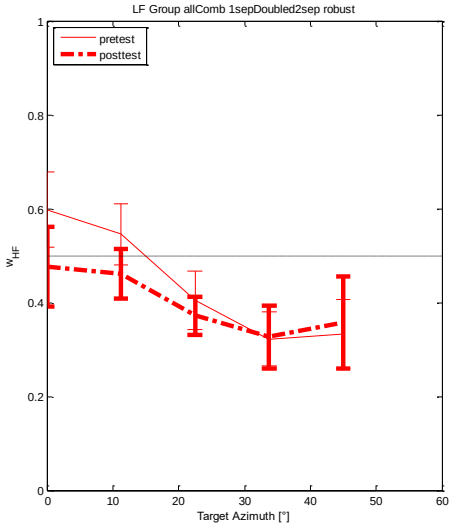
Averaged 1sepDoubled and 2sep with **robust fit**(fitted after they were averaged, no freq dependant)

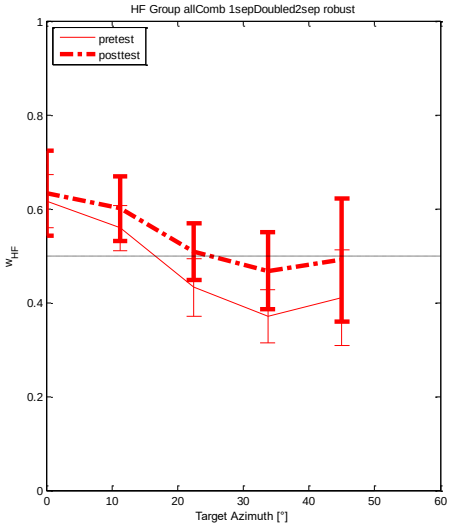




ANOVAs: anova_regression_collapsed_1sepDoub anova_regression_collapsed_1sepDoub anova_regression_collapsed_1sepDoub

1sepDoubled and 2sep version2 with **robust fit**(different combination of doubled stimuli for 1sep fitted with 2sep data):

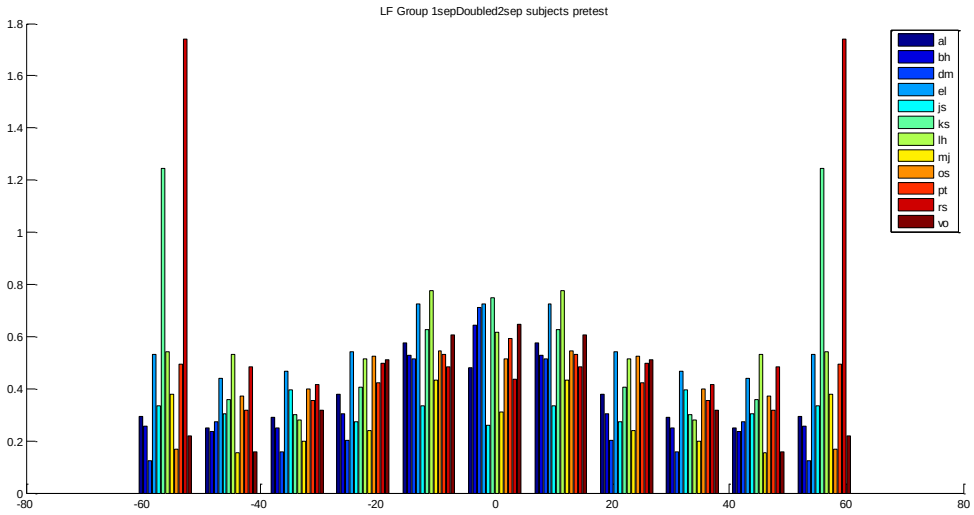


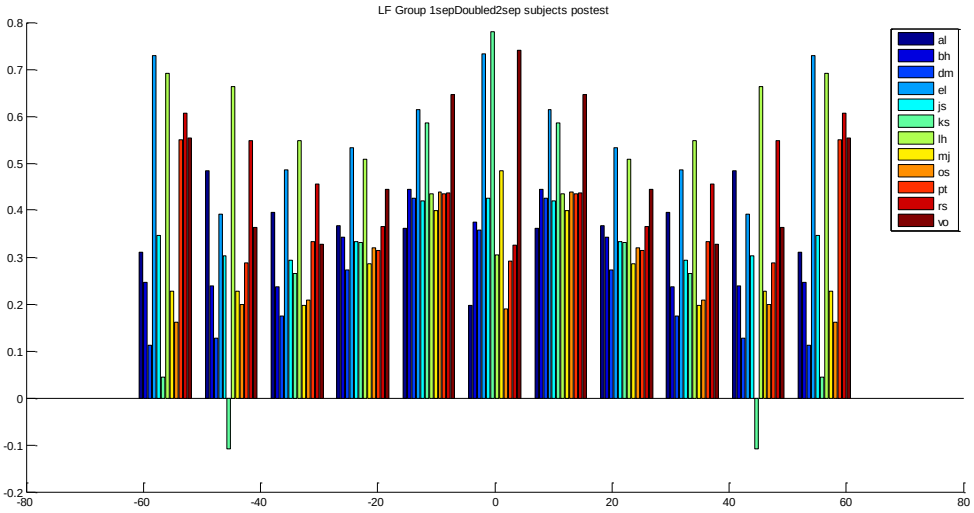


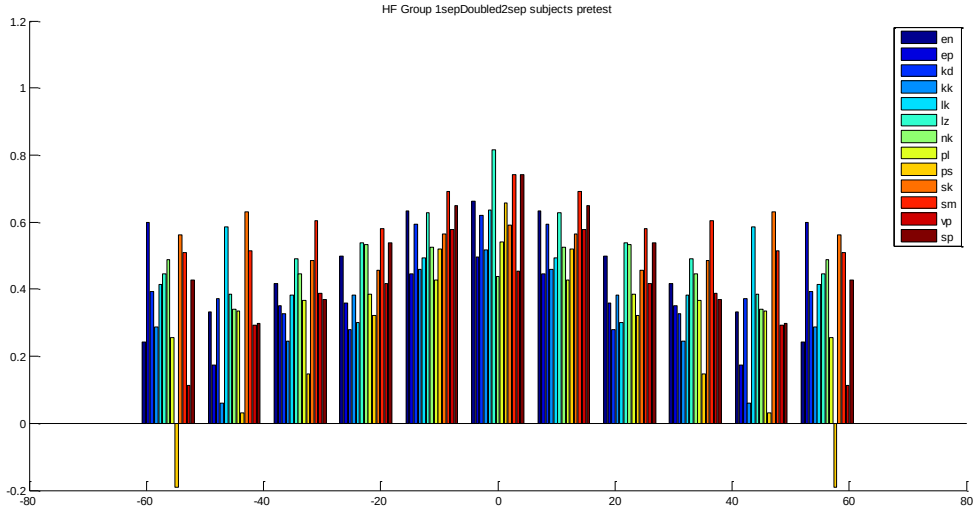
ANOVAs: anova_regression_collapsed_allComb_1 anova_regression_collapsed_allComb_1 anova_regression_collapsed_allComb_1

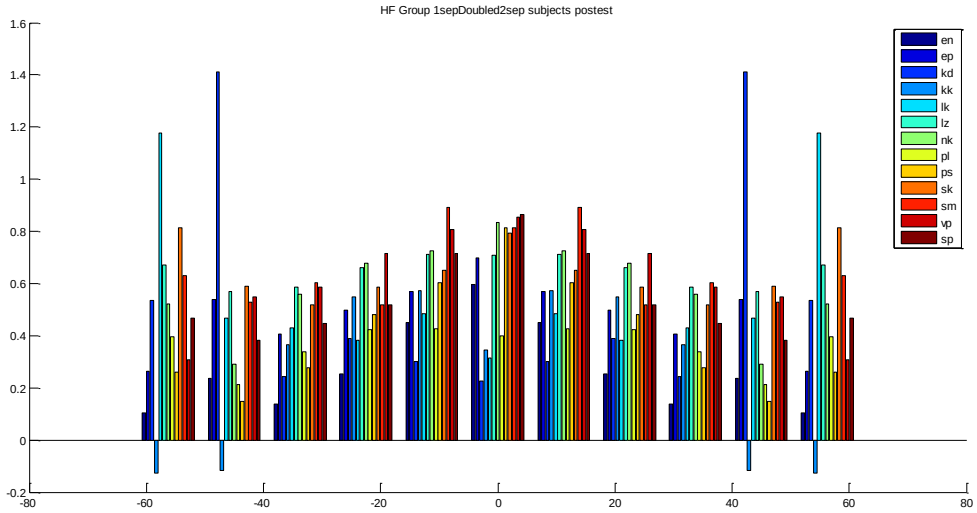
Robust fit did not make any significant change.

Subjects weights of regression model in version1 Averaged 1sepDoubled and 2sep (fitted after they were averaged, no freq dependant) collapsed:



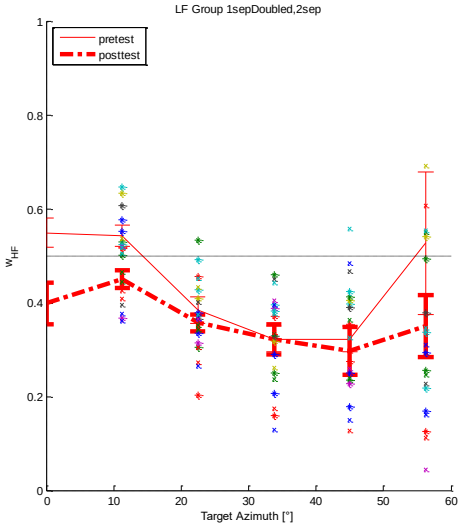


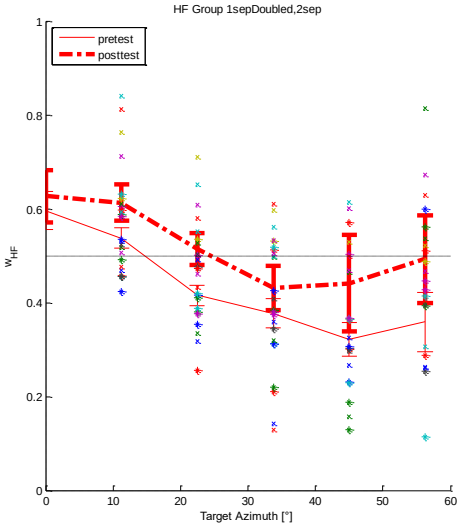




In following analysis I did again regress analysis, but I exclude one subjects with worst average weight from each group. In LF group it was „el“ and in HF group „en“. After that ANOVAs shows significant effect of time(pretest, posttest) for both group in both version of analysis.

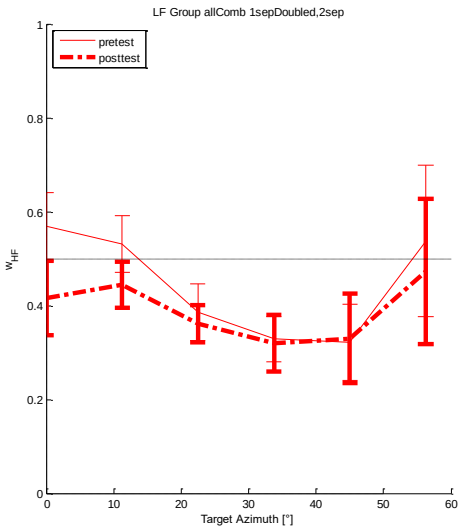
Version1 Averaged 1sepDoubled and 2sep (fitted after they were averaged, no freq dependant) collapsed with excluded subjects:

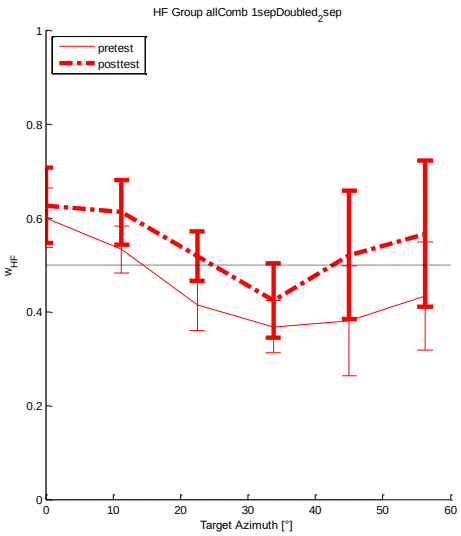




ANOVAs: anova_regression_collapsed_1sepDoub anova_regression_collapsed_1sepDoub anova_regression_collapsed_1sepDoub

Version2 Averaged 1sepDoubled and 2sep (different combination of doubled stimuli for 1sep fitted with 2sep data) collapsed after exclusion of one subject from each group:





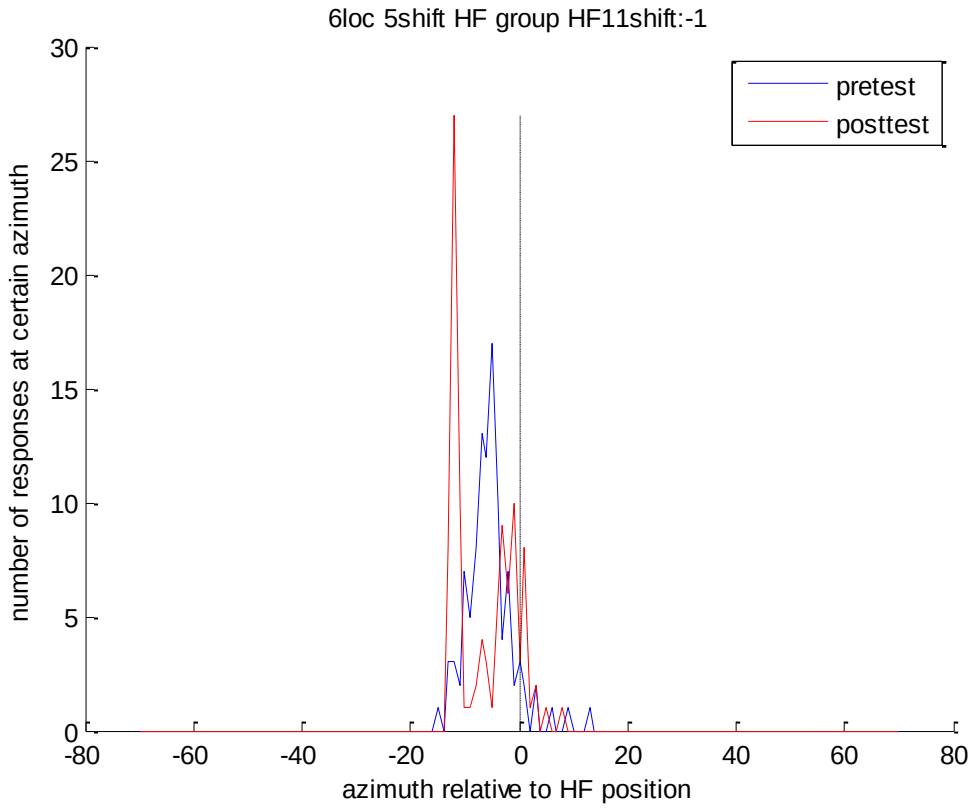
ANOVAs: anova_regression_collapsed_allComb_1 anova_regression_collapsed_allComb_1 anova_regression_collapsed_allComb_1

Responses distribution

Following figures shows sum of responses for 2channel data where position of HF stimuli is on certain position(from 0 to 56.25 with step 11.25) and position of LF is shifted from -2 to 2

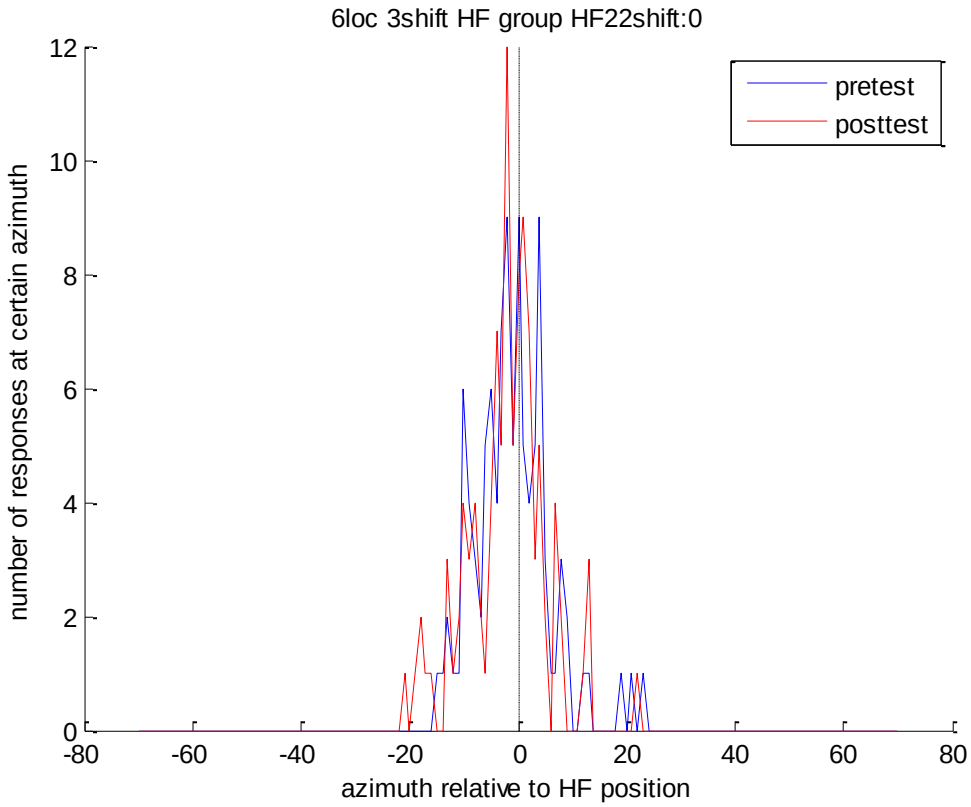
(following are some of the figures)

Figures: /nfs/data1/lab/Ondrej/Spaci/2ch_response_distribution_version3_6loc_5shift



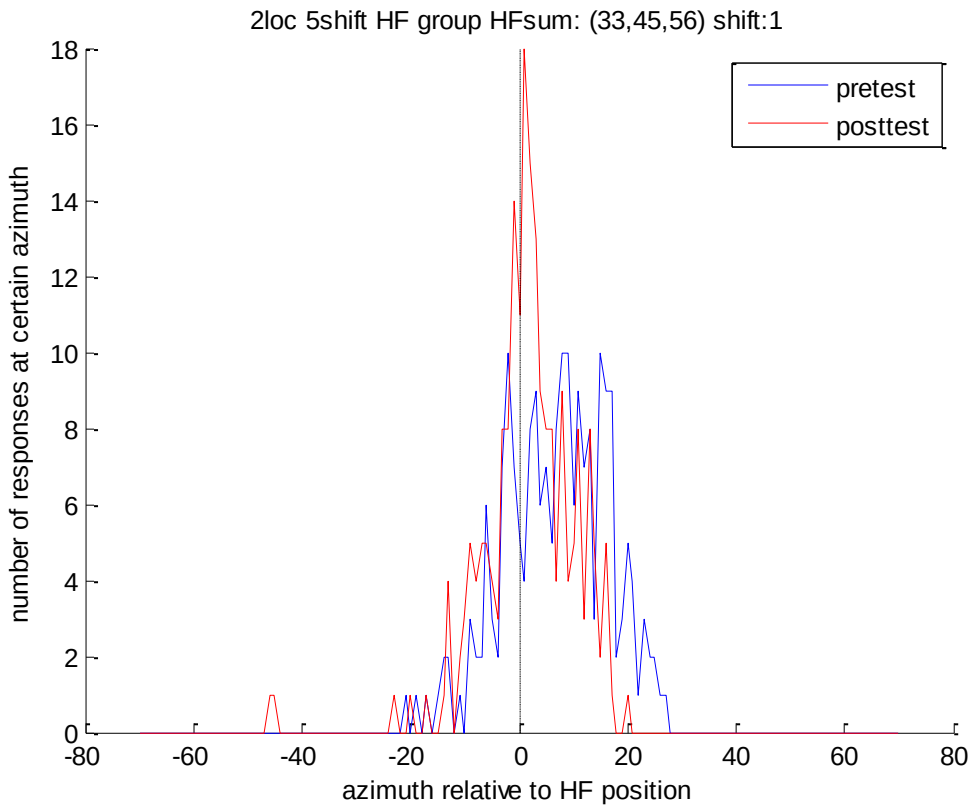
HF stimuli is on certain position(from 0 to 56.25 with step 11.25) and position of LF is shifted from 0 to 2

Figures: /nfs/data1/lab/Ondrej/Spaci/2ch_response_distribution_version3_6loc_3shift



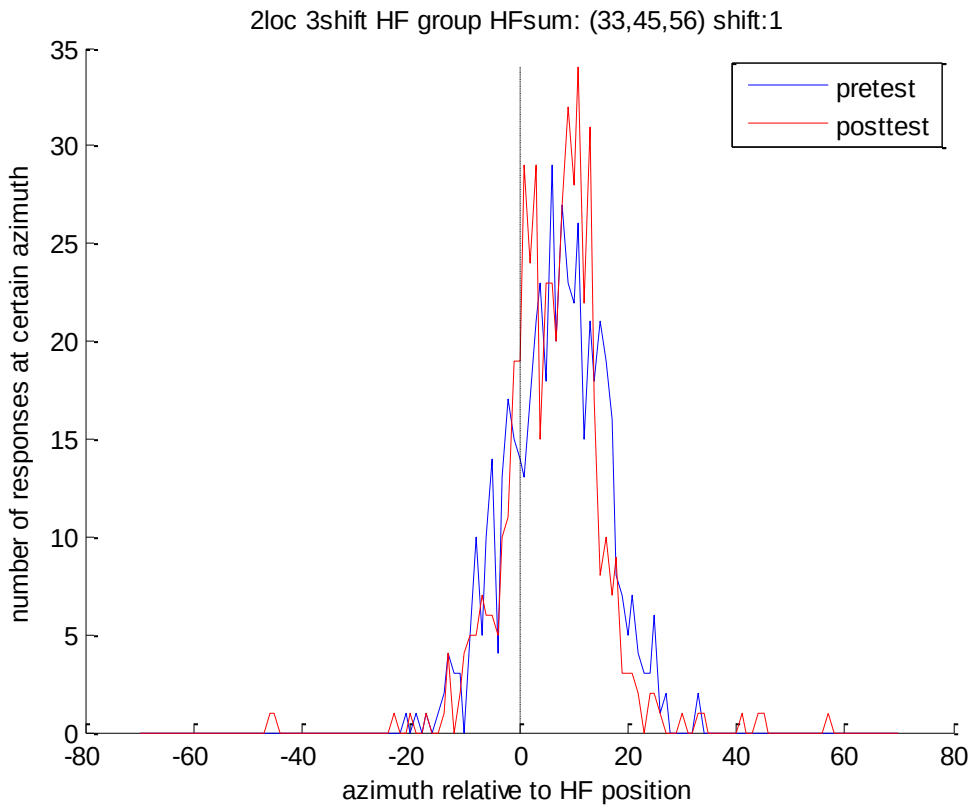
HF stimuli is on certain position (0,11.25,22.5) or (33.75,45,56.25) and position of LF is shifted from -2 to 2

Figures: /nfs/data1/lab/Ondrej/Spaci/2ch_response_distribution_version3_2loc_5shift



HF stimuli is on certain position (0,11.25,22.5) or (33.75,45,56.25) and position of LF is shifted from 0 to 2

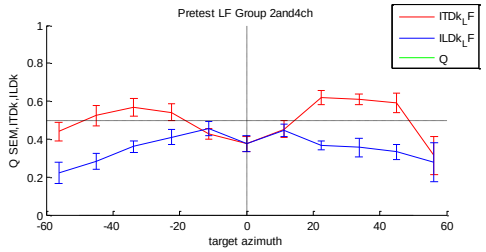
Figures: /nfs/data1/lab/Ondrej/Spaci/2ch_response_distribution_version3_2loc_3shift

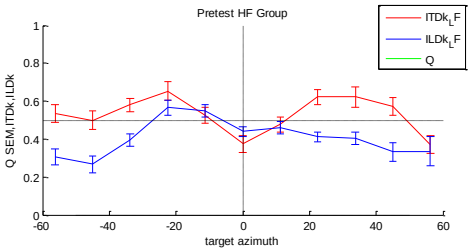


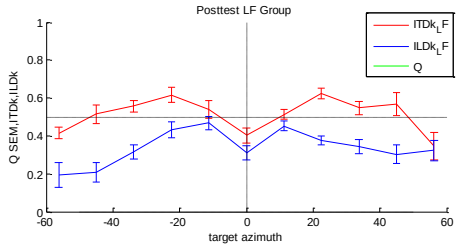
2and4ch

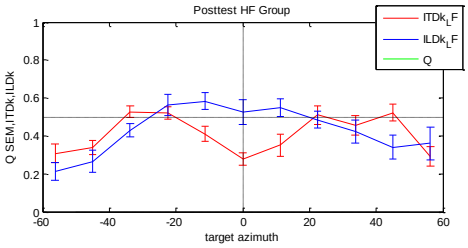
In following analysis we combined 2 and 4 channel data and also we looked on them separately. We distinguish 0.5 and 1.5 separation for 4-channel data and separations 1 and 2 for 2-channel data. Results from analysis done on combination of these data shows same pattern as on 2-channel data alone, it means increase of HF weight for HF group and decrease of HF weight for LF group, but the effect is more significant. All figures for subjects can be found here : /nfs/data1/lab/Ondrej/Spaci/regression_analysis/2and4ch

LFk and HFk all separation combined







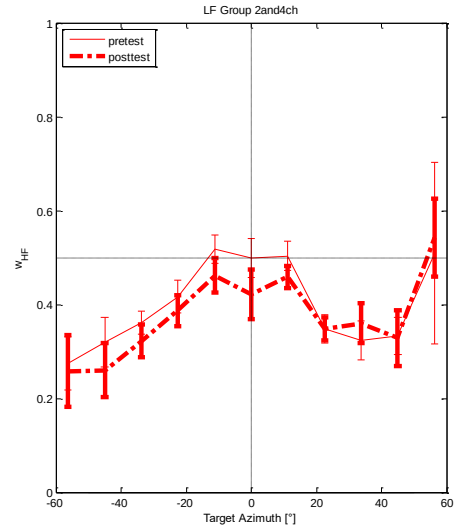


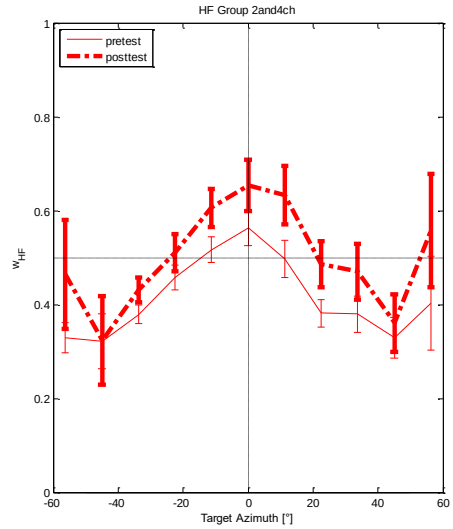
anova_regression_2 anova_regression_2 anova_regression_2
and4ch_HFgr_HFk.t and4ch_HFgr_LFk.tx and4ch_LFgr_HFk.tx

ANOVAs (they are made on 11 locations):

anova_regression_2 anova_regression_2 anova_regression_2
and4ch_LFgr_LFk.txt and4ch_LFgrHFgr_H and4ch_LFgrHFgr_LI

Weights all separation combined:



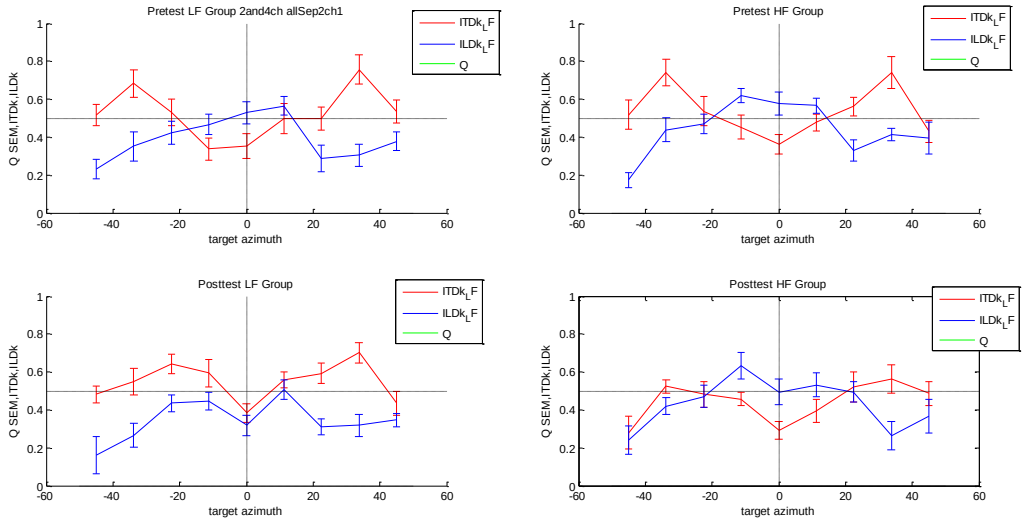


anova_regression_2 anova_regression_2 anova_regression_2
and4ch_weights_HF and4ch_weights_LF and4ch_weights_LF

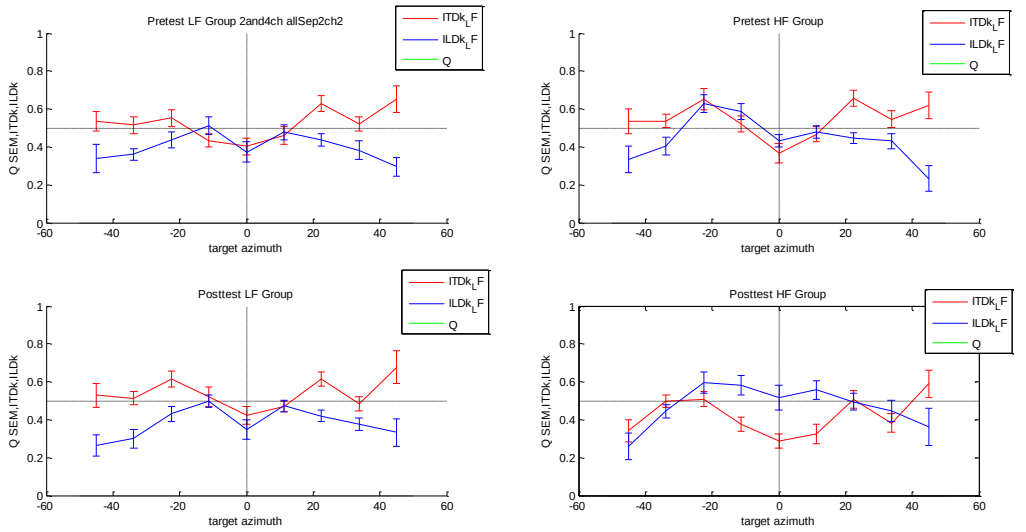
ANOVAs:

Not collapsed data:

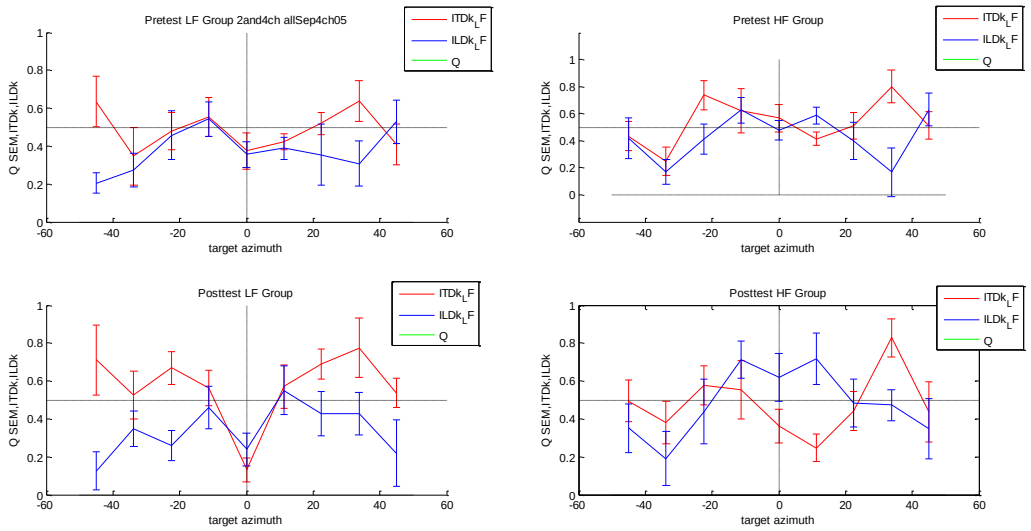
LFk and HFk for separation 1



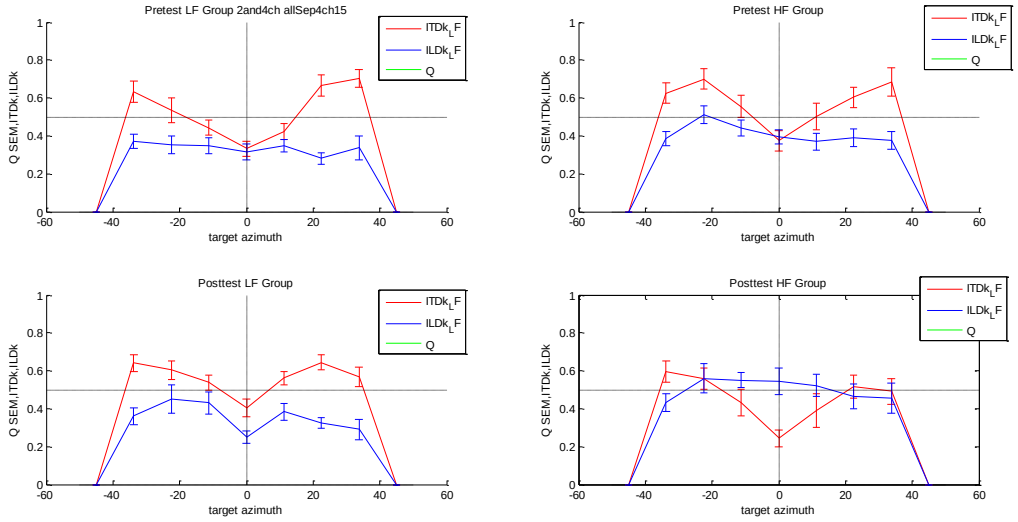
LFk and HFk for separation 2



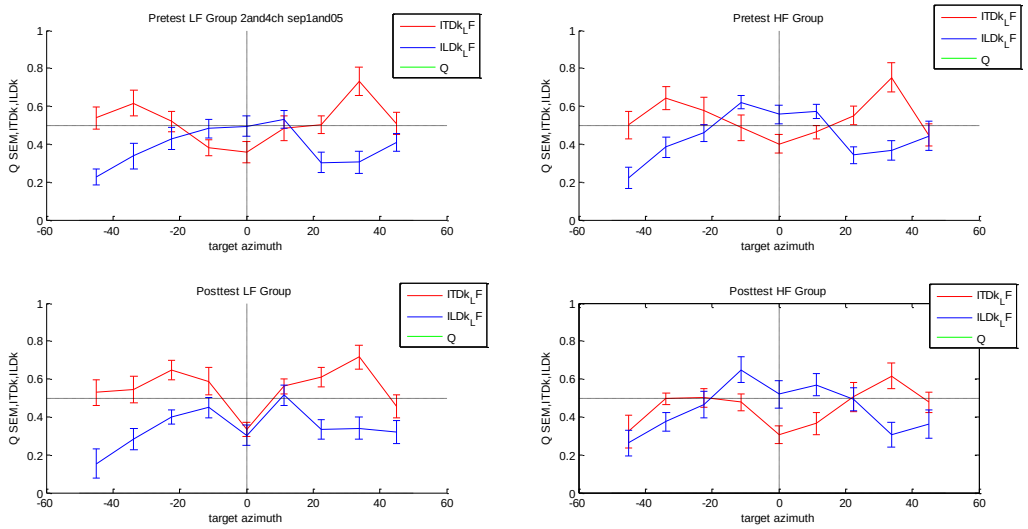
LFk and HFk for separation 0,5



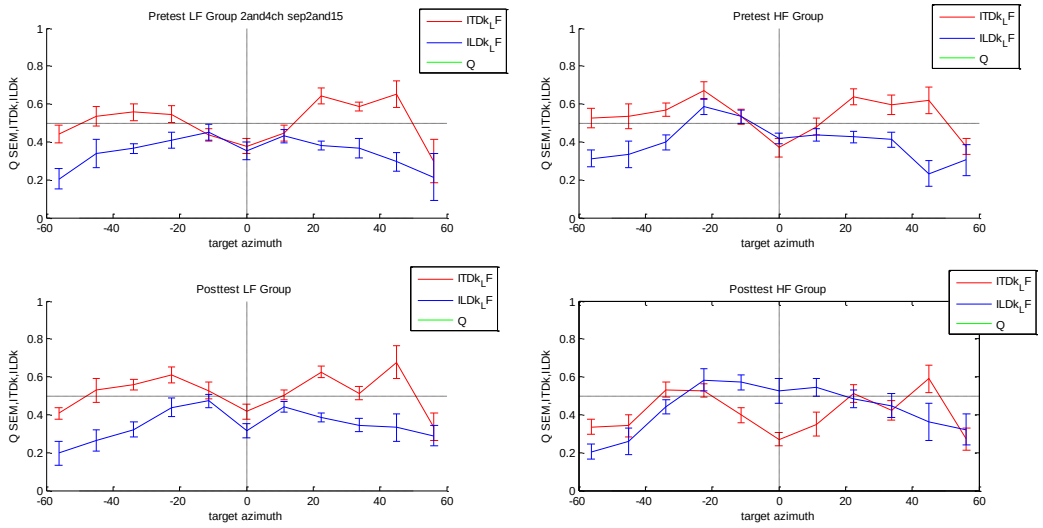
LFk and HFk for separation 1,5



LFk and HFk for separation 0,5 and 1:



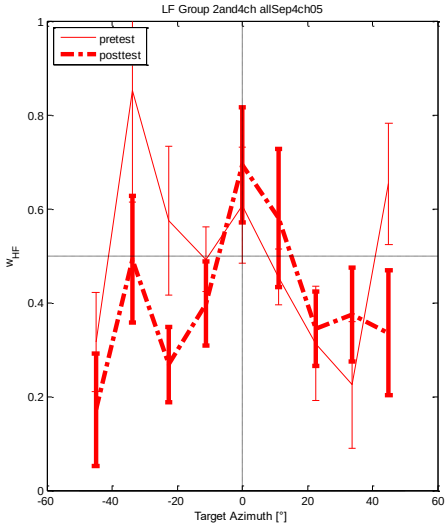
LFk and HFk for separation 1,5 and 2:

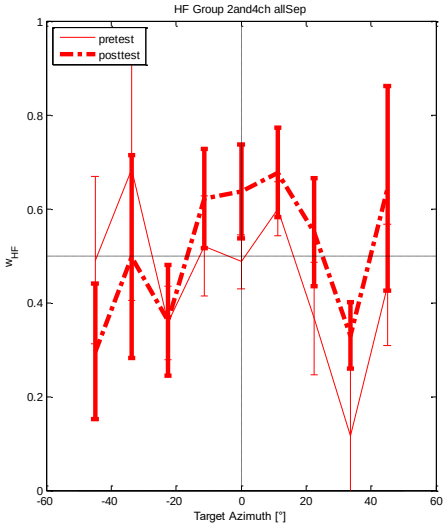


Weights for different separations

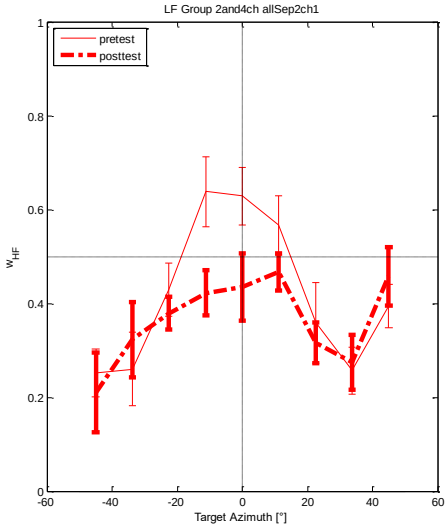
Weights for all separations fitted separately. ANOVA shows significant effect of time x group interaction and for HF group also significant effect of time.

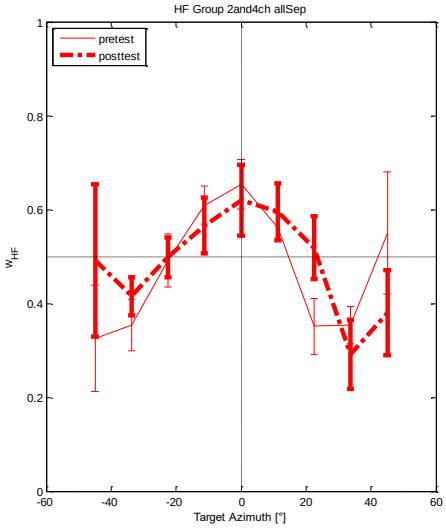
Weights for separation 0,5 not collapsed



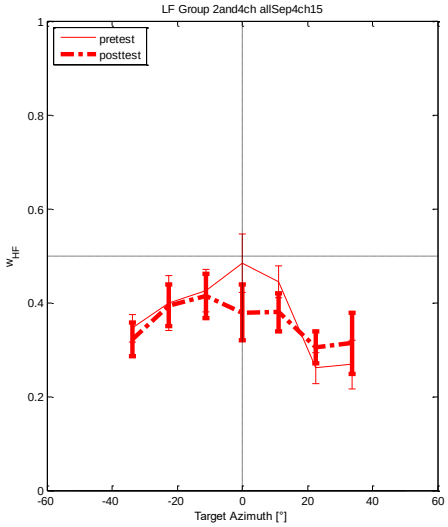


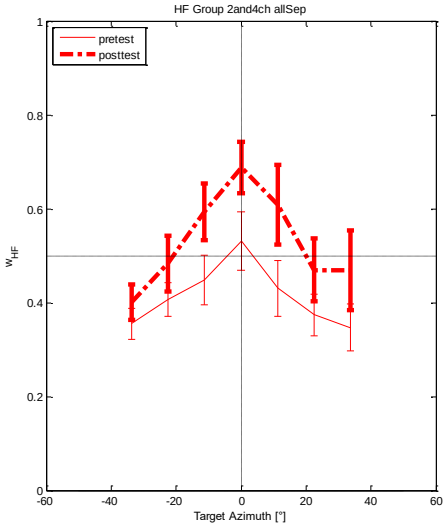
Weights for separation 1 not collapsed



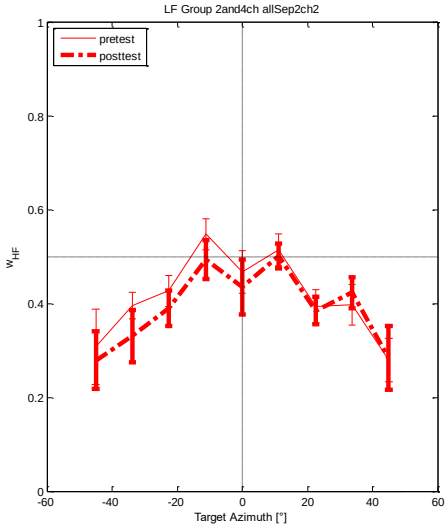


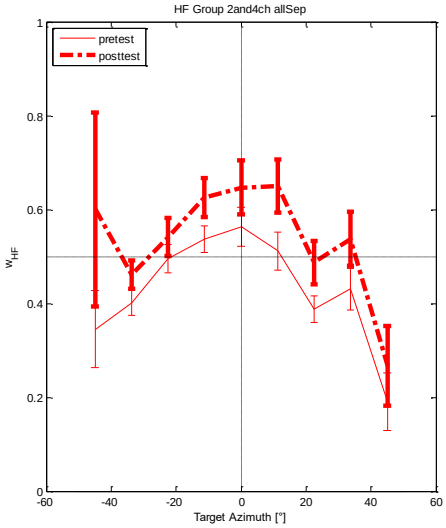
Weights for separation 1.5 not collapsed





Weights for separation 2 not collapsed





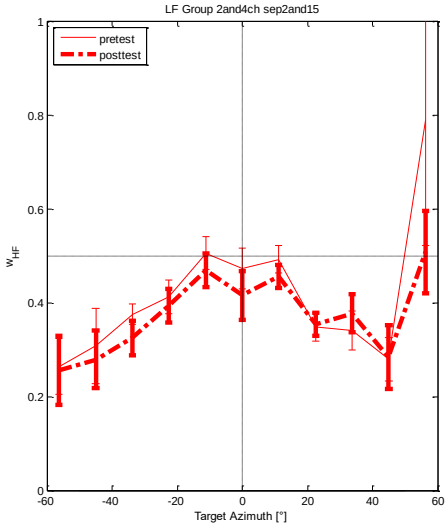
ANOVAs for non-collapsed weights on 7az:

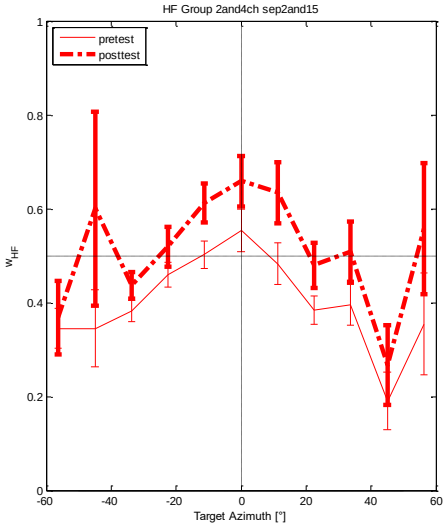
anova_regression_2and4ch_weights_LF

anova_regression_2and4ch_weights_HF

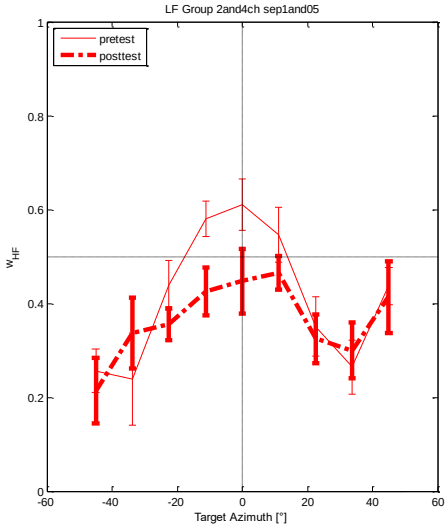
anova_regression_2and4ch_weights_LF

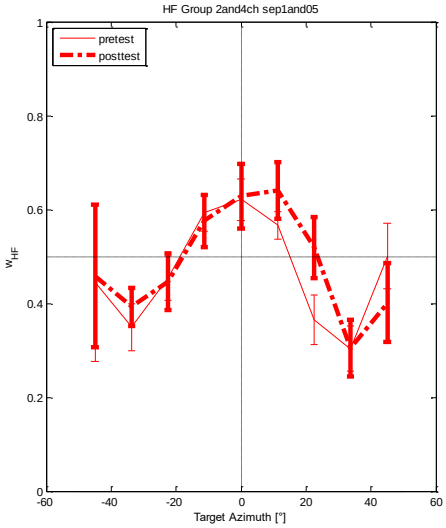
weights for separation 1,5 and 2:





weights for separation 0,5 and 1:





Weights with data collapsed before fitting

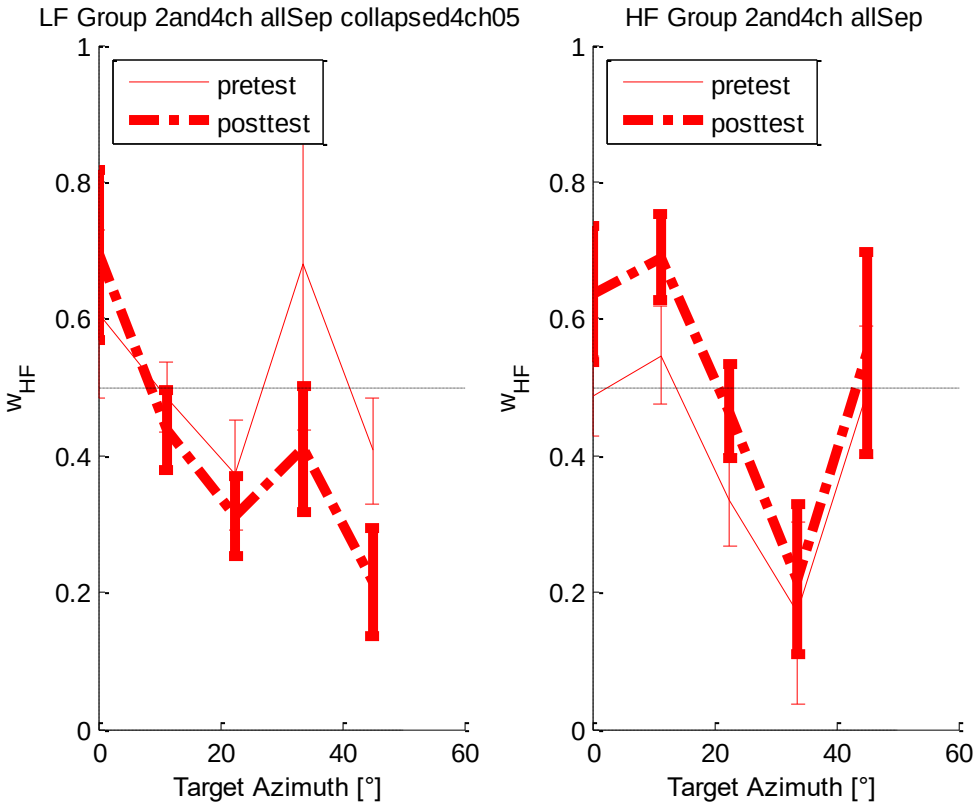
Following analysis shows weights of High-frequency sounds for all four separations separately. The formula used for modeling was same as in previous analysis :

$$R(\alpha,\ \Delta_{LF},\ \Delta_{HF}) = k_{LF}(\alpha) * \Delta_{LF} + k_{HF}(\alpha) * \Delta_{HF} + Q(\alpha); w_{HF} = \frac{atan\left(\frac{k_{HF}(\alpha)}{k_{LF}(\alpha)}\right)}{90}$$

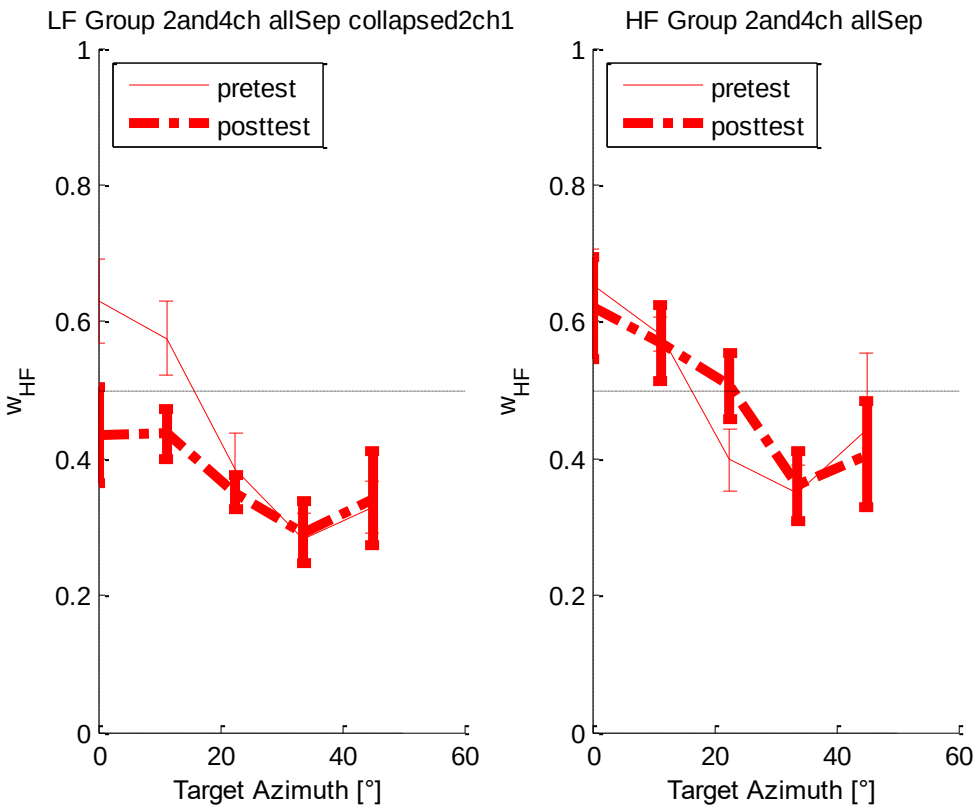
Now the raw data was collapsed from left to right side and averaged before fitting over y-axis. For example, response to the trail where the HF part of the stimuli was playing from azimuth -22.5° and LF part from 11.25° relative to HF position was averaged with the response to the trail where HF part of the stimuli was at position 22.5° and LF part was at position -11.25° relative to HF position. This

approach gives us smoother raw data and makes model more accurate. Previous collapsing was done on the weights which helped to cancel out deviations but did not make model more accurate. We ran ANOVAs on the weights of model with factors azimuth(only 4 azimuths in order to have same amount of data for all azimuths), time (pretest and posttest), separation (small and big) and channel (2 channel and 4 channel data). For the LF group we can see significant effect of time, it means decrease of HF weight from pretest to posttest while in the HF group we saw significant increase of HF weight. ANOVA with additional factor of group , shows significant interaction time x group.

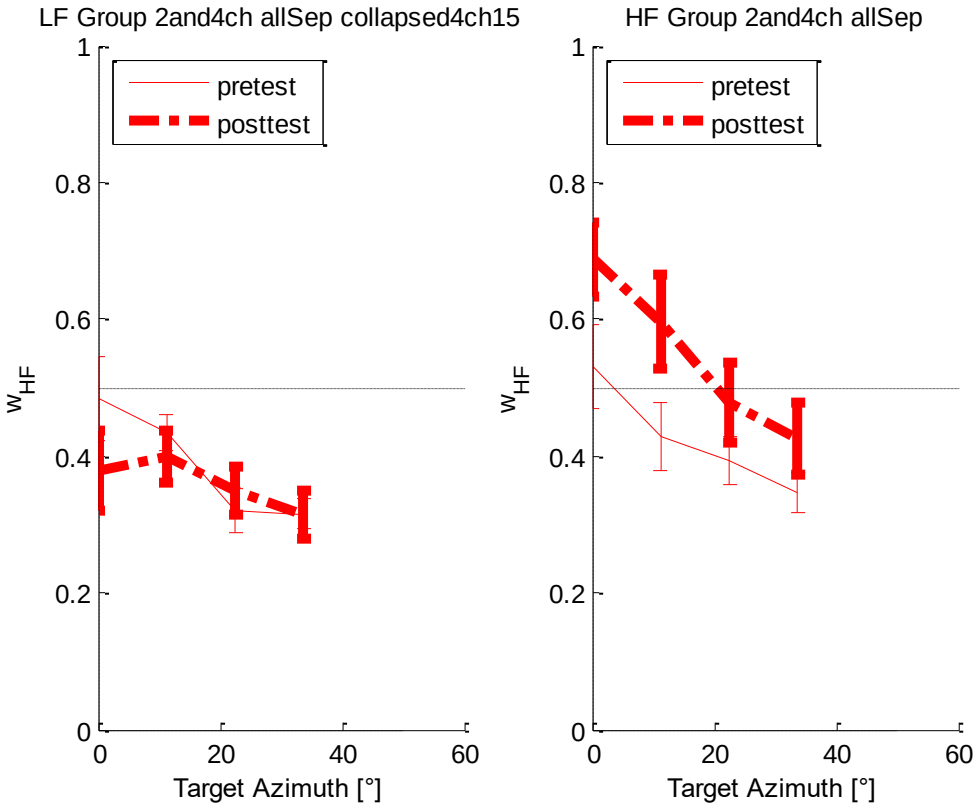
Weights for separation 0,5 collapsed before fitting



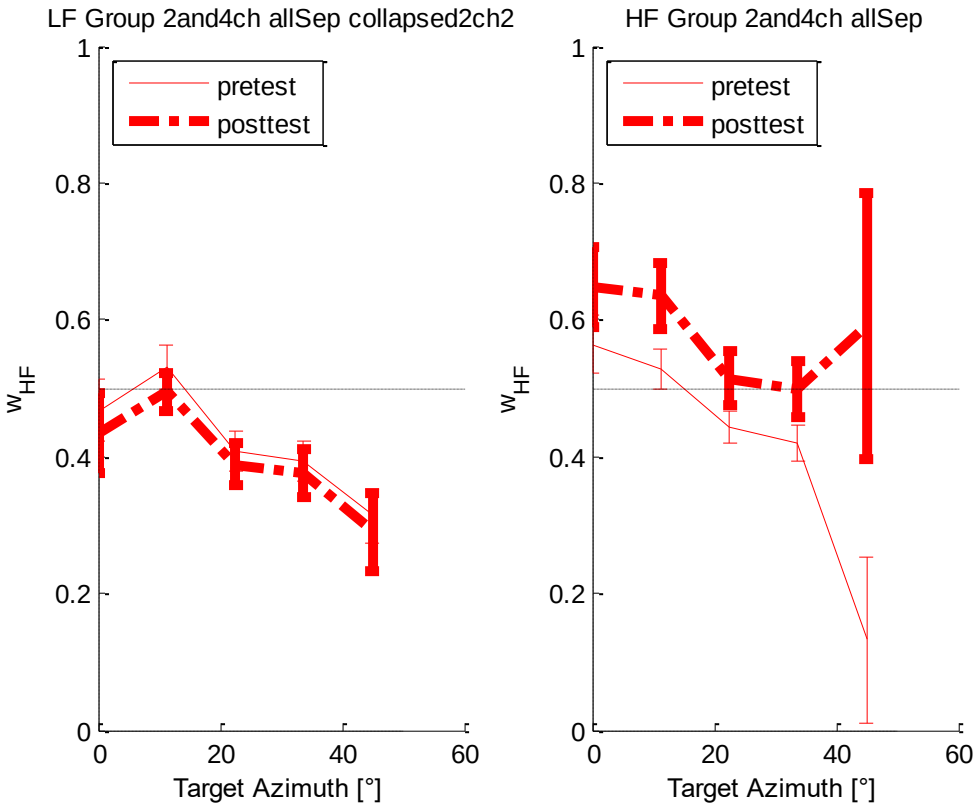
Weights for separation 1 collapsed before fitting



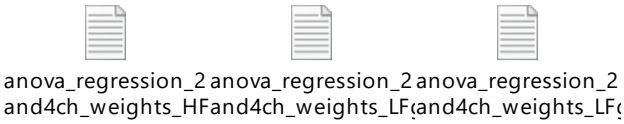
Weights for separation 1,5 collapsed before fitting



Weights for separation 2 collapsed before fitting

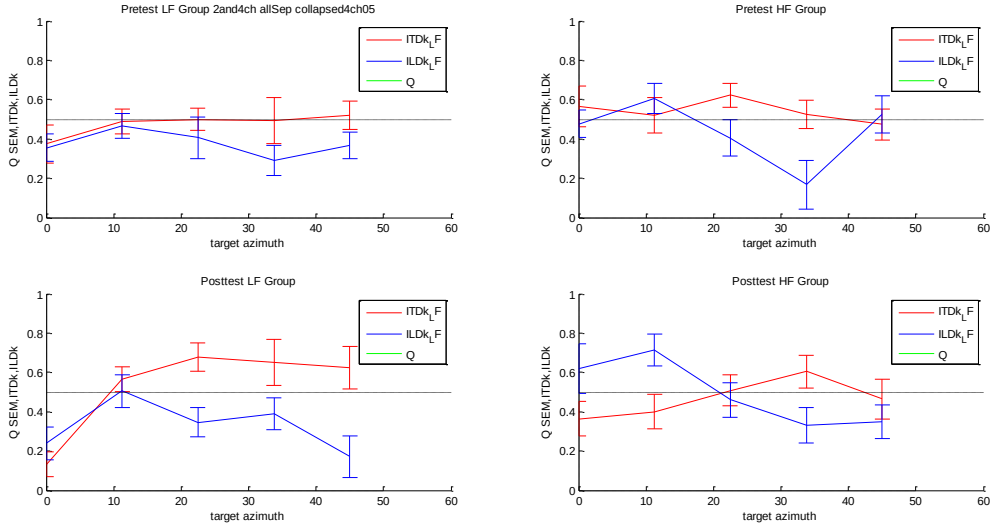


ANOVAs:

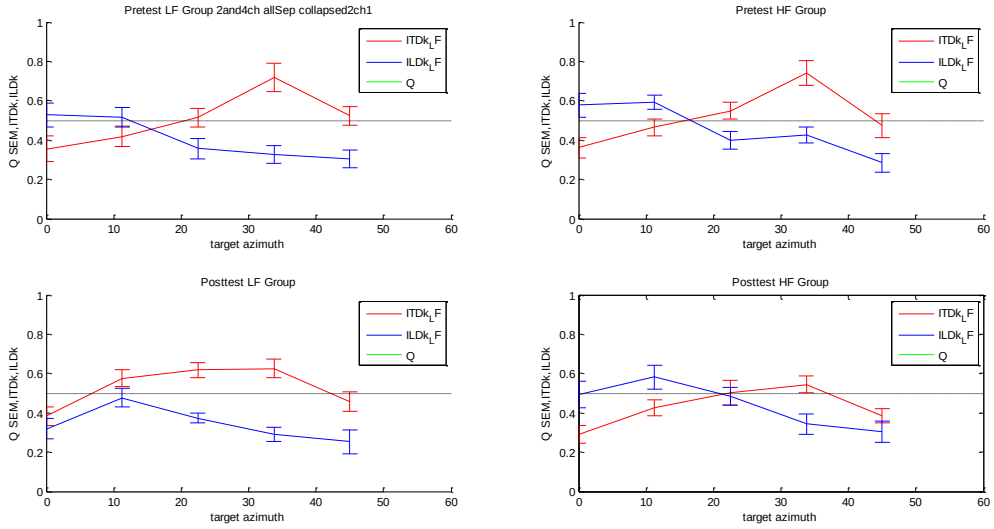


LFk and HFk parameters used for computing weights shows also group dependent development form pretest to posttest. LFk shows strong time x group interaction while HFk also shows significant effect of group.

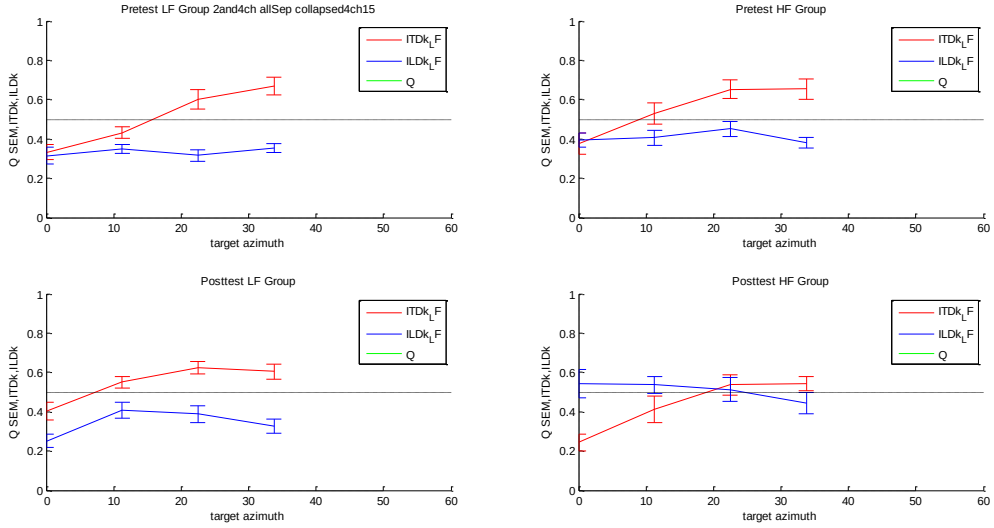
LFk and HFk for separation 0,5 collapsed before fitting



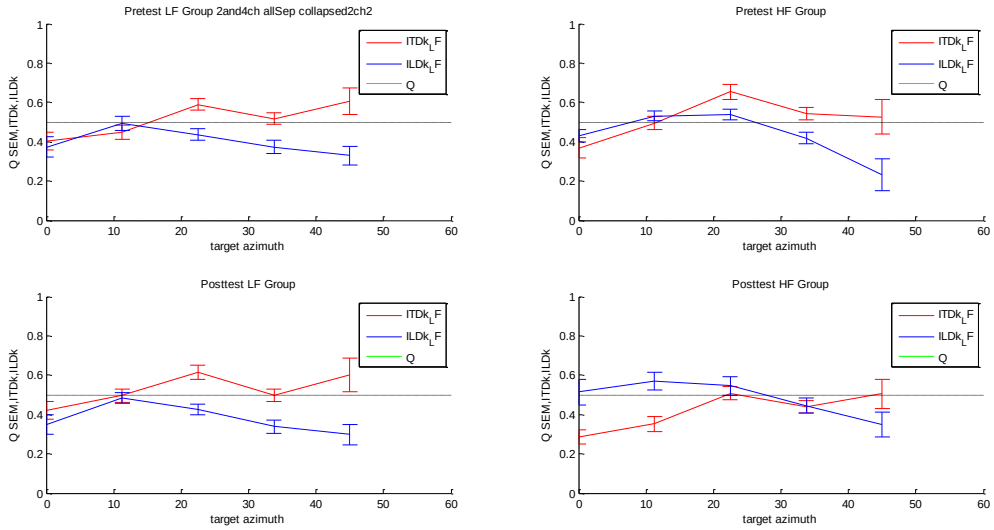
LFk and HFk for separation 1 collapsed before fitting



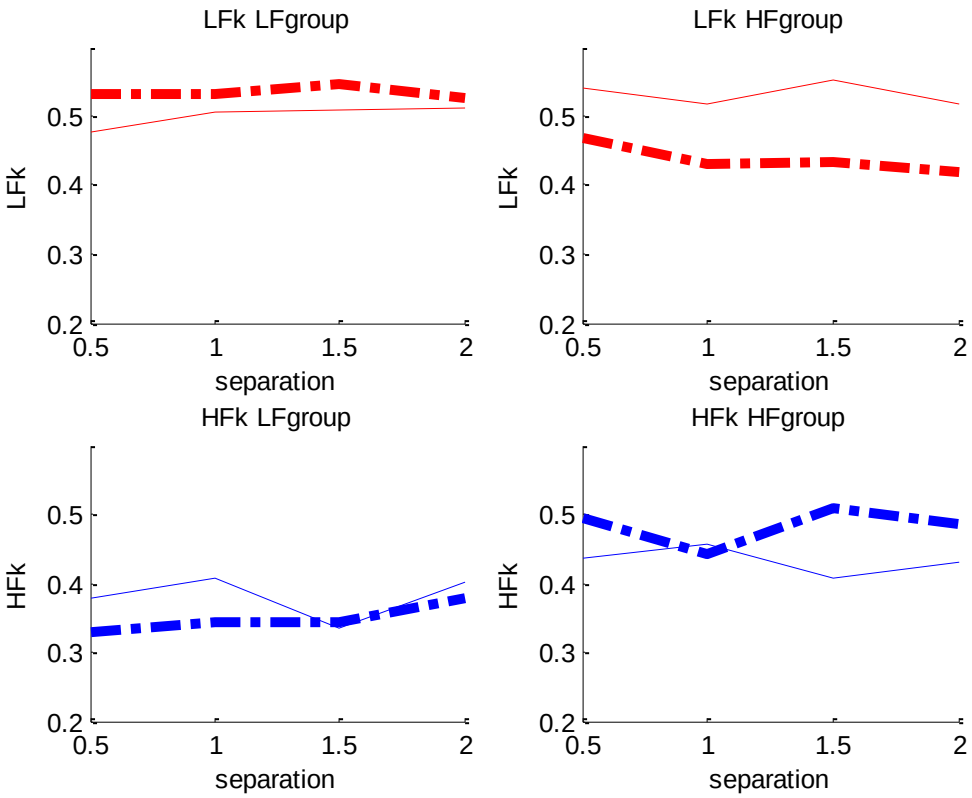
LFk and HFk for separation 1,5 collapsed before fitting



LFk and HFk for separation 2 collapsed before fitting



LFk and HFk as a function of separation for 2and4ch collapsed data (before fitting), locations are averaged



ANOVAs:

anova_regression_2and4ch_collapsed_4

anova_regression_2and4ch_collapsed_4

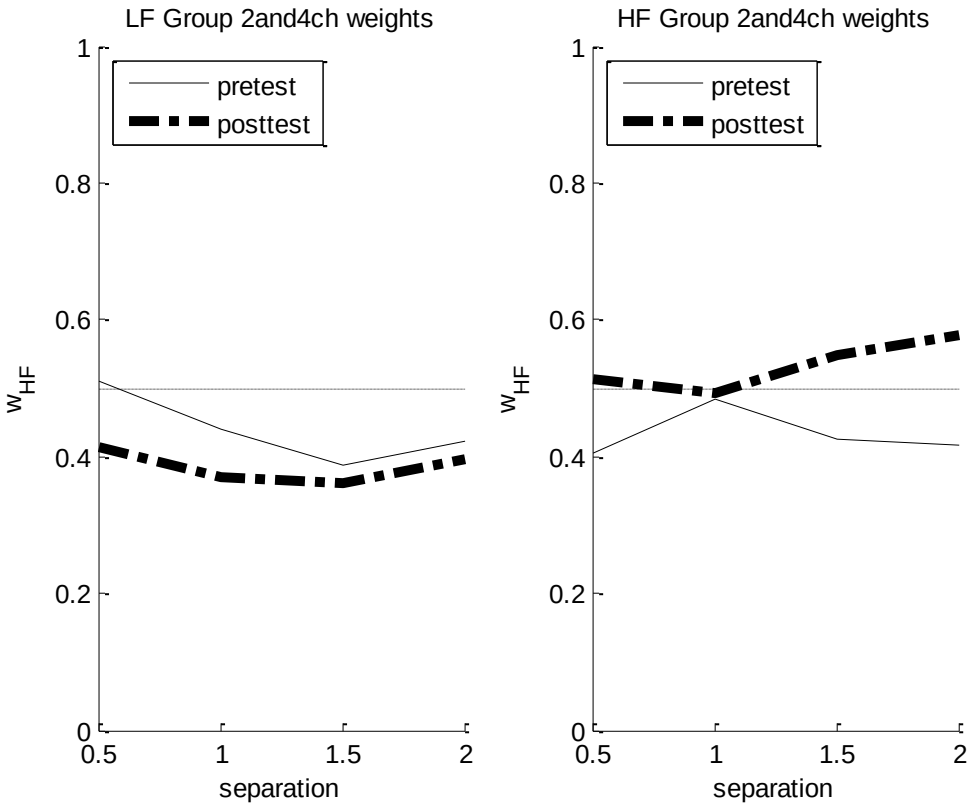
anova_regression_2and4ch_collapsed_4

anova_regression_2and4ch_collapsed_4

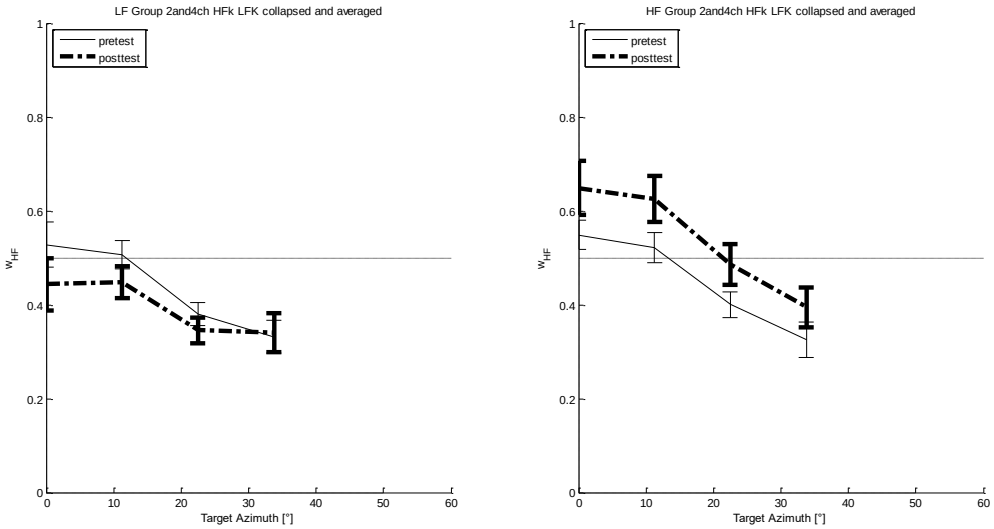
anova_regression_2and4ch_collapsed_4

anova_regression_2and4ch_collapsed_4

Weights as a function of separation for 2and4ch collapsed data (before fitting), locations are averaged



Weights of regression model with 2and4ch data, after HFk and LFK were collapsed and averaged via channels



Summary

The results shows that both group changed their weighting of HF component of sound. While LF group had lower HF weight from pretest to posttest most probably as result of a training, HF group increase this weight. Futher analysis are still needed in order to come to final conclusion. We still have to analyse data from HFI group, which was informed about the aim of training procedure, and also data from training sessions.