Sound Localization Performance Comparison of Different HRTF-Individualization Methods

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Technical Report

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Abstract

The bottleneck for an immersive binaural sound synthesis is the acquirement of individual Head-Related Transfer Functions (HRTF). Manifold HRTF approaches to circumvent the obstacle of HRTF measurement are topic in research. The localization performance of three more or less individualized HRTF-datasets is related to the individually measured HRTF. An intuitive experimental design, using laser pointing for indicating the perceived sound source direction, is introduced to evaluate those individualization approaches. Besides the impact of head-tracking is investigated. The results show that the azimuth localization error does not differ significantly for an generic dummy-head HRTF, the individually measured HRTF and the HRTF selected from a certain set of other person's HRTFs, if head-tracking is available. In the case without head-tracking the measured HRTF grants the smallest reversal rate. This results can be taken into account for designing an binaural auditory application.

Contents

1. Introduction

In our nature we are permanently surrounded by sound. Equipped with two outstanding sensors, our ears, we can classify distance, direction and loudness of sound sources. Early audio reproduction systems only offered a mono signal. This merely allowed a localization of the speaker but was not able to provide a feeling of being truly surrounded by the sound.Since the second half of the last century more or less sophisticated spatial reproduction systems were developed, like stereophony or dolby surround. As these approaches limited, we can not entirely benefit from our skill of binaural hearing. Binaural hearing would provide i.a. advantages like:

- directional hearing
- distance detection
- noise suppression
- reduced cognitive load

If we had the ability to reproduce a three-dimensional sound field, sound reproduction applications could offer these advantages. Facing the first two points, one can think of many fields of applications, like collision warning e.g, in avionics. Highly immersive virtual reality scenarios, video games or movies could be generated and many more. Our hearing system is also up to filter out relevant informations in a noisy ambiance, even if the noise energy is higher[11]. This ability is often called the "cocktail party effect"and leads to advantages in communications applications. Helicopter pilots for example have usually more than one communication partner and are exposed to a noisy environment. Speech intelligibility, and speaker recognition can be improved by binaural sound synthesis for the radio traffic. This is also a feature for multi-user-teleconference applications. Participants can be separated spatially, the cognitive load decreases [26].

Besides approaches like wave field synthesis [5] based on Huygens' principle, which works only in two dimensions and requires lots of loudspeakers, headphone playback can be used for three-dimensional sound synthesis by taking advantage of the Head-Related Transfer Functions (HRTF) theory. Ideal HRTFs represent the whole linear effects like attenuation, diffraction, reflection of a person's body on a sound wave propagating from a source to the eardrum. Once a dense set of HRTFs is available, one can synthesize nearly every sound field by headphone-playback of an audio signal processed with the HRTF (and by using a head tracker). Former researches have shown that generalized HRTF datasets can only offer a limited immersion. On the other hand it is very elaborate and time consuming to obtain a dense HRTF dataset by measureing individual persons.

1.1. Motivation

In the last decades researchers published topics on the impact of head tracking on localization performance, the influence of stimulus and the comparison of individual HRTF datasets to generalized ones, but usually separated. With the localization test designs varying a lot from one another, the results are far from unanimous. This problem prevents fair comparisons between the different experiments.

Prior research on HRTF individualization and the acquisition of a dense HRTF database at the Institute for Data-Processing has has already been conducted. This makes the goal of properly and fairly evaluating the different HRTF approaches in terms of sound localization even more appealing. It should be highlighted that the participants for the listening experiment are a subset of the group of the subjects from the HRTF measurements. So the measured HRTF can serve as a ground truth. Moreover not every conceivable application requires the same precision in localization. A collision warning system with an auditory assistance should be much more precise than the correct spatial arrangement of partners in a teleconference scenario. The setup complexity, including HRTF acquirement and usage of head tracking can be adapted to the application's requirements to save time and money.

On the roadmap to the results of the listening test, we will look to some theories of spatial hearing, HRTF theory, and localization test methods.

1.2. Objectives

The desired objective is to compare different three-dimensional audio processing approaches using HRTFs as fairly as possible. Therefore a suitable, preferably intuitive sound localization test method has to be developed. A cross validation between the different scenarios should be possible, meaning for example a comparison of localization performance with measured HRTFs without head tracking and the performance of generalized HRTF with head tracking.

2. Spatial Hearing in a Free Field and HRTF Theory

The human hearing system uses a number of cues to estimate the position of a sound source in a free field. Møller mentions especially coloration, Interaural Time Differences (ITDs), interaural phase differences and Interaural Level Differences (ILDs) [31]. The domains for the interaural cues are the horizontal and the frontal plane, where the ear input signals are not identical, except for directly in front or directly in back. Coloration is assumed to be crucial, when no or only slight differences occur in the ear signals, like in median plane, where ITDs and ILDs are zero for a symmetric head. As the human hearing system is complex, localization of a sound source can not be described completely by these separated cues. If the sound propagation from the source to the eardrum is treaded as an Linear Time Invariant (LTI) system, all effects and cues for localization can be described by the transfer function of this system. Hereinafter we will talk on different angles, so a coordinate system and three planes (horizontal, median, frontal) must be defined, which is used in this work.

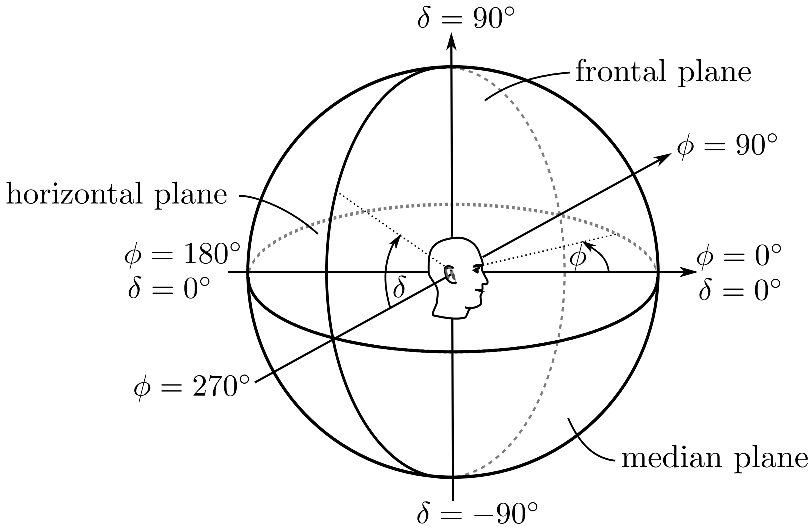


Figure 2.1.: Coordinate system used in this work.

The azimuth angle (ϕ) starts in front of the head, increasing to the left, running from 0° to 359°. Zero elevation (δ) is at ear level, 90° above listeners head and −90° below the head. The frontal plane separates the sphere into frontal and rear hemisphere, the median plane into left and right.

2.1. Duplex Theory

Lord Rayleigh used the two cues, ITD and ILD, to describe the human sound localization and coined the term of duplex theory [35]. It is assumed that ITD information is used for frequencies below approximately 1,5 kHz, whereas ILD are important for higher frequencies [18].

2.1.1. Interaural Time Difference

The ITD describes the difference in arrival time when a wavefront is hits the left and the right ear. For a simple gedankenexperiment, postulating the sound wave to be a plane wave and modeling the head as a sphere, we can calculate the detour of the wave front to the contralateral ear. Thereof we can easily determine the time difference between of the arrival times.

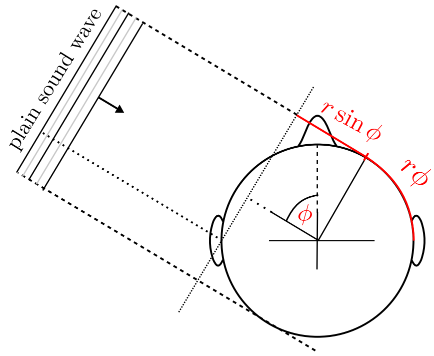


Figure 2.2.: Differently long ways for a plane sound wave and snowman model.

Above a certain frequency, where the wavelength becomes less than the head's diameter, the information gets ambiguous, because of an aliasing problem [10]. Further there exist an infinite number of locations on a bowl which all elicit the same time difference [35]. As Hornbostel mentioned the set of this points forms a cone [20], it is often called the cone of confusion. The set of points with the same ITDs, and also ILDs is discussed more detailed e.g. in [41].

The Just Noticable Difference (JND) of the ITD is smaller than 20 µs for pure tones between 500 Hz and 1 kHz [22]. See [24], [45], [22], [6] ,[19] for detailed observations on phase spectra and temporal cues in general.

2.1.2. Interaural Level Difference

The physiological properties of the head cause not only a difference in arrival time between left and right ear, but also a difference in the energy that arrives. Due to shading and absorption, the contralateral ear receives less energy than the ipsilateral one. Just like the ITD, the ILD also only provides information about the left-right displacement of the sound source. The JND of the ILDs varies relatively strong with the target ILD. Weiping et al. report a JND

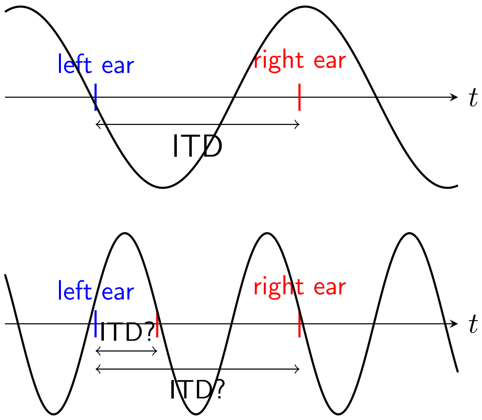


Figure 2.3.: Ambiguous ITD for smaller wavelength, based on [10].

of 1,73 dB at 2 kHz for an ILD of 0 dB, but 3,42 dB at the same frequency for a target ILD of 9 dB [43]. ITD and ILD cues can not solve the problem wether the source is in front or back hemisphere, or elevated. Figure 2.4 shows the ILDs extracted from a measured HRTF. Two identical ILD values are marked by red circles, one in the front hemisphere and one in the back.

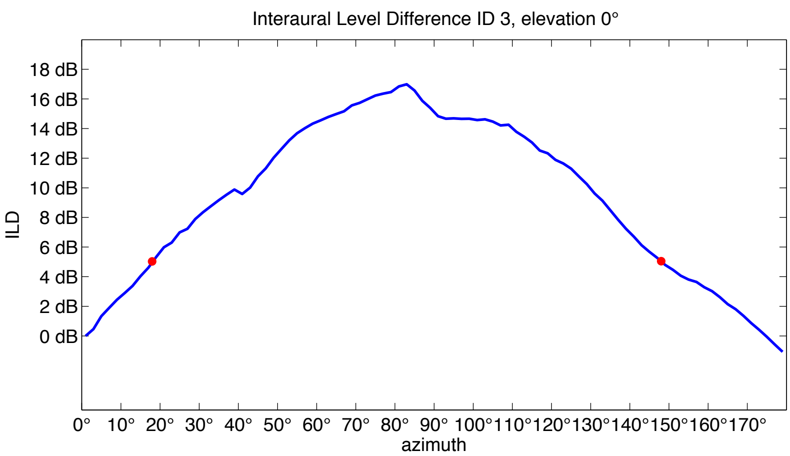


Figure 2.4.: ILD from measured HRTF for test-person ID03.

Further investigations were made on the dominance of ITD and ILD cues. Seeber et al. report that the ITD cue seems to be more dominant in ranges where both cues are giving information [38].

2.1.3. Limitations of the Duplex Theory

As mentioned the ITDs and ILDs give information about the left-right displacement. There must be some other cues used by the human hearing system to estimate the elevation and the front-back placement of a sound source. Considering the frequency dependence of head's absorption, diffraction etc., we end up at the coloration cue mentioned by Møller [31]. Blauert showed in listening tests that narrow-band noise, presented at certain frequencies perceives different elevation perception [6]. These frequency bands are called the *directional bands*. In contrast to the duplex theory, which uses binaural cues, the cues for elevation perception are monaural ones. [17], [8], [18], [6] contain more detailed information on frequency dependent cues.

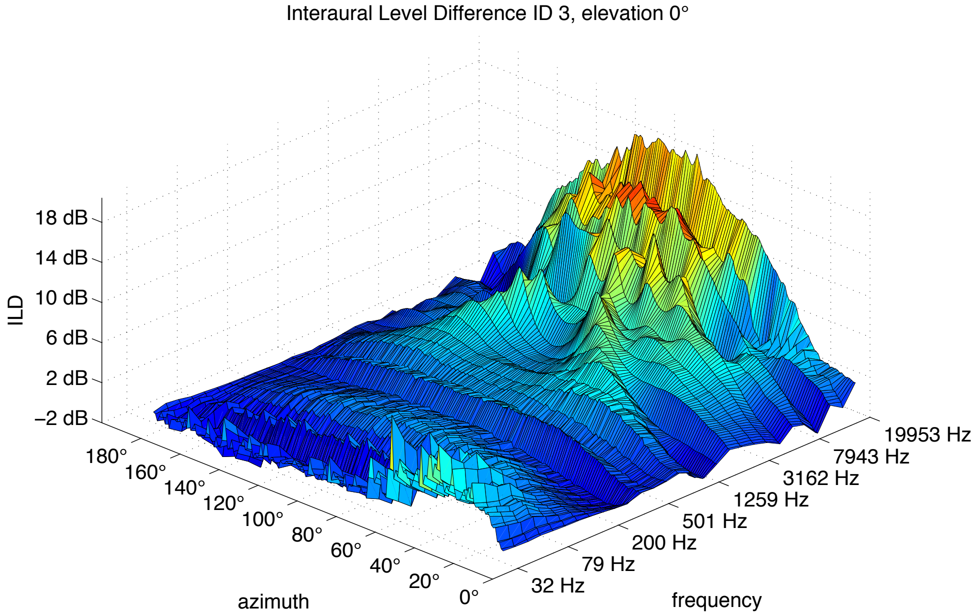


Figure 2.5.: 1/3 octave bands ILD from measured HRTF for testperson ID03.

2.2. HRTF Theory

In contrast to observing separated cues for spatial hearing, the system theory can describe the mechanisms of human sound localization. If we model the path of sound propagation form sound source to one ear as LTI system, this system is completely determined by its transfer function. Møller illustrates the last stage of sound transmission with an equivalent circuit diagram in [31], using frequency dependent impedances, a transmission line, and a thevenin source model. With the constraint of considering only linear effects all cues that are used to estimate the position of a sound source are included in this transfer function. Of course the separated cues discussed above can be derived from this transfer function.

Blauert gives the following definition for this transfer function [6]:

> *The* free-field transfer function *relates sound pressure at the point of measurement in the auditory canal of the experimental subject – preferably at the eardrum – to the sound pressure that would be measured, using the same sound source, at a point corresponding to the center of the head (i.e., at the origin of the coordinate system) while the subject is not present.*

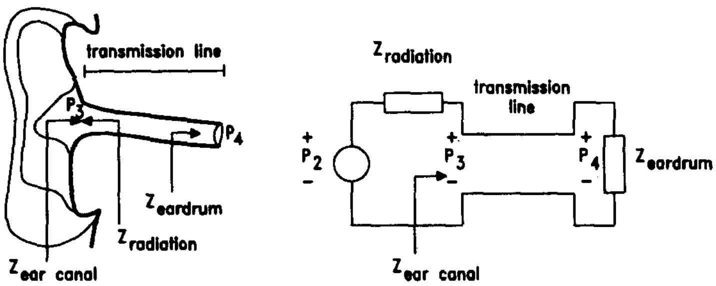


Figure 2.6.: Sound transmission through the external ear. Taken from [31]

This corresponds to p_4/p_1 in Møllers equivalent circuit, while p_1 is not shown in figure 2.6, because it is not existent during the measurement of p_4. Møller further defines another transfer function p_2/p_1, where p_2 is the sound pressure at the blocked ear canal. There is no distinct definition for the term "head-related transfer function". In this work HRTF is used for the sound pressure at blocked meatus conditions (p_2) related to p_1, because this definition was the basis for the LDV-HRTF-Database used for the localization test [36]. Observations showed that the direction dependent cues in spatial hearing do not, or only slightly, differ from the measurement position at the entrance of the blocked ear canal to the measurement position close to the eardrum [16], [28]. So we can assume that every directional cue is present at the chosen measurement position. The HRTF lies on concentric spheres, surrounding the head and is a function of f, ϕ, δ, r, meaning the frequency, the azimuth angle, the elevation angle and the distance.

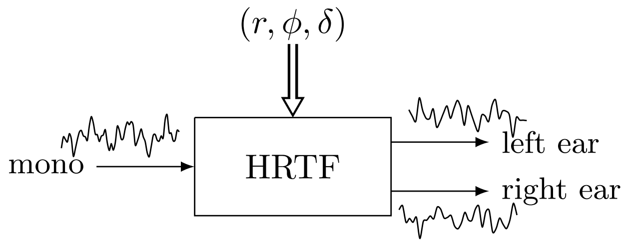


Figure 2.7.: LTI system representing the HRTF.

Measuring the HRTFs of human subjects allowed more detailed researches on physical cues in spatial hearing, e.g. influence of the shoulder or pinna reflections. Blauert gives an detailed account in [6]. The measured HRTFs serve not only for analysis but also for reproduction of a three-dimensional sound field when using headphones. For this application a mono-audio signal filtered by the measured HRTF for a specific direction and distance is presented via headphones. Although so called dummy heads were developed and used for measurements, whereby the inter-individual difference between a sibjects HRTFs and the dummy head HRTF can be to high to use such a generalized HRTF for ambitious applications [32].

2.3. Minimum Audible Angle

Having discussed some physical cues, one can ask how precisely human hearing system can take advantage of these provided cues for localization. The Minimum Audible Angle (MAA) can be determined for example by a Two Answers Forced Choice (2AFC) listening test. Where a threshold is found at which the test participants gave 75 % of correct answers. Mills used an apparatus to move a loudspeaker around the subject's head [29]. Results are shown for sinusoidal tones in figure 2.8. Three persons participated in his test. One can see that the MAA or so called localization blur depends highly on the direction. Blauert also refers to an experiment conducted by Preibisch-Effenberger and Haustein Schirmer with 600-900 participants and white noise pulses of 100 ms duration. Here the MAA was not measured by an 2AFC test. Subjects controlled a movable loudspeaker, which should be aligned with a fixed loudspeaker, the so called acoustical pointer. In general the smallest MAA is achievable in front of the head, increasing to side positions and decreasing again directly behind the subject.

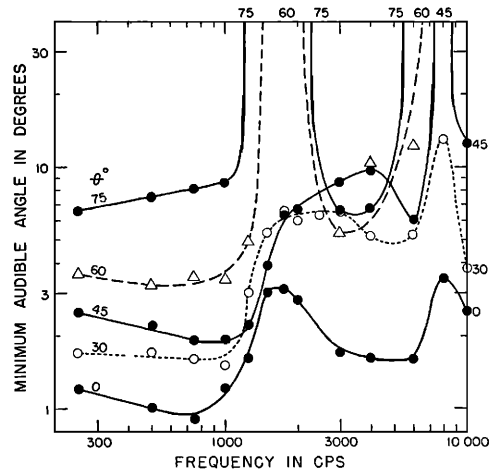


Figure 2.8.: Average minimum audible angle as a function of the stimulus frequency. The parameter (θ) is the azimuth of the reference tone pulse [29].

Listening tests on the MAA in the median plane suggests less accuracy in the elevation estimation. Wettschurek reports a MAA of 4° directly in front, where white noise served as stimulus, whereas Blauert (17°, speech by an unfamiliar person) and Damaske and Wagner (9°, speech by a familiar person) found larger values. Damaske and Wagner tested not only zero elevation and showed that the MAA increases with the elevation to 10° at 36°, with a peak (22°) directly above the subject [6].

2.4. Summary

Some physical cues that are assumed to provide information for localization were addressed. The well established duplex theory was introduced. Due to limitations of this theory the term of HRTF was introduced. The HRTF contains all physical cues, that can be described by an LTI system.

3. HRTF Datasets

HRTF measurements for 35 subjects and two dummy heads serve as the base for all HRTF approaches in the localization test. Subsets of the subject's HRTFs constitute a training set for the Partial Least Squares Regression (PLSR) and for the Determination method of OptimuM Impulse-response by Sound Orientation (DOMISO) selection method.

3.1. HRTF Measurements

All HRTF measurements were carried out in the institute's semi-anechoic chamber. Measuring a dense grid of HRTF data generally is time consuming and arduous, therefore an approach that allows for continuous rotation of the subject during measurement was used to speed up the procedure. The constant angular velocity is negligibly small compared to the duration of the Finite Impulse Response (FIR) filters that represent the HRTF. Snapshots from the continuous recording were taken at discrete angles, and HRIRs were computed using Normalized Mean Square (NLMS) adaptive filtering. A detailed description of this method is given in [37].

Figure 3.1.: Imprints and microphone placement for the HRTF measurements.

Custom ear plugs from silicone were made for each subject to block the ear canal and hold the miniature microphones in place. Every measurement day the transfer function at the center of head with the person being absent was determined. This transfer functions is reference sound pressure, called p_1 in section 2.2. Measurements were conducted and observed by the same instructors for all subjects to ensure the best possible reproducibility and to avoid unwanted differences between the measured HRTFs due to imprecise conduction. This included parameters like adjustment of the chair position and placement of the microphones. A detailed report on the measurement procedure and the measurement system is given in [36].

3.1.1. Data Analysis

The resolution of the measurements in the horizontal plane is one degree. Adressing 2.3, the resolution is sufficient. The measured datasets provide equally spaced elevations at $10°$ from $-10°$ to $40°$. According to the MAA reported in [6] the resolution seems to be sufficient for speech, but is slightly too large for noise. Based on standard teleconference scenarios, these six suitable elevations were selected. Taking advantage of head-tracking measuring more elevations would have been convenient, because this six positions can be to few for wider head movements.

The computational error to obtain the HRTFs from the continuous measurements by NLMS filtering is slightly higher than with traditional methods using sine sweeps or maximum length sequences. But the dramatic decrease of measurement duration prevails [37]. Furthermore, errors can occur if the subjects have to sit still for a prolonged period of time.

3.2. Dummy Head HRTF Data

In addition to the 35 HRTF measurements of human subjects, two dummy heads were measured in the same way. The KEMAR developed by "G.R.A.S sound and vibration"has a full torso and was used in previous experiments [14], [30]. This is why it was be chosen to provide the non individualized HRTF-data for the present work.

3.3. Individualization by Regression

The approach of the regression method is to compute a new HRTF out of a training set of measured HRTFs. For this purpose some anthropometric data [36] of the person, for whom a new HRTF should be calculated, is measured and used as input to a PLS regression [23]. The algorithm works on the magnitude spectrum for each single angle and tries to find the influence of the anthropometric data on the HRTFs in the training set. This influence is then used to create customized HRTFs for subjects not included in the training set. As the calculation works only on the magnitude spectrum, we get no temporal information for the synthesized HRTF. To compensate for that the subject with the most similar head diameter is selected from the training set. The ITDs belonging to that subject are appended to the customized HRTFs in order to obtain the missing time delay.

The optimization criteria for the PLSR algorithm, was to minimize the Spectral Distortion (SD) for all subjects. For the SD calculation, one subject was removed from the training set. Then a new HRTF for this subject was generated and compared to the measured one. This procedure was done for all measured HRTFs from the training corpus.

3.3.1. Data Analysis

The approach to minimize the SD globally over all subjects led to an equal magnitude at the same angles for each subjects. Thus the individualization was reduced to temporal cues. Evaluating the approach empirically with head-tracking, the sound source direction seemed to jump or sometimes freeze during head movements. The used PLSR algorithm works separately on each direction, so it was aspected that this approach leads to in-continuities in alteration of the data form one angle to the next. The partial differential quotient of the HRIR with respect to the azimuth angle was computed. It can be observed that the HRIR stays constant sometimes, while the angle is proceeding. Visualizing a single direction of the HRTF we can hardly see, that the regression method can approximate the original magnitude at lower frequencies. At higher frequencies the PLSR's magnitude can not follow the peaks and dips, this could be a reason for a poor front-back and elevation estimation.

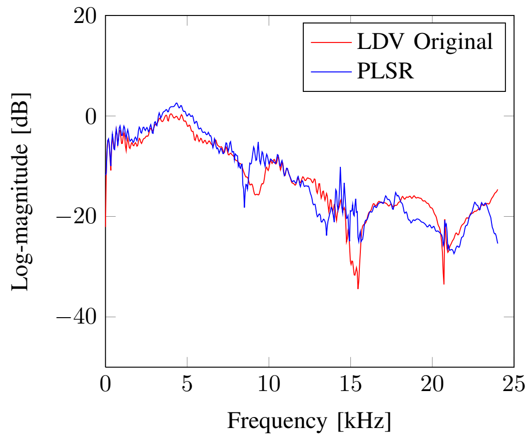


Figure 3.2.: XValid, PLSR, LDV, Subject 20, Azimuth 180°, Elevation 0° [23]

3.4. Individualization by Selection

The purpose of an individualization by selection is to avoid measurement, complex computations, and usage of generalized dummy-heads' HRTFs. Tests were designed to find the most acceptable and immersive HRTF data from a corpus of measured HRTFs of other persons [40],[21].

For the localization task, the DOMISO method from [21] was used. A subset of twelve measured HRTF data from the 35 measured persons served as corpus for the selection.The 23 remaining subjects participated in the selection listening test, such that the same HRTF data were provided to everyone. Grasser implemented the test to MATLAB, in accordance to the DOMISO method [15]. Pink noise bursts with a duration of one second were filtered with the HRTF at distinct positions in the horizontal plane, describing a circle around the head at zero degrees elevation. Two of these sound-samples were presented in each test, filtered by

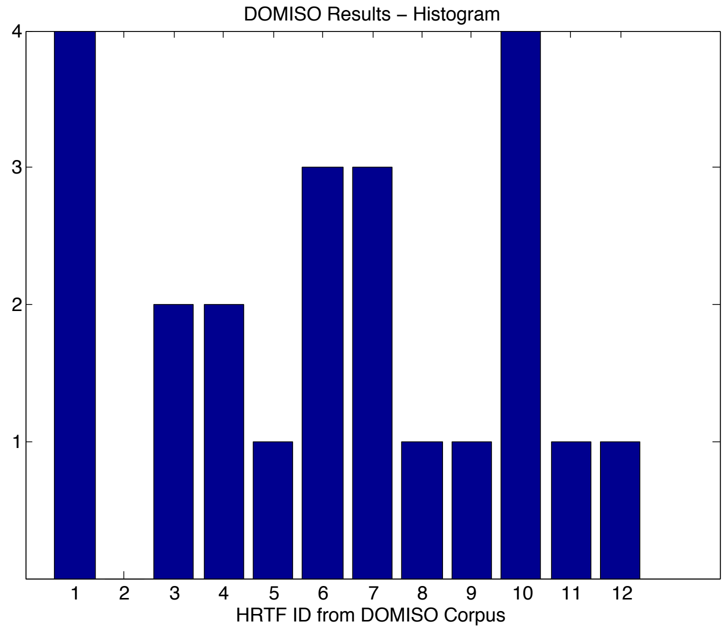


Figure 3.3.: Histogram for the DOMISO results.

two different HRTF from the corpus. The subjects could listen to the sounds as often as they wanted and completed each test by deciding sample A or sample B was more immersive. In the end, the best rated HRTF was determined.

3.4.1. Results and Data Analysis

As the topic to analyze the selection method is not a part of this work, we will not steep deep into an analysis of the results. A histogram for the twelve HRTFs belonging to the DOMISO corpus is given in 3.3. The selection is a very subjective method, as participants can choose their own criteria for the rating of the different presented HRTF datasets. This issue can be confirmed by mapping the physical cues, ITDs and ILDs on the results. Therefore the correlation coefficient for the ITDs and ILDs was computed to measure the similarity of the individually measured HRTF to the chosen DOMISO HRTF. As we used the correlation coefficient, constant displacements over the azimuth of ILDs and ITDs are disregarded. Figure 3.4 shows the correlation coefficients of four subjects who chose dataset one form the DOMISO corpus. One can see that some other subjects form the corpus would have offered better matching ITDs and/or ILDs. There must have been other criteria besides ILDs and ITDs to come to a decision.

3.5. Summary

Four different HRTF datasets were introduced. The data is more or less individualized and the effort of acquisition varies. The PLSR method should be exposed, as it is the only

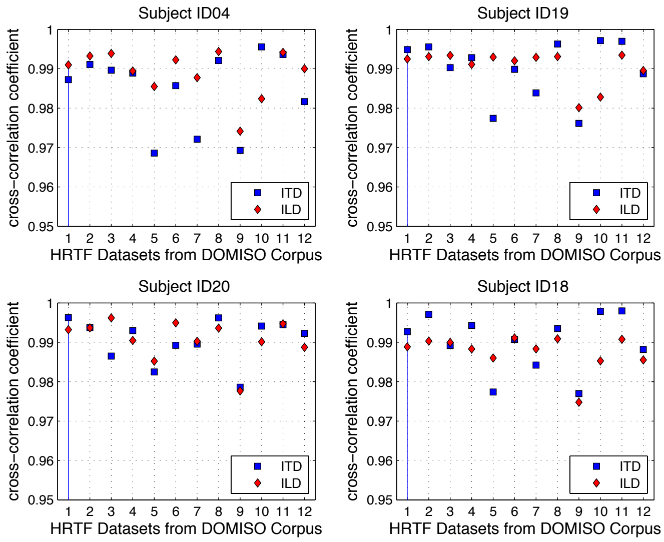


Figure 3.4.: Cross-correlation coefficients for four subjects who chose dataset one from the DOMISO corpus.

method which generates completely new data. All other data sets were obtained directly by measurement.

HRTF acquisition method	number of required datasets	time and labor for the user	individualization
KEMAR	1	–	no
PLSR	> 15	$\sim$ 5 min	yes
DOMISO	12	$\sim$ 20 min	yes
individual measurement	1	$\sim$ 50 min	optimal

Table 3.1.: Comparison of HRTF acquisition approaches for binaural playback, translated from [42].

4. Sound Localization Tests

This section is about sound localization test methods used in prior research. The topic how the testsubject can convey the perceived direction to the experimentator is addressed. The different elicitation methods have an impact on the results and are more or less intuitive. Furthermore some possible testsetups as well as results from prior research are described.

4.1. Elicitation Methods

Imagine you hear a sound and estimate the sound direction. How can you communicate the perceived position to someone else? This could be done more or less precise. You can point to the direction by hand, or give verbal hints from where the sound is coming. Some methods used in former experiments are called into question.

4.1.1. Identification Method

Among others Møller and Minnaar used the identification method in [32] and [30]. They presented a real-life scenario as well as one with virtual sound sources. For the real-life scenario they named the positions of the loudspeakers. These positions were drawn on a sheet provided to the subjects. The same positions were used for the binaural reproduction by headphones. The participants gave their answers by marking the estimated direction on the sketch with a digitizer.

As the loudspeakers were visible to the participants optical cues could support the sound localization task. This enhances the intuitiveness of the approach as projections from room coordinates to another coordinate system are not necessary. Also the proprioception, meaning how we perceive our own movements or our own body's position in the three-dimensional space, plays a minor roll.

As one can imagine, the problem of this method is that the answers are quantized to the possible positions. The task is rather to find the right speaker than to localize the sound direction. Therefore the localization error can not be defined as the deviation from the presented direction.

4.1.2. Answering in Spherical Coordinates

The subjects give answers by telling the perceived direction in spherical coordinates in the head-related coordinate system to the experimentator. The perceived position has to be mapped to another coordinate system, presented on screen or on an answering sheet. Using a computer has the advantage of automatization as the subject can handle the whole progress by itself. Begault and Chen used this test-method [4], [9].

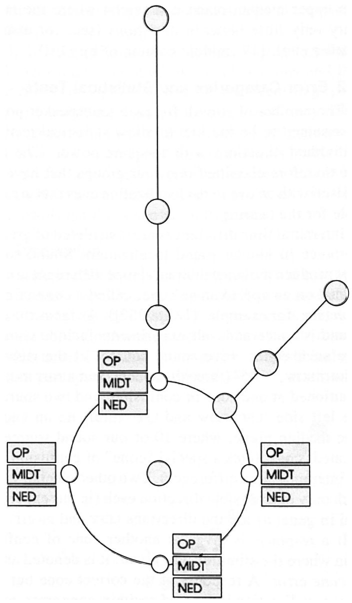


Figure 4.1.: Sketch of the loudspeaker arrangement given to the subject [32].

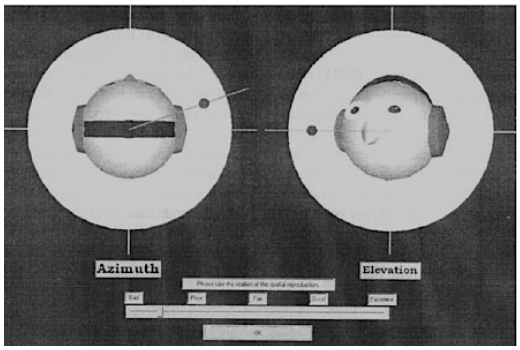


Figure 4.2.: Head-related coordinate system used by Begault [4].

Two tasks can be found. One is to localize the sound source, the second one is to map the perceived direction to coordinates. The determination of the coordinates will expectably vary strongly between different persons. This error could be mitigated by training and/or visual anchors for earmarking some distinct directions. Offering such anchors can introduce a bias, as the marked positions could be preferred by the subjects. The method is easy to implement. The grid where possible answers can be marked is limited by the resolution of the display size, or the size of the coordinate system given on the answering sheet. The whole horizontal plane can be covered.

4.1.3. Eye-Tracking

Implementing this method, one can benefit from measuring saccadic eye movements. It is assumed that the subject looks subliminally to the direction of sound incidence. Once a saccadic eye movement is initialized, it runs distinctly to the endpoint. The answering procedure is straightforward, subliminal and fast. On the other hand implementation is challenging, as saccadic eye movements elapsevery fast. This requires a precise and fast camera tracking of the eyes. Frens, Hofman and van Opstal used another method for recording the eye movement, because they darkened the room [13], [19]. They used a scleral search coil on subject's right eye, while the room was filled by an oscillating magnetic field. The effort to implement this method is not negligible. Another problem is that the head has to be fixed to guarantee that recorded movements are caused by eye-movements and not by head-movements. Furthermore it has to be discriminated between normal eye movements and saccadic ones. As the range of the eye movements is restricted, only positions in front of the subject can be tested. The usable range has to be figured out previously as the field of view varies from subject to subject.

4.1.4. Head-Tracking

Similar to eye tracking, the answer is given by looking to the direction of the perceived sound source position. A crucial difference is the fact that not the eyes are tracked, but only head's position. Furthermore the process is not as subliminal and the direction of the face may not correspond to the line of sight, depending on the proprioceptive skills. The experimentator has to brief the participants to look always straight ahead. This method requires head tracking, which should not be a problem, as head tracking is also a requirement for dynamic virtual sound synthesis. In contrast to the eye tracking method we can cover the whole horizontal plane, if subjects are allowed to move their bodies. Makous and Middlebrooks designed an experiment for localization of real sources, where the answers were given by the head's position [27].

4.1.5. Optical Pointer

Subjects announce the perceived position by pointing to the direction with an optical pointer. This can be realized by controlling a mounted laser pointer e.g., via a track ball [25], [39]. The method is not highly intuitive, but still easy to handle for the subjects, thus training is not necessary.

By moving the laser pointer indirectly via a controller, the localization task is assumed to be decoupled of the motoric apparatus and no disturbing proprioceptive effects are expected. The direction of the laser pointer can be measured i.a. by photo diodes. Due to the fact that the laser pointer is mounted, only directions in the frontal hemisphere can be presented to the listener. Some effort for the implementation is necessary to calibrate and readout the photo-sensitive sensors. For good coverage of and a high resolution grid lots of sensors are needed. Note that it is also conceivable to use a tracking system to determine direction of the pointer.

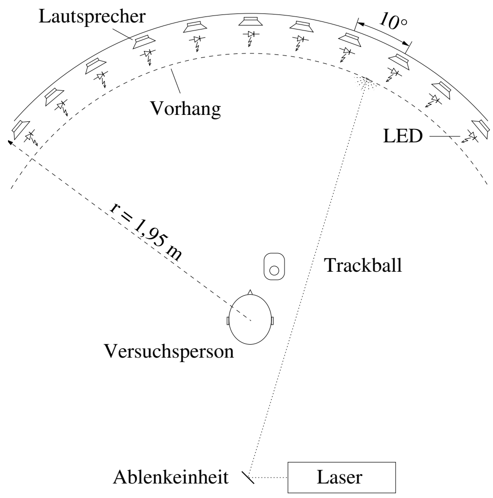


Figure 4.3.: Optical pointer method used by Seeber [39].

4.1.6. Laser Pointing

In accordance to the optical pointer method a laser pointer is deployed. The participant holds a pointing device in his hands. The device is equipped with a laser pointer and markers for a tracking system [34]. The testsubject is free to move and targets the position of the perceived direction. The method is very intuitive as the subject just moves the hand or turns the body to the desired direction. The laser pointer serves as optical affirmation. All directions lying on a sphere can be presented (besides very negative elevations, where the floor limits the range), but there can be proprioceptive issues, when subjects have to turn around to point to a rear position. As the answers are given in the three-dimensional room coordinate system, no projection by the test persons is needed. The spatial quantization for possible answered directions is given by the accuracy of the tracking system, which is normally very high. If a realtime capable tracking system is available, the implementation of this method is not very sophisticated.

4.2. Stimuli

As pointed out in the second chapter localization cues are frequency dependent. Therefore the influence of stimulus type, bandwidth and duration of the localization performance is in general not negligible. Pure tones are not attractive for real life applications, thus only some broadband stimuli will be discussed.

Hofman and van Opstal investigated the influence of stimulus length and temporal characteristics[19]. The stimuli were presented by a movable loudspeaker, answers were given by eye-tracking. The experiment was separated in three parts. First, Gaussian white noise with different duration from 3 ms to 80 ms was presented. Noise bursts with different burst durations and total duration of 300 ms were played back. Whereas frequency modulated sine sweeps of various periods served as stumuli for the last part of the experiment. Hofman and van Opstal state that the human auditory system needs about 80 ms of broadband noise to estimate the elevation of a sound source. For the azimuth estimation no restrictions due to the stimulus duration was found, the accuracy was similar for all stimuli durations.

Minnaar and Møller found out, that there was only a slight difference in localization performance between speech and white noise [30]. The tests were carried out using the identification method, stimulus duration was 1 s for noise and 2,2 s for speech, presented by loudspeaker and headphones processed by dummy-head's HRTFs.

A comparison of different stimuli is given by Chen [9]. Six different stimulus types with different durations between 0,5 s and 6 s were tested. Two different coin drops, speech, an alarm sound, male speech and dog bark were presented. Dynamic binaural sound-synthesis with generic dummy-head's HRTFs and head-tracking was used for playback. Subjects answered by moving an arrow in an coordinate system on the GUI to indicate the perceived direction. Chen tested only the azimuthal localization performance. She found out that the duration of stimulus is related to the localization performance. The smallest azimuthal error was found for a duration of 6 s increasing for shorter durations. Furthermore she found only a small difference regarding the localization accuracy as long as the stimuli were broadband.

4.2.1. Localization of Real Sources

Makous and Middlebrooks report azimuth error between 1,9° directly in front and 16,6° behind the subject with elevation of 45° [27]. The elevation error is between 3,3° and 12,3°. Answers were collected by head-tracking, white noise served as stimulus. Hofman and van Opstal mention azimuth errors between 3,3° and 5,4° for the azimuth and 5,9° to 8,3° for the elevation error [19]. Answers were given by tracking the saccadic eye movements.

4.2.2. Localization of Virtual Sources

Localization of Virtual Sources with Individual and Generic HRTFs

Some prior research has been made on this topic, as measuring individual HRTFs is very difficult and annoying. Besides of the impact of head-tracking and reverberation Begault tested the influence on localization of individual and generic HRTFs [4]. In his experiment he presented a speech stimulus and acquired answers in a given coordinate system and found out that there was no significant difference between generic and individual HRTFs for azimuth accuracy. Head-tracking had significant impact on front-back judgement. Whereas Møller reports that the difference of localization errors is significant for non-individual HRTFs in azimuth and elevation [32]. Møllers conclusion is responsible, if we mention the monaural cues, that are assumed for elevation estimation. Supposing that the cues are given by changes in the HRTF magnitude, it is consequential that the individual HRTF should provide a better performance. One can also assume that the performance of a generic HRTF is constant, whereas the quality of the individual measurement is sensitive to the measurement methods and conditions. These facts prevent a fair comparison of different experiments.

Localization of Virtual Sources with Head-Tracking

In the case of the impact of head-tracking the statements are more evident. As in real-life, the listener can use head movements to solve uncertainty wether the sound source is in the frontal or in the rear hemisphere. Referring to Begault's experiment again, he reported that providing head-tracking decreased the reversal rate from 59 % to 28 %. The mean of the reversal corrected azimuth error is around 16° with head-tracking and approximately 20° without. The significant influence of head-tracking can be underlined by the results of Pedersen's localization experiment [34] and investigations of Wightman and Kistler on the impact of head or source movement on the reversal rate [44].

5. Test Design and Implementation

In the previous chapter some methods for sound localization tests were presented. The decision for the laser-pointing method will be briefly justified. Furthermore an overview of the testsetup, the test design and the software implementation will be provided.

5.1. Test method

As the localization test methods offer certain advantages but also entail some problems a suitable method has to be found. Therefore we claim some desired attributes for the design of the experiment:

5.1.1. Requirements

- preferably easy and intuitive handling for the subjects
- avoidance of coordinate projections by the subjects
- no training required for the subjects
- preferably precise record of the answered positions
- automatized procedure
- in main realizable at institutes lab with existing equipment
- coverage of the whole horizontal plane
- repeatability
- preferably fair comparison of different data
- quick answering procedure regarding real-life applications
- continuous or high resolution answering grid

5.1.2. Comparison of Test Methods with Constraint to the Requirements

Some methods for sound localization were introduced moreover some advantages and disadvantages of the approaches were mentioned. Regarding the desired attributes and the brief comparison given in table 5.1 the decision was reached to implement the laser pointing method.

	Ident. Meth.	Spherical Coord.	Eye-Track.	Head-Track.	Opt. Pointer	Laser Pointer
intuitiv	●●●	●●	●●●	●●	●●	●●●
projection	–	neccesary	–	–	–	–
freed. of action	●●	●●		●●●	●●	●●●
spat. resolution		●	●●●	●●●	●●	●●●
coverage	●●●	●●●	●	●●●	●	●●●
realizable	●●●	●●●	●	●●●	●●	●●●
propriocept.	rear hemisph.	–	–	everywhere	—	rear hemisph.

Table 5.1.: Comparison of the localization test methods.

The identification method is believed to be too imprecise for the comparison, as the differences between the HRTFs are assumed to be slight. The answers that would be acquired by using spherical coordinates are assumed to be affected by the projection to the spherical coordinates, as the projective skills vary from subject to subject. With eye-tracking and the optical pointer method no directions in the rear hemisphere could be presented.

5.2. Testsetup

Figure 5.1.: Fleece mounted at the ceiling to serve as cylindric projection surface for the laserdot.

The experiment took place at the institute's semi-anechoic chamber. To offer head tracking, the DTrack2 system by A.R.T. GmbH was available [2]. As the HRTFs were measured at a spherical grid of constant radius and answers should be given in spherical coordinates, a fleece was mounted at the ceiling, providing a room with cylindrical shape with a radius of 1,5 m. The Laptop was placed in front of the subject, but not at, but below eye level, to offer a sufficient area for the pointing. As a claim freedom of movement for the subjects was

Room	4,7 m x 3,7 m x 2,8 m, t_{60} = 0,08 s
Computer	Lenovo Thinkpad T520 (Ubuntu Studio)
Audio interface	Roland UA 25 EX
Headphones	Beyerdynamic DT990 Pro with tracking marker
Tracking	A.R.T. DTrack2

Table 5.2.: Equipment for the experiment.

mentioned. Therefore the Human User Device (HUD) to control the test-software is based on a wireless presenter. The slot for the usb dongle of the presenter serves to mount a stacking for the *measurement tool*-marker of the tracking system. This stacking was custom designed and printed with a 3D-plotter. The laser-pointer is placed axially under the marker. The participant is seated on a height adjustable swivel chair. The headphones-cable was mounted on the ceiling to ensure that subjects can move without having to watch out for the cable.

Figure 5.2.: Participant holding the pointing device.

5.3. Implementation

In this section the test-software should be introduced. Programming was done in C++ for the user interface and in C for audio processing. Except for the demonstration tests, the whole procedure is controlled completely by the testsubject. The procedure is predefined by a configuration file, relevant information is written at runtime to log-files by which the answered angles are computed offline with MATLAB.

5.3.1. Head-Tracking and Dynamic Convolution

The A.R.T. Tracking system at the institute uses infrared-sensitive cameras. The cameras suffuse the measurement area with IR-signals and record the reflections from tracking bodies, which are equipped with small balls, coated by an IR reflecting lacquer. There are two types of bodies, one with six Degrees Of Freedom (6DOF), the simpler ones are 3DOF. The tracking system sends new data every 33 ms via ethernet to the test-software. A virtual sound source is rendered after specifying a sound file to be played back, the desired source position in head-related coordinates and a certain HRTF database. The system picks the HRTF from the defined HRTF database which is suitable to the desired sound source coordinates. If the head-tracking option is enabled, the HRTF picked from the database is updated at runtime. The audio stream is partitioned to blocks of a length of 512 samples. A von Hann window is applied to avoid artifacts by re-assembling the audio-stream after convolution. Partitioned convolution with actual HRTF data is done in frequency domain [33]. The processed audio stream is sent to JackAudio and from there to the DAC of the audio interface. The audio latency is 22 ms. The fans of the tracking cameras caused a noise level of approximately 45 dB unweighted at the eardrum.

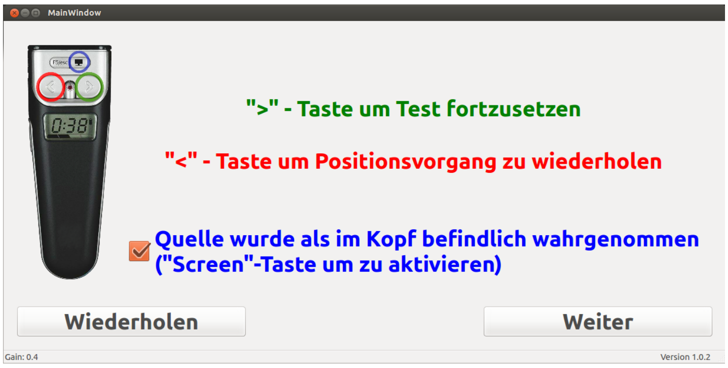
5.3.2. Graphical User Interface and Test Procedure

The Graphical User Interface (GUI) provides a page for each calibration, playback and answering. The calibration page supports the experimentator to control the headphone position. The page for playback ensures that the participant faces approximately directly in front. The subject gets an optical feedback by a cross representing the actual head rotation in a two-dimensional coordinate system. The playback can only be started, when head rotation is within a tolerance range ($\phi = 0 + \epsilon, \delta = 0 + \epsilon$). This ensures that the orientation in the dark room is not lost, and the test-person is keeping up with the experiment's progress.

Once the head position is in the tolerance range, one can start the playback. The software provides the playback of the stimulus convolved with the HRTF of the direction to be tested, relative to the actual head position. If tracking is enabled, the HRTF is updated continuously when the subject moves around. The tracking data at playback-starting time are written to the log file and the page for the answer acquisition appears.

When the participant aims the position of perceived sound incidence, this position can be stored by pressing the 'next'-button. The answer can be corrected and repeated by the subject. Any further playback is restricted, because the subject could keep the perceived position in mind and refine the answer step by step repeating the playback. After locking the position, one can give additional information by indicating a checkbox if the sound seemed to be in-head. The answering procedure is completed, by clicking the 'next'-button. To foreclose non-valid tracking data, the actual test is repeated automatically, if tracking data are zero at answering time.The user is unaware of this procedure as the progress bar is not updating after every single test.

(a) Participant completed half of the scenario, facing to the front to unlock playback.



(b) GUI for locking perceived position.

Figure 5.3.: Participant locked indicated position and selects the 'inhead' checkbox.

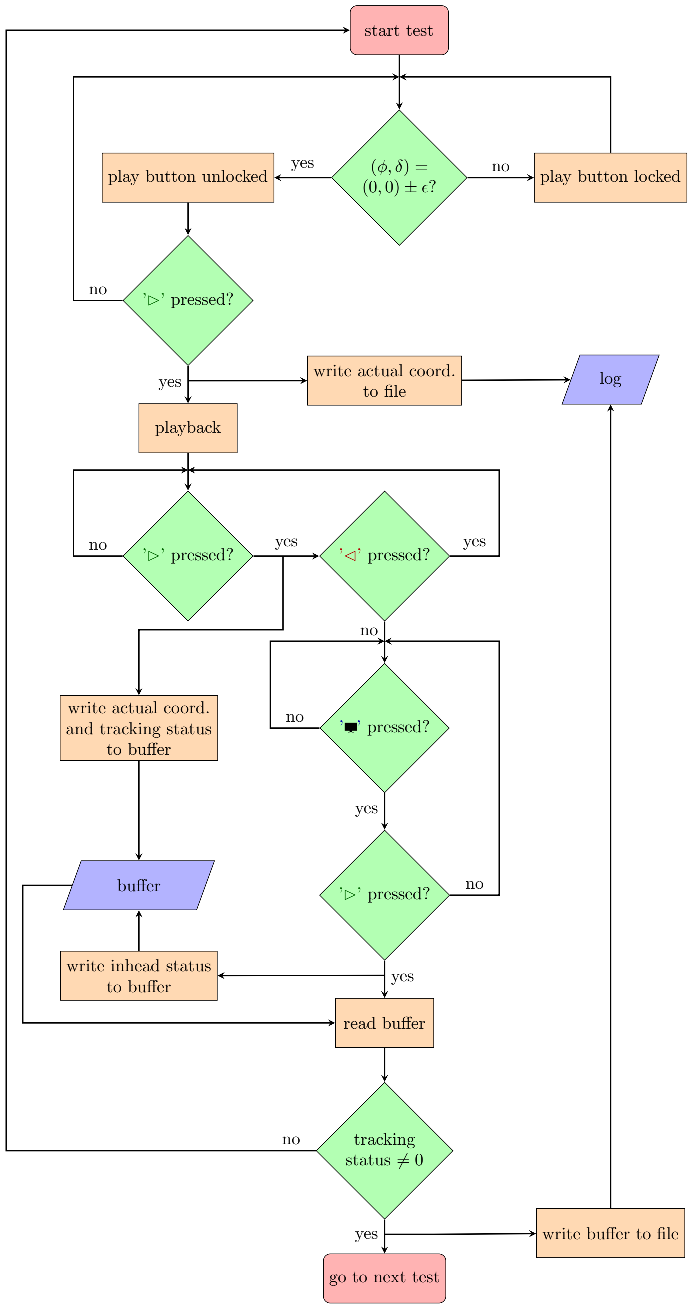


Figure 5.4.: Flow-chart visualizing the test procedure.

5.3.3. Data Acquisition

All test data are available in text from from the log files. Tracking data are stored frame by frame, furthermore user interactions and audio buffer under-runs (xruns) are recorded. The task is now to restore the position of the laserdot on the fleece and transform it to the head-related coordinate system. For each the head-mounted marker and the pointer the three room coordinates and a rotation matrix, with respect to the room coordinate system are stored frame by frame, every time when new tracking data arrive.

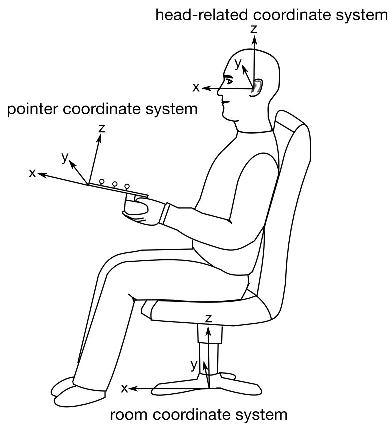


Figure 5.5.: The three coordinate systems used for the angle calculation.

We can transform the line given by the position of pointer coordinate system's origin and the direction of the pointing device (x-direction) to room coordinates. We get the position of the laserdot if we intersect this line with an ideal cylinder, representing the fleece. Once we have solved this problem, we can transform the coordinate of the laser-dot to the head-related coordinate system at playback-time. If we represent this point in spherical coordinates we have figured out the perceived sound source direction answered by a subject. The button to lock the position reacts pretty well, so that a slight press is sufficient. But the act of pressing the button does cause some trembling. Therefore the data for the calculation are taken one frame before the button is pressed.

5.3.4. Error Analysis

Tracking and calculation method was evaluated by mounting the pointing device on a tripod and adjusting the laser to a distinct position which served as a ground truth. The accuracy was within the range of some millimeters. Of course the fleece could not be mounted as a perfectly shaped cylinder. Varying the radius of the cylinder model for the calculation $\pm$ 50 mm showed that the deviation in azimuth and elevation for is slightly more than half a degree.

More errors have to be taken in account. Disturbing noise and movements by the subjects during HRTF measurements also have an unwanted effect. As no positions in the room are marked, and the test is carried out in darkness the answers are assumed to be influenced by the proprioceptive skills of each single subject. Of course one can not quantify or determine these errors.

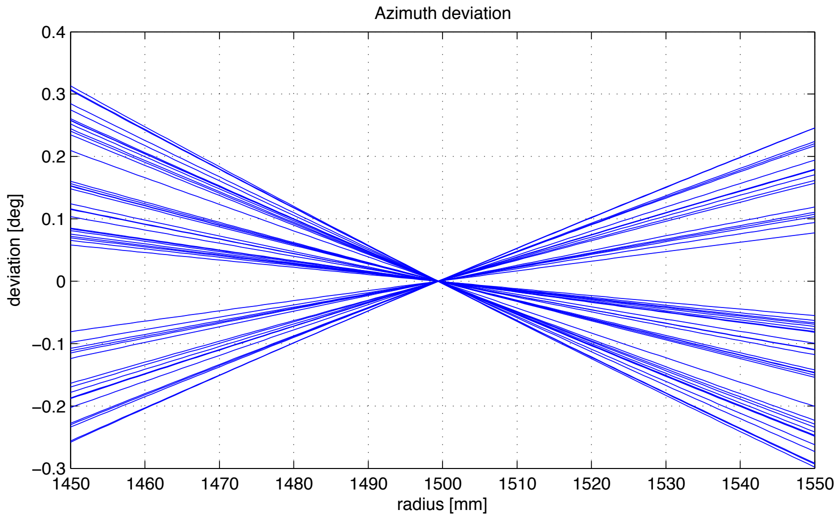


Figure 5.6.: Deviation of calculated azimuth angle varying the radius of the cylindric model.

5.4. Test Design

5.4.1. Stimuli

Stimulus parameters have a distinct influence on the sound localization. Hofman and van Opstal state that the hearing system needs some integration time for the elevation estimation, whereas the localization in horizontal plane is assumed to be unaffected of stimulus duration [19]. Results in [9] contradict the assumption that localization in horizontal plane is not related to stimulus duration. This can be explained by the fact that Chen provided head-tracking in her experiment. The longer stimulus duration permits to move the head in a way to decrease the estimated area of perceived sound direction step by step. Considering the theory of monaural cues for elevation perception one can assume that there has to be enough energy at the higher frequencies, because the changes in the spectrum occur at high frequencies [6]. The usage of noise stimuli has a long tradition in listening experiments. Broadband-noise contains energy in every frequency band, thus every supposable cue of the human listening system can be fed. On the other hand synthesized noise sounds do not occur in nature and are not suitable for real life applications. Thus a noise burst stimulus and a male speech stimulus were used for the present experiment.

The duration of 2 s was chosen, to give enough time for head movements, but not for finding and facing to the source. Regarding applications the duration between sound incidence and localization should not be too long.

The noise bursts were designed according to Seeber [39], with the difference that the the total duration was extended.

The speech stimulus is a frozen stimulus, meaning it is simply repeated, whereas the noise bursts are presented as pseudo-frozen stimuli, as 40 realizations of the random noise were calculated for each noise burst scenario by using MATLAB. Noise bursts were presented with a level of 65 dB$_{SPL}$. The two stimuli should be presented at the same loudness. As the

Type	Duration	Bandwidth	
Noise Bursts	2 s	0,125 kHz – 20 kHz	30 ms Gaussian distributed Noise (Gaussian-shaped window, 3 ms rise and fall, 70 ms pause)
Male Speech	2 s	≈ 0,1 kHz – 10 kHz	Recorded under semi-anechoic conditions

Table 5.3.: Stimulus properties.

loudness perception is not directly related to the level of the sound-pressure and stimuli are different, it was tried to guarantee equal loudness level for both. The calibration was done by placing a dummy head equipped with headphones in listener's place. The loudness level of the stimuli was calculated according to [1]. In contrast to the sound pressure level this method considers the properties of the human auditory system in frequency domain. The loudness calculation does not consider the temporal structure. As the stimuli are time-variant the loudness calculation is not perfect in this case, but still a better deal than equalizing the sound pressure level.

5.4.2. Scenarios and Test-Order

Scenarios

Offering two stimuli types, enabled and disabled dynamic sound synthesis with head-tracking and four sets of HRTFs for each subject, we get 2 by 2 by 4 arrangements. From this arrangements four scenarios are built:

1. Noise Bursts with Head-Tracking
2. Speech with Head-Tracking
3. Noise Bursts without Head-Tracking
4. Speech without Headtracking

The four HRTF-datasets were tested within each scenario. As the focus of this thesis is to evaluate the different HRTFs it is suitable to present them all within one scenario. Moreover, the procedure for the subjects is different for the cases of with and without tracking which is why switching between these cases during one scenario is not recommended in case with or without head-tracking switching the tracking type in between one scenario is not recommendable.

Testing four HRTF-sets, two tracking types and two stimuli can make the test procedure exhausting for the participant. Therefore the angles to be presented are limited. According to [34] this was done by partitioning the horizontal plane in twelve sectors. In a second step opposite angles on the left were removed from the right side. As mentioned in 3.1.1 only six elevations were measured and only one negative elevation. This is problematic for the head-tracking scenario. Assume that an angle at eye level is presented. Raising the head results in

Azimuth (ϕ)	Elevation (δ)
0°	0°, 10°, 20°, 30°, 40°
24°	0°, 10°, 20°, 30°, 40°
72°	0°, 10°, 20°, 30°, 40°
120°	0°, 10°, 20°, 30°, 40°
168°	0°, 10°, 20°, 30°, 40°
216°	0°, 10°, 20°, 30°, 40°
264°	0°, 10°, 20°, 30°, 40°
312°	0°, 10°, 20°, 30°, 40°

Table 5.4.: Presented angles for each HRTF set in each of the four scenarios.

HRTF data for negative elevations being needed to hold the sound source position constant in the room. Therefore the negative elevation was removed from the set of presented angles as a slight head movement would would cause that the elevation can not be updated and stays constant in the head-related coordinate system but not in the room. In total this leads to the following 40 presented angles:

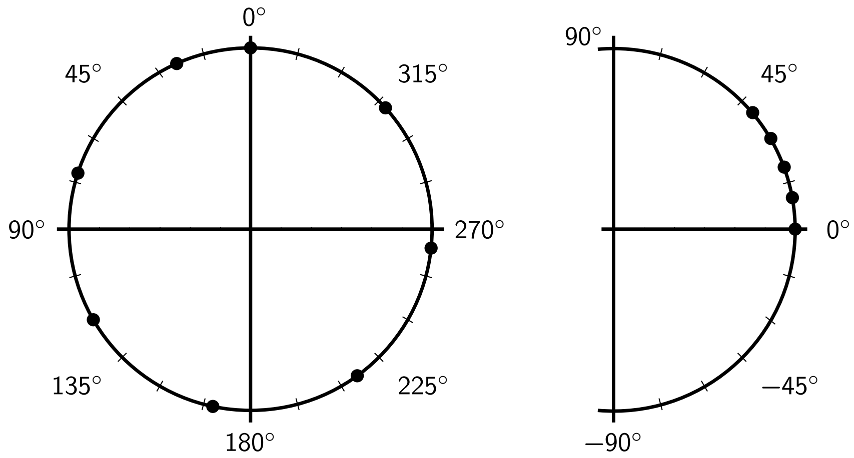


Figure 5.7.: Presented angles in azimuth (left) and elevation (right).

Test-Order

The experiment is designed for "naive listeners", as most of the subjects never participated at localization experiments. Therefore it is assumed that there can be some learning effects by the subjects running through the four scenarios [30], [46]. A balanced test-design is established to minimize an influence on the experiment caused by training effects. All participants were arranged in four groups, whereby each group passed the experiment in an different order, determined by a Balanced Latin Square (BLS) [7].

Changing the HRTF-dataset from one presented angle to the next turned out to be confusing and annoying. Therefore it was decided to present the four different HRTF-datasets block-wise. We can take advantage of BLS design again, by altering the HRTF-sets that each scenario starts with a different HRTF set and the sequence is never the same. Table 5.5 gives an overview of the test order.

Test-group 1

Noise with Tracking				Speech w/o Tracking				Speech with Tracking				Noise w/o Tracking			
H4	H3	H1	H2	H3	H2	H4	H1	H1	H4	H2	H3	H2	H3	H1	H4

Test-group 2

Speech with Tracking				Noise with Tracking				Noise w/o Tracking				Speech w/o Tracking			
H3	H2	H4	H1	H2	H3	H1	H4	H4	H3	H1	H2	H1	H4	H2	H3

Test-group 3

Noise w/o Tracking				Speech with Tracking				Speech w/o Tracking				Noise with Tracking			
H2	H3	H1	H4	H1	H4	H2	H3	H3	H2	H4	H1	H4	H3	H1	H2

Test-group 4

Speech w/o Tracking				Noise w/o Tracking				Noise with Tracking				Speech with Tracking			
H1	H4	H2	H3	H4	H3	H1	H2	H2	H3	H1	H4	H3	H2	H4	H1

Table 5.5.: Test-order: H1: Individual HRTF, H2: KEMAR HRTF, H3: Regression HRTF, H4: Selected HRTF.

In the end there are 40 spatial positions under test for each HRTF-set. This leads to 160 tests per scenario. The order of the angles to be presented within one HRTF-dataset was randomized.

6. Experiment and Results

As the whole implementation was described one can be curious about the outcome. But first, we give an overview of the participants and the statistical appliances for the data analysis.

6.1. Subjects and Realization of the Listening Test

Twenty paid subjects participated in the localization experiment: students and doctoral candidates, aged between 20 and 30 years, two female and 18 male. They were mostly inexperienced with sound localization experiments. No screening on their hearing ability was applied.

The time needed to pass one scenario was around 20 minutes – 35 minutes. Therefore the overall procedure was split up into four sessions. After one session a break of at least 10 minutes was applied. Subjects were free to extend the time for rest. When a subject absolved two scenarios the session was ended. The missing scenarios were tested tested after a long enough break, with the minimum being one test in the morning and one in the afternoon.

The test procedure including the oral introduction can be described as follows.

You enter the lab and are invited to sit down on the swivel chair and to adjust it to a comfortable height. The headphones are handed to you to adjust the size and to wear them ad libitum. The experimentator starts the test-software and summons you to look straight ahead, while the headphones are rearranged by the experimentator to ensure a proper position of the head-mounted tracking marker. The demonstration is started and you can see a cross within a coordinate system on the screen, showing your head rotation in azimuth and elevation. Now an oral introduction is given, how to control the test-software by the pointing device. You are told not to move the head during playback in case of a scenario without head tracking, whereas you are free to move during playback in case of head-tracking. After locking the perceived position you should mark the checkbox if the sound was perceived in-head. As different HRTF-datasets are presented you are advised that some sound examples can evoke conflicting or confusing perception, but you are told to answer anyway. In five demonstration tests you get familiar with controlling the software and sensitized for effects of head-tracking. In case of disabled head-tracking you have to move your head during demo-playback to hear the unwanted effect that the source position stays constant relative to the head. For the scenarios with head-tracking you are advised to move the head also to extreme elevations. This is to realize that the sound-source is staying constant in room for some elevations, but moves in room by staying constant relative to the head for extreme elevations as no HRTF-data are available. When you passed the demonstration, the display is dimmed, the test is unlocked and you are free to start as the experimentator leaves the room and turns of the lights.

Except for the tracking and stimulus type, no hints on the experimental design are given to the subjects. Playback volume was only changed when the participant felt very queasy.

Remarks

- Subject 04 interrupted scenario 1 to take a rest of 3 minutes
- Subject 11 repeated scenario 4 due to a software crash.
- Subject 14 repeated scenario 3 because data were not written to file

6.2. Data-Analysis

6.2 The localization error is defined as the mean error of the unsigned deviation from the perceived angle to the presented angle. The localization error in azimuth is additionally corrected for reversals. Positions close to 90° and 270° are not corrected, as well as answered positions close to the right while presented position was close to the left and vice versa. This is visualized in figure 6.1 for a presented angle of 50°. These assumptions for reversal corrections are similar to [9]. Front-back and back-front reversals as well as in-head answers are given in percent.

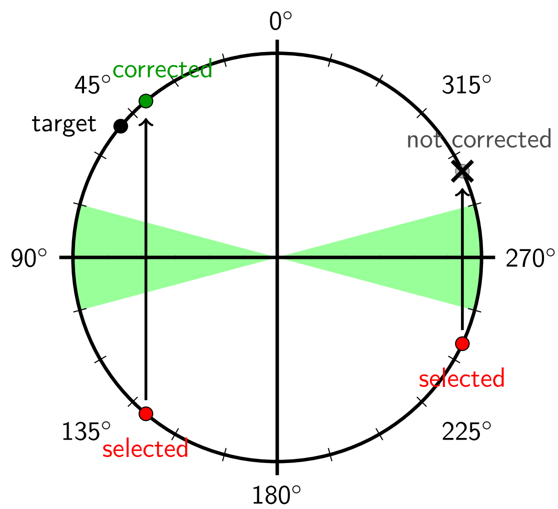


Figure 6.1.: Reversal handling for corrected azimuth error calculation.

Presentation

Three plot styles are used to present the data, namely box-plots, scatter-plots and bar-graphs. Boxplots according to [12] are used to visualize the distribution of the localization error. The line in the middle represents the median of the sample. The boarders of the box indicate the 25th and 75th percentiles. The range of the whiskers outside of the box is 1.5 of the length of the 75th, respectively 25th percentile. Data lying out of the whisker range are considered as outliers and marked by a cross. The notch represents the 95 % confidence interval. Additionally the mean of the sample is given by a red diamond.

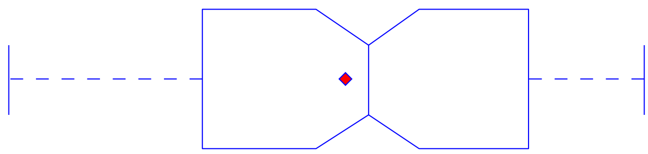


Figure 6.2.: Example for the used boxplots.

Scatterplots visualize the distribution of the answered directions. A histogram is calculated for each presented direction, counting how much answers lie in a certain range. Here a range of 5° is chosen. All data lying in this range are represented by one filled circle plotted, whose size is directly related to the number of values lying in this range. For example if a certain number of answers is counted in a range between 20° and 25° a filled circle is plotted with the center at 22,5°, whose diameter is related the number of answers. The bisecting line is the ground truth, whereas the dashed line is the regression line for the mean errors at each presented angle.

Reversal and 'in-head' data are simply presented by bar plots showing their amount in percent.

Analysis

As mentioned further, the mean of the absolute error serves for the analysis. But we also want to make statements wether the differences in means are significant or not. To handle this task we can choose the Analysis Of VAriance (ANOVA), as recommended in [4], [9] or [3]. This method compares the variance within a sample to the variance between the samples. The ratio of these variances is the so called F-ratio, which is a measure of the ratio of systematic variation to unsystematic variation [12]. Let us summarize how we can make statements on the differences of the means. At first we formulate the null-hypothesis H_0. In our case the choice is for example: *There is no significant difference between the means of the localization error between the HRTF types*. If the systematic variation is increasing faster than the unsystematic one (this means that the F-ratio is increasing) the chance to reject the null-hypothesis is increasing. One output from the ANOVA is the p-value, which indicates the probability that the current observation occurs if the null-hypothesis is true. Popular thresholds are $p = 0.05$ or $p = 0.01$. We will use $p = 0.05$ in our case, according to [4]. Summarizing we can say: If the p-value from the ANOVA is smaller than 0.05 we can reject the null-hypothesis and state that there is a significant difference between the mean of the observed samples. If $p > 0.05$ we can make the statement that there is no significant difference between the means.

It has to be mentioned that the ANOVA can only give informations if there is a significant difference between the means of the observed samples, but not if the significant difference is between means of sample A B or C, if we apply more than two samples to the ANOVA.

If we want to know which means of the samples are different from the others we have to apply a post-hoc-method. In this case we will use the Least-Significant-Difference (LSD) test. Breaking it down the output of the LSD test for comparing a pair of two groups is the estimated difference in mean and the 95 % confidence interval. If the confidence interval contains 0,00° the difference is not significant at the chosen 0.05-level. See [12] for a more detailed description.

6.3. Results

In each scenario 160 answers were recorded that leads to 12800 answers over all scenarios and subjects. To maintain an overview figure 6.3 should help. On the top, we get the overall localization errors for all collected data, which is pretty uninteresting. So we can split up the data to compare different scenarios. Because of the huge results of the experiment only few plots are given in this section. One can find all tested scenarios in the appendix.

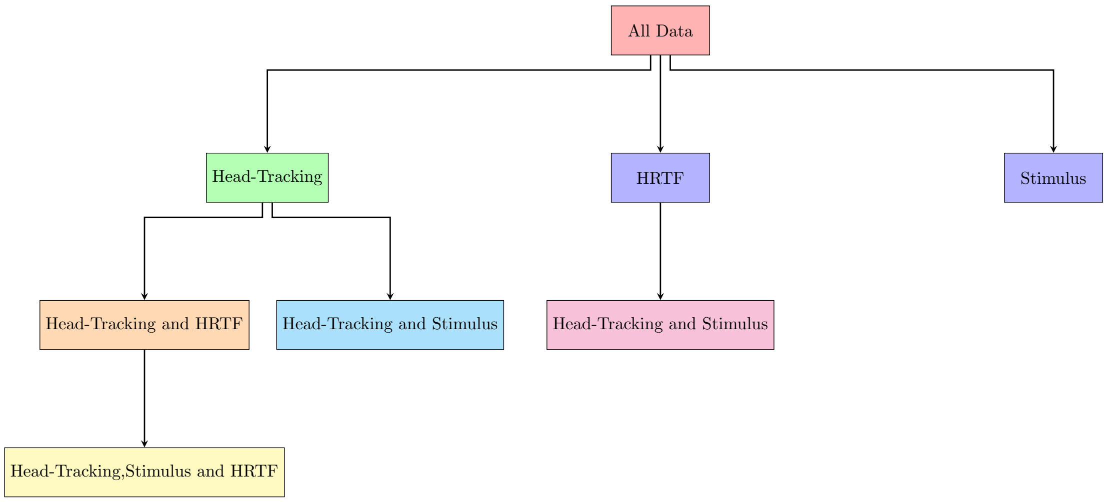


Figure 6.3.: Splitting up the data to the different attributes under test.

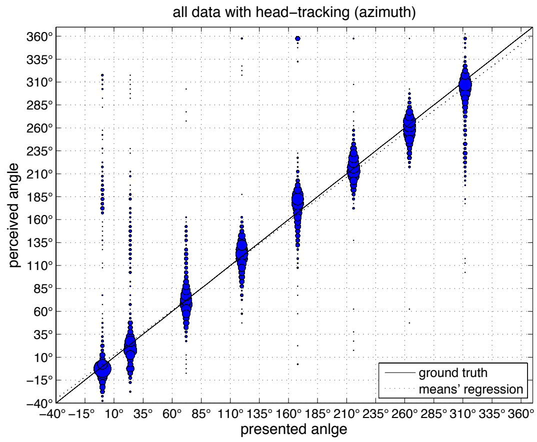
6.3.1. Azimuthal Localization Performance

Let us now investigate the localization error in the horizontal plane and also the reversal-corrected azimuthal error. If we correct reversals we get something like the localization accuracy. As figure 6.3 suggests we shuffle all data together. If necessary, meaning that small differences in one attribute can be hided by the impact of other attributes, we strip the data down again.

Comparison of the Tracking Types

For this comparison data across all HRTF-sets and both stimuli types are collected such that we end up with two groups: One with and one without head-tracking. The means of the two groups are significantly different with $p < 0.01$ for the azimuth and $p < 0.01$ for the corrected azimuth error. As the errors with head-tracking are smaller, the p-values indicate that the usage of head-tracking highly decreases the reversal-rate and increases the localization accuracy, meaning the corrected azimuth error is decreased from 17,78° to 12,97°.

The scatterplots mirror both statements. One can see the appearance of a second diagonal trend, starting top left running to bottom right in case without head-tracking. This is due to front-back and/or back-front confusions. Referencing to the scatter-plot of the corrected error, we can see that the answers with head-tracking are more concentrated at the bisection line whereas answers are spread in case without head-tracking. Providing head-tracking decreases the reversal rate from 23,1 % to 5,2 %. Astonishingly the number of in-head perceived samples can not be reduced as dramatically as the reversals. All plots to the results can be found in appendix A.2.



(a) Azimuth answers with head-tracking.

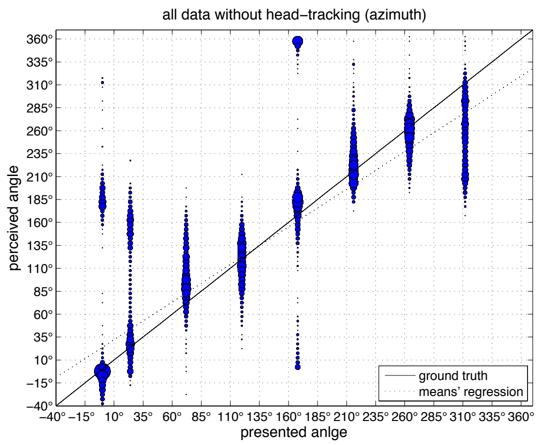


Figure 6.4.: Azimuth answers without head-tracking.

Comparison of the Two Stimuli

As one can guess, for this comparison we sum up all data across HRTF-sets and both tracking types to separate the data into two groups of different stimuli. The box-plots show us that the azimuth localization error is smaller for the speech stimulus. The azimuth error is varying only slightly for the two stimuli, but the p-value of 0.142 is above the 0.05 limit that we can not say there is a significant difference. If we correct the reversals the result is changing on noise bursts' behalf and this difference is significant ($p = 0.0211$). In general the difference in localization performance for the different stimuli is not as clear as for the tracking types.

More reversals are counted for the speech stimuli, this could be explained by the fact, that the bandwidth is smaller than for noise. Hence spectral cues in the HRTFs at higher frequencies which are assumed to support the decision weather the sound source is in front or rear hemisphere can not be taken into account by the hearing system. All results are printed in A.3.

Comparison of the HRTF-Datasets

The ANOVA for the four groups indicates that there is significant difference of the means (azimuth: $p < 0.01$, corrected azimuth: $p < 0.01$).This is all information that we can get from the analysis of variance. We have to apply the LSD-test for the pairwise comparison.The confidence intervals for each HRTF-set compared to each other are given in A.4. It is remarked that there is a significant difference if the confidence interval has no zero-crossing. This is the case for the measured HRTF versus the HRTF from selection. The estimated differences in the means increase if we correct the reversals. But also for the corrected azimuth error the difference is not significant for measured and selected HRTF, but for all other pairs. The poorest localization performance is observed for the HRTF form the PLSR. But we kept in mind that this is the only HRTF approach calculating a new HRTF, while all other approaches go back to measured HRTFs. As the impact of head-tracking is very strong, but not the differences between stimuli and most of the HRTFs, it is useful to split up the data again, and analyze the localization performance with and without head-tracking.

Comparison of the two Stimuli with and without Head-Tracking

The arrangement of the investigated options corresponds to the four test scenarios. The result that there is a significant difference between the stimuli for the uncorrected localization error can not be confirmed. In both cases, with and without head-tracking, we can state that there is no significant difference between speech and noise bursts. For the corrected azimuth error, the result from the comparison of stimuli without considering head-tracking stays the same, meaning there is no significant difference. Details are given in the appendix A.5.

Comparison of the HRTF-Datasets with and without Head-Tracking

Investigating the HRTF-datasets with and without head-tracking leads to 28 pairwise comparisons. We can see that the analysis without considering head-tracking hided interesting facts. Spotting the case of head-tracking we see that the measured HRTF, the selected HRTF and the KEMAR HRTF show no significant differences to each other. It seems that the differences in localization error with different HRTFs decrease, if head-tracking can be offered. Although the difference in means for measured and selected HRTF is not significant, it is surprising that in our results the selected HRTF beats the measured HRTF. As the difference is very small, this can be due to the fact that for a small number of subjects surrounding noise or head-movements disturbed the HRTF-measurement, which was not probably not the case for the selected HRTF. The comparable performance of the KEMAR HRTF to the measured one is in conflict to results from a prior quality of experience listening test on the same data [42]. One can suppose that the measured HRTF can offer a better immersion or realism but not a better localization performance.

Without head-tracking the situation changes for the uncorrected azimuth localization error. The differences are significant for each pairwise constellation which means we can now rank by names. The best performance without offering head-tracking can be achieved by the individual measured HRTF, followed by the selected HRTF from DOMISO and the KEMAR. Again the HRTF from the PLSR yields to the highest error. If we correct the results for reversals the measured HRTF can still assert it's rank in our case, but the difference to the selected HRTF is no longer significant. We can assume that reversals can be avoided in a better way by using the individually measured HRTF when no head-tracking is available.

If we cross-compare HRTFs with and without tracking we can state that the impact of head-tracking on the absolute localization error is much higher than the impact of the HRTF approaches. Only if we cancel out the reversals, we see that the performance of HRTFs without head-tracking can stick with the regression HRTF with head-tracking.

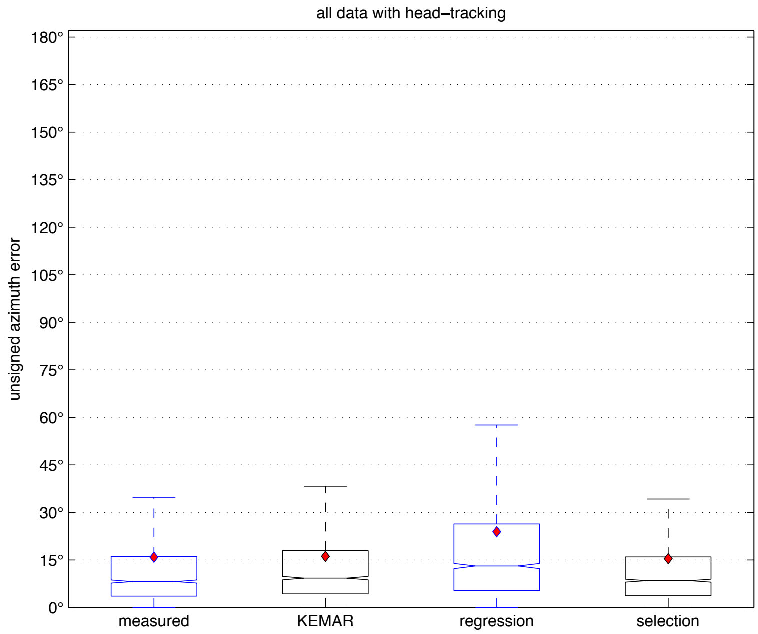
As the difference between the stimuli is not significant for each tracking type the data are not totally split up to different HRTF, different stimuli and different head-tracking as we would get 120 pairwise comparisons. Nevertheless these results can be found in A.8.

Influence of Externalization

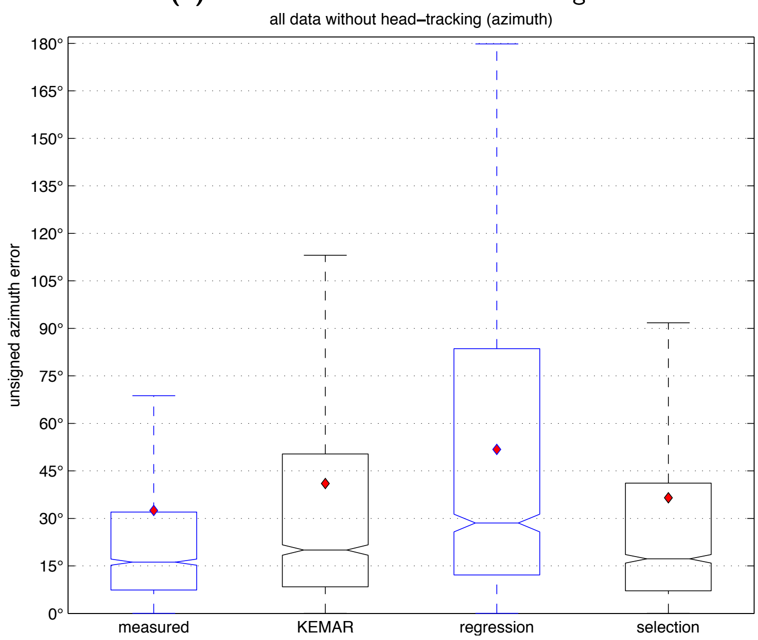
The subjects were introduced to give an indication if the synthesized sound seemed to be located 'in-head'. The question is wether the localization performance is affected when the source was perceived to be positioned in the head. To answer this question an ANOVA is applied to find out if there is a significant difference between the localization error for all answers, where the 'in-head' checkbox was marked and for answers which where perceived to be external. One can see that the localization error is lower for the external perceived positions. This indicates that localization performance could be improved by trying to post-process the HRTFs in a way that all directions are perceived to be external. Adding an room information to the HRTFs could support the externalization [4]. The boxplots are provided in appendix B.9.

6.3.2. Elevation Localization Performance

From the scatter plots one can see that the elevation was consequently underestimated, independent of the scenario and the HRTF. The impact of head-tracking on the elevation



(a) Azimuth error with head-tracking.



(b) Azimuth error without head-tracking.

Figure 6.5.: Boxplots for the HRTFs with and without head-tracking.

localization performance is not as dramatic as on the azimuth localization performance. But the difference in elevation estimation is still significant for the head-tracking-attribute.

In contrast to the influence of head-tracking, the impact of the stimulus increases for the

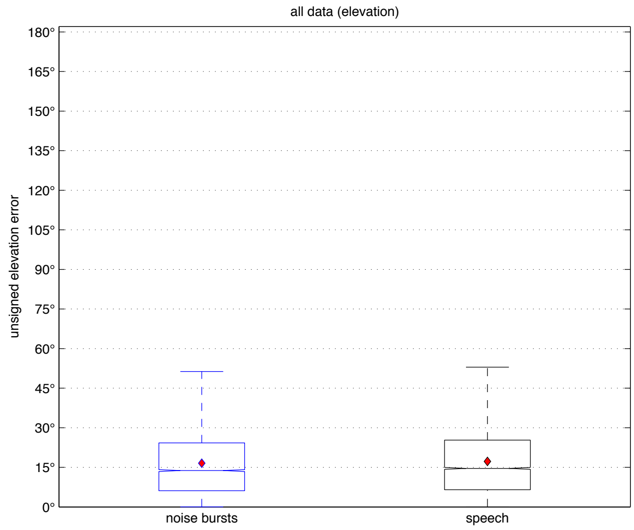


Figure 6.6.: Elevation error for the different stimuli.

elevation. There is a significant difference between noise bursts and speech. The localization error is smaller for noise bursts. One can assume this is due to the spectral distribution of the stimuli. There is an higher amount of energy at high frequencies for the noise bursts. The monaural cues for the elevation perception are peaks in the HRTFs, which occur mostly at higher frequencies.

Regarding the HRTF-sets the individually measured HRTF guarantees the best elevation localization performance. This is in accordance to Blauert's directional bands theory, as monaural cues are considered to be responsible for elevation estimation. Subjects are familiar with the spectral cues offered by their individual HRTF. As there are no difference-cues like ITD or ILD for elevation, the human hearing system can only distinguish by experience whether a peak in a certain frequency band comes from the stimulus or the HRTF magnitude. This could be a possible explanation for the systematic underestimation, as the measured HRTF can only be an approximation of the real one.

For the detailed elevation results it is referred to the appendix B.

6.3.3. Individual Differences

In the present experiment the individual differences between the subjects are large, which is not surprising as naive listeners were recruited for the test. Neither screening of the hearing ability was applied, nor closed loop training to sensitize the subjects on the localization task, was provided. Subject 11 for example passed the scenario with noise bursts and head-tracking with a mean azimuth error of 4,52° and 4,58° with the selected and individual HRTF. No reversal occurred for any HRTF-data in this scenario. In contrast to the global result without head tracking Subject 11 had less reversals and better azimuth accuracy for the selected HRTF than for the individual one. To show the other extreme, the performance of Subject 20 should be discussed. Also in case with head-tracking the reversal rate is very high, and the

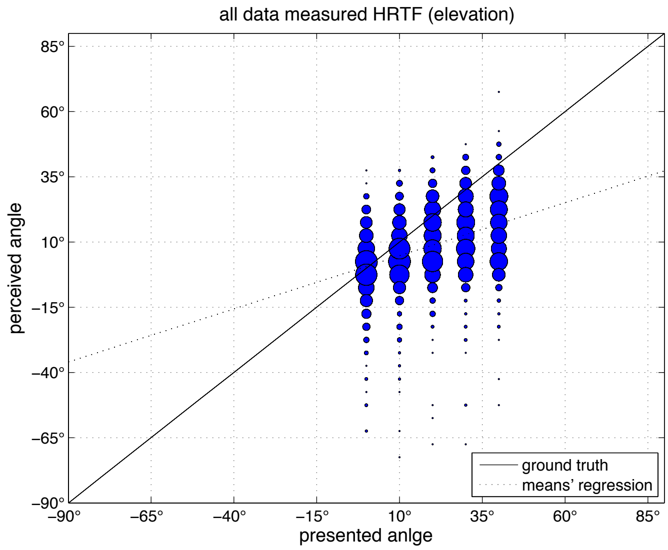


Figure 6.7.: Elevation answers for all data with the measured HRTF.

localization performance poor. One can assume, that this person was not taking advantage of head-movements, as the difference in performance between the head-tracking scenarios and the scenarios without head-tracking is not high. Subject 19 can serve as example for reliable expected results. The localization performance with head-tracking is pretty good, individual an selected HRTF perform better than KEMAR and regression HRTF, no reversal can be observed. If head-tracking is disabled, the reversal rate decreases strongly, also the localization accuracy is diminished. Boxplots on the individual results can be found in appendix C.

7. Conclusion

The motivation of the present research was to evaluate different HRTF individualization methods investigated in prior researches at the Institute for Data Processing. Four datasets of HRTFs were up for discussion. HRTF measurements of 35 subjects formed the foundation for the individualization methods.

Results from other researchers can not be fairly compared as the acquisition of HRTF datasets, the test methods and designs are different. Some researches contradict each other's results and it can be stated that the localization performance is highly sensitive to the datasets under test, the subjects under test and the test design. This is why a suitable localization test method had to be found for evaluating our HRTF data. The method that was implemented offers more than the introduced advantages. If needed one can investigate the localization of moving sound sources, as the participants can follow this source with the pointing device. Furthermore, all head movements are recorded during the test. Computing the trajectories could give answers how the testsubject behaves when the source can be tracked and if there is an other behavior if the localization fails.

Besides the development of the listening test the experiments were conducted. 20 participants passed the listening test by spending in total approximately 90 hours in the lab. A strong impact of head-tracking was detected.This is in accordance to other researches on virtual auditory synthesis.Reversals were dramatically reduced and the localization was more precise. In general the mean localization error for all data is comparable to prior researches. Considering the results for the elevation localization, it was found that the performance is significantly better for the noise stimuli and also for the individual HRTF. In general the elevation directions were underestimated. Furthermore the data shows that externalization is helpful for the localization task. Designing a virtual auditory display, one can use the present results for a trade-off between effort and performance.

For the HRTF-sets it can be stated that head-tracking reduces the differences in localization error. No significant differences between measured HRTF, KEMAR HRTF and selected HRTF for the azimuth error could be found. In contrast to that the differences in the means of the azimuth error are significant for all HRTF-datasets if head-tracking is not available, whereas the lowest error was obtained using the individually measured HRTF. The localization performance is no more significant if we correct the reversals. This illustrates that the individual measured HRTF mitigates the reversal rate. Considering the regression HRTF coming in last place, it has to be remarked that this was the only computational method in the present experiment. Refining the algorithms and the procedure this method could be a useful alternative to a generalized HRTF.

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A. Azimuth Localization Error Plots

The data are presented as described in section 6.2. To provide a clear arrangement no outliers are printed in the boxplot. For the post-hoc tests tables with the confidence intervals are provided. Red colored entries indicate a significant difference between the means.

A.1. All Data

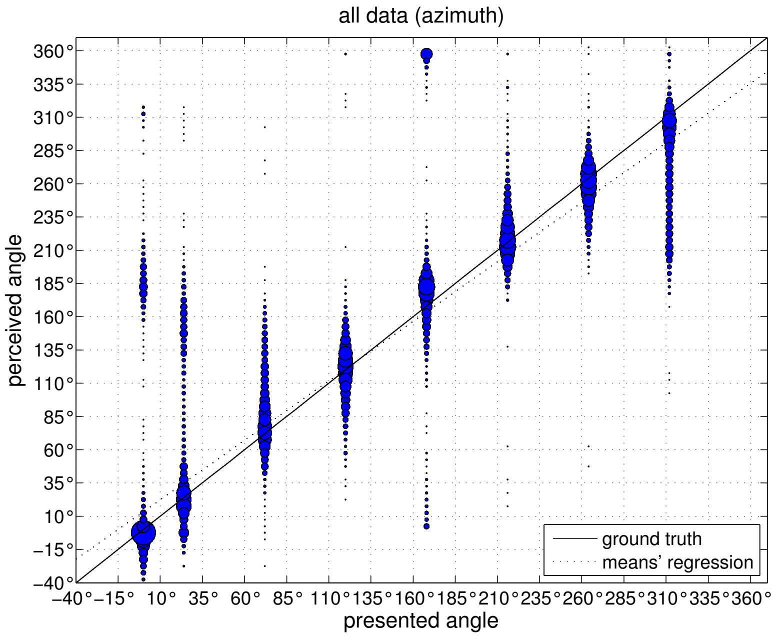


Figure A.1.: Scatterplot, azimuth answers.

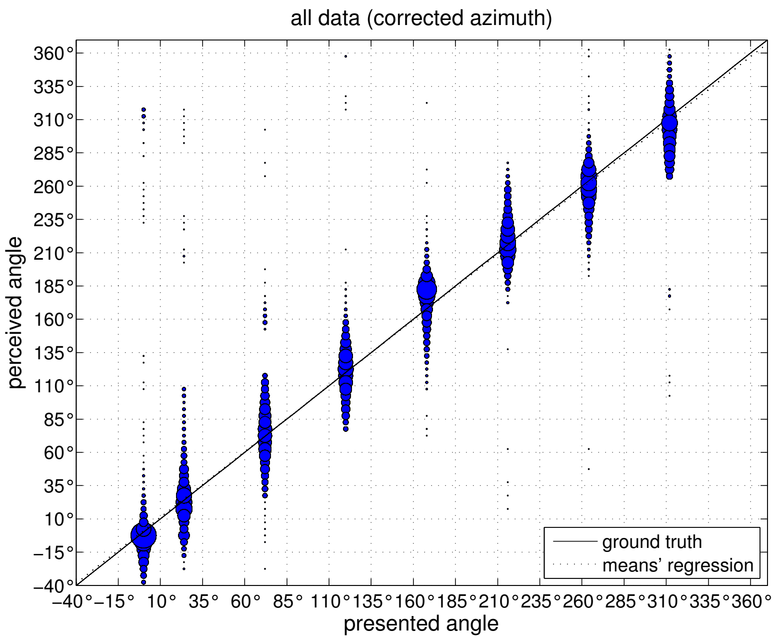
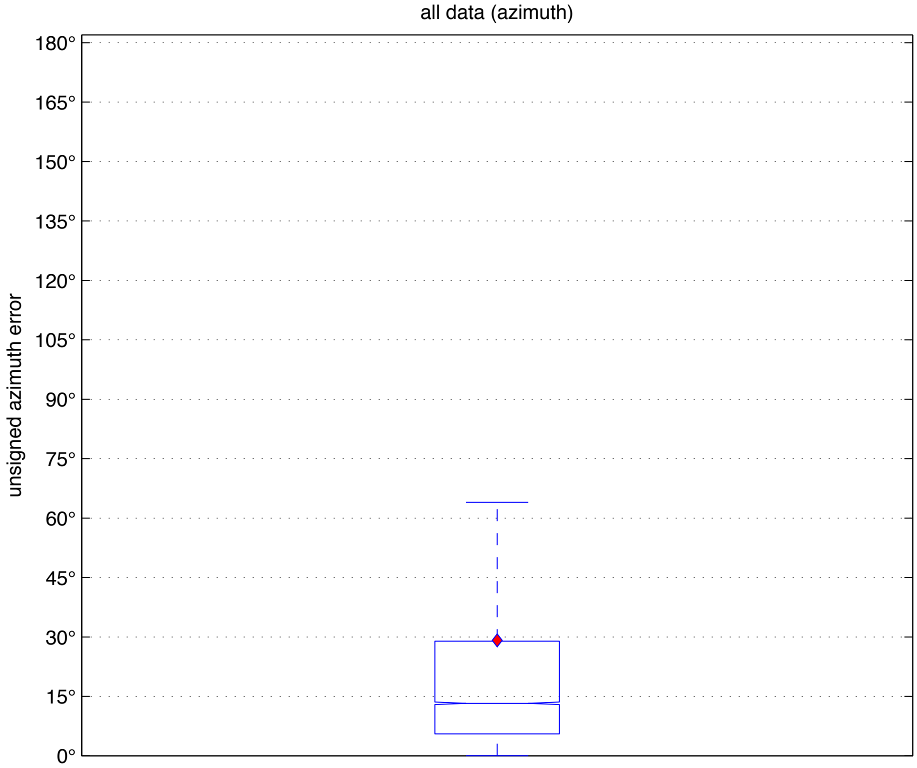
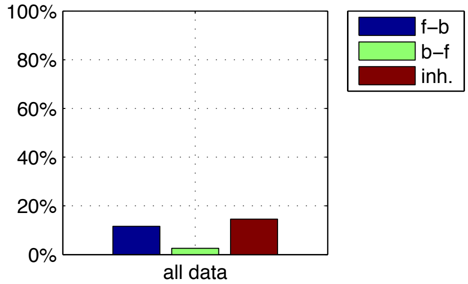


Figure A.2.: Scatterplot, reversal corrected azimuth answers.



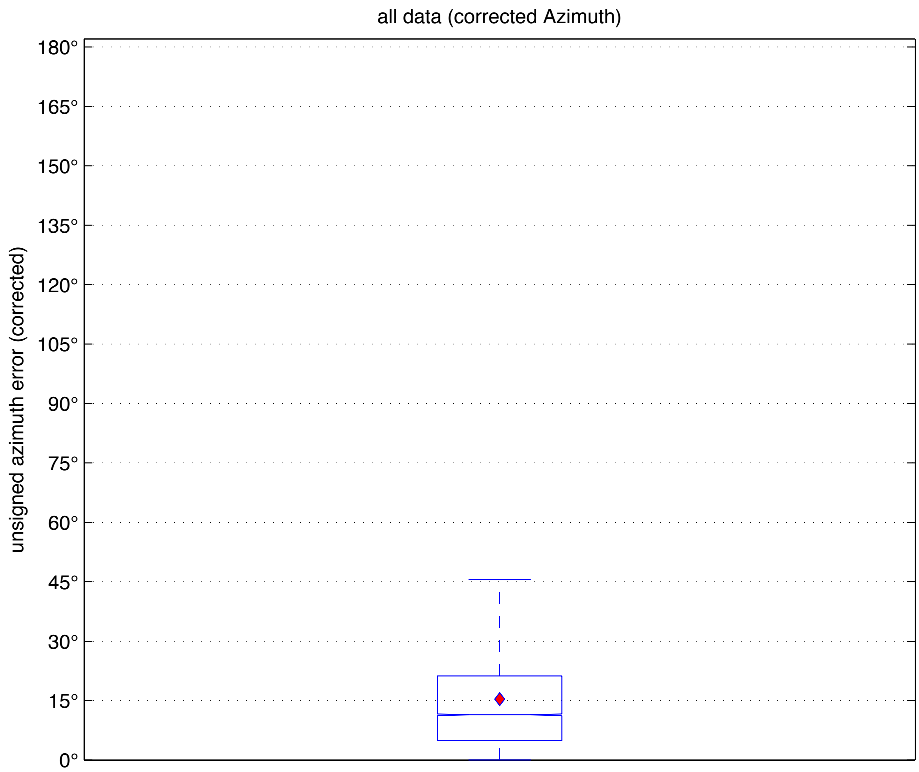
all data	
mean	29.15°
std. dev.	41.45°
median	13.25°



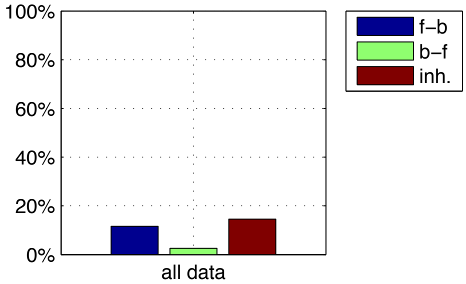
all data

	total	f–b	b–f
conf.	14.2%	11.6%	2.6%
inheads	14.6%		

Figure A.3.: Boxplot, azimuth error.



all data	
mean	15.38°
std. dev.	15.73°
median	11.41°



all data	total	f–b	b–f
conf.	14.2%	11.6%	2.6%
inhead	14.6%		

Figure A.4.: Boxplot, reversal corrected azimuth error.

A.2. Comparison of Head-Tracking

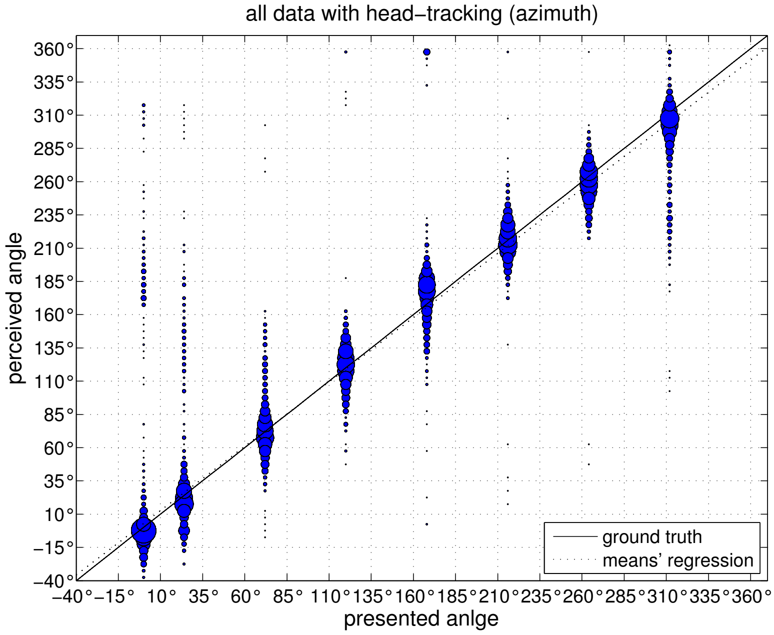


Figure A.5.: Scatterplot, azimuth answers with head-tracking.

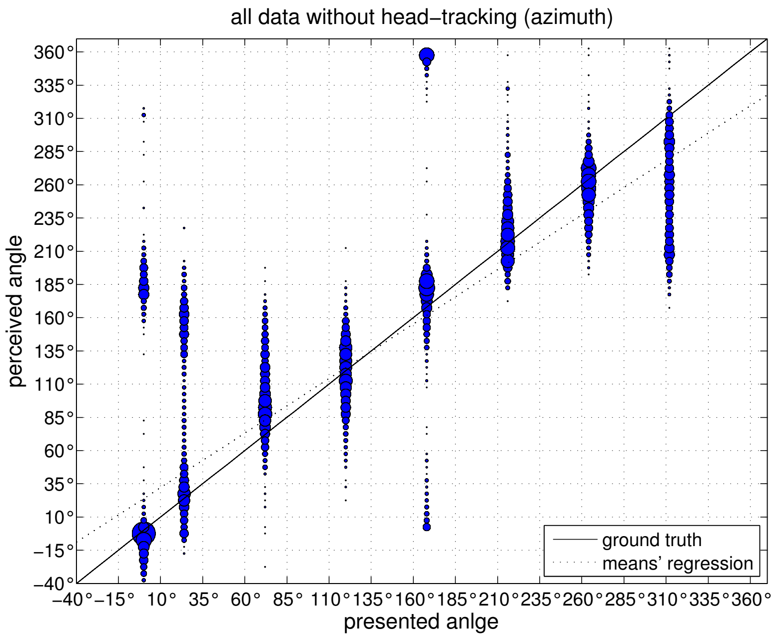
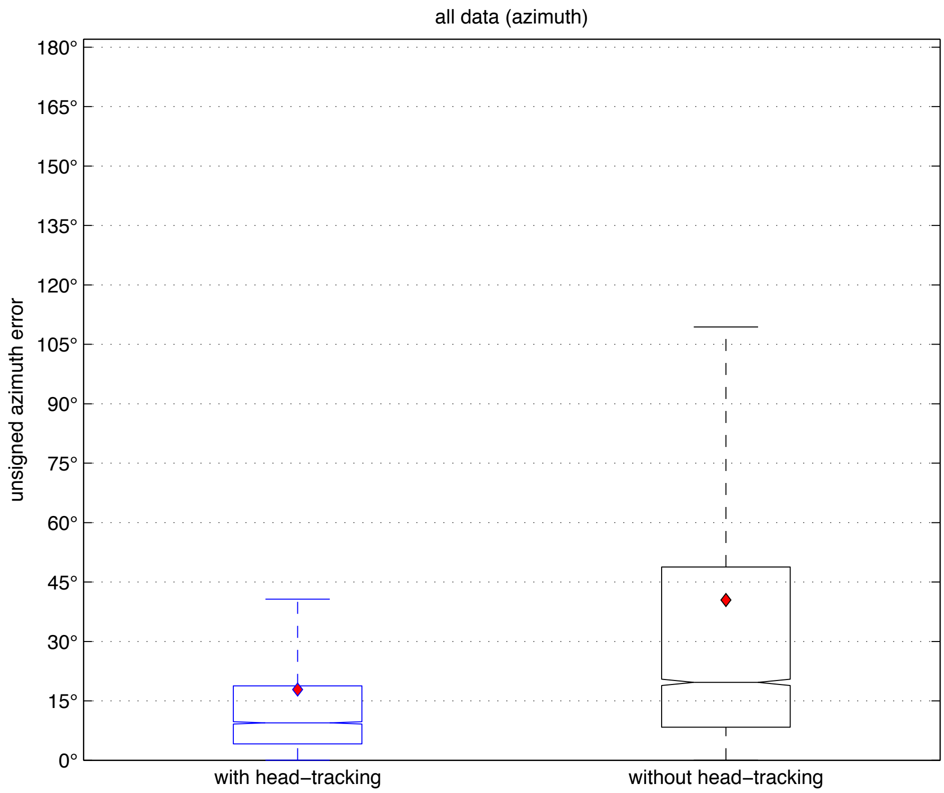
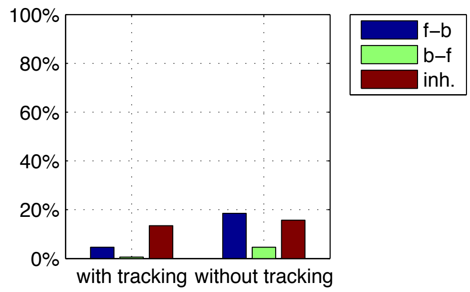


Figure A.6.: Scatterplot, azimuth answers, without head-tracking.



	with tracking	without tracking
mean	17.85°	40.45°
std. dev.	28.54°	48.65°
median	9.44°	19.67°



	with tracking			without tracking		
	total	f–b	b–f	total	f–b	b–f
conf.	5.2%	4.6%	0.6%	23.1%	18.5%	4.6%
inheads	13.4%			15.7%		

Figure A.7.: Boxplot, azimuth error, $p < 0.01$

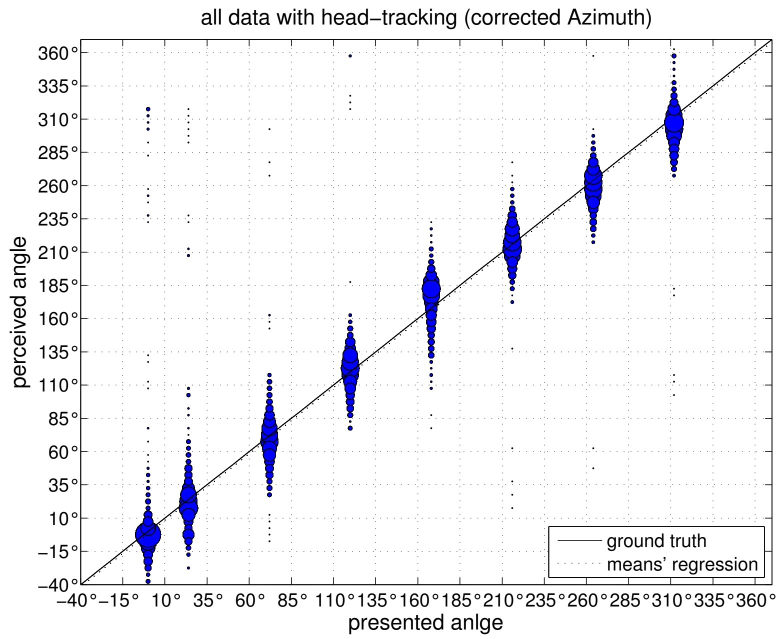


Figure A.8.: Scatterplot, reversal corrected azimuth answers with head-tracking.

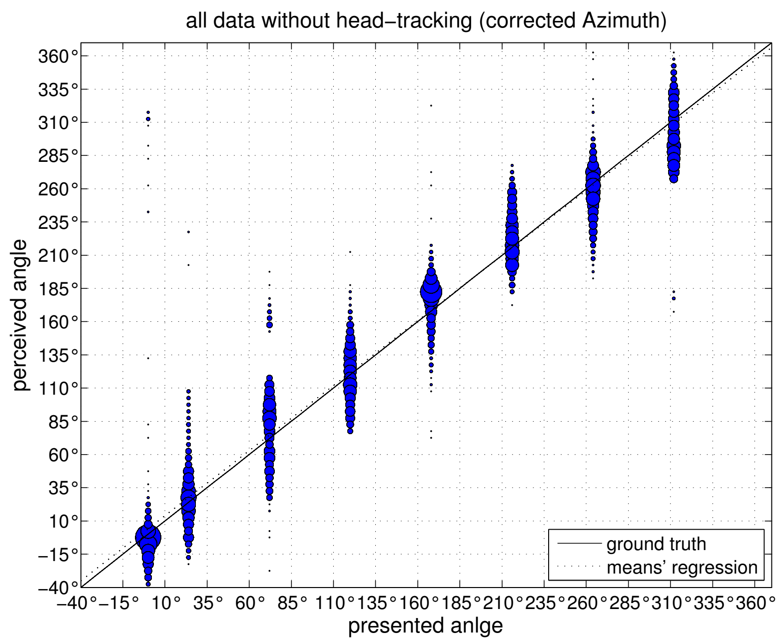
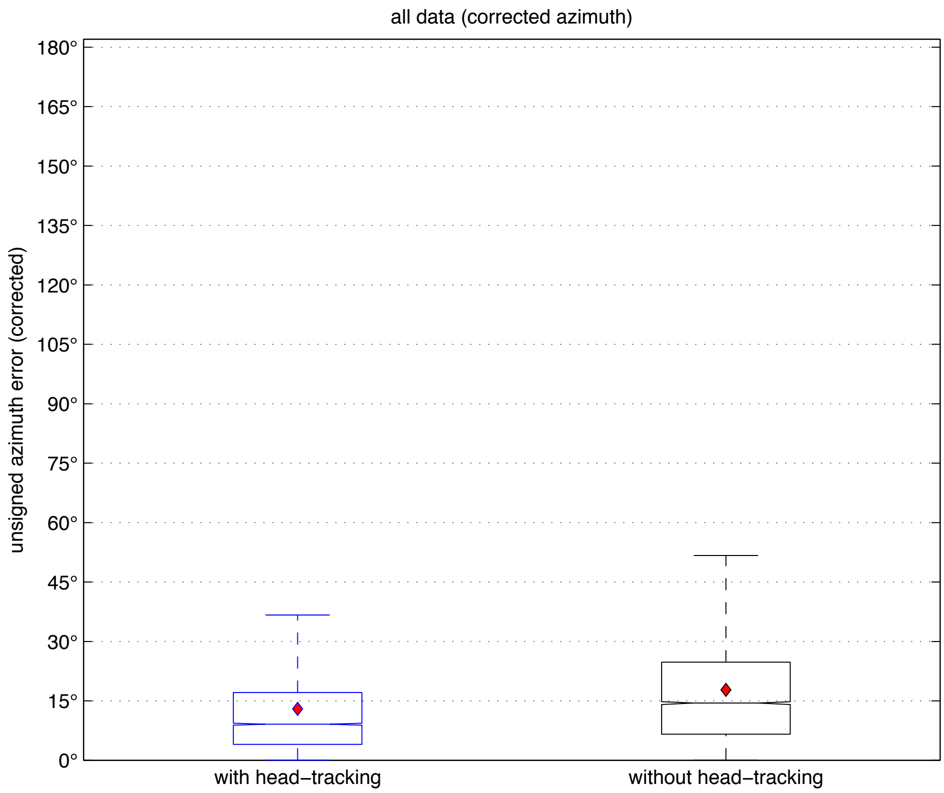
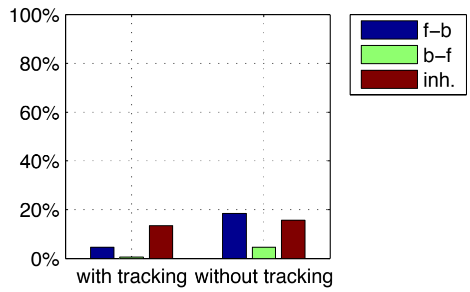


Figure A.9.: Scatterplot, reversal corrected azimuth answers without head-tracking.



	with tracking	without tracking
mean	12.97°	17.78°
std. dev.	15.35°	15.74°
median	9.09°	14.45°



	with tracking			without tracking		
	total	f–b	b–f	total	f–b	b–f
conf.	5.2%	4.6%	0.6%	23.1%	18.5%	4.6%
inheads	13.4%			15.7%		

Figure A.10.: Boxplot reversal corrected azimuth error, $p < 0.01$

A.3. Comparison of Stimuli

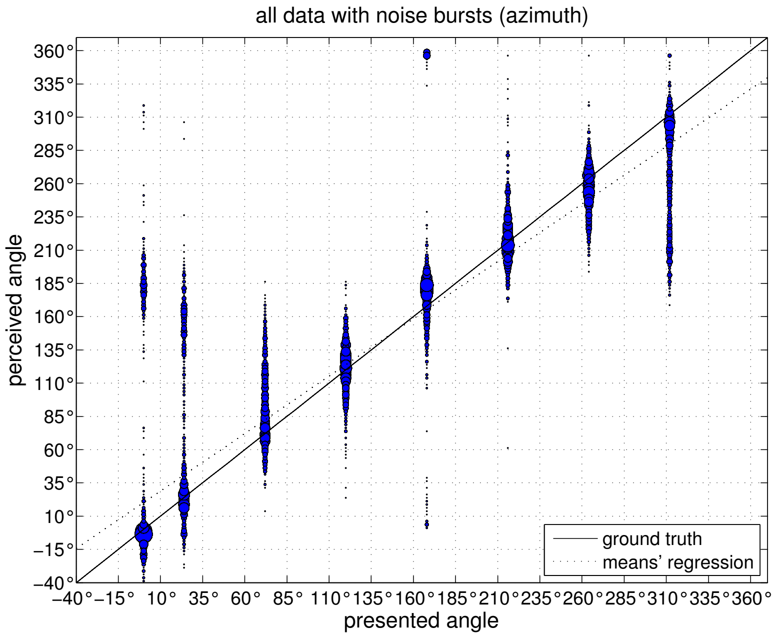


Figure A.11.: Scatterplot, azimuth answers with noise.

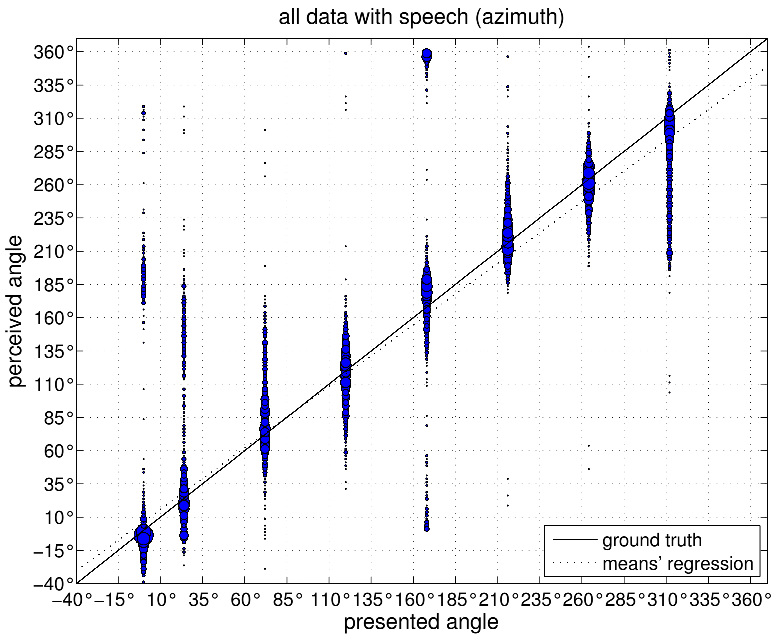
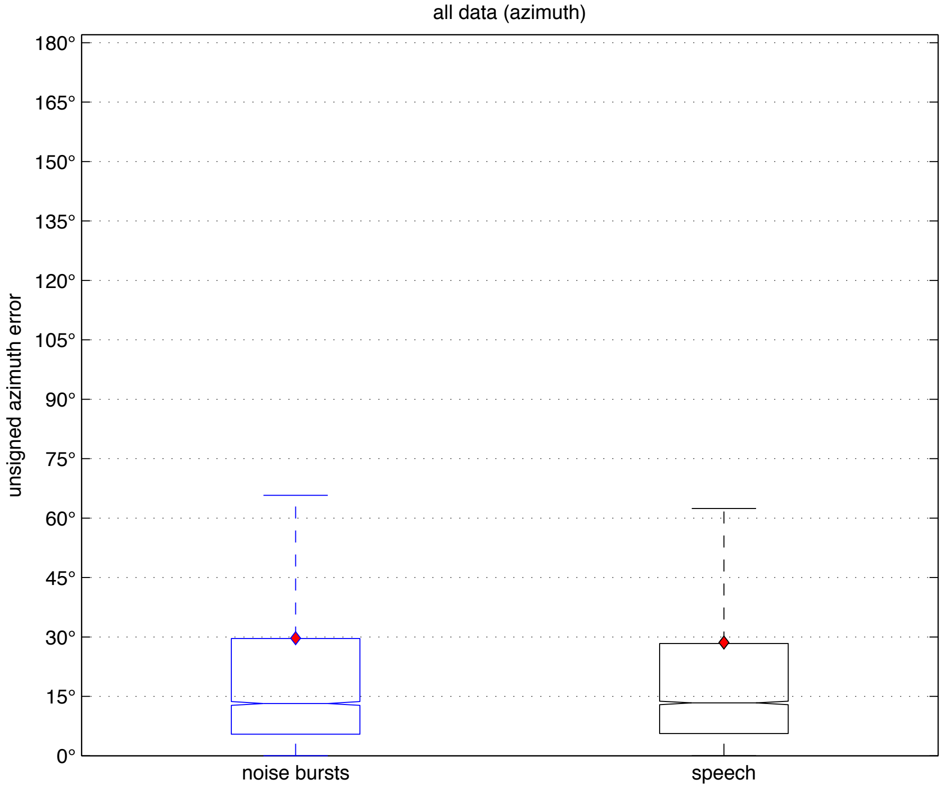
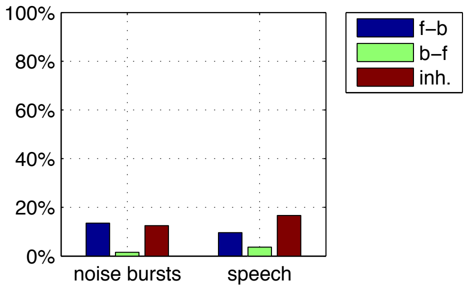


Figure A.12.: Scatterplot, azimuth answers with speech.



	noise bursts	speech
mean	29.69°	28.61°
std. dev.	42.02°	40.88°
median	13.21°	13.35°



	noise bursts			speech		
	total	f–b	b–f	total	f–b	b–f
conf.	15.1%	13.5%	1.5%	13.3%	9.6%	3.7%
inheads	12.5%			16.7%		

Figure A.13.: Boxplot, azimuth error, $p = 0.142$.

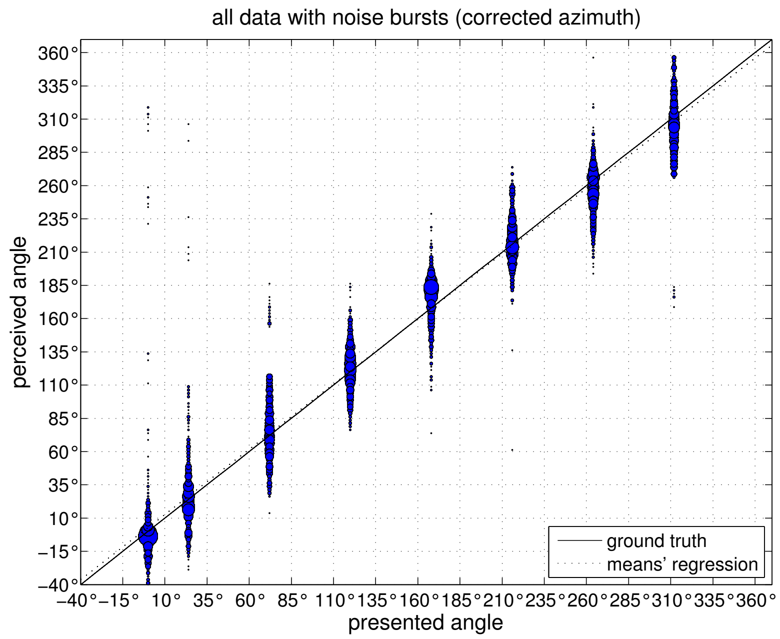


Figure A.14.: Scatterplot, reversal corrected azimuth answers with noise.

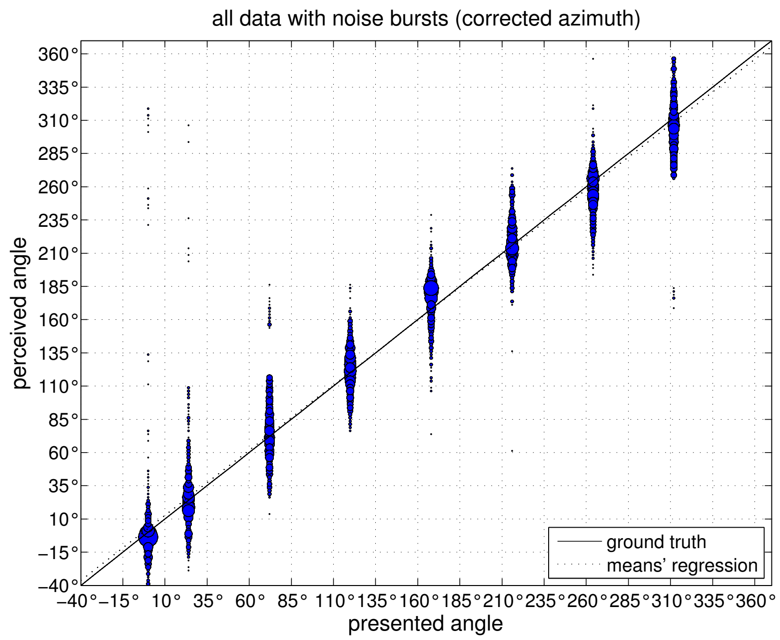
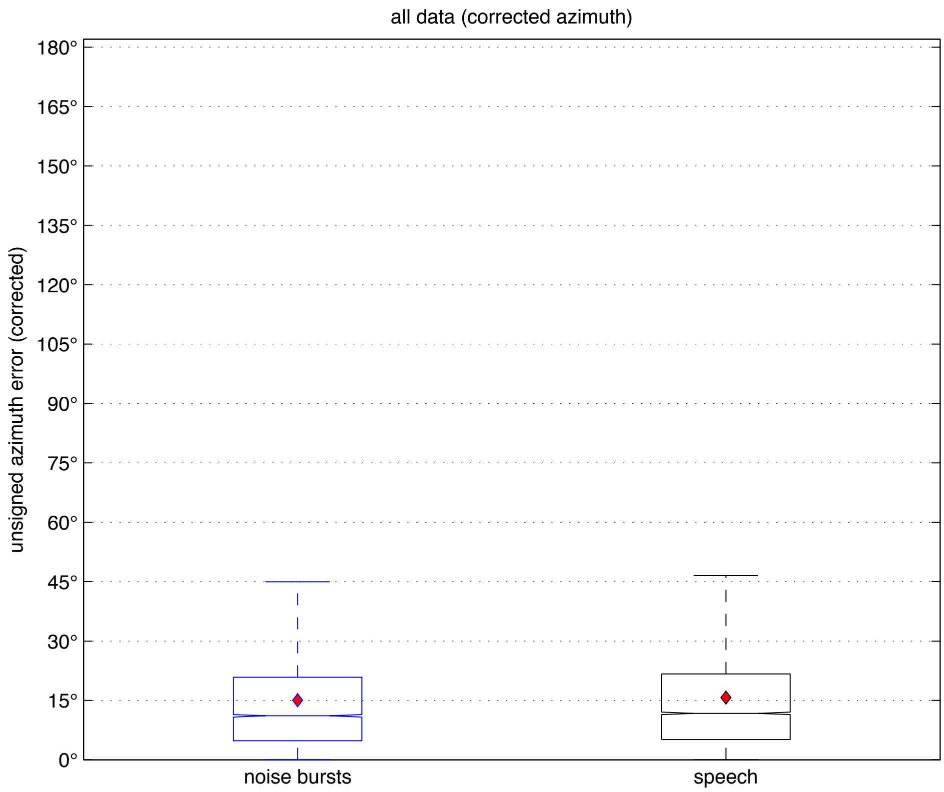
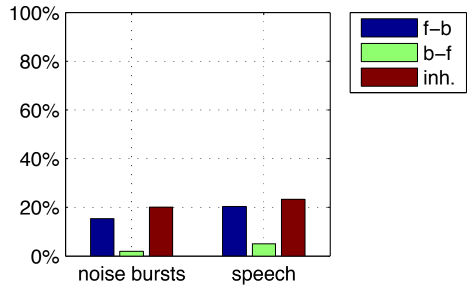


Figure A.15.: Scatterplot, reversal corrected azimuth answers with speech.



	noise bursts	speech
mean	15.06°	15.70°
std. dev.	15.17°	16.26°
median	11.13°	11.74°



	noise bursts			speech		
	total	f–b	b–f	total	f–b	b–f
conf.	17.3%	15.4%	1.9%	25.4%	20.4%	5.0%
inheads	20.1%			23.3%		

Figure A.16.: Boxplot, reversal corrected azimuth error, $p = 0.0211$.

A.4. Comparison of HRTF-Sets

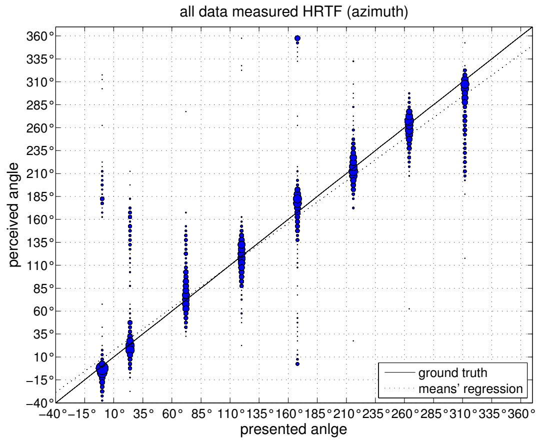


Figure A.17.: Scatterplot, azimuth answers with measured HRTF.

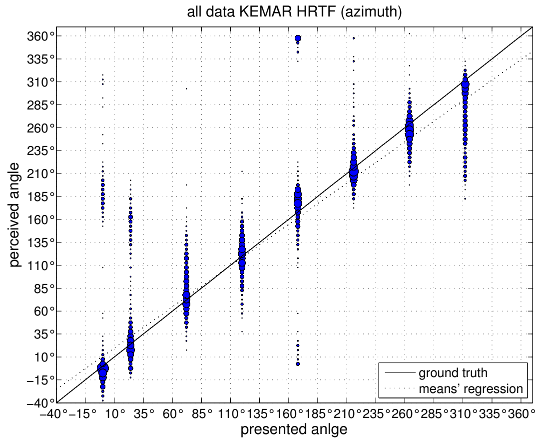


Figure A.18.: Scatterplot, azimuth answers with KEMAR HRTF.

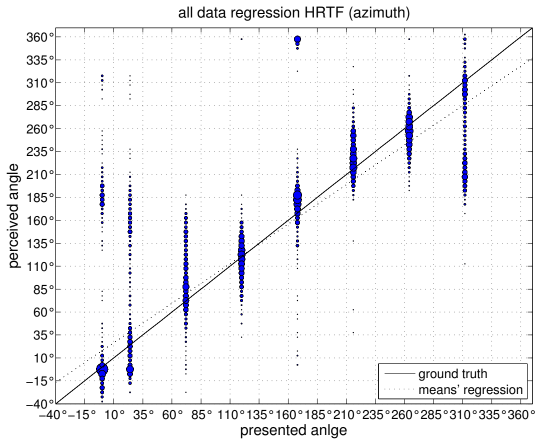


Figure A.19.: Scatterplot, azimuth answers with regression HRTF.

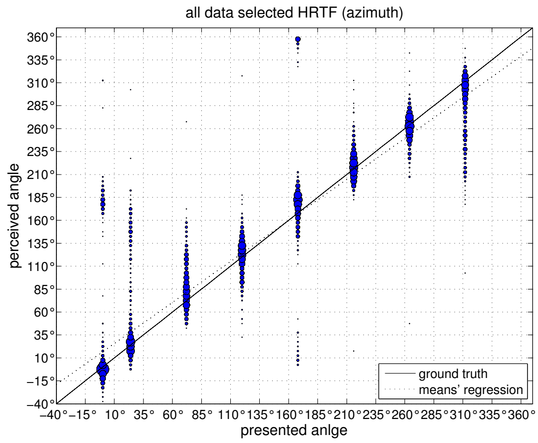
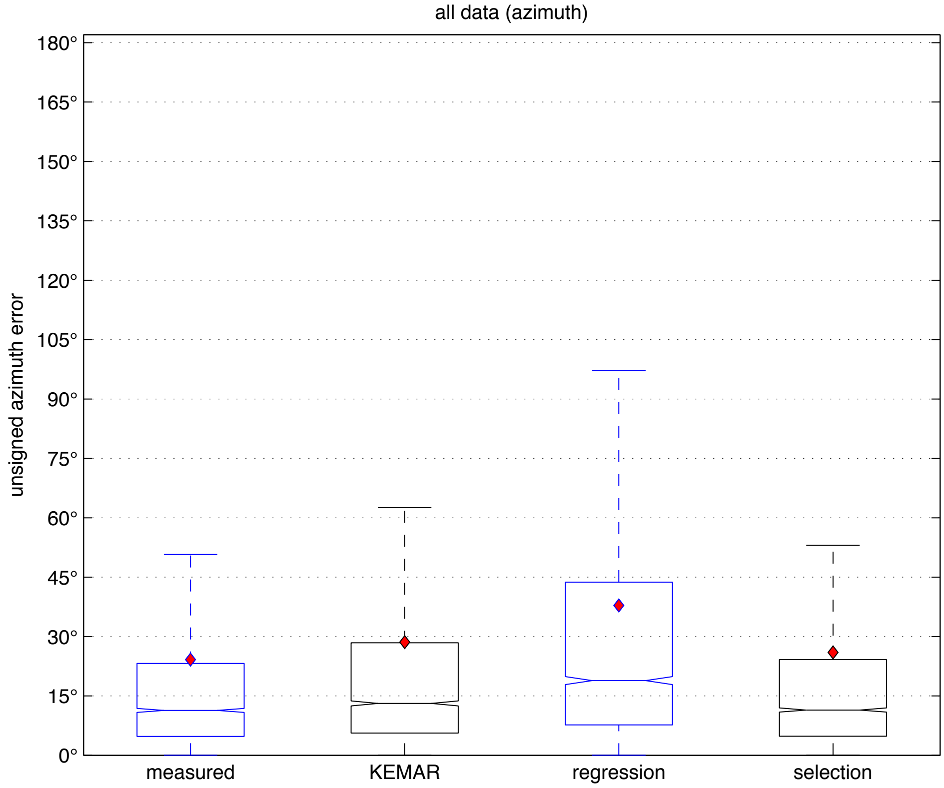
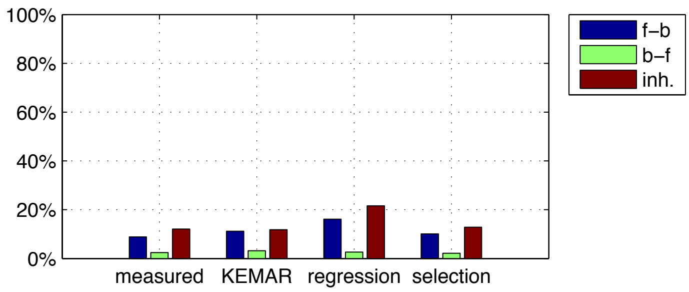


Figure A.20.: Scatterplot, azimuth answers with selected HRTF.



	measured	KEMAR	regression	selection
mean	24.19°	28.58°	37.86°	25.98°
std. dev.	36.87°	41.04°	46.29°	39.73°
median	11.35°	13.11°	18.87°	11.45°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	11.2%	8.8%	2.4%	14.4%	11.2%	3.2%	18.8%	16.1%	2.7%	12.2%	11.2%	2.2%
inheads	12.1%			11.8%			21.6%			12.8%		

Figure A.21.: Boxplot, azimuth error.

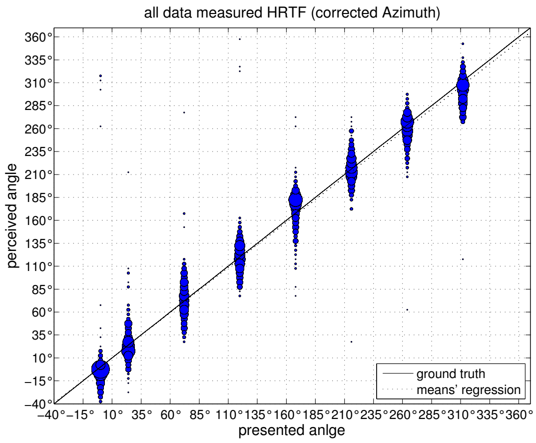


Figure A.22.: Scatterplot, reversal corrected azimuth answers with measured HRTF.

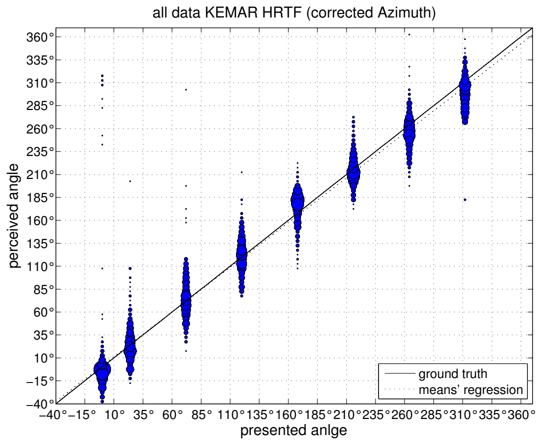


Figure A.23.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF.

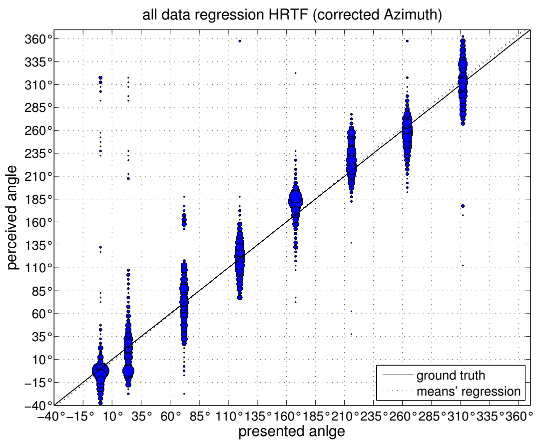


Figure A.24.: Scatterplot, reversal corrected azimuth answers with regression HRTF.

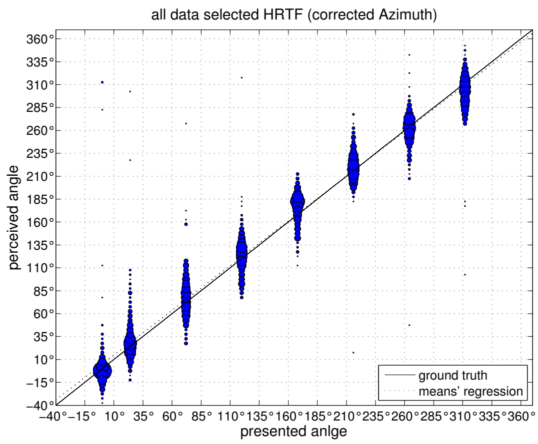
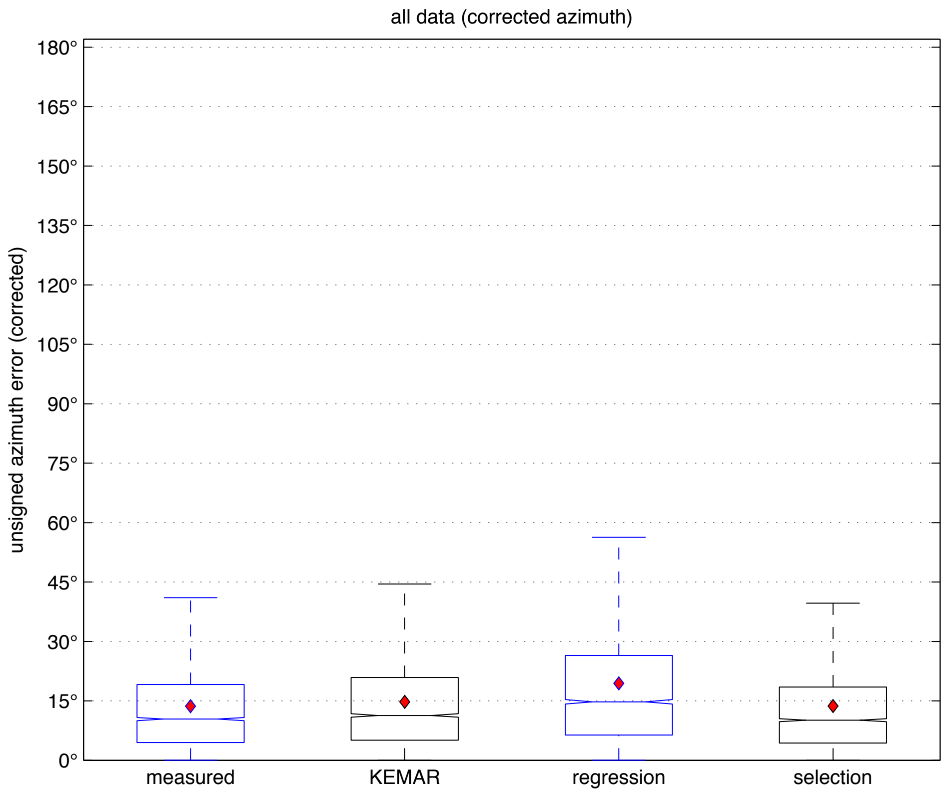
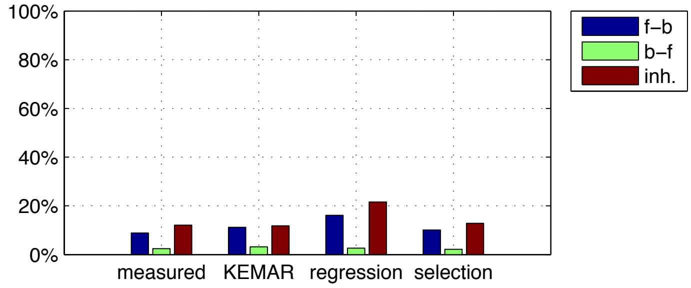


Figure A.25.: Scatterplot, reversal corrected azimuth answers with selected HRTF.



	measured	KEMAR	regression	selection
mean	13.65°	14.73°	19.43°	13.70°
std. dev.	13.78°	13.65°	19.79°	14.13°
median	10.40°	11.32°	14.76°	10.12°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	11.2%	8.8%	2.4%	14.4%	11.2%	3.2%	18.8%	16.1%	2.7%	12.2%	11.2%	2.2%
inheads	12.1%			11.8%			21.6%			12.8%		

Figure A.26.: Boxplot, reversal corrected azimuth error.

Measured HRTF	KEMAR HRTF	$[-6{,}41°, -2{,}38°]$
Measured HRTF	Regression HRTF	$[-15{,}68°, -11{,}65°]$
Measured HRTF	Selection HRTF	$[-3{,}80°, 0{,}23°]$
KEMAR HRTF	Regression HRTF	$[-11{,}29°, -7{,}26°]$
KEMAR HRTF	Selection HRTF	$[0{,}59°, 4{,}62°]$
Regression HRTF	Selection HRTF	$[9{,}87°, 13{,}90°]$

Table A.1.: Azimuth error: least significant difference for the HRTF-datasets.

Measured HRTF	KEMAR HRTF	$[-1{,}84°, -0{,}32°]$
Measured HRTF	Regression HRTF	$[-6{,}54°, -5{,}01°]$
Measured HRTF	Selection HRTF	$[-0{,}81°, 0{,}71°]$
KEMAR HRTF	Regression HRTF	$[-5{,}46°, -3{,}93°]$
KEMAR HRTF	Selection HRTF	$[0{,}27°, 1{,}79°]$
Regression HRTF	Selection HRTF	$[4{,}97°, 6{,}49°]$

Table A.2.: Corrected azimuth error: least significant difference for the HRTF-datasets.

A.5. Comparison of Stimuli with and without Head-Tracking

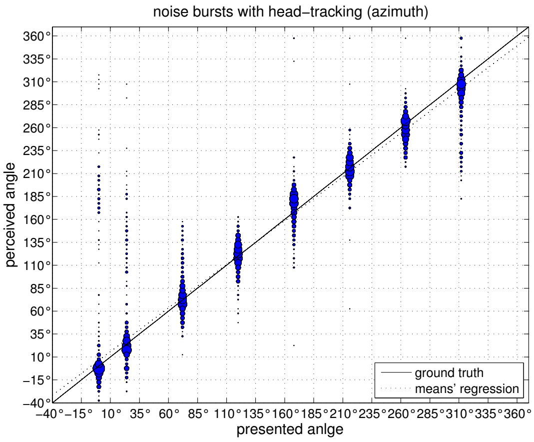


Figure A.27.: Scatterplot, azimuth answers with head-tracking, noise bursts.

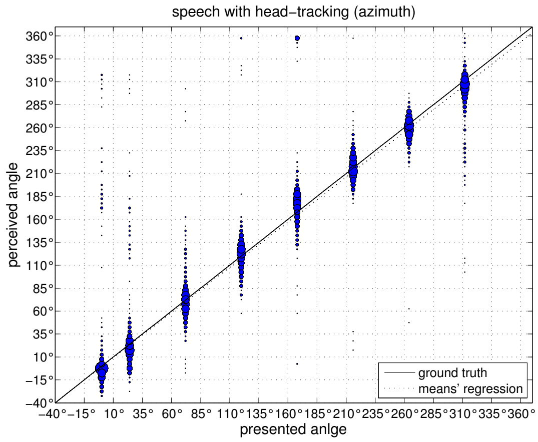


Figure A.28.: Scatterplot, azimuth answers with head-tracking, speech.

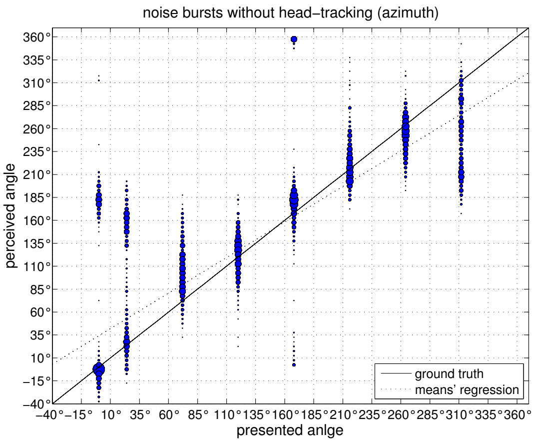


Figure A.29.: Scatterplot, azimuth answers without headtracking, noise bursts.

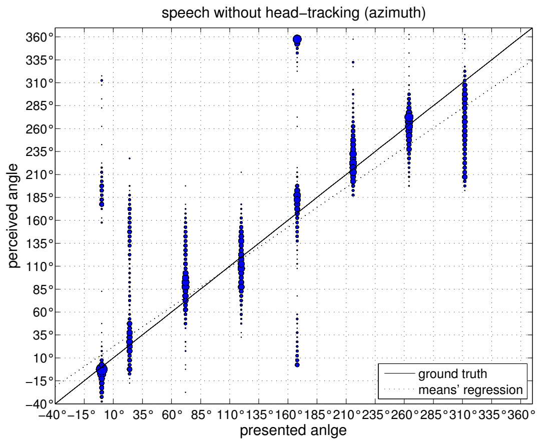
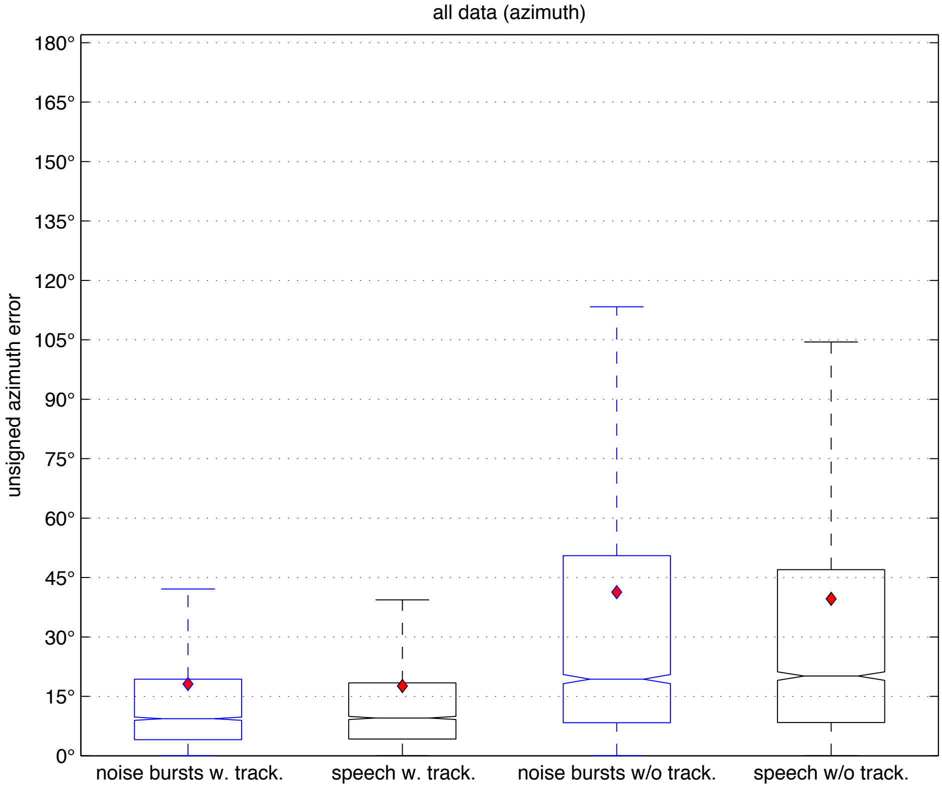
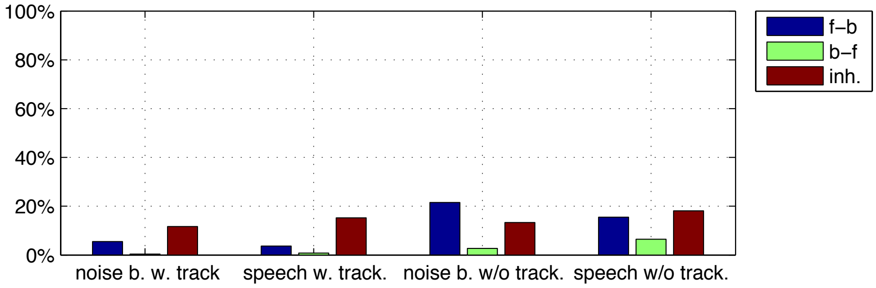


Figure A.30.: Scatterplot, azimuth answers without head-tracking, speech.



	noise b. w. Track.	speech w. Track.	noise b. w/o Track.	speech w/o Track.
mean	18.10°	17.60°	41.28°	39.62°
std. dev.	28.50°	28.58°	49.50°	47.79°
median	9.36°	9.54°	19.35°	20.12°



	noise b. w. track.			speech w. track.			noise b. w/o track.			speech w/o track.		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	5.9%	5.5%	0.4%	4.5%	3.7%	0.8%	24.2%	21.5%	2.7%	22.0%	3.7%	6.5%
inheads	11.7%			15.2%			13.3%			18.1%		

Figure A.31.: Boxplot, azimuth error.

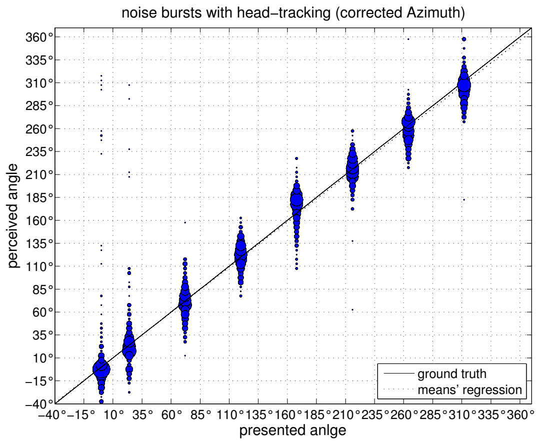


Figure A.32.: Scatterplot, reversal corrected azimuth answers with head-tracking, noise bursts.

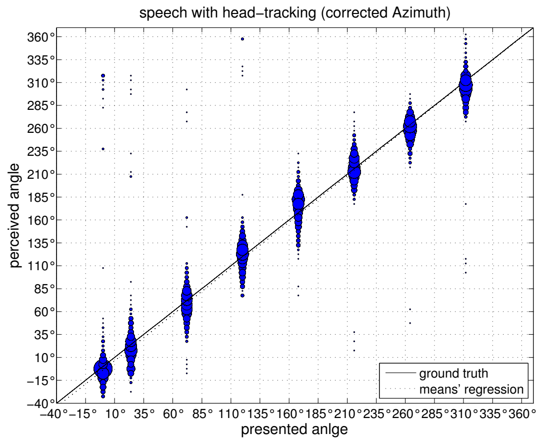


Figure A.33.: Scatterplot, reversal corrected azimuth answers with head-tracking, speech.

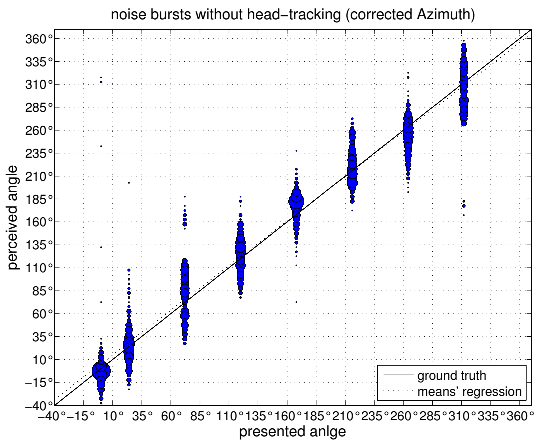


Figure A.34.: Scatterplot, reversal corrected azimuth answers without head-tracking, noise bursts.

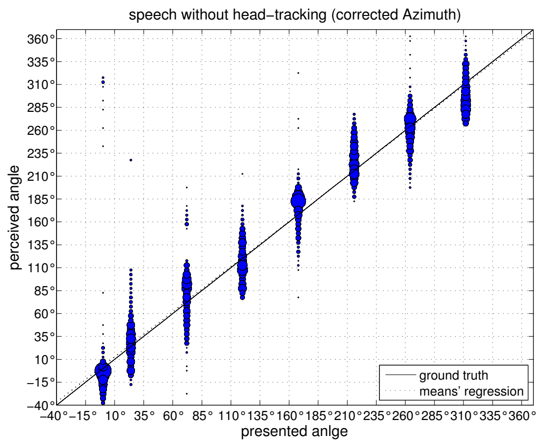
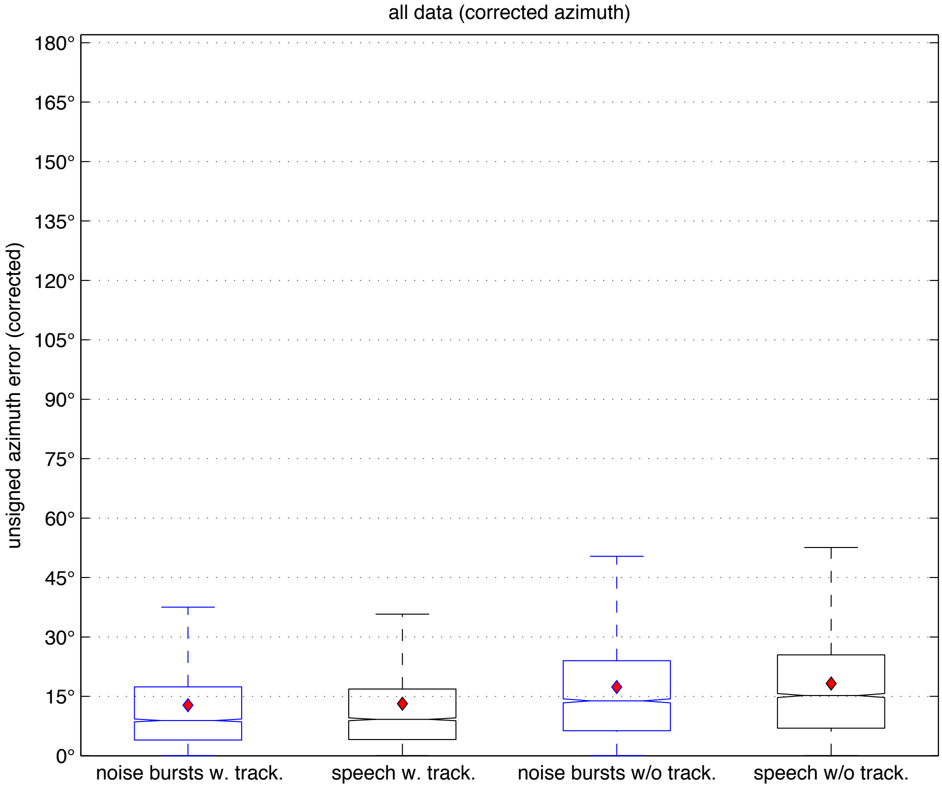
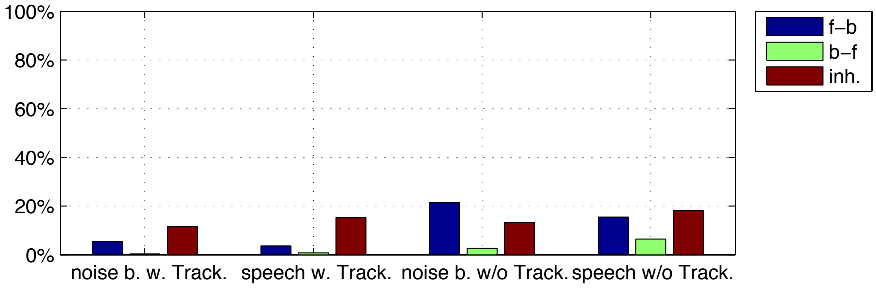


Figure A.35.: Scatterplot, reversal corrected azimuth answers without head-tracking, speech.



	noise b. w. track.	speech w. track.	noise b. w/o track.	speech w/o track.
mean	12.77°	13.17°	17.34°	18.23°
std. dev.	14.09°	16.52°	15.85°	15.61°
median	8.92°	9.21°	13.87°	15.21°



	noise b. w. tracking			speech w. track			noise b. w/o track.			speech w/o track.		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	5.9%	5.5%	0.4%	4.5%	3.7%	0.8%	24.2%	21.5%	2.7%	22.0%	3.7%	6.5%
inheads	11.7%			15.2%			13.3%			18.1%		

Figure A.36.: Boxplot, reversal corrected azimuth error.

Noise Bursts w. Tracking	Speech w. Tracking	$[-1{,}46°, 2{,}45°]$
Noise Bursts w. Tracking	Noise w/o Tracking	$[-25{,}14°, -21{,}23°]$
Noise Bursts w. Tracking	Speech w/o Tracking	$[-23{,}48°, -19{,}57°]$
Speech w. Tracking	Noise w/o Tracking	$[-25{,}64°, -21{,}73°]$
Speech w. Tracking	Speech w/o Tracking	$[-23{,}97°, -20{,}07°]$
Noise w/o Tracking	Speech w/o Tracking	$[-0{,}29°, 3{,}62°]$

Table A.3.: Azimuth error: least significant difference for the stimuli with and without head-tracking.

Noise Bursts w. Tracking	Speech w. Tracking	$[-1{,}15°, 0{,}37°]$
Noise Bursts w. Tracking	Noise w/o Tracking	$[-5{,}33°, -3{,}80°]$
Noise Bursts w. Tracking	Speech w/o Tracking	$[-6{,}22°, -4{,}69°]$
Speech w. Tracking	Noise w/o Tracking	$[-4{,}93°, -3{,}41°]$
Speech w. Tracking	Speech w/o Tracking	$[-5{,}82°, -4{,}30°]$
Noise w/o Tracking	Speech w/o Tracking	$[-1{,}65°, -0{,}13°]$

Table A.4.: Corrected azimuth error: least significant difference for the stimuli with and without head-tracking.

A.6. Comparison of HRTF-Sets with and without head-tracking

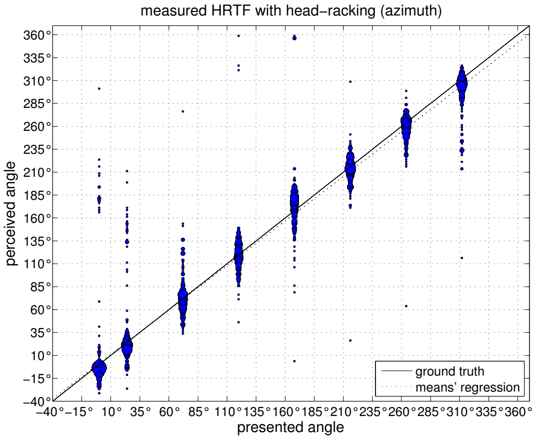


Figure A.37.: Scatterplot, azimuth answers with measured HRTF with head-tracking.

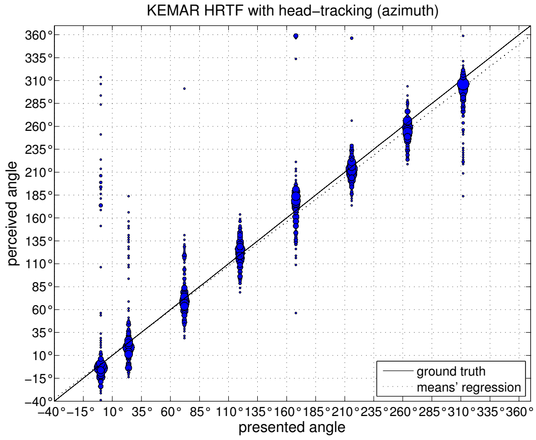


Figure A.38.: Scatterplot, azimuth answers with KEMAR HRTF with head-tracking.

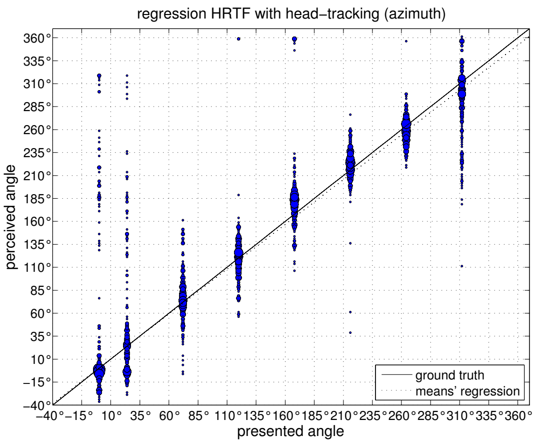


Figure A.39.: Scatterplot, azimuth answers with regression HRTF with head-tracking.

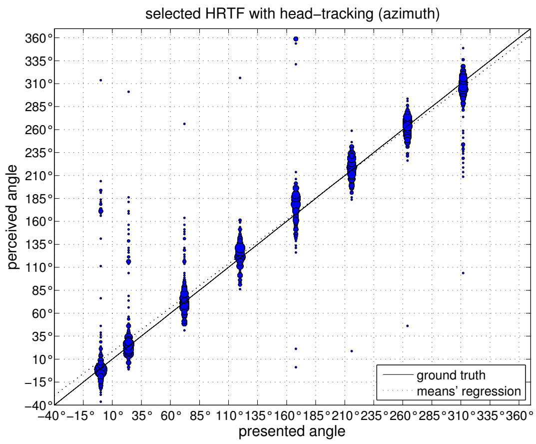
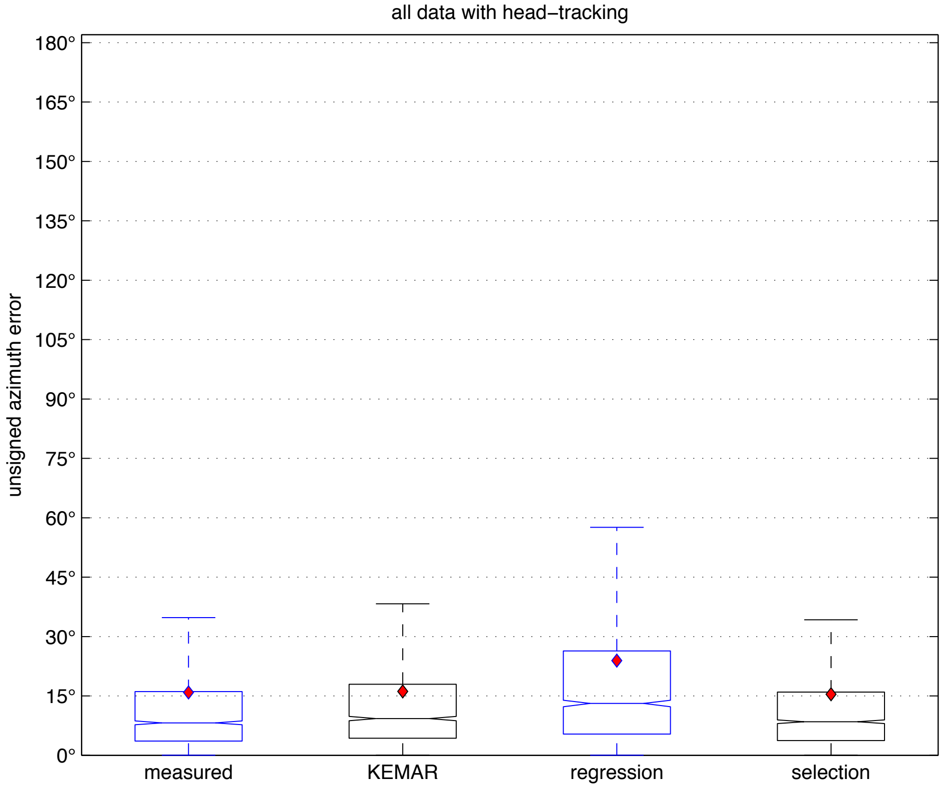
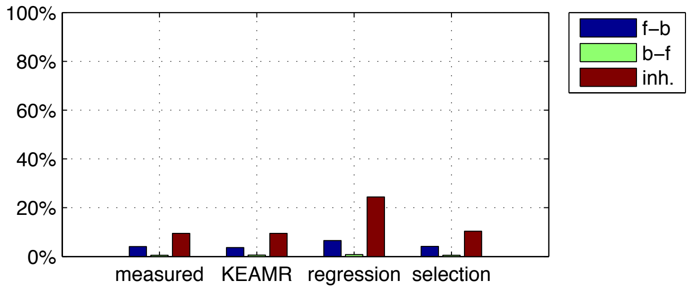


Figure A.40.: Scatterplot, azimuth answers with selected HRTF with head-tracking.



	measured	KEMAR	regression	selection
mean	15.89°	16.14°	23.93°	15.44°
std. dev.	27.20°	24.91°	33.48°	27.00°
median	8.20°	9.28°	13.09°	8.48°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	4.6%	4.1%	0.5%	4.2%	3.7%	0.6%	7.4%	6.6%	0.8%	4.6%	3.7%	0.5%
inheads	9.5%			9.5%			24.4%			10.4%		

Figure A.41.: Boxplot, azimuth error with head-tracking.

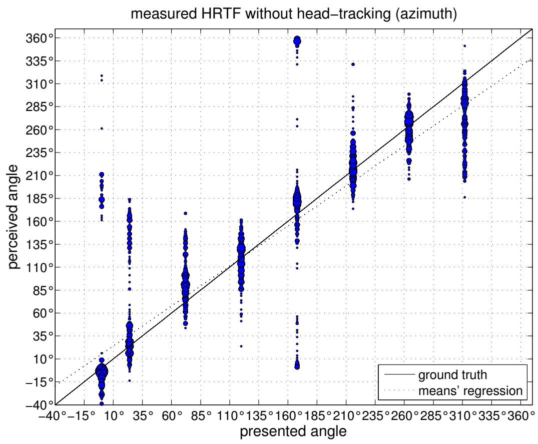


Figure A.42.: Scatterplot, azimuth answers with measured HRTF without head-tracking.

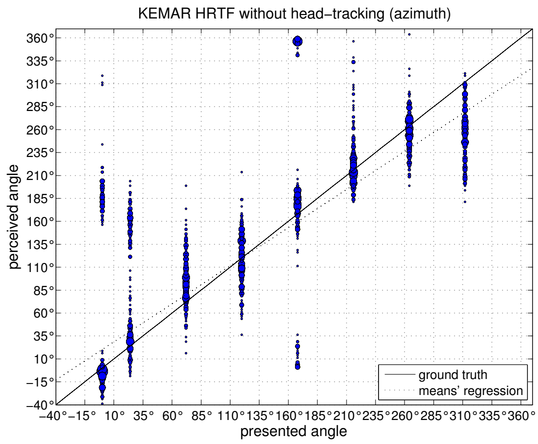


Figure A.43.: Scatterplot, azimuth answers with KEMAR HRTF without head-tracking.

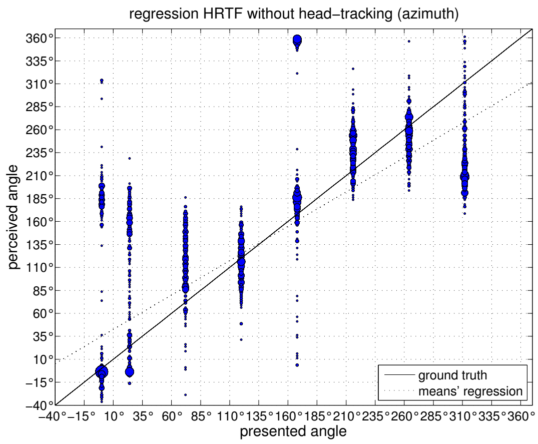


Figure A.44.: Scatterplot, azimuth answers with regression HRTF without head-tracking.

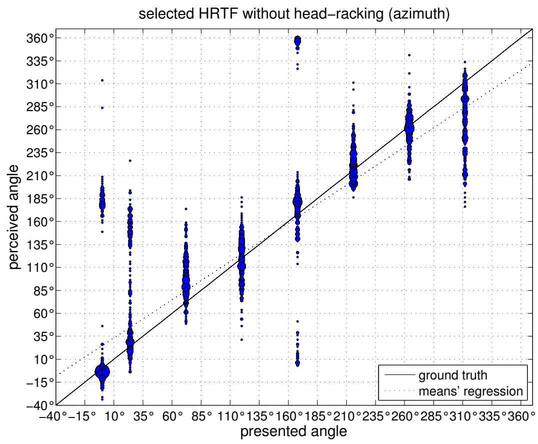
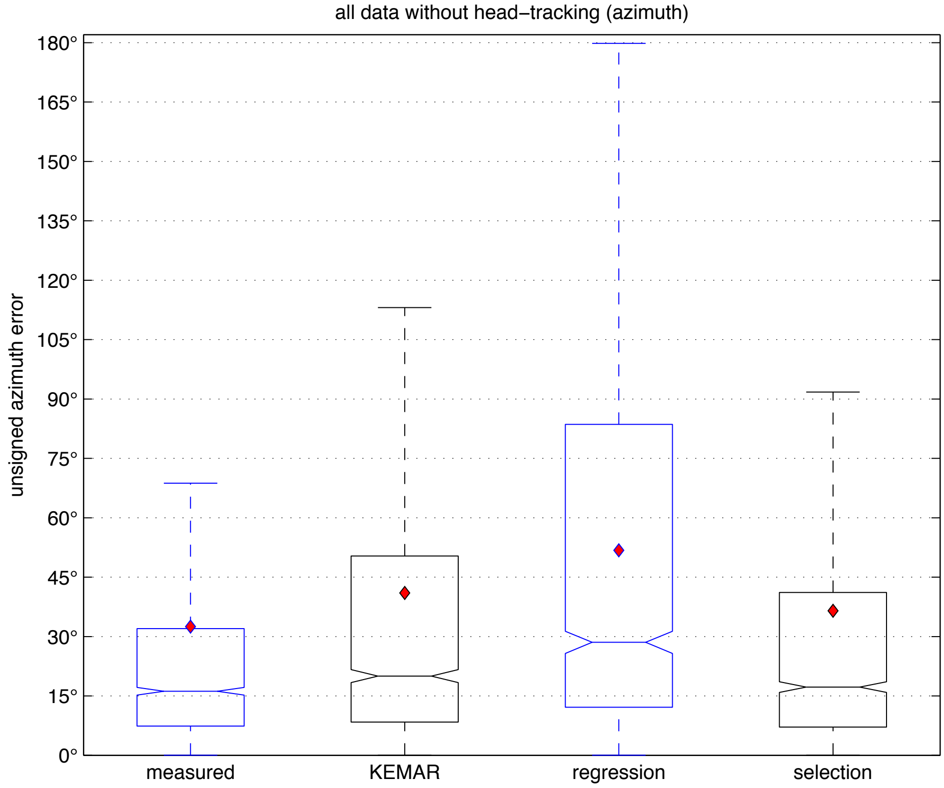
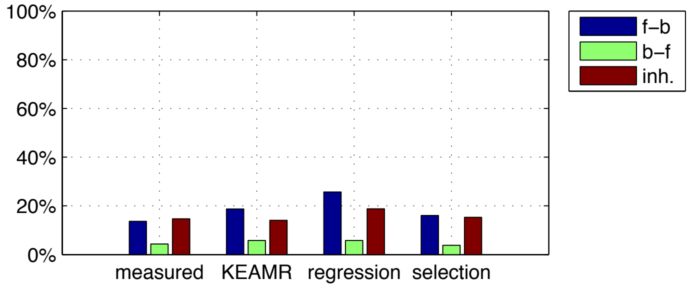


Figure A.45.: Scatterplot, azimuth answers with selected HRTF without head-tracking.



	measured	KEMAR	regression	selection
mean	32.49°	41.02°	51.78°	36.52°
std. dev.	42.93°	49.39°	52.70°	46.97°
median	16.18°	20.00°	28.54°	17.24°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	17.9%	13.6%	4.3%	24.5%	18.8%	5.8%	30.2%	25.7%	4.5%	19.9%	18.8%	3.8%
inheads	14.7%			14.1%			18.8%			15.3%		

Figure A.46.: Boxplot, azimuth error without head-tracking.

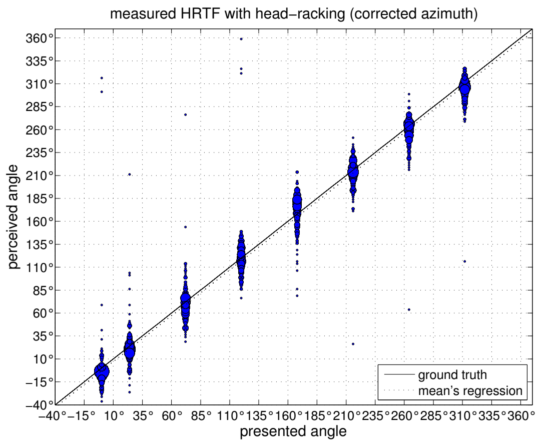


Figure A.47.: Scatterplot, reversal corrected azimuth answers with measured HRTF with head-tracking.

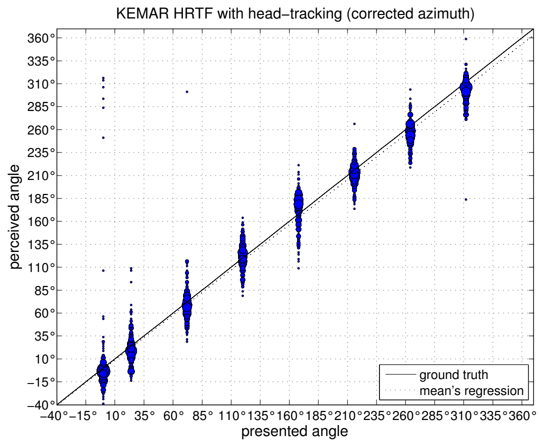


Figure A.48.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF with head-tracking.

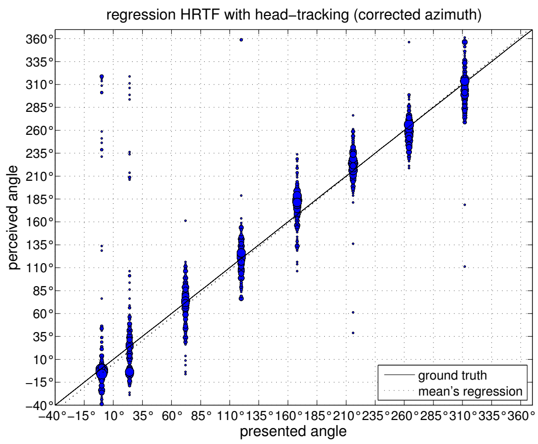


Figure A.49.: Scatterplot, reversal corrected azimuth answers with regression HRTF with head-tracking.

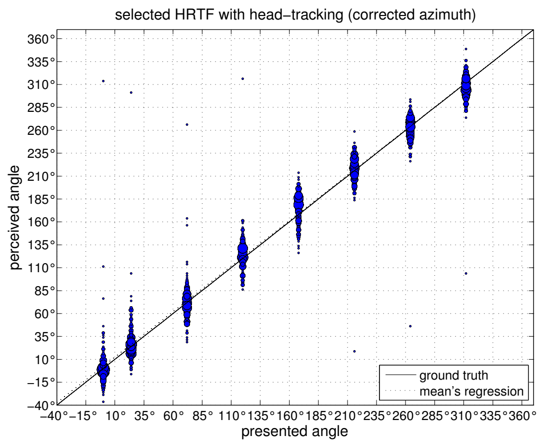
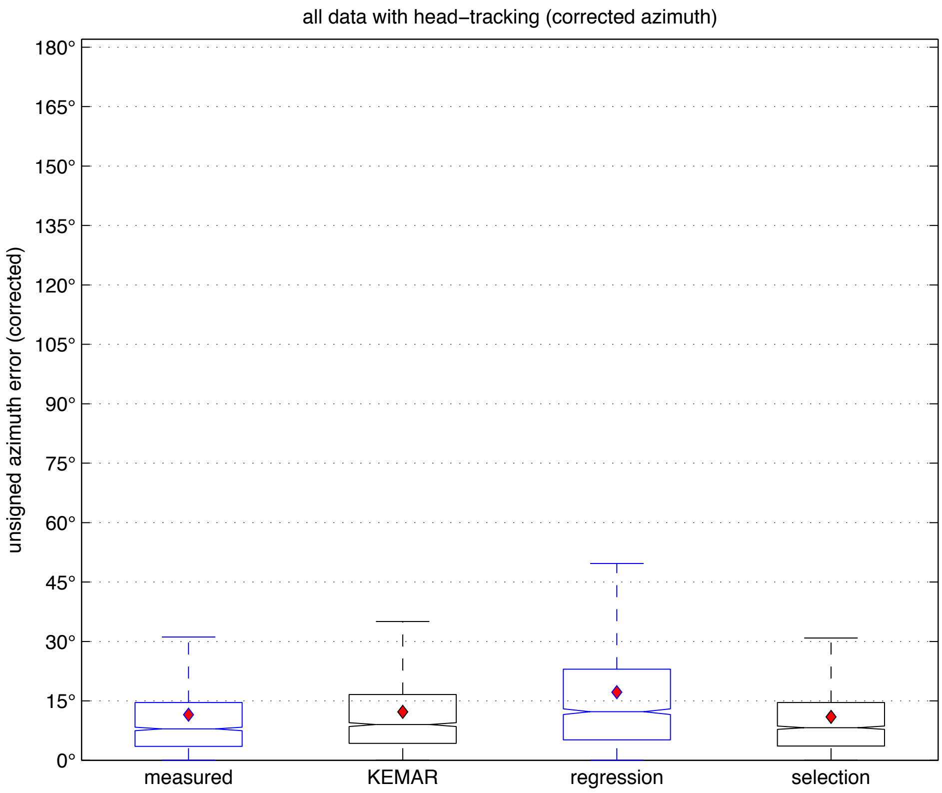
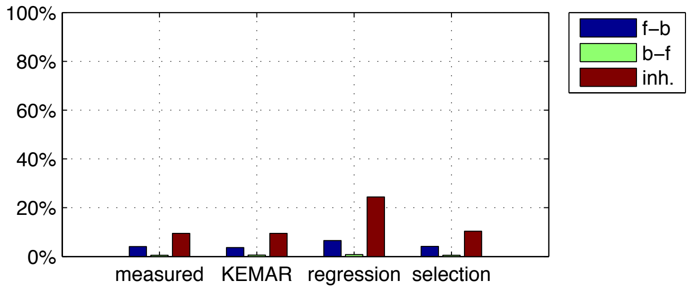


Figure A.50.: Scatterplot, reversal corrected azimuth answers with selected HRTF with head-tracking.



	measured	KEMAR	regression	selection
mean	11.49°	12.21°	17.20°	10.98°
std. dev.	14.66°	11.96°	19.85°	12.90°
median	7.92°	9.02°	12.27°	8.23°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	4.6%	4.1%	0.5%	4.2%	3.7%	0.6%	7.4%	6.6%	0.8%	4.6%	3.7%	0.5%
inheads	9.5%			9.5%			24.4%			10.4%		

Figure A.51.: Boxplot, reversal corrected azimuth error with head-tracking.

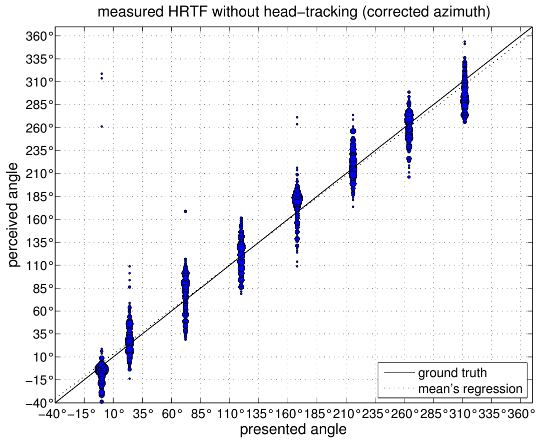


Figure A.52.: Scatterplot, reversal corrected azimuth answers with measured HRTF without head-tracking.

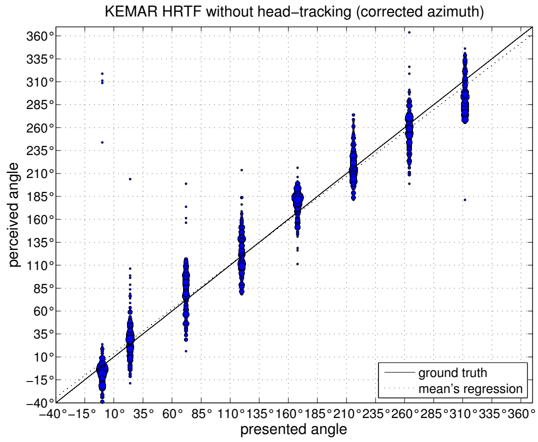


Figure A.53.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF without head-tracking.

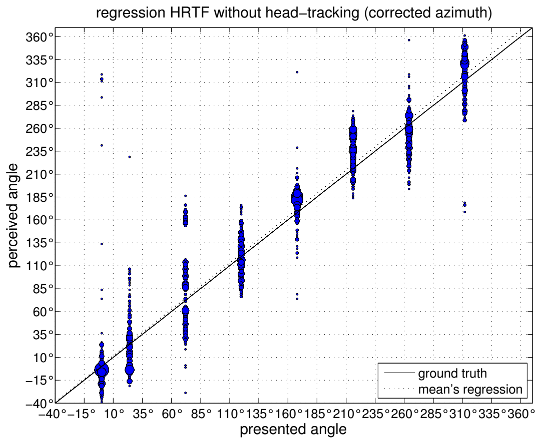


Figure A.54.: Scatterplot, reversal corrected azimuth answers with regression HRTF without head-tracking.

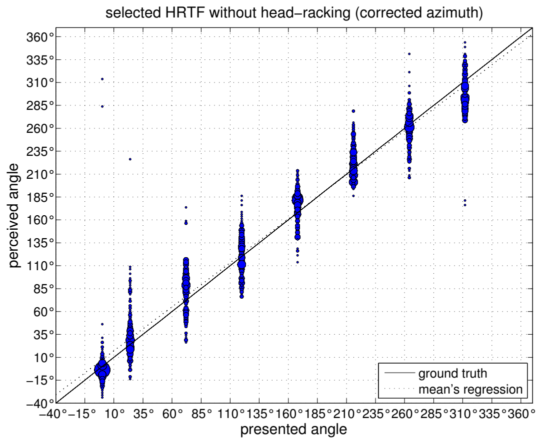
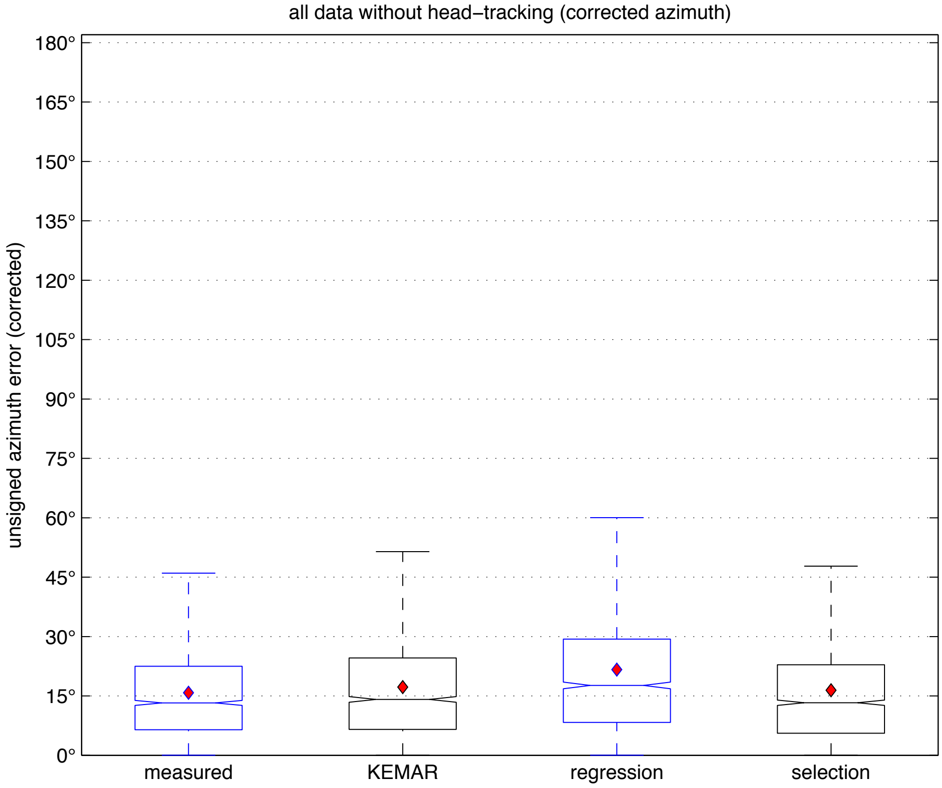
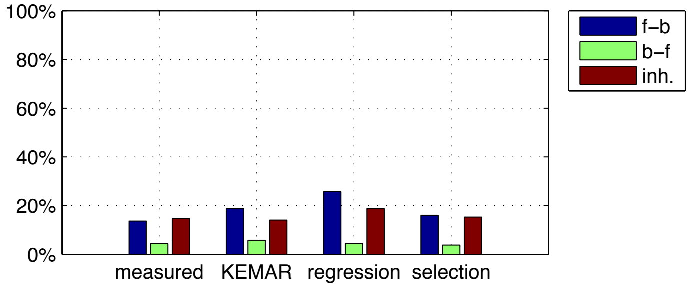


Figure A.55.: Scatterplot, reversal corrected azimuth answers with selected HRTF without head-tracking.



	measured	KEMAR	regression	selection
mean	15.81°	17.25°	21.66°	16.42°
std. dev.	12.48°	14.73°	19.48°	14.77°
median	13.25°	14.11°	17.65°	13.28°



	measured			KEMAR			regresion			selection		
	total	f−b	b−f	total	f−b	b−f	total	f−b	b−f	total	f−b	b−f
conf.	17.9%	13.6%	4.3%	24.5%	18.8%	5.8%	30.2%	25.7%	4.5%	19.9%	18.8%	3.8%
inheads	14.7%			14.1%			18.8%			15.3%		

Figure A.56.: Boxplot reversal corrected azimuth error without head-tracking.

Measured HRTF w. Tracking	KEMAR HRTF w. Tracking	$[-2{,}99°, 2{,}48°]$
Measured HRTF w. Tracking	Regression HRTF w. Tracking	$[-10{,}78°, -5{,}31°]$
Measured HRTF w. Tracking	Selection HRTF w. Tracking	$[-2{,}29°, 3{,}19°]$
Measured HRTF w. Tracking	Measured HRTF w/o Tracking	$[-19{,}35°, -13{,}87°]$
Measured HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-27{,}87°, -22{,}40°]$
Measured HRTF w. Tracking	Regression HRTF w/o Tracking	$[-38{,}63°, -33{,}16°]$
Measured HRTF w. Tracking	Selection HRTF w/o Tracking	$[-23{,}37°, -17{,}89°]$
KEMAR HRTF w. Tracking	Regression HRTF w. Tracking	$[-10{,}53°, -5{,}05°]$
KEMAR HRTF w. Tracking	Selection HRTF w. Tracking	$[-2{,}03°, 3{,}44°]$
KEMAR HRTF w. Tracking	Measured HRTF w/o Tracking	$[-19{,}09°, -13{,}62°]$
KEMAR HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-27{,}62°, -22{,}14°]$
KEMAR HRTF w. Tracking	Regression HRTF w/o Tracking	$[-38{,}38°, -32{,}90°]$
KEMAR HRTF w. Tracking	Selection HRTF w/o Tracking	$[-23{,}11°, -17{,}64°]$
Regression HRTF w. Tracking	Selection HRTF w. Tracking	$[5{,}76°, 11{,}23°]$
Regression HRTF w. Tracking	Measured HRTF w/o Tracking	$[-11{,}30°, -5{,}82°]$
Regression HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-19{,}83°, -14{,}35°]$
Regression HRTF w. Tracking	Regression HRTF w/o Tracking	$[-30{,}58°, -25{,}11°]$
Regression HRTF w. Tracking	Selection HRTF w/o Tracking	$[-15{,}32°, -9{,}85°]$
Selection HRTF w. Tracking	Measured HRTF w/o Tracking	$[-19{,}80°, -14{,}32°]$
Selection HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-28{,}32°, -22{,}85°]$
Selection HRTF w. Tracking	Regression HRTF w/o Tracking	$[-39{,}08°, -33{,}61°]$
Selection HRTF w. Tracking	Selection HRTF w/o Tracking	$[-23{,}82°, -18{,}34°]$
Measured HRTF w/o Tracking	KEMAR HRTF w/o Tracking	$[-11{,}26°, -5{,}79°]$
Measured HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-22{,}02°, -16{,}55°]$
Measured HRTF w/o Tracking	Selection HRTF w/o Tracking	$[-6{,}76°, -1{,}28°]$
KEMAR HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-13{,}50°, -8{,}02°]$
KEMAR HRTF w/o Tracking	Selection HRTF w/o Tracking	$[1{,}77°, 7{,}24°]$
Regression HRTF w/o Tracking	Selection HRTF w/o Tracking	$[12{,}53°, 18{,}00°]$

Table A.5.: Azimuth error: least significant difference for the HRTF-datasets with and without head-tracking.

Measured HRTF w. Tracking	KEMAR HRTF w. Tracking	$[-1{,}79°, 0{,}34°]$
Measured HRTF w. Tracking	Regression HRTF w. Tracking	$[-6{,}77°, -4{,}64°]$
Measured HRTF w. Tracking	Selection HRTF w. Tracking	$[-0{,}55°, 1{,}58°]$
Measured HRTF w. Tracking	Measured HRTF w/o Tracking	$[-5{,}38°, -3{,}25°]$
Measured HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-6{,}82°, -4{,}69°]$
Measured HRTF w. Tracking	Regression HRTF w/o Tracking	$[-11{,}23°, -9{,}10°]$
Measured HRTF w. Tracking	Selection HRTF w/o Tracking	$[-5{,}99°, -3{,}86°]$
KEMAR HRTF w. Tracking	Regression HRTF w. Tracking	$[-6{,}05°, -3{,}92°]$
KEMAR HRTF w. Tracking	Selection HRTF w. Tracking	$[0{,}17°, 2{,}30°]$
KEMAR HRTF w. Tracking	Measured HRTF w/o Tracking	$[-4{,}66°, -2{,}53°]$
KEMAR HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-6{,}10°, -3{,}97°]$
KEMAR HRTF w. Tracking	Regression HRTF w/o Tracking	$[-10{,}51°, -8{,}38°]$
KEMAR HRTF w. Tracking	Selection HRTF w/o Tracking	$[-5{,}27°, -3{,}14°]$
Regression HRTF w. Tracking	Selection HRTF w. Tracking	$[5{,}15°, 7{,}28°]$
Regression HRTF w. Tracking	Measured HRTF w/o Tracking	$[0{,}32°, 2{,}45°]$
Regression HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-1{,}12°, 1{,}01°]$
Regression HRTF w. Tracking	Regression HRTF w/o Tracking	$[-5{,}53°, -3{,}40°]$
Regression HRTF w. Tracking	Selection HRTF w/o Tracking	$[-0{,}29°, 1{,}84°]$
Selection HRTF w. Tracking	Measured HRTF w/o Tracking	$[-5{,}90°, -3{,}77°]$
Selection HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-7{,}33°, -5{,}20°]$
Selection HRTF w. Tracking	Regression HRTF w/o Tracking	$[-11{,}74°, -9{,}62°]$
Selection HRTF w. Tracking	Selection HRTF w/o Tracking	$[-6{,}50°, -4{,}37°]$
Measured HRTF w/o Tracking	KEMAR HRTF w/o Tracking	$[-2{,}50°, -0{,}37°]$
Measured HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-6{,}91°, -4{,}78°]$
Measured HRTF w/o Tracking	Selection HRTF w/o Tracking	$[-1{,}67°, 0{,}46°]$
KEMAR HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-5{,}48°, -3{,}35°]$
KEMAR HRTF w/o Tracking	Selection HRTF w/o Tracking	$[-0{,}23°, 1{,}90°]$
Regression HRTF w/o Tracking	Selection HRTF w/o Tracking	$[4{,}18°, 6{,}31°]$

Table A.6.: Corrected azimuth error: least significant difference for the HRTF-datasets with and without head-tracking.

A.7. Comparison of HRTF-Sets for the Two Stimuli

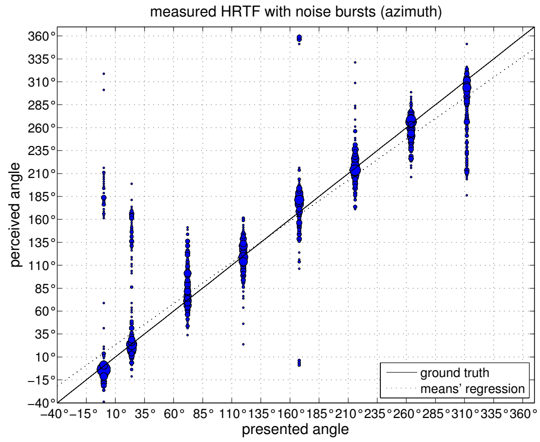


Figure A.57.: Scatterplot, azimuth answers with measured HRTF with noise bursts.

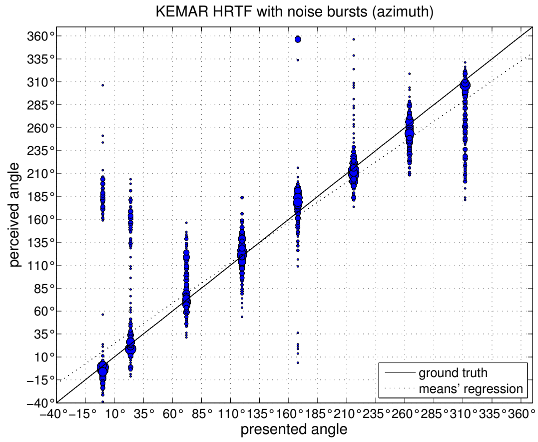


Figure A.58.: Scatterplot, azimuth answers with KEMAR HRTF with noise bursts.

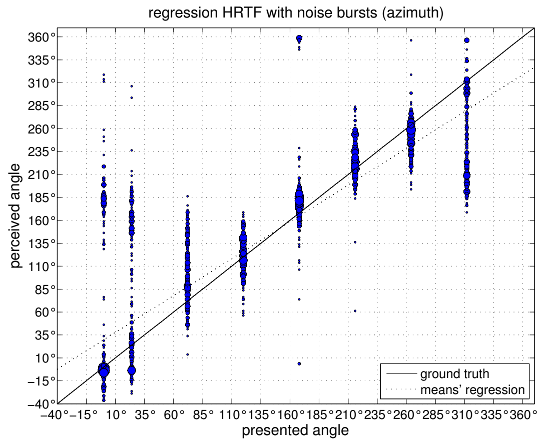


Figure A.59.: Scatterplot, azimuth answers with regression HRTF with noise bursts.

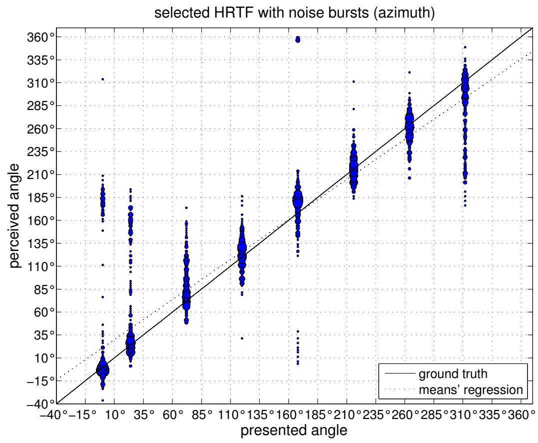
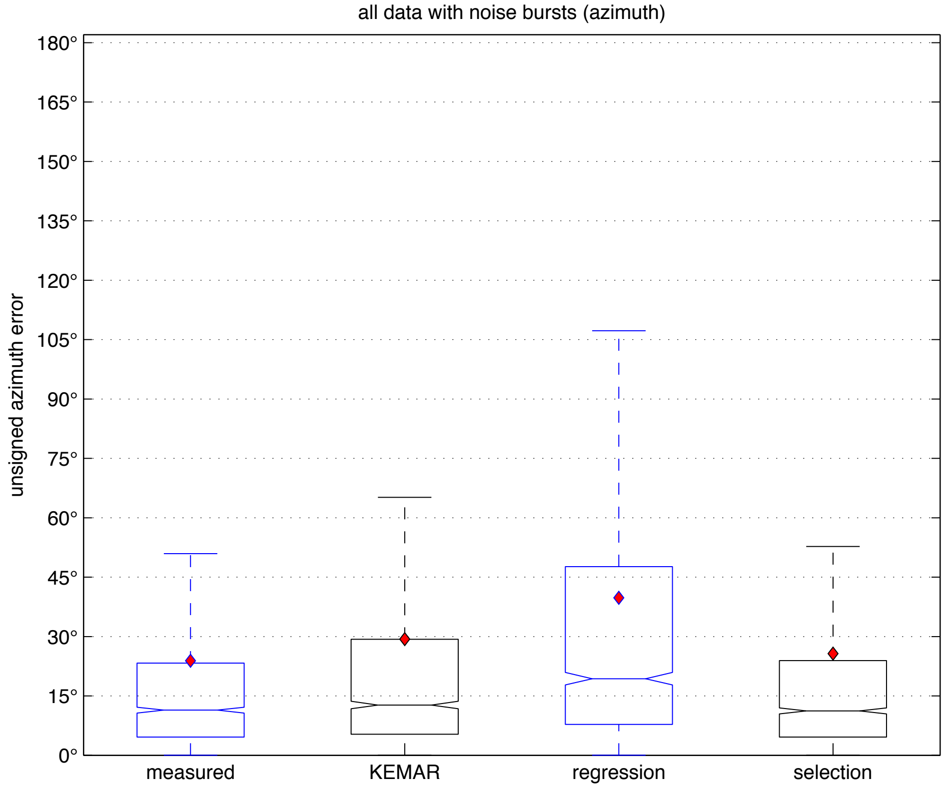
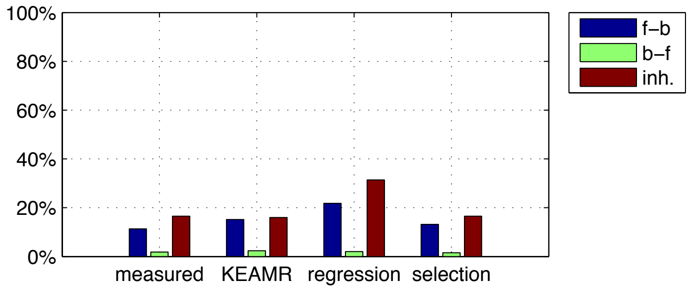


Figure A.60.: Scatterplot, azimuth answers with selected HRTF with noise bursts.



	measured	KEMAR	regression	selection
mean	23.89°	29.36°	39.81°	25.70°
std. dev.	35.97°	42.43°	47.79°	39.18°
median	11.41°	12.70°	19.35°	11.21°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	13.1%	11.3%	1.8%	17.6%	15.2%	2.4%	23.8%	21.8%	2.0%	14.8%	15.2%	1.6%
inheads	16.6%			16.0%			31.4%			16.5%		

Figure A.61.: Boxplot, azimuth error with noise bursts.

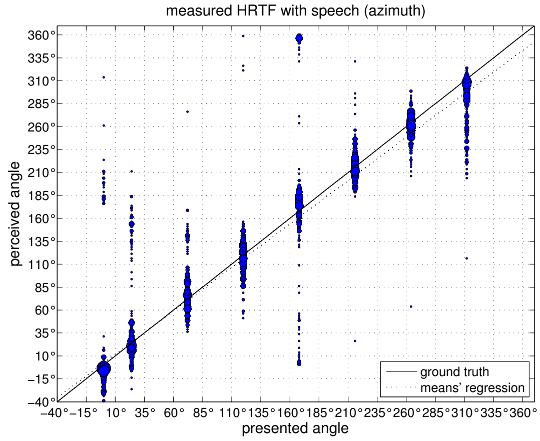


Figure A.62.: Scatterplot, azimuth answers with measured HRTF with speech.

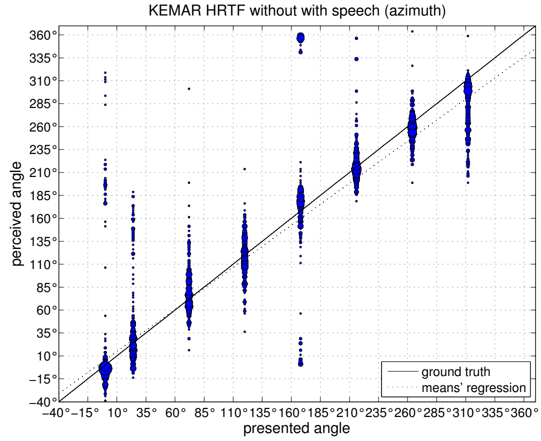


Figure A.63.: Scatterplot, azimuth answers with KEMAR HRTF with speech.

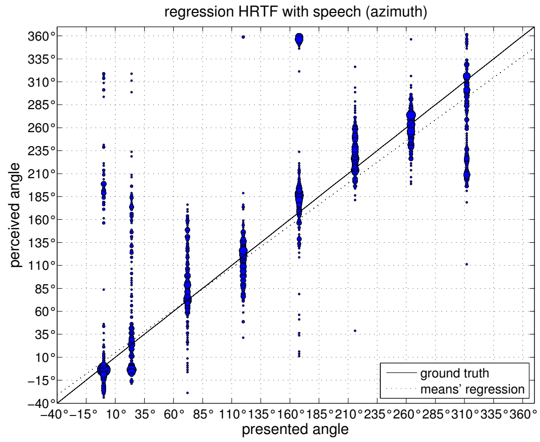


Figure A.64.: Scatterplot, azimuth answers with regression HRTF with speech.

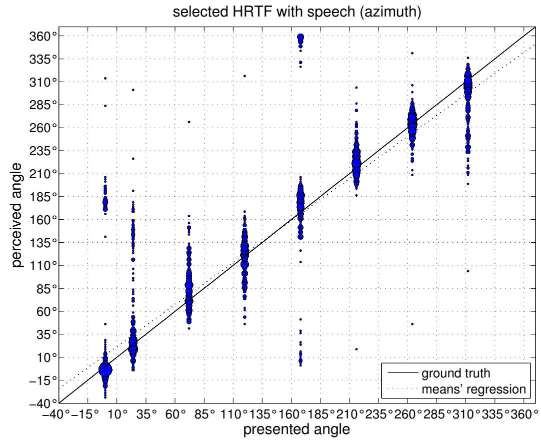
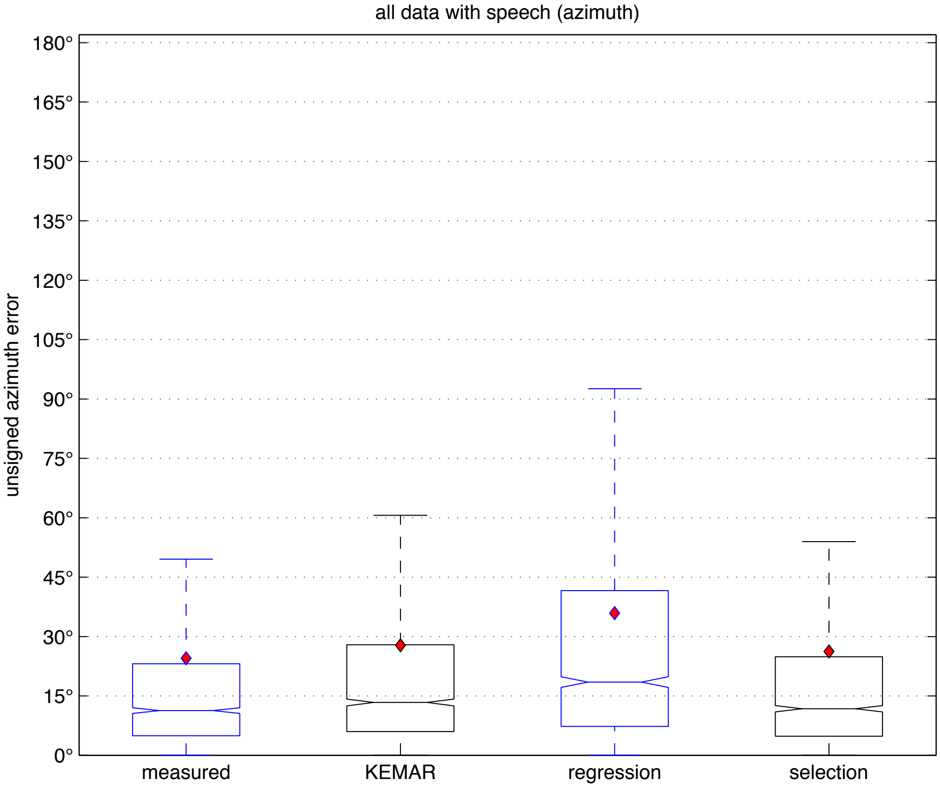
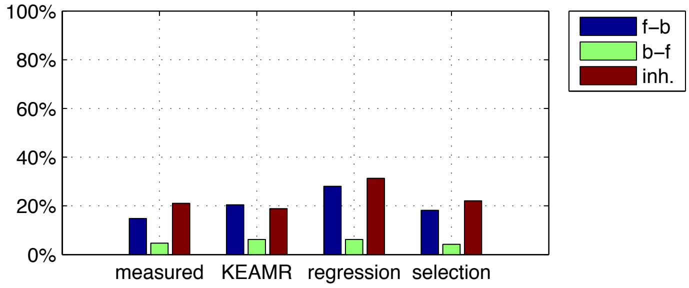


Figure A.65.: Scatterplot, azimuth answers with selected HRTF with speech.



	measured	KEMAR	regression	selection
mean	24.49°	27.80°	35.91°	26.25°
std. dev.	37.76°	39.60°	44.66°	40.28°
median	11.28°	13.35°	18.51°	11.77°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	19.5%	14.8%	4.7%	26.6%	20.4%	6.2%	33.0%	28.1%	4.9%	22.4%	20.4%	4.2%
inheads	21.1%			18.9%			31.3%			22.1%		

Figure A.66.: Boxplot, azimuth error with speech.

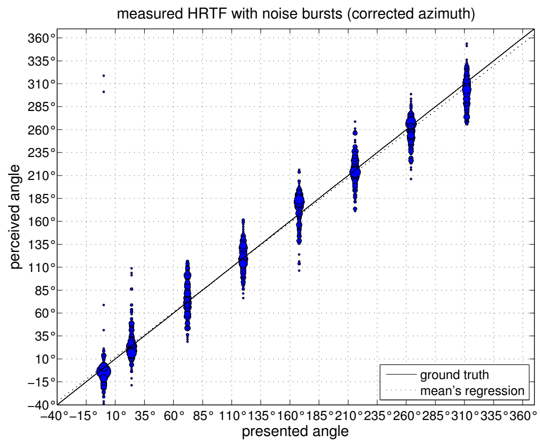


Figure A.67.: Scatterplot, reversal corrected azimuth answers with measured HRTF with noise bursts.

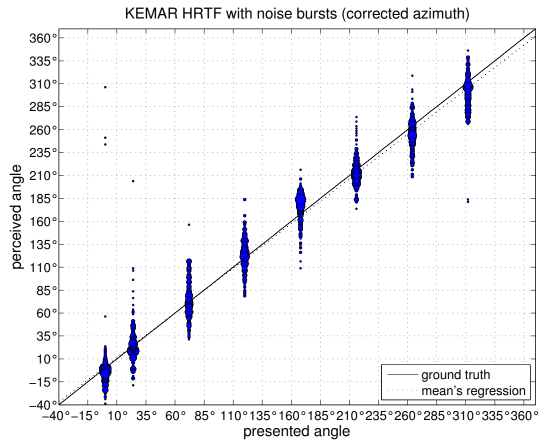


Figure A.68.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF with noise bursts.

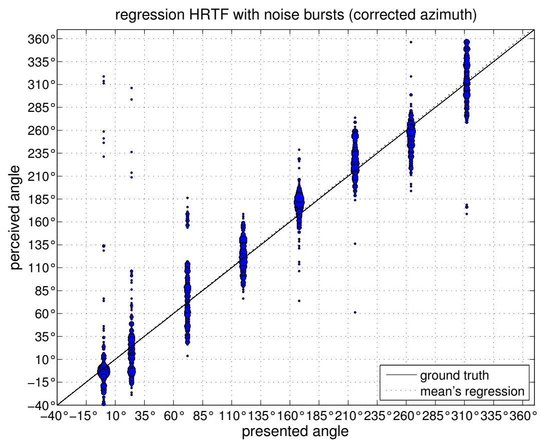


Figure A.69.: Scatterplot, reversal corrected azimuth answers with regression HRTF with noise bursts.

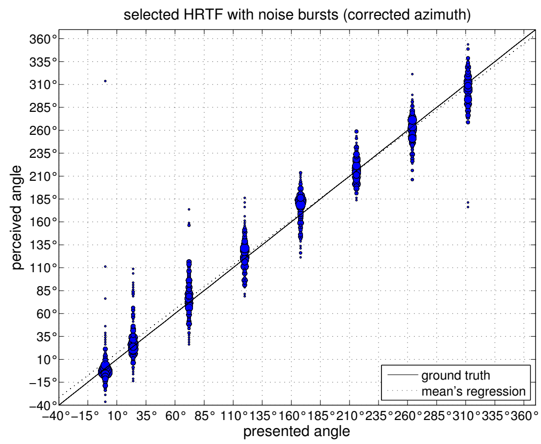
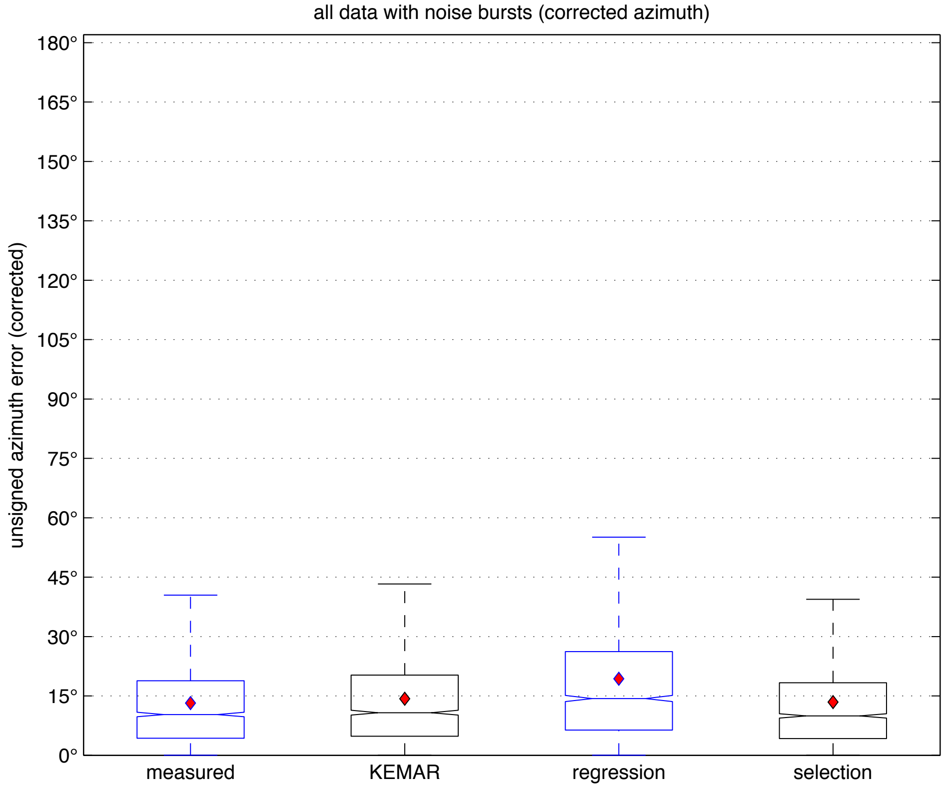
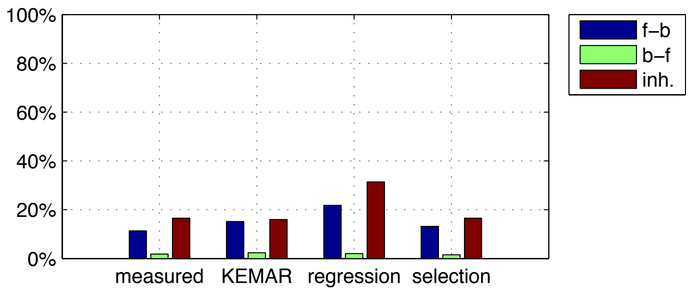


Figure A.70.: Scatterplot, reversal corrected azimuth answers with selected HRTF with noise bursts.



	measured	KEMAR	regression	selection
mean	13.19°	14.28°	19.33°	13.43°
std. dev.	11.49°	13.82°	19.91°	13.29°
median	10.30°	10.77°	14.35°	9.95°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	13.1%	11.3%	1.8%	17.6%	15.2%	2.4%	23.8%	21.8%	2.0%	14.8%	15.2%	1.6%
inheads	16.6%			16.0%			31.4%			16.5%		

Figure A.71.: Boxplot, reversal corrected azimuth error with noise bursts.

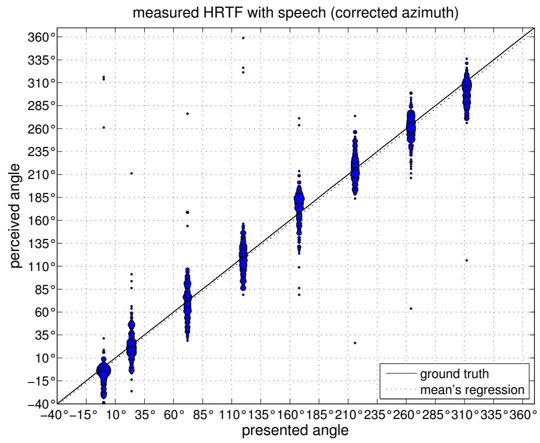


Figure A.72.: Scatterplot, reversal corrected azimuth answers with measured HRTF with speech.

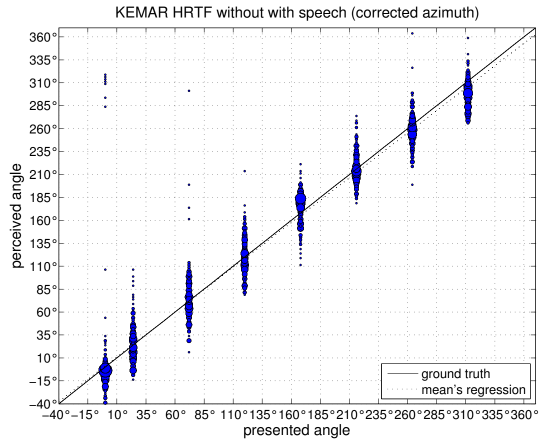


Figure A.73.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF with speech.

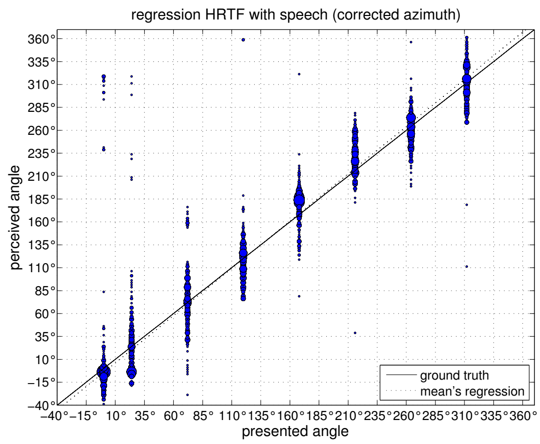


Figure A.74.: Scatterplot, reversal corrected azimuth answers with regression HRTF with speech.

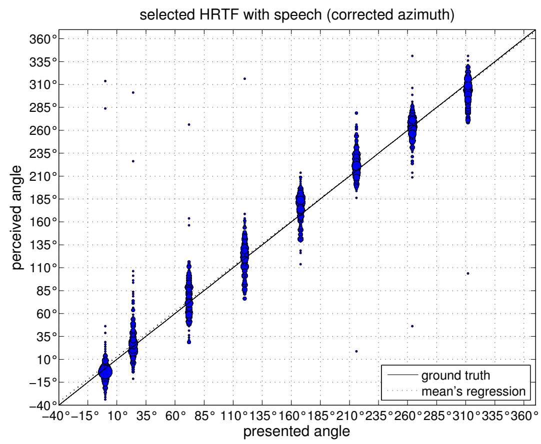
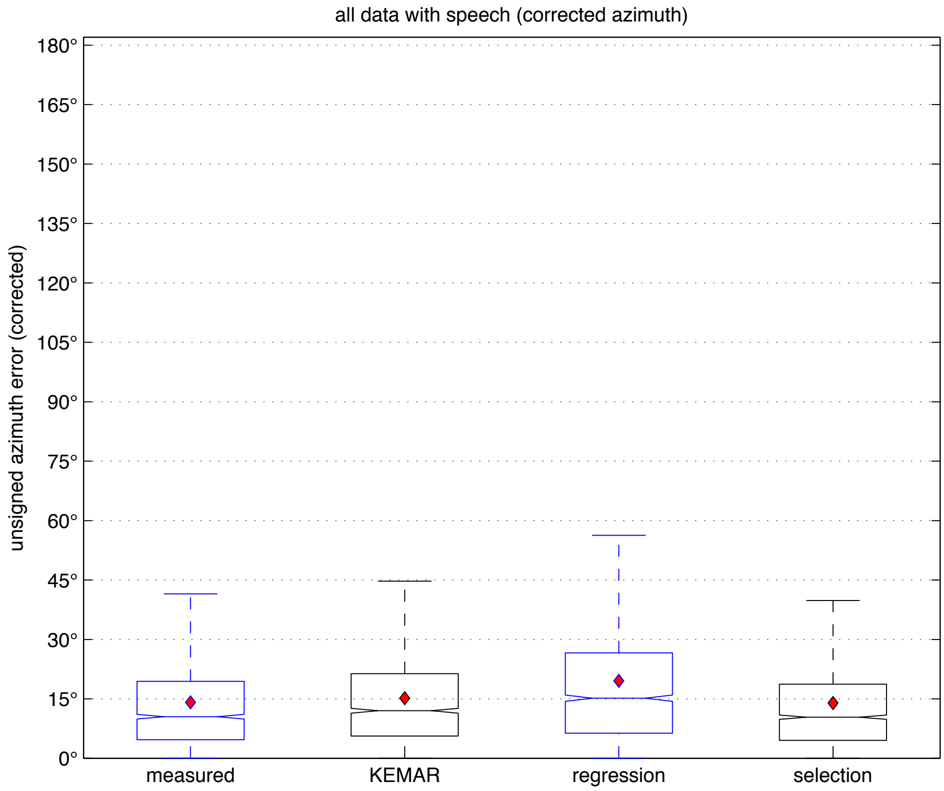
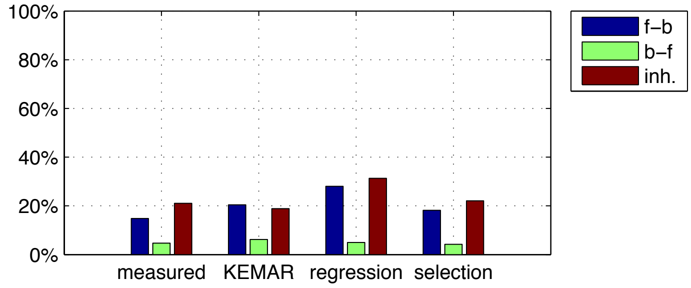


Figure A.75.: Scatterplot, reversal corrected azimuth answers with selected HRTF with speech.



	measured	KEMAR	regression	selection
mean	14.11°	15.18°	19.53°	13.97°
std. dev.	15.73°	13.46°	19.68°	14.91°
median	10.49°	12.01°	15.15°	10.37°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	19.5%	14.8%	4.7%	26.6%	20.4%	6.2%	33.0%	28.1%	4.9%	22.4%	20.4%	4.2%
inheads	21.1%			18.9%			31.3%			22.1%		

Figure A.76.: Boxplot, reversal corrected azimuth error with speech.

Noise Bursts,Measured HRTF	Noise Bursts,KEMAR HRTF	$[-8{,}32°, -2{,}62°]$
Noise Bursts,Measured HRTF	Noise Bursts, Regression HRTF	$[-18{,}77°, -13{,}07°]$
Noise Bursts,Measured HRTF	Noise Bursts, Selection HRTF	$[-4{,}66°, 1{,}04°]$
Noise Bursts,Measured HRTF	Speech Measured HRTF	$[-3{,}45°, 2{,}25°]$
Noise Bursts,Measured HRTF	Speech KEMAR HRTF	$[-6{,}76°, -1{,}06°]$
Noise Bursts,Measured HRTF	Speech Regression HRTF	$[-14{,}87°, -9{,}17°]$
Noise Bursts,Measured HRTF	Speech Selection HRTF	$[-5{,}21°, 0{,}49°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Regression HRTF	$[-13{,}30°, -7{,}60°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Selection HRTF	$[0{,}81°, 6{,}51°]$
Noise Bursts,KEMAR HRTF	Speech Measured HRTF	$[2{,}02°, 7{,}72°]$
Noise Bursts,KEMAR HRTF	Speech KEMAR HRTF	$[-1{,}29°, 4{,}41°]$
Noise Bursts,KEMAR HRTF	Speech Regression HRTF	$[-9{,}39°, -3{,}70°]$
Noise Bursts,KEMAR HRTF	Speech Selection HRTF	$[0{,}26°, 5{,}96°]$
Noise Bursts, Regression HRTF	Noise Bursts, Selection HRTF	$[11{,}26°, 16{,}96°]$
Noise Bursts, Regression HRTF	Speech Measured HRTF	$[12{,}47°, 18{,}17°]$
Noise Bursts, Regression HRTF	Speech KEMAR HRTF	$[9{,}16°, 14{,}85°]$
Noise Bursts, Regression HRTF	Speech Regression HRTF	$[1{,}05°, 6{,}75°]$
Noise Bursts, Regression HRTF	Speech Selection HRTF	$[10{,}71°, 16{,}41°]$
Noise Bursts, Selection HRTF	Speech Measured HRTF	$[-1{,}64°, 4{,}06°]$
Noise Bursts, Selection HRTF	Speech KEMAR HRTF	$[-4{,}95°, 0{,}75°]$
Noise Bursts, Selection HRTF	Speech Regression HRTF	$[-13{,}06°, -7{,}36°]$
Noise Bursts, Selection HRTF	Speech Selection HRTF	$[-3{,}40°, 2{,}30°]$
Speech Measured HRTF	Speech KEMAR HRTF	$[-6{,}16°, -0{,}46°]$
Speech Measured HRTF	Speech Regression HRTF	$[-14{,}27°, -8{,}57°]$
Speech Measured HRTF	Speech Selection HRTF	$[-4{,}61°, 1{,}09°]$
Speech KEMAR HRTF	Speech Regression HRTF	$[-10{,}95°, -5{,}25°]$
Speech KEMAR HRTF	Speech Selection HRTF	$[-1{,}30°, 4{,}40°]$
Speech Regression HRTF	Speech Selection HRTF	$[6{,}81°, 12{,}51°]$

Table A.7.: Azimuth error: least significant difference for the HRTF-datasets with different stimuli.

Noise Bursts,Measured HRTF	Noise Bursts,KEMAR HRTF	$[-2{,}17°, -0{,}01°]$
Noise Bursts,Measured HRTF	Noise Bursts, Regression HRTF	$[-7{,}22°, -5{,}06°]$
Noise Bursts,Measured HRTF	Noise Bursts, Selection HRTF	$[-1{,}32°, 0{,}84°]$
Noise Bursts,Measured HRTF	Speech Measured HRTF	$[-2{,}00°, 0{,}15°]$
Noise Bursts,Measured HRTF	Speech KEMAR HRTF	$[-3{,}07°, -0{,}92°]$
Noise Bursts,Measured HRTF	Speech Regression HRTF	$[-7{,}42°, -5{,}26°]$
Noise Bursts,Measured HRTF	Speech Selection HRTF	$[-1{,}86°, 0{,}30°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Regression HRTF	$[-6{,}13°, -3{,}97°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Selection HRTF	$[-0{,}23°, 1{,}93°]$
Noise Bursts,KEMAR HRTF	Speech Measured HRTF	$[-0{,}91°, 1{,}24°]$
Noise Bursts,KEMAR HRTF	Speech KEMAR HRTF	$[-1{,}98°, 0{,}17°]$
Noise Bursts,KEMAR HRTF	Speech Regression HRTF	$[-6{,}32°, -4{,}17°]$
Noise Bursts,KEMAR HRTF	Speech Selection HRTF	$[-0{,}77°, 1{,}39°]$
Noise Bursts, Regression HRTF	Noise Bursts, Selection HRTF	$[4{,}82°, 6{,}98°]$
Noise Bursts, Regression HRTF	Speech Measured HRTF	$[4{,}14°, 6{,}29°]$
Noise Bursts, Regression HRTF	Speech KEMAR HRTF	$[3{,}07°, 5{,}22°]$
Noise Bursts, Regression HRTF	Speech Regression HRTF	$[-1{,}27°, 0{,}88°]$
Noise Bursts, Regression HRTF	Speech Selection HRTF	$[4{,}28°, 6{,}44°]$
Noise Bursts, Selection HRTF	Speech Measured HRTF	$[-1{,}76°, 0{,}39°]$
Noise Bursts, Selection HRTF	Speech KEMAR HRTF	$[-2{,}83°, -0{,}68°]$
Noise Bursts, Selection HRTF	Speech Regression HRTF	$[-7{,}18°, -5{,}02°]$
Noise Bursts, Selection HRTF	Speech Selection HRTF	$[-1{,}62°, 0{,}54°]$
Speech Measured HRTF	Speech KEMAR HRTF	$[-2{,}15°, 0{,}01°]$
Speech Measured HRTF	Speech Regression HRTF	$[-6{,}49°, -4{,}33°]$
Speech Measured HRTF	Speech Selection HRTF	$[-0{,}93°, 1{,}22°]$
Speech KEMAR HRTF	Speech Regression HRTF	$[-5{,}42°, -3{,}27°]$
Speech KEMAR HRTF	Speech Selection HRTF	$[0{,}14°, 2{,}29°]$
Speech Regression HRTF	Speech Selection HRTF	$[4{,}48°, 6{,}63°]$

Table A.8.: Corrected azimuth error: least significant difference for the HRTF-datasets with different stimuli.

A.8. Comparison of HRTF-Sets with Different Stimuli with and without Head-Tracking

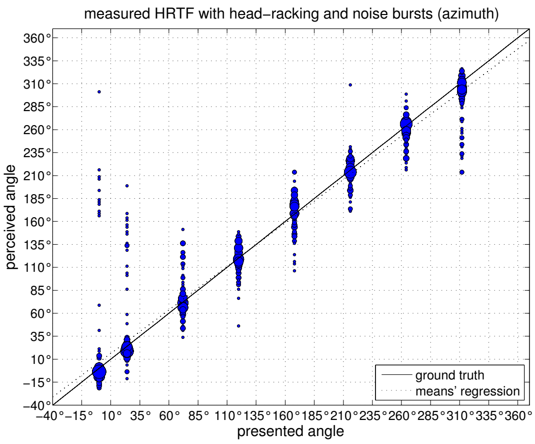


Figure A.77.: Scatterplot, azimuth answers with measured HRTF with head-tracking and noise bursts.

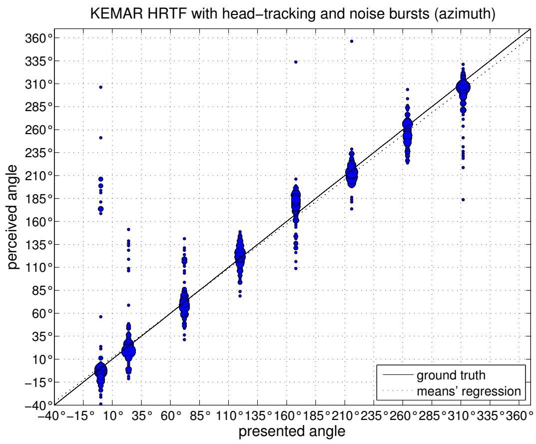


Figure A.78.: Scatterplot, azimuth answers with KEMAR HRTF with head-tracking and noise bursts.

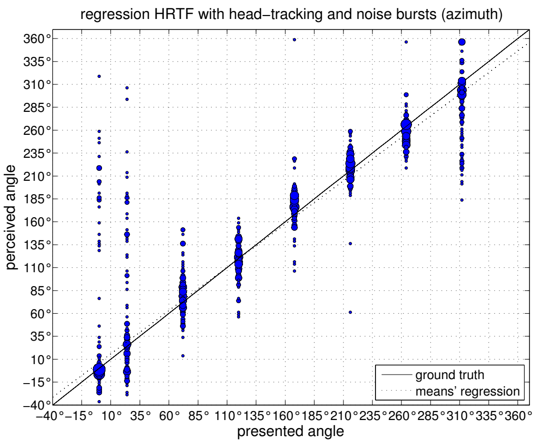


Figure A.79.: Scatterplot, azimuth answers with regression HRTF with head-tracking and noise bursts.

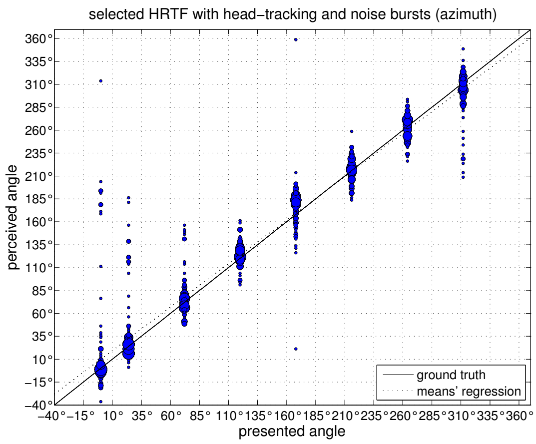
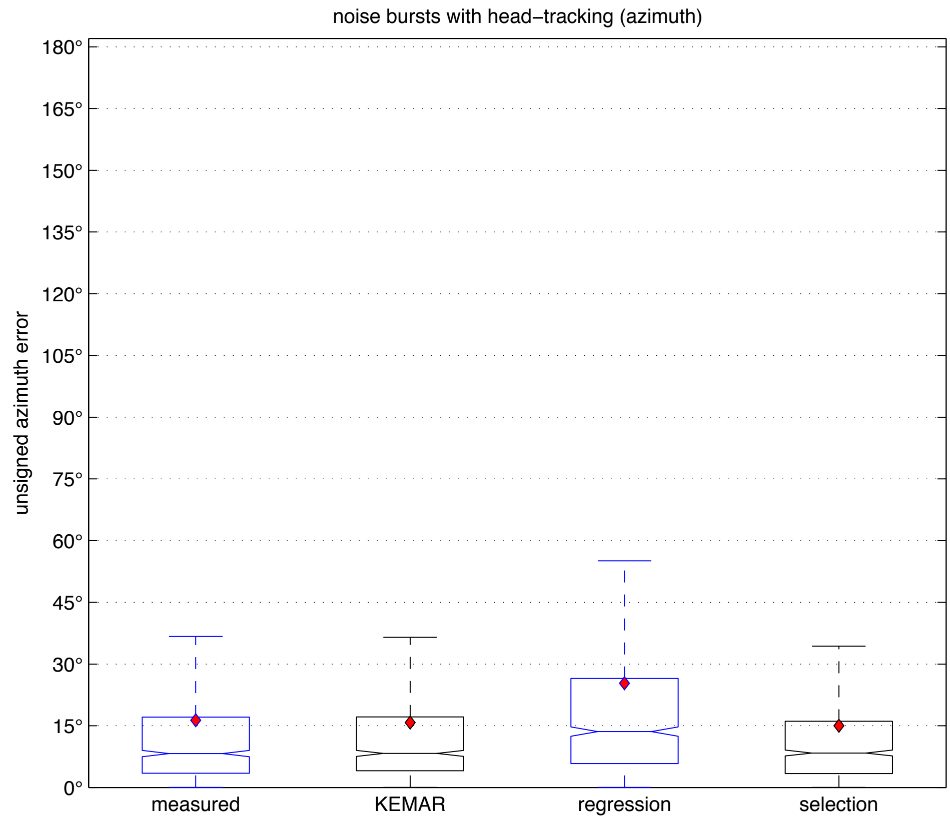
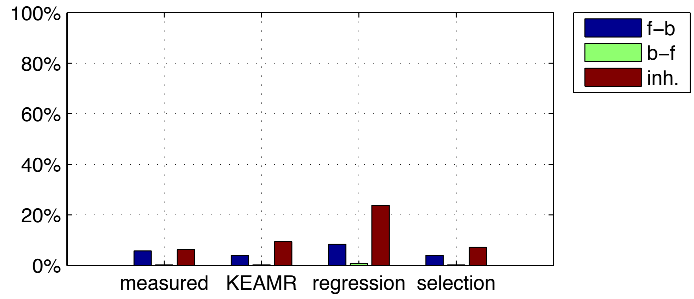


Figure A.80.: Scatterplot, azimuth answers with selected HRTF with head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	16.34°	15.75°	25.31°	14.98°
std. dev.	26.73°	25.17°	34.79°	24.96°
median	8.23°	8.28°	13.59°	8.37°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	6.0%	5.8%	0.2%	4.2%	4.0%	0.2%	9.1%	8.4%	0.8%	4.2%	4.0%	0.2%
inheads	6.2%			9.4%			23.8%			7.2%		

Figure A.81.: Boxplot, azimuth error with head-tracking and noise bursts.

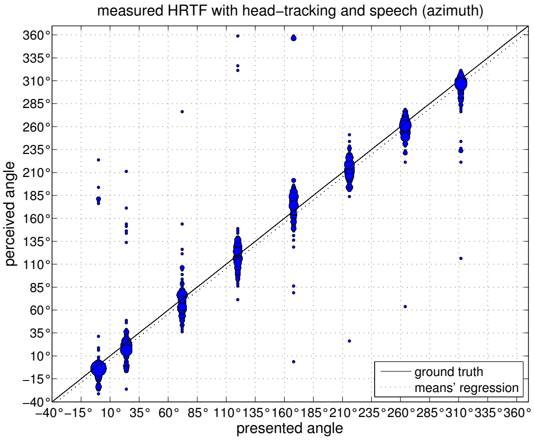


Figure A.82.: Scatterplot, azimuth answers with measured HRTF with head-tracking and speech.

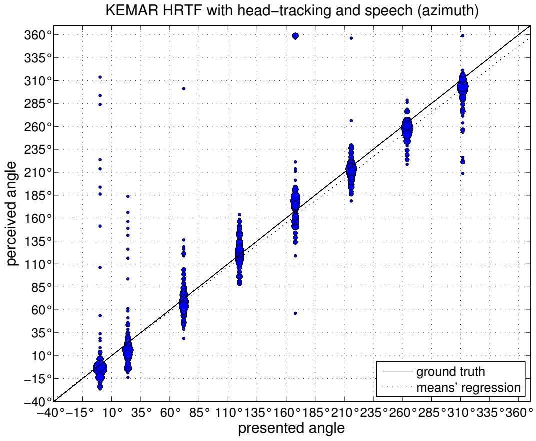


Figure A.83.: Scatterplot, azimuth answers with KEMAR HRTF with head-tracking and speech.

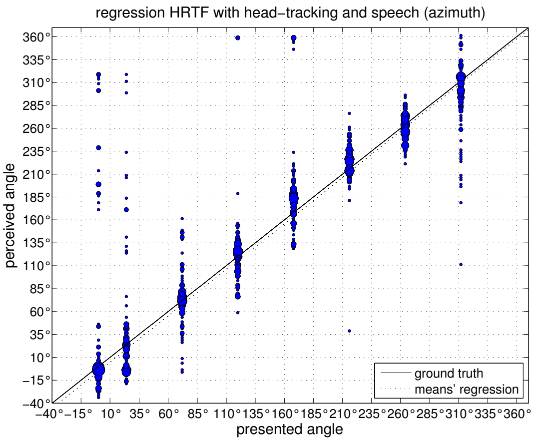


Figure A.84.: Scatterplot, azimuth answers with regression HRTF with head-tracking and speech.

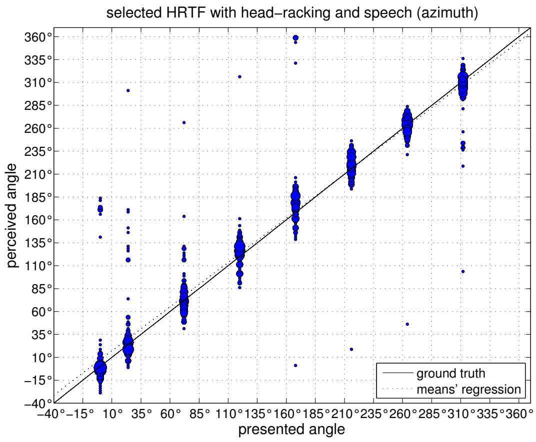
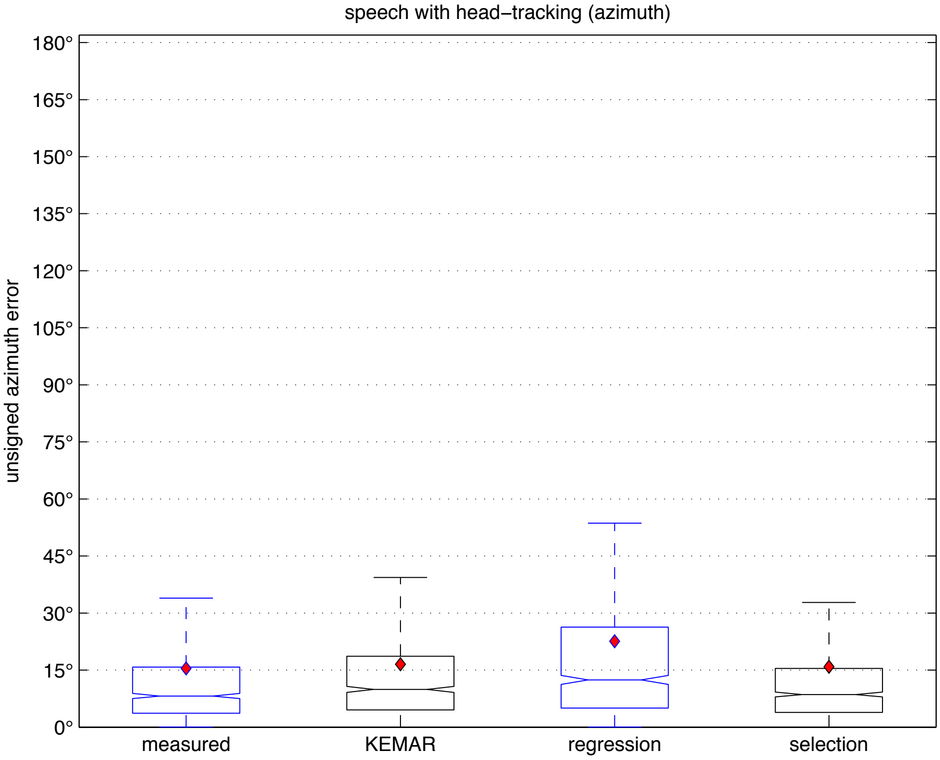
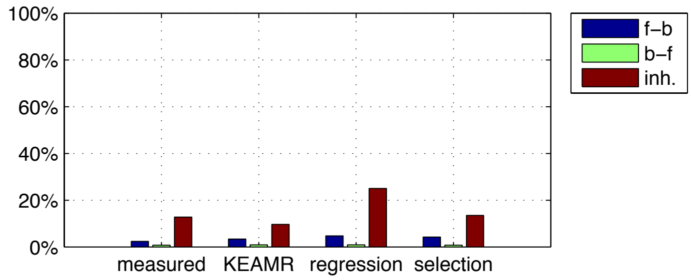


Figure A.85.: Scatterplot, azimuth answers with selected HRTF with head-tracking and speech.



	measured	KEMAR	regression	selection
mean	15.43°	16.53°	22.56°	15.89°
std. dev.	27.66°	24.66°	32.07°	28.90°
median	8.19°	9.93°	12.44°	8.58°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	3.1%	2.4%	0.8%	4.2%	3.4%	0.9%	5.6%	4.8%	0.9%	5.0%	3.4%	0.8%
inheads	12.8%			9.6%			25.0%			13.5%		

Figure A.86.: Boxplot, azimuth error with head-tracking and speech.

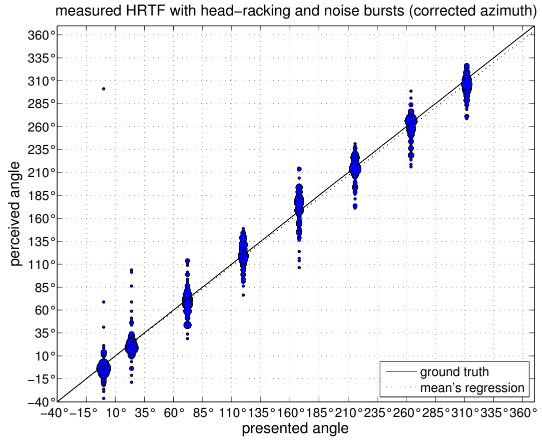


Figure A.87.: Scatterplot, reversal corrected azimuth answers with measured HRTF with head-tracking and noise bursts.

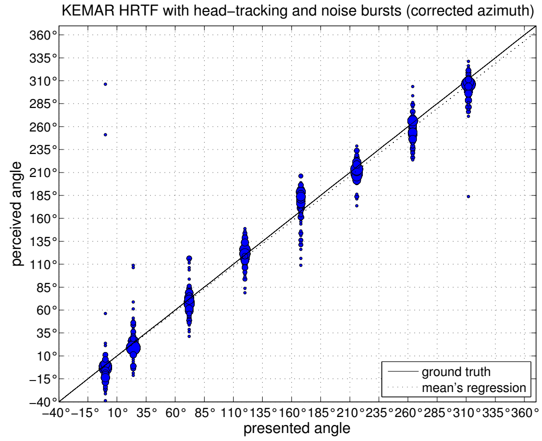


Figure A.88.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF with head-tracking and noise bursts.

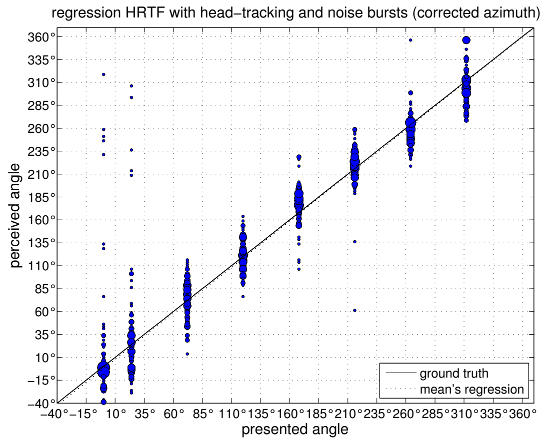


Figure A.89.: Scatterplot, reversal corrected azimuth answers with regression HRTF with head-tracking and noise bursts.

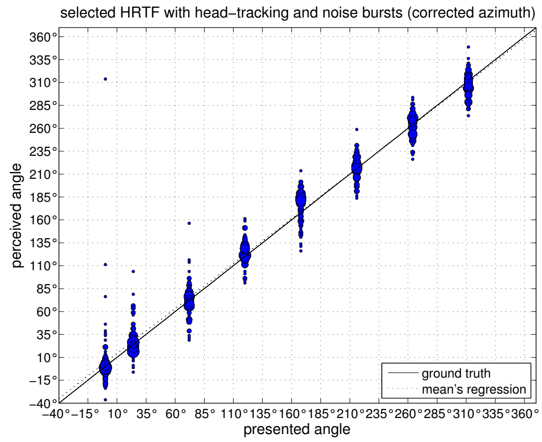
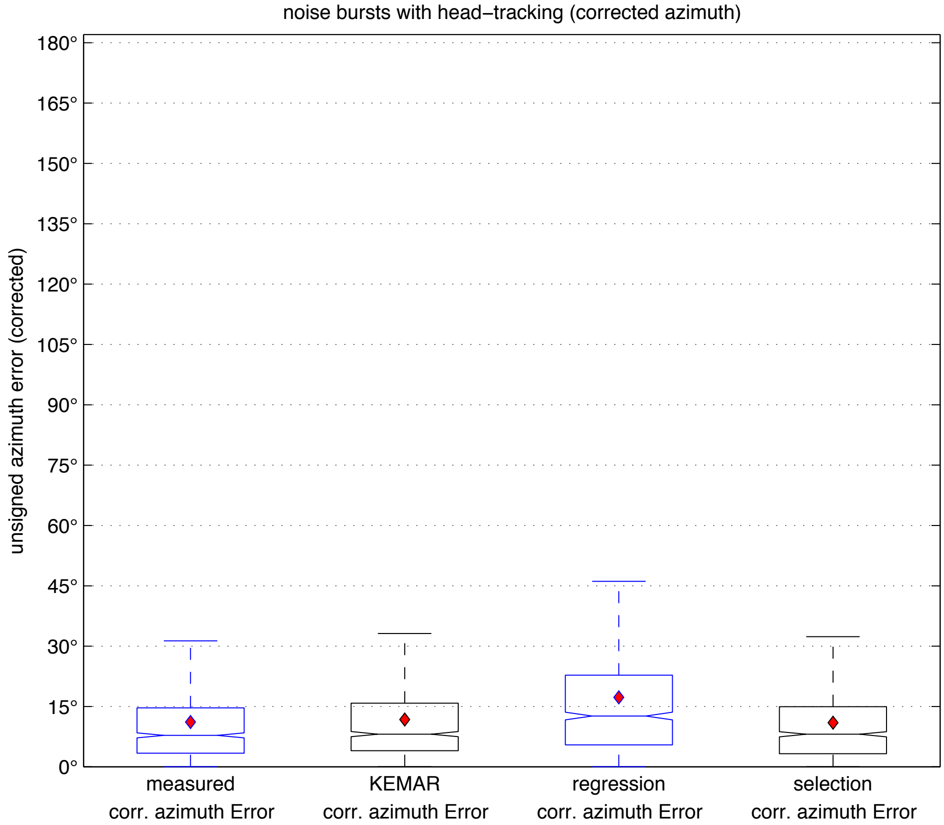
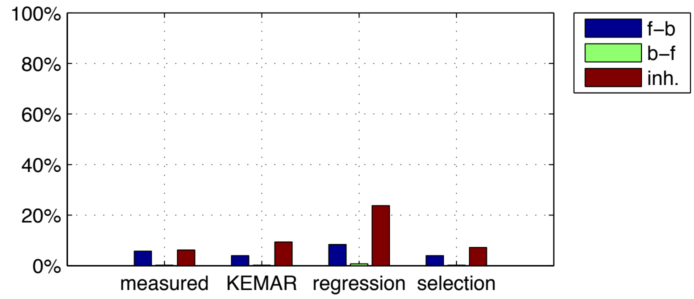


Figure A.90.: Scatterplot, reversal corrected azimuth answers with selected HRTF with head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	11.14°	11.74°	17.24°	10.97°
std. dev.	11.14°	11.93°	19.52°	10.98°
median	7.81°	8.12°	12.61°	8.08°



	measured			KEMAR			regresion			selection		
	total	f−b	b−f	total	f−b	b−f	total	f−b	b−f	total	f−b	b−f
conf.	6.0%	5.8%	0.2%	4.2%	4.0%	0.2%	9.1%	8.4%	0.8%	4.2%	4.0%	0.2%
inheads	6.2%			9.4%			23.8%			7.2%		

Figure A.91.: Boxplot, reversal corrected azimuth error with head-tracking and noise bursts.

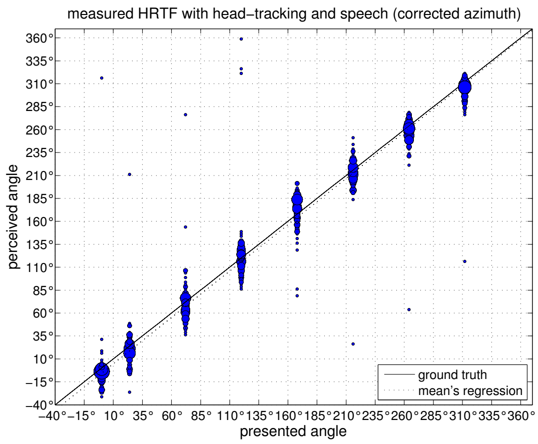


Figure A.92.: Scatterplot, reversal corrected azimuth answers with measured HRTF with head-tracking and speech.

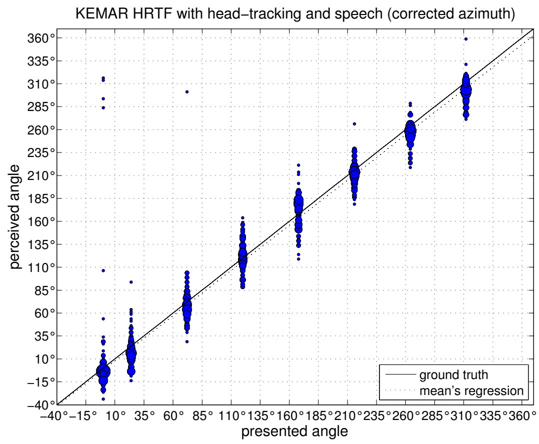


Figure A.93.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF with head-tracking and speech.

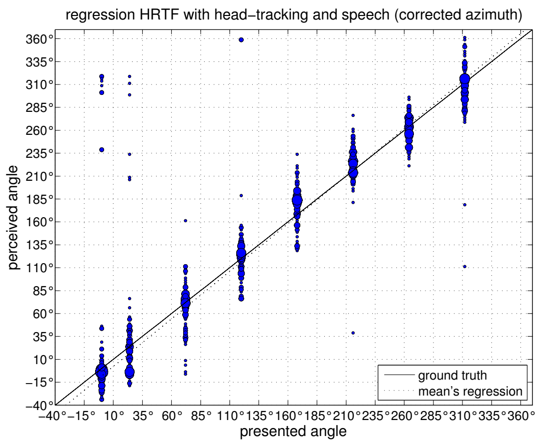


Figure A.94.: Scatterplot, reversal corrected azimuth answers with regression HRTF with head-tracking and speech.

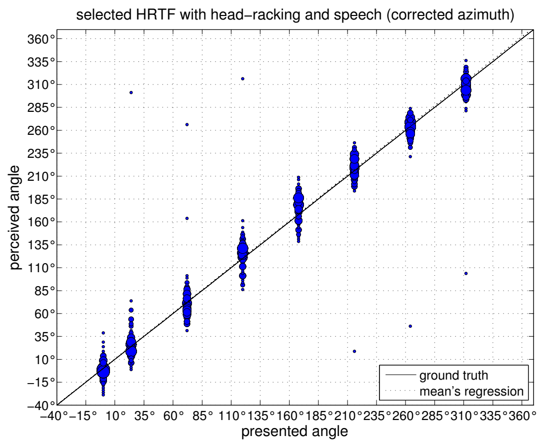
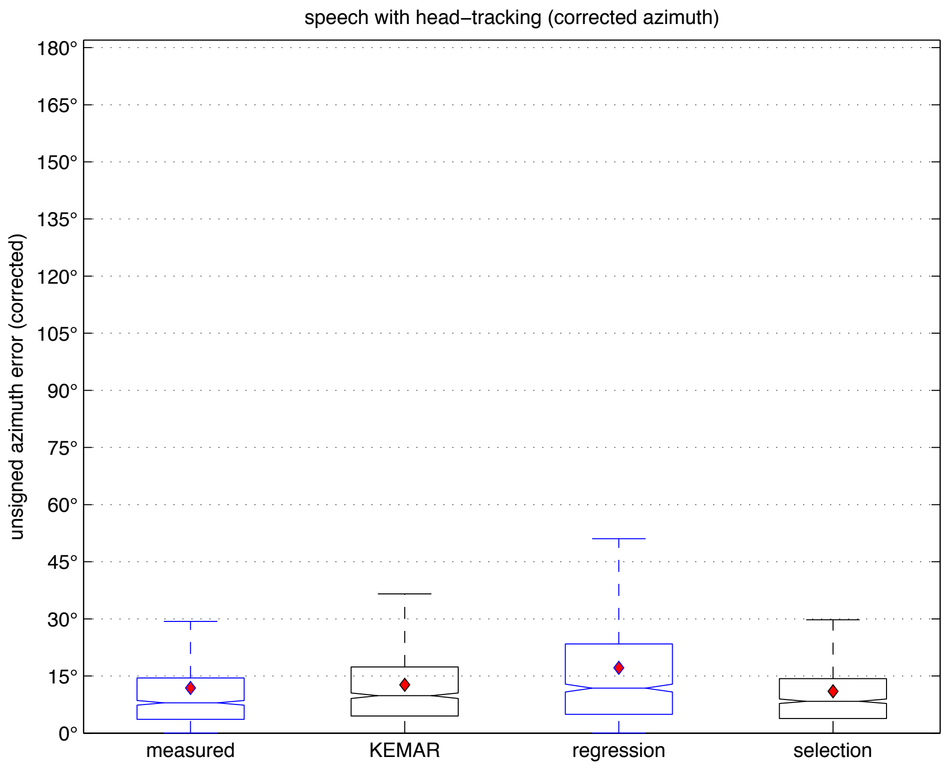
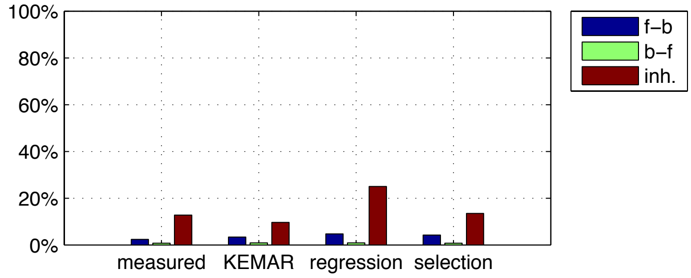


Figure A.95.: Scatterplot, reversal corrected azimuth answers with selected HRTF with head-tracking and speech.



	measured	KEMAR	regression	selection
mean	11.84°	12.68°	17.15°	10.99°
std. dev.	17.49°	11.97°	20.20°	14.57°
median	7.96°	9.83°	11.81°	8.36°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	3.1%	2.4%	0.8%	4.2%	3.4%	0.9%	5.6%	4.8%	0.9%	5.0%	3.4%	0.8%
inheads	12.8%			9.6%			25.0%			13.5%		

Figure A.96.: Boxplot, reversal corrected azimuth error with head-tracking and speech.

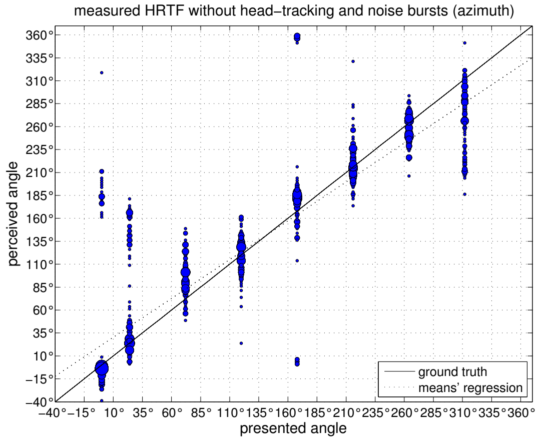


Figure A.97.: Scatterplot, azimuth answers with measured HRTF without head-tracking and noise bursts.

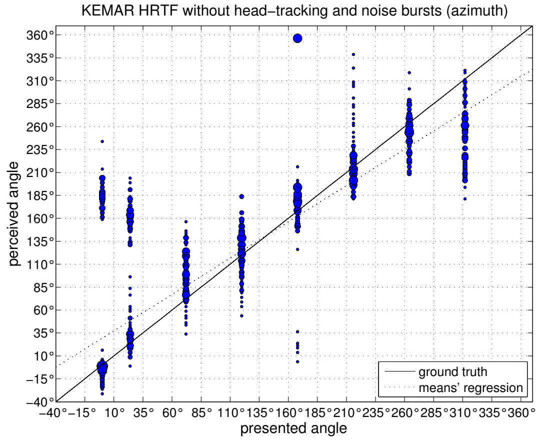


Figure A.98.: Scatterplot, azimuth answers with KEMAR HRTF without head-tracking and noise bursts.

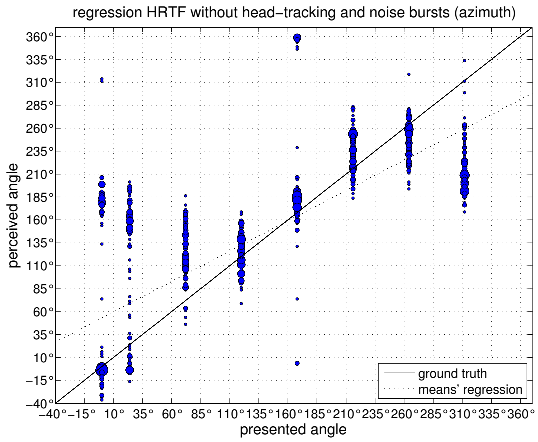


Figure A.99.: Scatterplot, azimuth answers with regression HRTF without head-tracking and noise bursts.

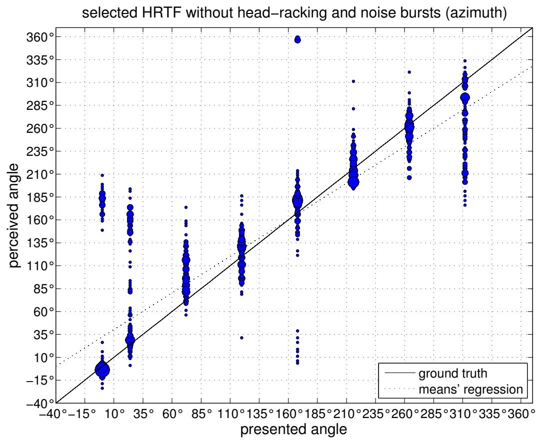
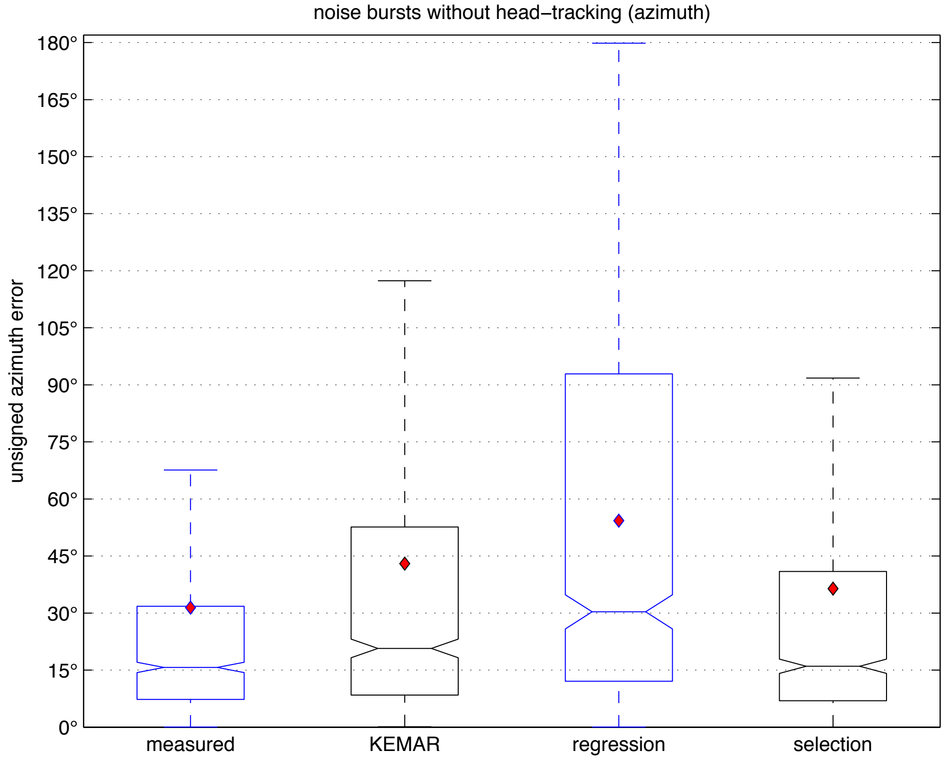
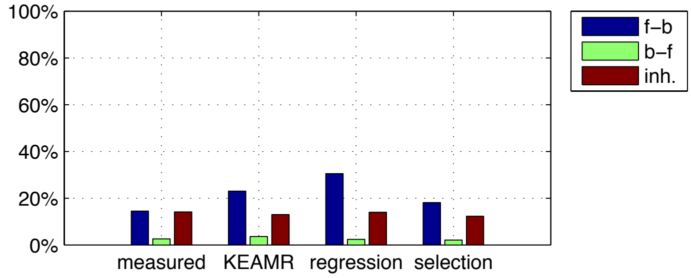


Figure A.100.: Scatterplot, azimuth answers with selected HRTF without head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	31.44°	42.97°	54.31°	36.42°
std. dev.	41.97°	50.97°	54.22°	47.10°
median	15.70°	20.70°	30.33°	15.99°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	17.1%	11600.0%	2100.0%	26.6%	18400.0%	2900.0%	32.9%	24400.0%	1900.0%	20.2%	18400.0%	1700.0%
inheads	14.1%			13.0%			14.0%			12.2%		

Figure A.101.: Boxplot, azimuth error without head-tracking and noise bursts.

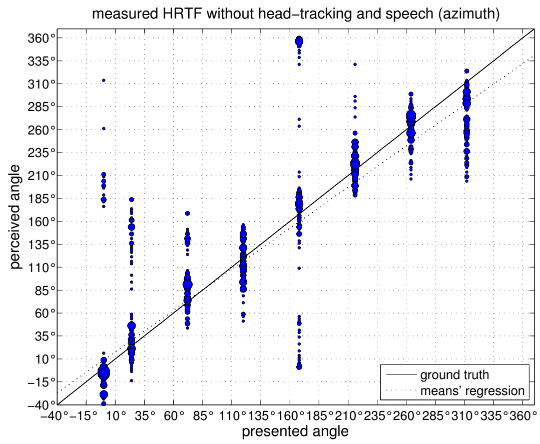


Figure A.102.: Scatterplot, azimuth answers with measured HRTF without head-tracking and speech.

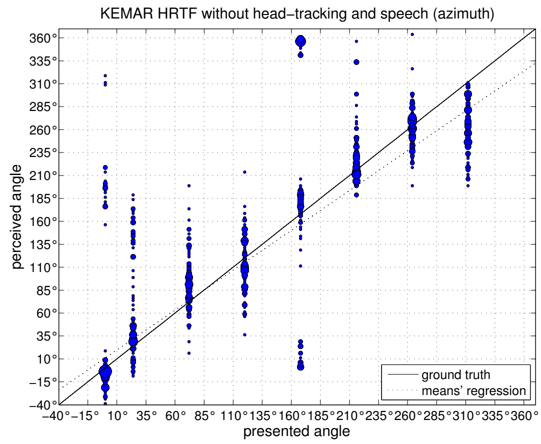


Figure A.103.: Scatterplot, azimuth answers with KEMAR HRTF without head-tracking and speech.

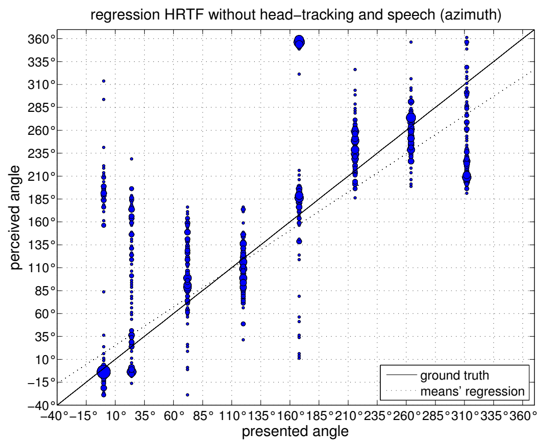


Figure A.104.: Scatterplot, azimuth answers with regression HRTF without head-tracking and speech.

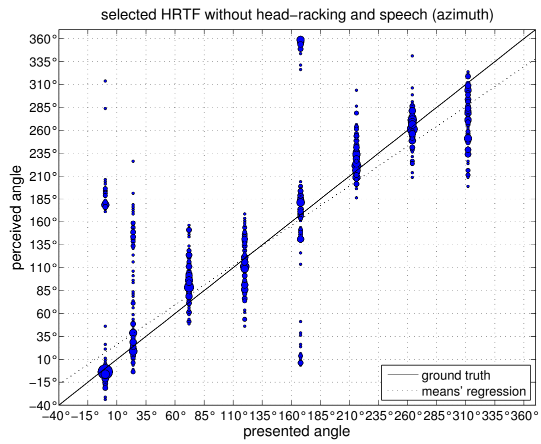
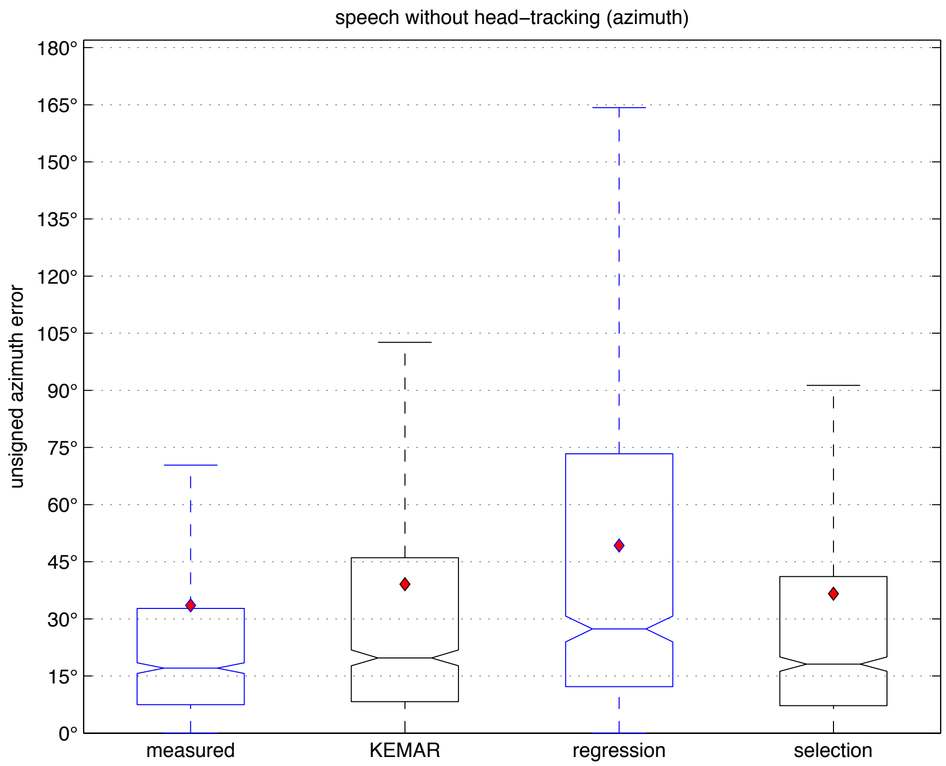
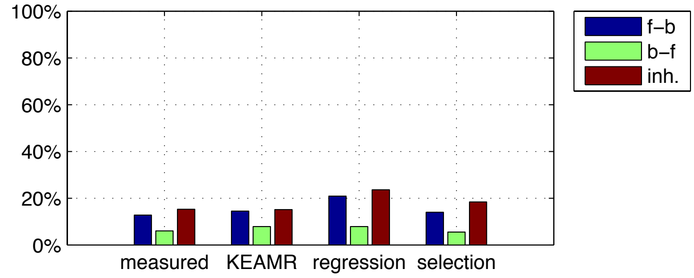


Figure A.105.: Scatterplot, azimuth answers with selected HRTF without head-tracking and speech.



	measured	KEMAR	regression	selection
mean	33.55°	39.07°	49.26°	36.61°
std. dev.	43.87°	47.70°	51.05°	46.88°
median	17.04°	19.75°	27.35°	18.10°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	18.8%	12.8%	6.0%	11.2%	14.5%	7.9%	27.5%	20.9%	6.6%	19.5%	14.5%	5.5%
inheads	15.2%			15.1%			25.0%			13.5%		

Figure A.106.: Boxplot, azimuth error without head-tracking and speech.

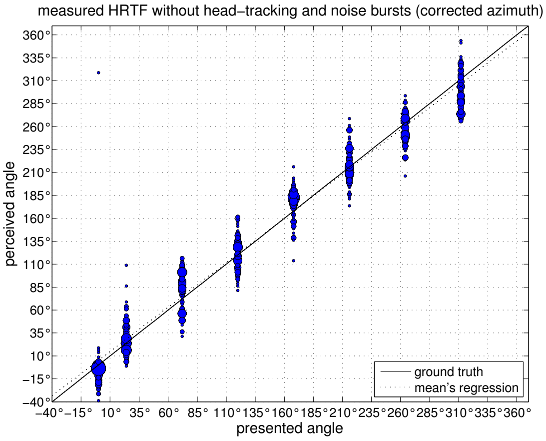


Figure A.107.: Scatterplot, reversal corrected azimuth answers with measured HRTF without head-tracking and noise bursts.

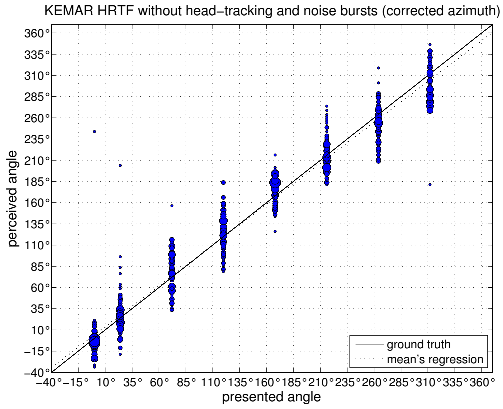


Figure A.108.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF without head-tracking and noise bursts.

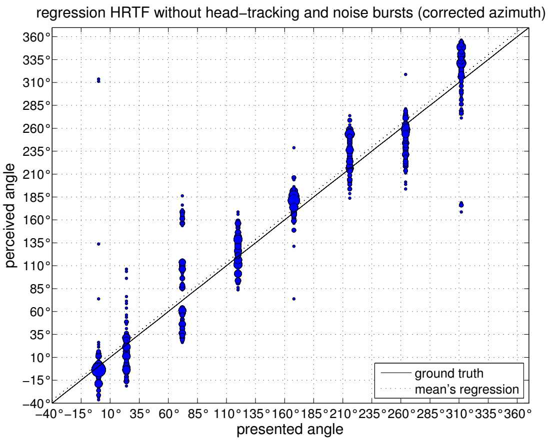


Figure A.109.: Scatterplot, reversal corrected azimuth answers with regression HRTF without head-tracking and noise bursts.

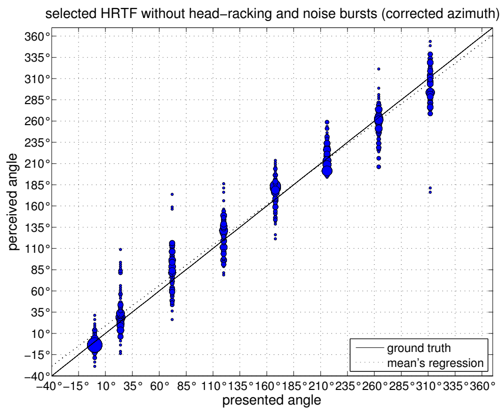
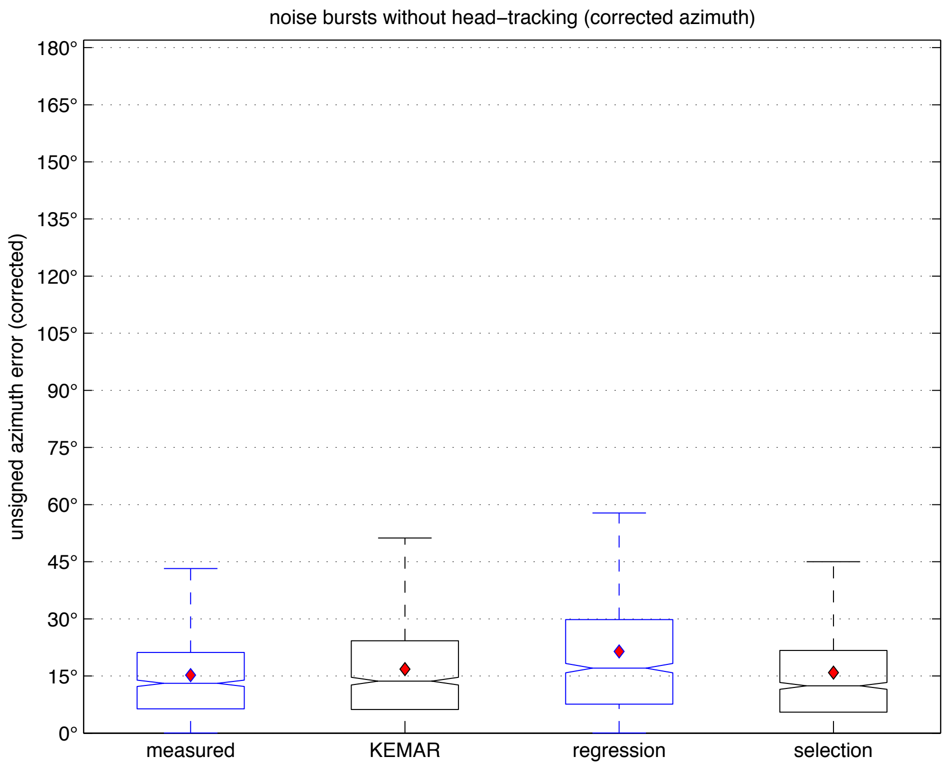
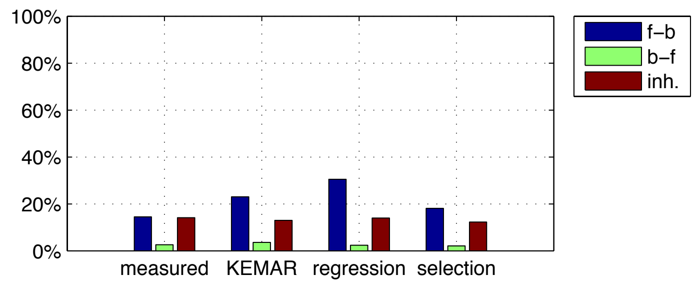


Figure A.110.: Scatterplot, reversal corrected azimuth answers with selected HRTF without head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	15.23°	16.82°	21.42°	15.88°
std. dev.	11.48°	15.06°	20.09°	14.86°
median	13.08°	13.65°	17.06°	12.40°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	17.1%	14.5%	2.6%	26.6%	23.0%	3.6%	27.5%	30.5%	2.4%	20.2%	23.0%	2.1%
inheads	14.1%			13.0%			14.0%			12.2%		

Figure A.111.: Boxplot, reversal corrected azimuth error without head-tracking and noise bursts.

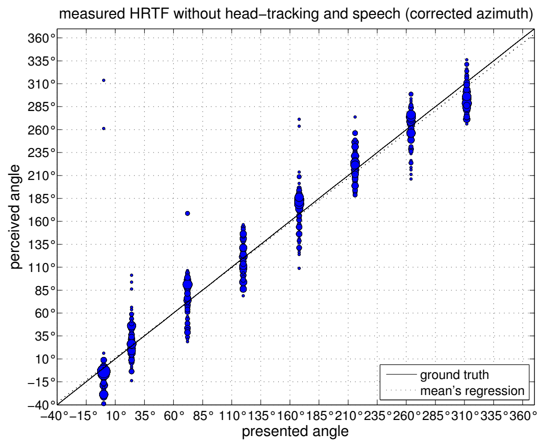


Figure A.112.: Scatterplot, reversal corrected azimuth answers with measured HRTF without head-tracking and speech.

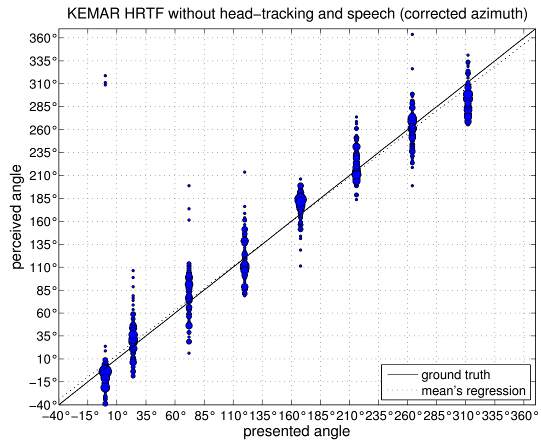


Figure A.113.: Scatterplot, reversal corrected azimuth answers with KEMAR HRTF without head-tracking and speech.

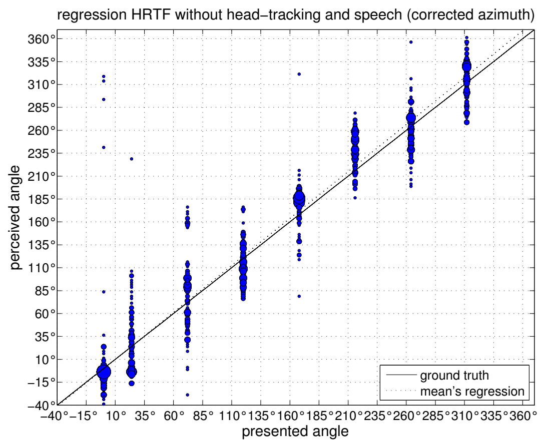


Figure A.114.: Scatterplot, reversal corrected azimuth answers with regression HRTF without head-tracking and speech.

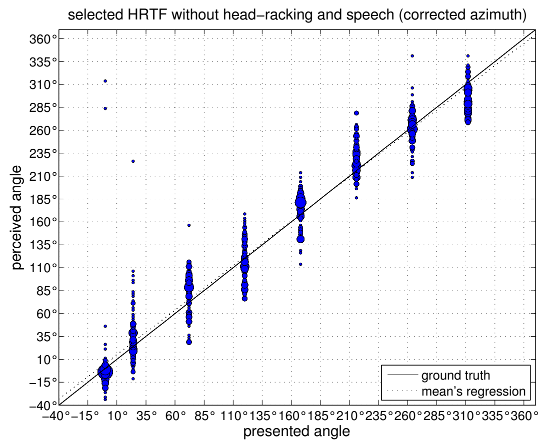
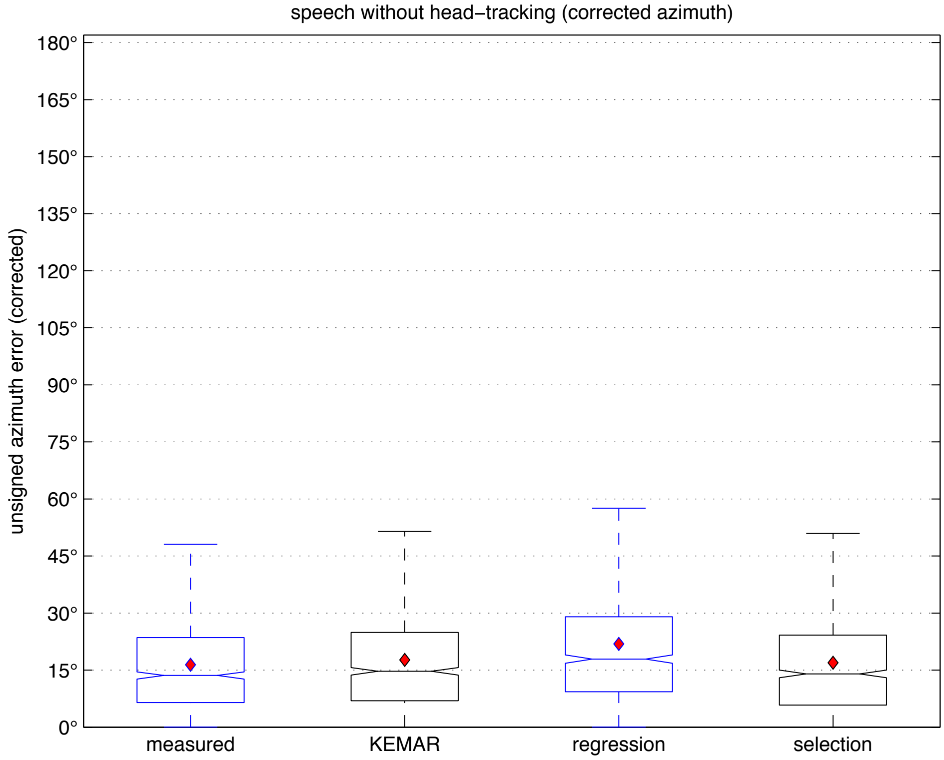
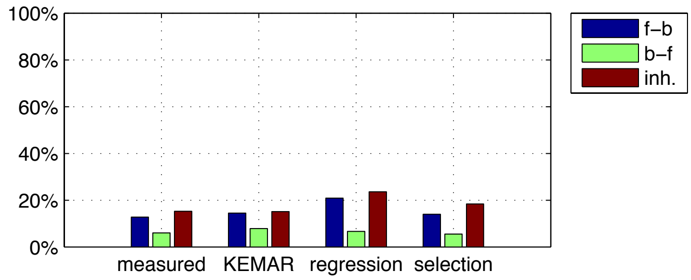


Figure A.115.: Scatterplot, reversal corrected azimuth answers with selected HRTF without head-tracking and speech.



	measured	KEMAR	regression	selection
mean	16.39°	17.68°	21.90°	16.95°
std. dev.	13.38°	14.38°	18.85°	14.66°
median	13.59°	14.68°	17.89°	13.99°



	measured			KEMAR			regresion			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	18.8%	12.8%	6.0%	22.4%	14.5%	7.9%	27.5%	20.9%	6.6%	19.5%	14.5%	5.5%
inheads	15.2%			15.1%			23.6%			18.4%		

Figure A.116.: Boxplot, reversal corrected azimuth error without head-tracking and speech.

Noise B., Measured w. Track.	Noise B., KEMAR w. Track.	[−3,28°, 4,46°]
Noise B., Measured w. Track.	Noise B., Regr. w. Track.	[−12,84°, −5,10°]
Noise B., Measured w. Track.	Noise B., Selection w. Track.	[−2,51°, 5,23°]
Noise B., Measured w. Track.	Speech, Measured w. Track.	[−2,96°, 4,78°]
Noise B., Measured w. Track.	Speech, KEMAR w. Track.	[−4,06°, 3,68°]
Noise B., Measured w. Track.	Speech, Regr. w. Track.	[−10,09°, −2,35°]
Noise B., Measured w. Track.	Speech, Selection w. Track.	[−3,42°, 4,32°]
Noise B., Measured w. Track.	Noise B., Measured w/o Track.	[−18,97°, −11,23°]
Noise B., Measured w. Track.	Noise B., KEMAR w/o Track.	[−30,50°, −22,76°]
Noise B., Measured w. Track.	Noise B., Regr. w/o Track.	[−41,84°, −34,10°]
Noise B., Measured w. Track.	Noise B., Selection w/o Track.	[−23,95°, −16,21°]
Noise B., Measured w. Track.	Speech, Measured w/o Track.	[−21,08°, −13,34°]
Noise B., Measured w. Track.	Speech, KEMAR w/o Track.	[−26,60°, −18,86°]
Noise B., Measured w. Track.	Speech, Regr. w/o Track.	[−36,78°, −29,05°]
Noise B., Measured w. Track.	Speech, Selection w/o Track.	[−24,14°, −16,40°]
Noise B., KEMAR w. Track.	Noise B., Regr. w. Track.	[−13,42°, −5,69°]
Noise B., KEMAR w. Track.	Noise B., Selection w. Track.	[−3,10°, 4,64°]
Noise B., KEMAR w. Track.	Speech, Measured w. Track.	[−3,55°, 4,19°]
Noise B., KEMAR w. Track.	Speech, KEMAR w. Track.	[−4,65°, 3,09°]
Noise B., KEMAR w. Track.	Speech, Regr. w. Track.	[−10,68°, −2,94°]
Noise B., KEMAR w. Track.	Speech, Selection w. Track.	[−4,01°, 3,73°]
Noise B., KEMAR w. Track.	Noise B., Measured w/o Track.	[−19,56°, −11,82°]
Noise B., KEMAR w. Track.	Noise B., KEMAR w/o Track.	[−31,09°, −23,35°]
Noise B., KEMAR w. Track.	Noise B., Regr. w/o Track.	[−42,42°, −34,69°]
Noise B., KEMAR w. Track.	Noise B., Selection w/o Track.	[−24,54°, −16,80°]
Noise B., KEMAR w. Track.	Speech, Measured w/o Track.	[−21,67°, −13,93°]
Noise B., KEMAR w. Track.	Speech, KEMAR w/o Track.	[−27,19°, −19,45°]
Noise B., KEMAR w. Track.	Speech, Regr. w/o Track.	[−37,37°, −29,63°]
Noise B., KEMAR w. Track.	Speech, Selection w/o Track.	[−24,73°, −16,99°]
Noise B., Regr. w. Track.	Noise B., Selection w. Track.	[6,46°, 14,20°]
Noise B., Regr. w. Track.	Speech, Measured w. Track.	[6,01°, 13,75°]
Noise B., Regr. w. Track.	Speech, KEMAR w. Track.	[4,91°, 12,65°]
Noise B., Regr. w. Track.	Speech, Regr. w. Track.	[−1,12°, 6,62°]
Noise B., Regr. w. Track.	Speech, Selection w. Track.	[5,55°, 13,29°]
Noise B., Regr. w. Track.	Noise B., Measured w/o Track.	[−10,00°, −2,26°]
Noise B., Regr. w. Track.	Noise B., KEMAR w/o Track.	[−21,53°, −13,79°]
Noise B., Regr. w. Track.	Noise B., Regr. w/o Track.	[−32,87°, −25,13°]
Noise B., Regr. w. Track.	Noise B., Selection w/o Track.	[−14,98°, −7,24°]
Noise B., Regr. w. Track.	Speech, Measured w/o Track.	[−12,11°, −4,37°]
Noise B., Regr. w. Track.	Speech, KEMAR w/o Track.	[−17,63°, −9,90°]
Noise B., Regr. w. Track.	Speech, Regr. w/o Track.	[−27,82°, −20,08°]

Noise B., Regr. w. Track.	Speech, Selection w/o Track.	$[-15{,}17°, -7{,}43°]$
Noise B., Selection w. Track.	Speech, Measured w. Track.	$[-4{,}32°, 3{,}42°]$
Noise B., Selection w. Track.	Speech, KEMAR w. Track.	$[-5{,}42°, 2{,}32°]$
Noise B., Selection w. Track.	Speech, Regr. w. Track.	$[-11{,}45°, -3{,}71°]$
Noise B., Selection w. Track.	Speech, Selection w. Track.	$[-4{,}78°, 2{,}96°]$
Noise B., Selection w. Track.	Noise B., Measured w/o Track.	$[-20{,}33°, -12{,}59°]$
Noise B., Selection w. Track.	Noise B., KEMAR w/o Track.	$[-31{,}86°, -24{,}12°]$
Noise B., Selection w. Track.	Noise B., Regr. w/o Track.	$[-43{,}19°, -35{,}46°]$
Noise B., Selection w. Track.	Noise B., Selection w/o Track.	$[-25{,}31°, -17{,}57°]$
Noise B., Selection w. Track.	Speech, Measured w/o Track.	$[-22{,}44°, -14{,}70°]$
Noise B., Selection w. Track.	Speech, KEMAR w/o Track.	$[-27{,}96°, -20{,}22°]$
Noise B., Selection w. Track.	Speech, Regr. w/o Track.	$[-38{,}14°, -30{,}40°]$
Noise B., Selection w. Track.	Speech, Selection w/o Track.	$[-25{,}50°, -17{,}76°]$
Speech, Measured w. Track.	Speech, KEMAR w. Track.	$[-4{,}97°, 2{,}77°]$
Speech, Measured w. Track.	Speech, Regr. w. Track.	$[-11{,}00°, -3{,}26°]$
Speech, Measured w. Track.	Speech, Selection w. Track.	$[-4{,}33°, 3{,}41°]$
Speech, Measured w. Track.	Noise B., Measured w/o Track.	$[-19{,}88°, -12{,}14°]$
Speech, Measured w. Track.	Noise B., KEMAR w/o Track.	$[-31{,}41°, -23{,}67°]$
Speech, Measured w. Track.	Noise B., Regr. w/o Track.	$[-42{,}74°, -35{,}01°]$
Speech, Measured w. Track.	Noise B., Selection w/o Track.	$[-24{,}86°, -17{,}12°]$
Speech, Measured w. Track.	Speech, Measured w/o Track.	$[-21{,}99°, -14{,}25°]$
Speech, Measured w. Track.	Speech, KEMAR w/o Track.	$[-27{,}51°, -19{,}77°]$
Speech, Measured w. Track.	Speech, Regr. w/o Track.	$[-37{,}69°, -29{,}95°]$
Speech, Measured w. Track.	Speech, Selection w/o Track.	$[-25{,}05°, -17{,}31°]$
Speech, KEMAR w. Track.	Speech, Regr. w. Track.	$[-9{,}90°, -2{,}16°]$
Speech, KEMAR w. Track.	Speech, Selection w. Track.	$[-3{,}23°, 4{,}51°]$
Speech, KEMAR w. Track.	Noise B., Measured w/o Track.	$[-18{,}78°, -11{,}04°]$
Speech, KEMAR w. Track.	Noise B., KEMAR w/o Track.	$[-30{,}31°, -22{,}57°]$
Speech, KEMAR w. Track.	Noise B., Regr. w/o Track.	$[-41{,}64°, -33{,}91°]$
Speech, KEMAR w. Track.	Noise B., Selection w/o Track.	$[-23{,}76°, -16{,}02°]$
Speech, KEMAR w. Track.	Speech, Measured w/o Track.	$[-20{,}89°, -13{,}15°]$
Speech, KEMAR w. Track.	Speech, KEMAR w/o Track.	$[-26{,}41°, -18{,}67°]$
Speech, KEMAR w. Track.	Speech, Regr. w/o Track.	$[-36{,}59°, -28{,}85°]$
Speech, KEMAR w. Track.	Speech, Selection w/o Track.	$[-23{,}95°, -16{,}21°]$
Speech, Regr. w. Track.	Speech, Selection w. Track.	$[2{,}80°, 10{,}54°]$
Speech, Regr. w. Track.	Noise B., Measured w/o Track.	$[-12{,}75°, -5{,}01°]$
Speech, Regr. w. Track.	Noise B., KEMAR w/o Track.	$[-24{,}28°, -16{,}54°]$
Speech, Regr. w. Track.	Noise B., Regr. w/o Track.	$[-35{,}62°, -27{,}88°]$
Speech, Regr. w. Track.	Noise B., Selection w/o Track.	$[-17{,}73°, -9{,}99°]$
Speech, Regr. w. Track.	Speech, Measured w/o Track.	$[-14{,}86°, -7{,}12°]$
Speech, Regr. w. Track.	Speech, KEMAR w/o Track.	$[-20{,}38°, -12{,}65°]$

Speech, Regr. w. Track.	Speech, Regr. w/o Track.	$[-30{,}57°, -22{,}83°]$
Speech, Regr. w. Track.	Speech, Selection w/o Track.	$[-17{,}92°, -10{,}18°]$
Speech, Selection w. Track.	Noise B., Measured w/o Track.	$[-19{,}42°, -11{,}68°]$
Speech, Selection w. Track.	Noise B., KEMAR w/o Track.	$[-30{,}95°, -23{,}21°]$
Speech, Selection w. Track.	Noise B., Regr. w/o Track.	$[-42{,}29°, -34{,}55°]$
Speech, Selection w. Track.	Noise B., Selection w/o Track.	$[-24{,}40°, -16{,}66°]$
Speech, Selection w. Track.	Speech, Measured w/o Track.	$[-21{,}53°, -13{,}79°]$
Speech, Selection w. Track.	Speech, KEMAR w/o Track.	$[-27{,}05°, -19{,}32°]$
Speech, Selection w. Track.	Speech, Regr. w/o Track.	$[-37{,}24°, -29{,}50°]$
Speech, Selection w. Track.	Speech, Selection w/o Track.	$[-24{,}59°, -16{,}85°]$
Noise B., Measured w/o Track.	Noise B., KEMAR w/o Track.	$[-15{,}40°, -7{,}66°]$
Noise B., Measured w/o Track.	Noise B., Regr. w/o Track.	$[-26{,}74°, -19{,}00°]$
Noise B., Measured w/o Track.	Noise B., Selection w/o Track.	$[-8{,}85°, -1{,}11°]$
Noise B., Measured w/o Track.	Speech, Measured w/o Track.	$[-5{,}98°, 1{,}76°]$
Noise B., Measured w/o Track.	Speech, KEMAR w/o Track.	$[-11{,}50°, -3{,}76°]$
Noise B., Measured w/o Track.	Speech, Regr. w/o Track.	$[-21{,}68°, -13{,}95°]$
Noise B., Measured w/o Track.	Speech, Selection w/o Track.	$[-9{,}04°, -1{,}30°]$
Noise B., KEMAR w/o Track.	Noise B., Regr. w/o Track.	$[-15{,}21°, -7{,}47°]$
Noise B., KEMAR w/o Track.	Noise B., Selection w/o Track.	$[2{,}68°, 10{,}42°]$
Noise B., KEMAR w/o Track.	Speech, Measured w/o Track.	$[5{,}55°, 13{,}29°]$
Noise B., KEMAR w/o Track.	Speech, KEMAR w/o Track.	$[0{,}03°, 7{,}77°]$
Noise B., KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-10{,}15°, -2{,}41°]$
Noise B., KEMAR w/o Track.	Speech, Selection w/o Track.	$[2{,}49°, 10{,}23°]$
Noise B., Regr. w/o Track.	Noise B., Selection w/o Track.	$[14{,}02°, 21{,}76°]$
Noise B., Regr. w/o Track.	Speech, Measured w/o Track.	$[16{,}89°, 24{,}63°]$
Noise B., Regr. w/o Track.	Speech, KEMAR w/o Track.	$[11{,}36°, 19{,}10°]$
Noise B., Regr. w/o Track.	Speech, Regr. w/o Track.	$[1{,}18°, 8{,}92°]$
Noise B., Regr. w/o Track.	Speech, Selection w/o Track.	$[13{,}83°, 21{,}56°]$
Noise B., Selection w/o Track.	Speech, Measured w/o Track.	$[-1{,}00°, 6{,}74°]$
Noise B., Selection w/o Track.	Speech, KEMAR w/o Track.	$[-6{,}52°, 1{,}21°]$
Noise B., Selection w/o Track.	Speech, Regr. w/o Track.	$[-16{,}71°, -8{,}97°]$
Noise B., Selection w/o Track.	Speech, Selection w/o Track.	$[-4{,}06°, 3{,}68°]$
Speech, Measured w/o Track.	Speech, KEMAR w/o Track.	$[-9{,}39°, -1{,}65°]$
Speech, Measured w/o Track.	Speech, Regr. w/o Track.	$[-19{,}57°, -11{,}84°]$
Speech, Measured w/o Track.	Speech, Selection w/o Track.	$[-6{,}93°, 0{,}81°]$
Speech, KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-14{,}05°, -6{,}31°]$
Speech, KEMAR w/o Track.	Speech, Selection w/o Track.	$[-1{,}41°, 6{,}33°]$
Speech, Regr. w/o Track.	Speech, Selection w/o Track.	$[8{,}77°, 16{,}51°]$

Table A.9.: Azimuth error: least significant difference for the HRTF-datasets with and without tracking and different stimuli.

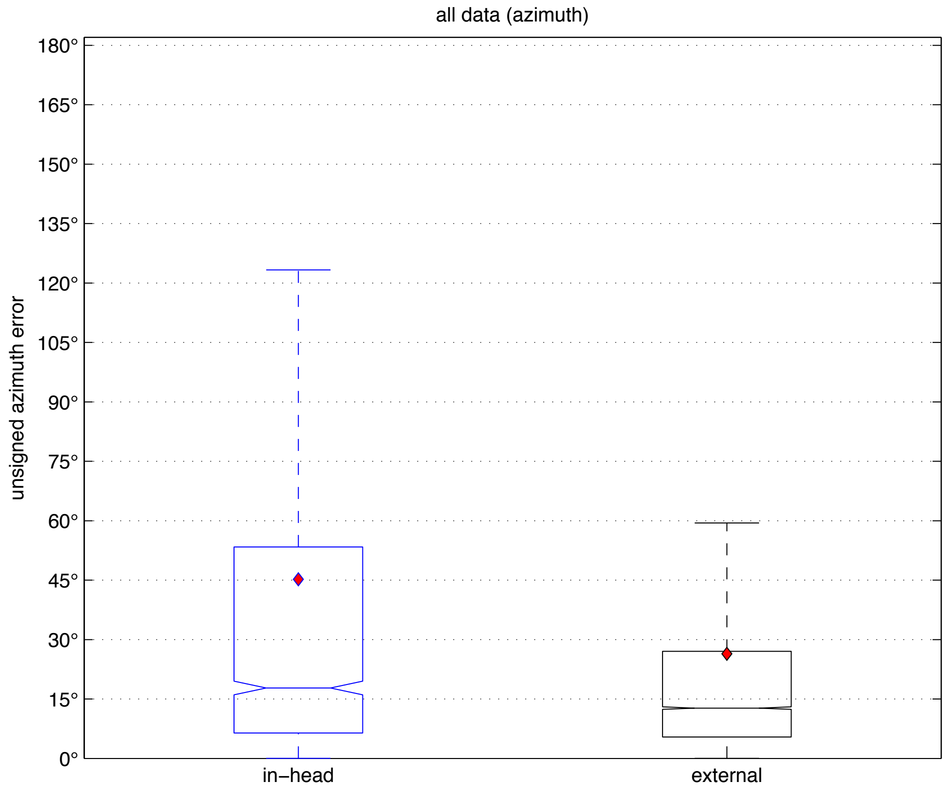
Noise B., Measured w. Track.	Noise B., KEMAR w. Track.	[−2,11°, 0,91°]
Noise B., Measured w. Track.	Noise B., Regr. w. Track.	[−7,60°, −4,59°]
Noise B., Measured w. Track.	Noise B., Selection w. Track.	[−1,34°, 1,68°]
Noise B., Measured w. Track.	Speech, Measured w. Track.	[−2,21°, 0,80°]
Noise B., Measured w. Track.	Speech, KEMAR w. Track.	[−3,05°, −0,04°]
Noise B., Measured w. Track.	Speech, Regr. w. Track.	[−7,52°, −4,51°]
Noise B., Measured w. Track.	Speech, Selection w. Track.	[−1,35°, 1,66°]
Noise B., Measured w. Track.	Noise B., Measured w/o Track.	[−5,60°, −2,59°]
Noise B., Measured w. Track.	Noise B., KEMAR w/o Track.	[−7,18°, −4,17°]
Noise B., Measured w. Track.	Noise B., Regr. w/o Track.	[−11,78°, −8,77°]
Noise B., Measured w. Track.	Noise B., Selection w/o Track.	[−6,25°, −3,24°]
Noise B., Measured w. Track.	Speech, Measured w/o Track.	[−6,75°, −3,74°]
Noise B., Measured w. Track.	Speech, KEMAR w/o Track.	[−8,04°, −5,03°]
Noise B., Measured w. Track.	Speech, Regr. w/o Track.	[−12,26°, −9,25°]
Noise B., Measured w. Track.	Speech, Selection w/o Track.	[−7,32°, −4,30°]
Noise B., KEMAR w. Track.	Noise B., Regr. w. Track.	[−7,00°, −3,99°]
Noise B., KEMAR w. Track.	Noise B., Selection w. Track.	[−0,73°, 2,28°]
Noise B., KEMAR w. Track.	Speech, Measured w. Track.	[−1,61°, 1,41°]
Noise B., KEMAR w. Track.	Speech, KEMAR w. Track.	[−2,45°, 0,56°]
Noise B., KEMAR w. Track.	Speech, Regr. w. Track.	[−6,92°, −3,90°]
Noise B., KEMAR w. Track.	Speech, Selection w. Track.	[−0,75°, 2,26°]
Noise B., KEMAR w. Track.	Noise B., Measured w/o Track.	[−5,00°, −1,99°]
Noise B., KEMAR w. Track.	Noise B., KEMAR w/o Track.	[−6,58°, −3,57°]
Noise B., KEMAR w. Track.	Noise B., Regr. w/o Track.	[−11,18°, −8,17°]
Noise B., KEMAR w. Track.	Noise B., Selection w/o Track.	[−5,65°, −2,64°]
Noise B., KEMAR w. Track.	Speech, Measured w/o Track.	[−6,15°, −3,14°]
Noise B., KEMAR w. Track.	Speech, KEMAR w/o Track.	[−7,44°, −4,43°]
Noise B., KEMAR w. Track.	Speech, Regr. w/o Track.	[−11,66°, −8,65°]
Noise B., KEMAR w. Track.	Speech, Selection w/o Track.	[−6,71°, −3,70°]
Noise B., Regr. w. Track.	Noise B., Selection w. Track.	[4,76°, 7,77°]
Noise B., Regr. w. Track.	Speech, Measured w. Track.	[3,89°, 6,90°]
Noise B., Regr. w. Track.	Speech, KEMAR w. Track.	[3,05°, 6,06°]
Noise B., Regr. w. Track.	Speech, Regr. w. Track.	[−1,42°, 1,59°]
Noise B., Regr. w. Track.	Speech, Selection w. Track.	[4,75°, 7,76°]
Noise B., Regr. w. Track.	Noise B., Measured w/o Track.	[0,50°, 3,51°]
Noise B., Regr. w. Track.	Noise B., KEMAR w/o Track.	[−1,08°, 1,93°]
Noise B., Regr. w. Track.	Noise B., Regr. w/o Track.	[−5,69°, −2,67°]
Noise B., Regr. w. Track.	Noise B., Selection w/o Track.	[−0,15°, 2,86°]
Noise B., Regr. w. Track.	Speech, Measured w/o Track.	[−0,65°, 2,36°]
Noise B., Regr. w. Track.	Speech, KEMAR w/o Track.	[−1,95°, 1,06°]
Noise B., Regr. w. Track.	Speech, Regr. w/o Track.	[−6,17°, −3,15°]

Noise B., Regr. w. Track.	Speech, Selection w/o Track.	$[-1{,}22°, 1{,}79°]$
Noise B., Selection w. Track.	Speech, Measured w. Track.	$[-2{,}38°, 0{,}63°]$
Noise B., Selection w. Track.	Speech, KEMAR w. Track.	$[-3{,}22°, -0{,}21°]$
Noise B., Selection w. Track.	Speech, Regr. w. Track.	$[-7{,}69°, -4{,}68°]$
Noise B., Selection w. Track.	Speech, Selection w. Track.	$[-1{,}52°, 1{,}49°]$
Noise B., Selection w. Track.	Noise B., Measured w/o Track.	$[-5{,}77°, -2{,}76°]$
Noise B., Selection w. Track.	Noise B., KEMAR w/o Track.	$[-7{,}35°, -4{,}34°]$
Noise B., Selection w. Track.	Noise B., Regr. w/o Track.	$[-11{,}95°, -8{,}94°]$
Noise B., Selection w. Track.	Noise B., Selection w/o Track.	$[-6{,}42°, -3{,}41°]$
Noise B., Selection w. Track.	Speech, Measured w/o Track.	$[-6{,}92°, -3{,}91°]$
Noise B., Selection w. Track.	Speech, KEMAR w/o Track.	$[-8{,}21°, -5{,}20°]$
Noise B., Selection w. Track.	Speech, Regr. w/o Track.	$[-12{,}43°, -9{,}42°]$
Noise B., Selection w. Track.	Speech, Selection w/o Track.	$[-7{,}49°, -4{,}47°]$
Speech, Measured w. Track.	Speech, KEMAR w. Track.	$[-2{,}35°, 0{,}66°]$
Speech, Measured w. Track.	Speech, Regr. w. Track.	$[-6{,}82°, -3{,}80°]$
Speech, Measured w. Track.	Speech, Selection w. Track.	$[-0{,}65°, 2{,}36°]$
Speech, Measured w. Track.	Noise B., Measured w/o Track.	$[-4{,}90°, -1{,}89°]$
Speech, Measured w. Track.	Noise B., KEMAR w/o Track.	$[-6{,}48°, -3{,}47°]$
Speech, Measured w. Track.	Noise B., Regr. w/o Track.	$[-11{,}08°, -8{,}07°]$
Speech, Measured w. Track.	Noise B., Selection w/o Track.	$[-5{,}55°, -2{,}54°]$
Speech, Measured w. Track.	Speech, Measured w/o Track.	$[-6{,}05°, -3{,}04°]$
Speech, Measured w. Track.	Speech, KEMAR w/o Track.	$[-7{,}34°, -4{,}33°]$
Speech, Measured w. Track.	Speech, Regr. w/o Track.	$[-11{,}56°, -8{,}55°]$
Speech, Measured w. Track.	Speech, Selection w/o Track.	$[-6{,}61°, -3{,}60°]$
Speech, KEMAR w. Track.	Speech, Regr. w. Track.	$[-5{,}97°, -2{,}96°]$
Speech, KEMAR w. Track.	Speech, Selection w. Track.	$[0{,}19°, 3{,}20°]$
Speech, KEMAR w. Track.	Noise B., Measured w/o Track.	$[-4{,}06°, -1{,}04°]$
Speech, KEMAR w. Track.	Noise B., KEMAR w/o Track.	$[-5{,}64°, -2{,}63°]$
Speech, KEMAR w. Track.	Noise B., Regr. w/o Track.	$[-10{,}24°, -7{,}23°]$
Speech, KEMAR w. Track.	Noise B., Selection w/o Track.	$[-4{,}71°, -1{,}69°]$
Speech, KEMAR w. Track.	Speech, Measured w/o Track.	$[-5{,}21°, -2{,}19°]$
Speech, KEMAR w. Track.	Speech, KEMAR w/o Track.	$[-6{,}50°, -3{,}49°]$
Speech, KEMAR w. Track.	Speech, Regr. w/o Track.	$[-10{,}72°, -7{,}71°]$
Speech, KEMAR w. Track.	Speech, Selection w/o Track.	$[-5{,}77°, -2{,}76°]$
Speech, Regr. w. Track.	Speech, Selection w. Track.	$[4{,}66°, 7{,}67°]$
Speech, Regr. w. Track.	Noise B., Measured w/o Track.	$[0{,}41°, 3{,}42°]$
Speech, Regr. w. Track.	Noise B., KEMAR w/o Track.	$[-1{,}17°, 1{,}84°]$
Speech, Regr. w. Track.	Noise B., Regr. w/o Track.	$[-5{,}77°, -2{,}76°]$
Speech, Regr. w. Track.	Noise B., Selection w/o Track.	$[-0{,}24°, 2{,}77°]$
Speech, Regr. w. Track.	Speech, Measured w/o Track.	$[-0{,}74°, 2{,}27°]$
Speech, Regr. w. Track.	Speech, KEMAR w/o Track.	$[-2{,}03°, 0{,}98°]$

Speech, Regr. w. Track.	Speech, Regr. w/o Track.	$[-6{,}25°, -3{,}24°]$
Speech, Regr. w. Track.	Speech, Selection w/o Track.	$[-1{,}30°, 1{,}71°]$
Speech, Selection w. Track.	Noise B., Measured w/o Track.	$[-5{,}75°, -2{,}74°]$
Speech, Selection w. Track.	Noise B., KEMAR w/o Track.	$[-7{,}33°, -4{,}32°]$
Speech, Selection w. Track.	Noise B., Regr. w/o Track.	$[-11{,}94°, -8{,}93°]$
Speech, Selection w. Track.	Noise B., Selection w/o Track.	$[-6{,}40°, -3{,}39°]$
Speech, Selection w. Track.	Speech, Measured w/o Track.	$[-6{,}90°, -3{,}89°]$
Speech, Selection w. Track.	Speech, KEMAR w/o Track.	$[-8{,}20°, -5{,}19°]$
Speech, Selection w. Track.	Speech, Regr. w/o Track.	$[-12{,}42°, -9{,}41°]$
Speech, Selection w. Track.	Speech, Selection w/o Track.	$[-7{,}47°, -4{,}46°]$
Noise B., Measured w/o Track.	Noise B., KEMAR w/o Track.	$[-3{,}09°, -0{,}08°]$
Noise B., Measured w/o Track.	Noise B., Regr. w/o Track.	$[-7{,}69°, -4{,}68°]$
Noise B., Measured w/o Track.	Noise B., Selection w/o Track.	$[-2{,}16°, 0{,}86°]$
Noise B., Measured w/o Track.	Speech, Measured w/o Track.	$[-2{,}66°, 0{,}36°]$
Noise B., Measured w/o Track.	Speech, KEMAR w/o Track.	$[-3{,}95°, -0{,}94°]$
Noise B., Measured w/o Track.	Speech, Regr. w/o Track.	$[-8{,}17°, -5{,}16°]$
Noise B., Measured w/o Track.	Speech, Selection w/o Track.	$[-3{,}22°, -0{,}21°]$
Noise B., KEMAR w/o Track.	Noise B., Regr. w/o Track.	$[-6{,}11°, -3{,}10°]$
Noise B., KEMAR w/o Track.	Noise B., Selection w/o Track.	$[-0{,}57°, 2{,}44°]$
Noise B., KEMAR w/o Track.	Speech, Measured w/o Track.	$[-1{,}07°, 1{,}94°]$
Noise B., KEMAR w/o Track.	Speech, KEMAR w/o Track.	$[-2{,}37°, 0{,}64°]$
Noise B., KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-6{,}59°, -3{,}58°]$
Noise B., KEMAR w/o Track.	Speech, Selection w/o Track.	$[-1{,}64°, 1{,}37°]$
Noise B., Regr. w/o Track.	Noise B., Selection w/o Track.	$[4{,}03°, 7{,}04°]$
Noise B., Regr. w/o Track.	Speech, Measured w/o Track.	$[3{,}53°, 6{,}54°]$
Noise B., Regr. w/o Track.	Speech, KEMAR w/o Track.	$[2{,}23°, 5{,}25°]$
Noise B., Regr. w/o Track.	Speech, Regr. w/o Track.	$[-1{,}98°, 1{,}03°]$
Noise B., Regr. w/o Track.	Speech, Selection w/o Track.	$[2{,}96°, 5{,}97°]$
Noise B., Selection w/o Track.	Speech, Measured w/o Track.	$[-2{,}01°, 1{,}01°]$
Noise B., Selection w/o Track.	Speech, KEMAR w/o Track.	$[-3{,}30°, -0{,}29°]$
Noise B., Selection w/o Track.	Speech, Regr. w/o Track.	$[-7{,}52°, -4{,}51°]$
Noise B., Selection w/o Track.	Speech, Selection w/o Track.	$[-2{,}57°, 0{,}44°]$
Speech, Measured w/o Track.	Speech, KEMAR w/o Track.	$[-2{,}80°, 0{,}21°]$
Speech, Measured w/o Track.	Speech, Regr. w/o Track.	$[-7{,}02°, -4{,}01°]$
Speech, Measured w/o Track.	Speech, Selection w/o Track.	$[-2{,}07°, 0{,}94°]$
Speech, KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-5{,}72°, -2{,}71°]$
Speech, KEMAR w/o Track.	Speech, Selection w/o Track.	$[-0{,}78°, 2{,}24°]$
Speech, Regr. w/o Track.	Speech, Selection w/o Track.	$[3{,}44°, 6{,}45°]$

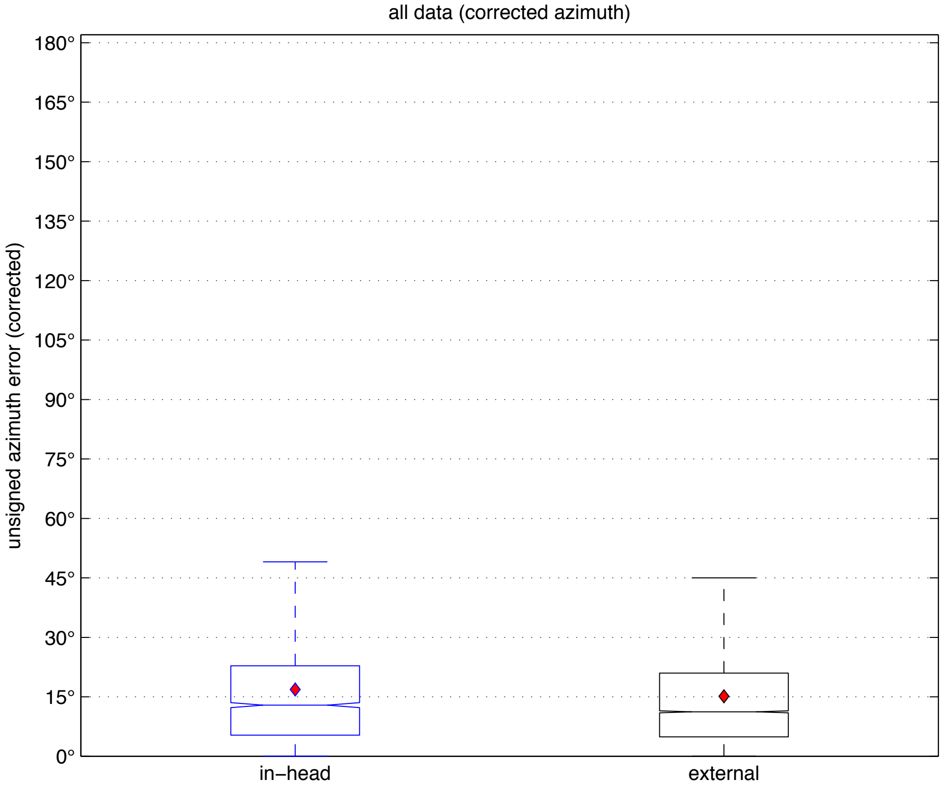
Table A.10.: Corrected azimuth error: least significant difference for the HRTF-datasets with and without head-tracking and different stimuli.

A.9. In-Head and External



	in−head	external
mean	45.22°	26.41°
std. dev.	57.83°	37.28°
median	17.78°	12.71°

Figure A.117.: Boxplot, azimuth error in-head and external.



	in−head	external
mean	16.83°	15.13°
std. dev.	17.63°	15.37°
median	12.89°	11.21°

Figure A.118.: Boxplot, corrected azimuth error in-head and external.

B. Elevation Localization Error Plots

B.1. All Data

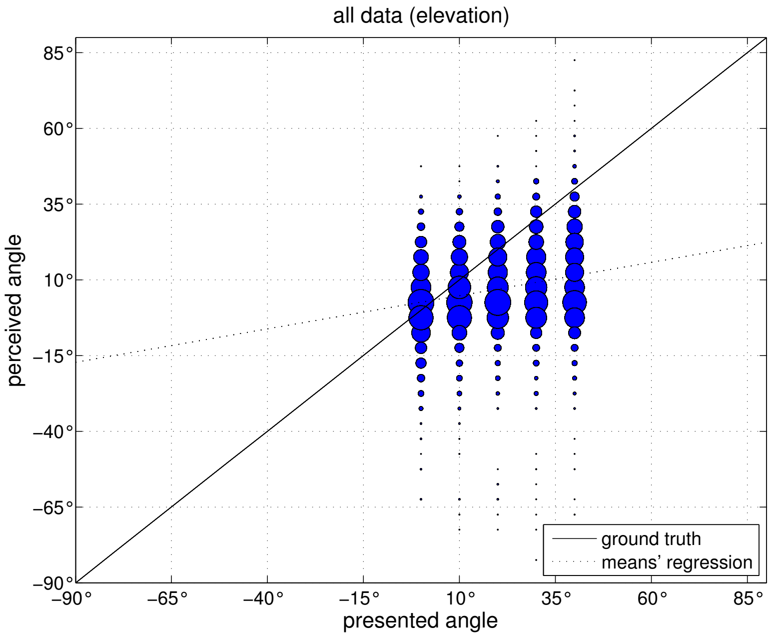
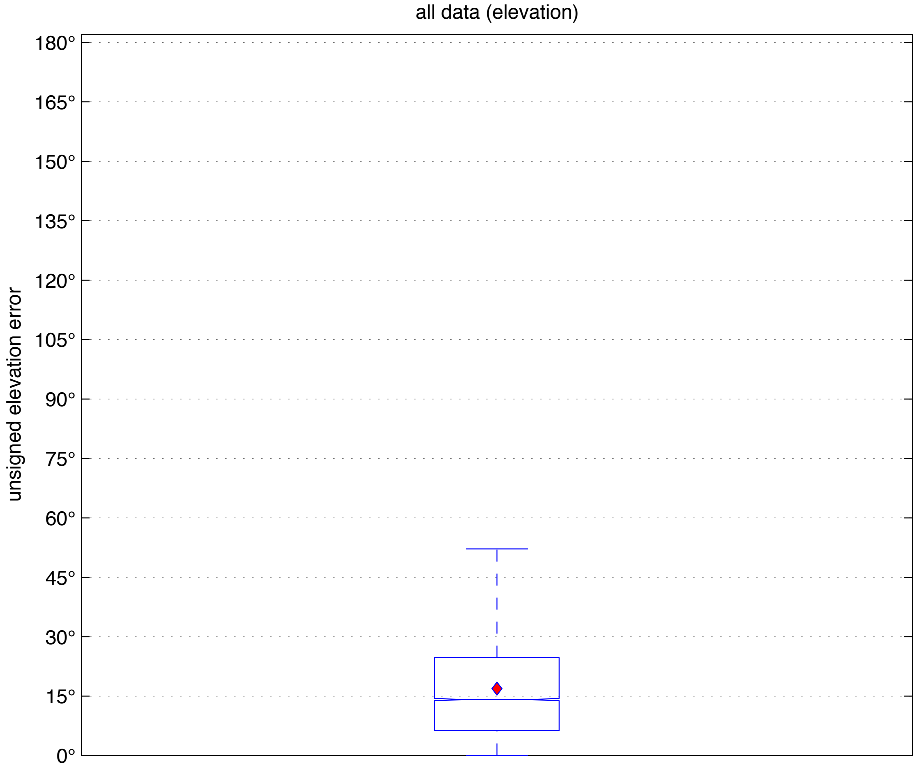


Figure B.1.: Elevation answers.



	all data
mean	16.88°
std. dev.	13.13°
median	14.14°

Figure B.2.: Boxplot, elevation error.

B.2. Comparison of Head-Tracking

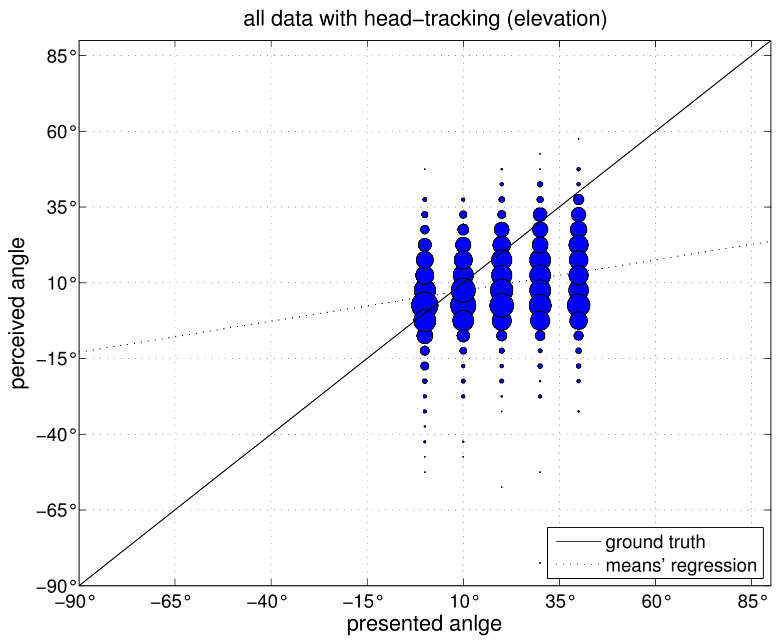


Figure B.3.: Scatterplot, elevation answers with head-tracking

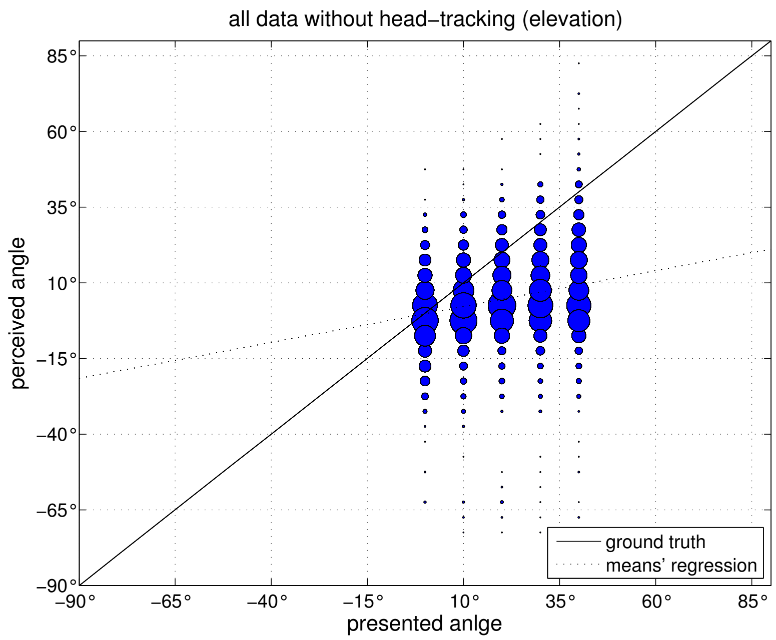
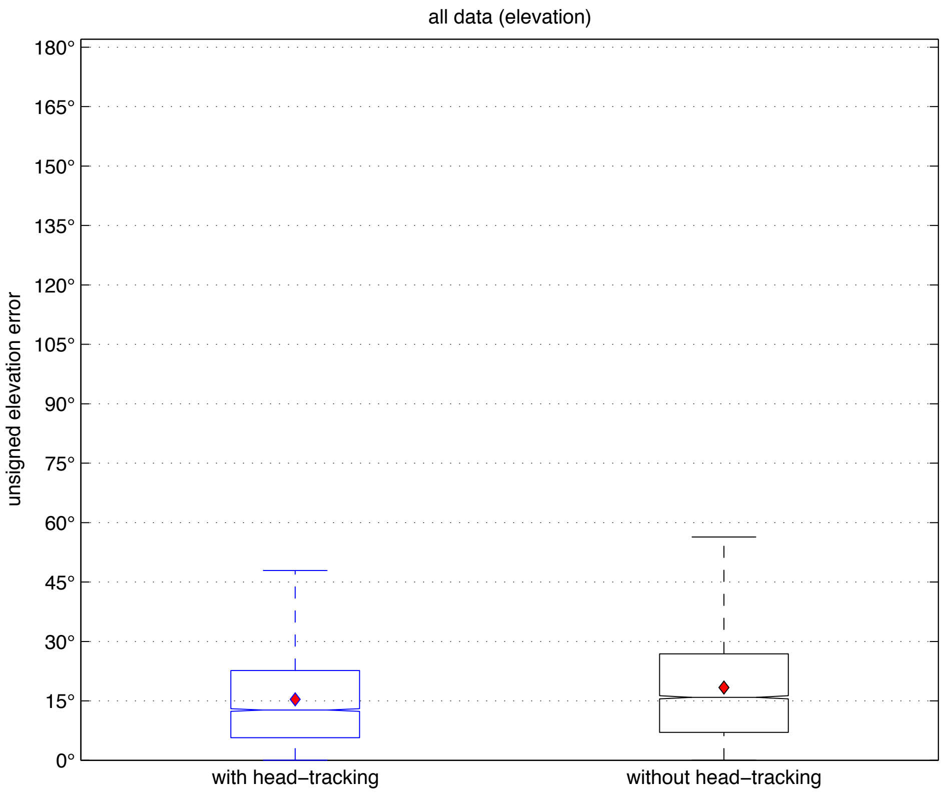


Figure B.4.: Scatterplot, elevation answers without head-tracking



	with tracking	without tracking
mean	15.40°	18.36°
std. dev.	11.98°	14.03°
median	12.67°	15.90°

Figure B.5.: Boxplot, elevation error, $p < 0.01$

B.3. Comparison of Stimuli

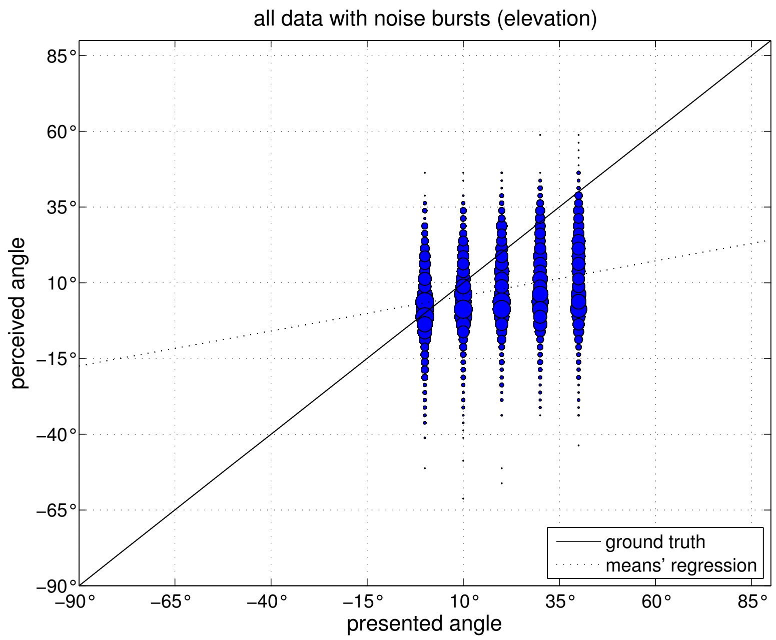


Figure B.6.: Scatterplot, elevation answers with noise.

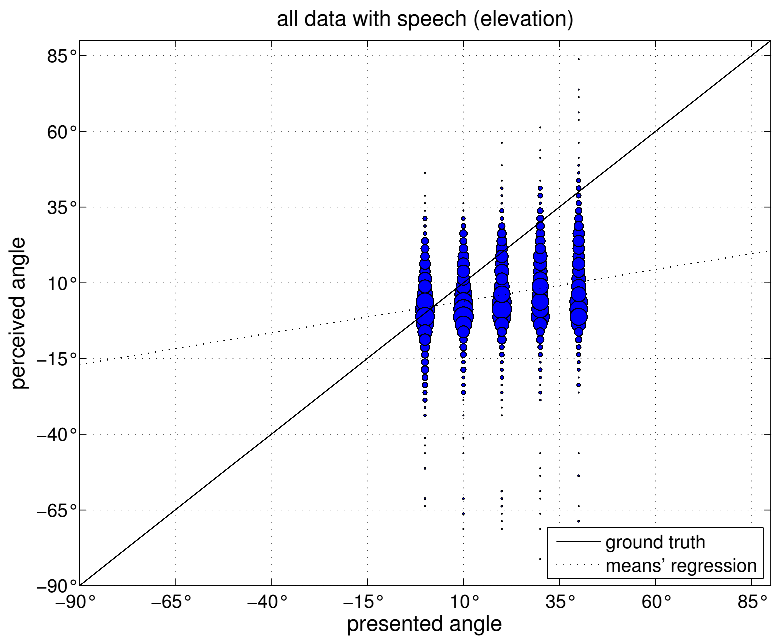
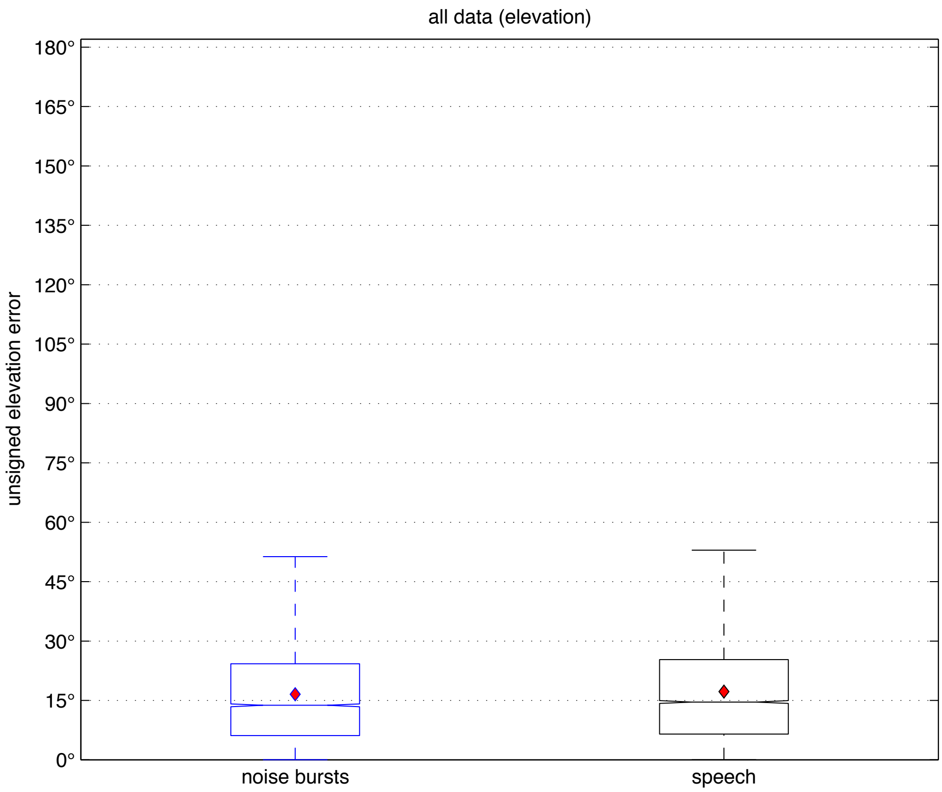


Figure B.7.: Scatterplot, elevation answers with speech.



	noise bursts	speech
mean	16.54°	17.22°
std. dev.	12.80°	13.44°
median	13.78°	14.60°

Figure B.8.: Boxplot, elevation error, $p < 0.01$

B.4. Comparison of HRTF-Sets

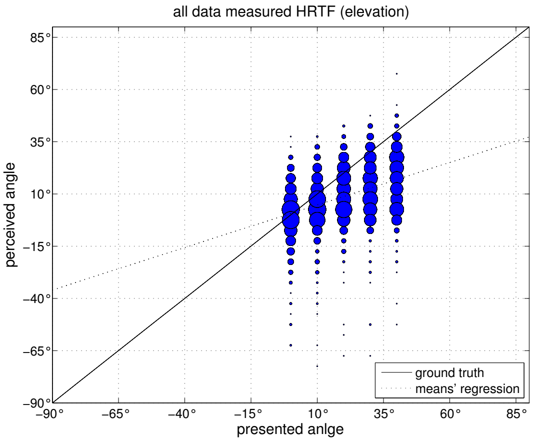


Figure B.9.: Scatterplot, elevation answers with measured HRTF.

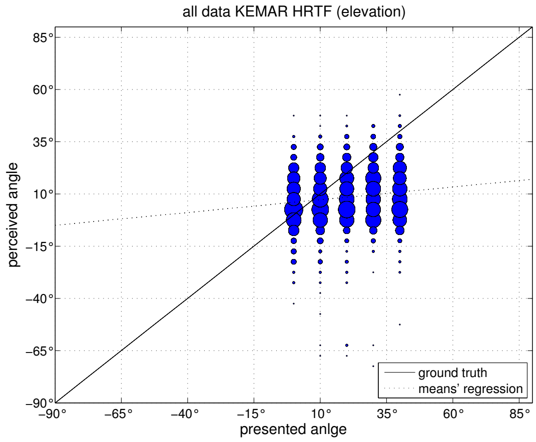


Figure B.10.: Scatterplot, elevation answers with KEMAR HRTF.

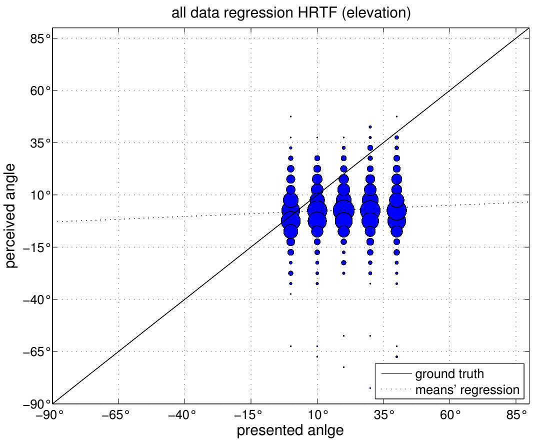


Figure B.11.: Scatterplot, elevation answers with regression HRTF.

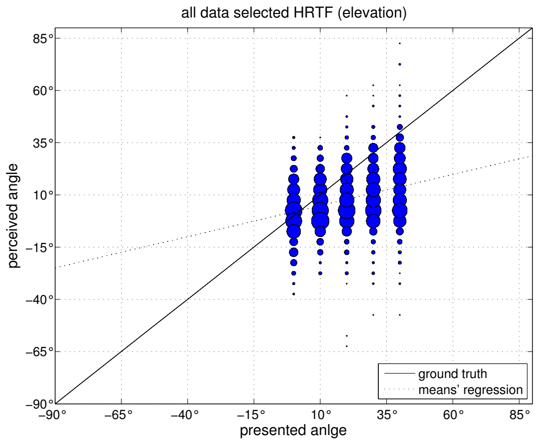
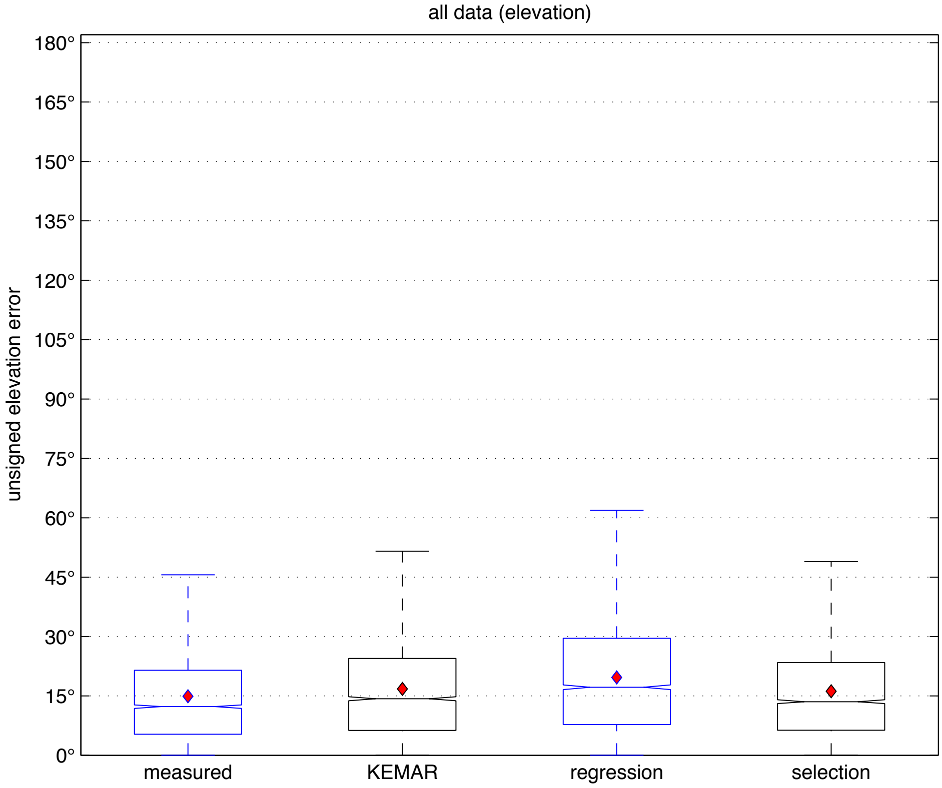


Figure B.12.: Scatterplot, elevation answers with selected HRTF.



	measured	KEMAR	regression	selection
mean	14.92°	16.75°	19.65°	16.20°
std. dev.	12.39°	12.77°	14.41°	12.39°
median	12.30°	14.30°	17.19°	13.54°

Figure B.13.: Boxplot, elevation error.

Measured HRTF	KEMAR HRTF	$[-2{,}47°, -1{,}20°]$
Measured HRTF	Regression HRTF	$[-5{,}37°, -4{,}10°]$
Measured HRTF	Selection HRTF	$[-1{,}92°, -0{,}64°]$
KEMAR HRTF	Regression HRTF	$[-3{,}54°, -2{,}26°]$
KEMAR HRTF	Selection HRTF	$[-0{,}08°, 1{,}20°]$
Regression HRTF	Selection HRTF	$[2{,}82°, 4{,}09°]$

Table B.1.: Elevation error: least significant difference for the HRTF-datasets.

B.5. Comparison of Stimuli with and without Head-Tracking

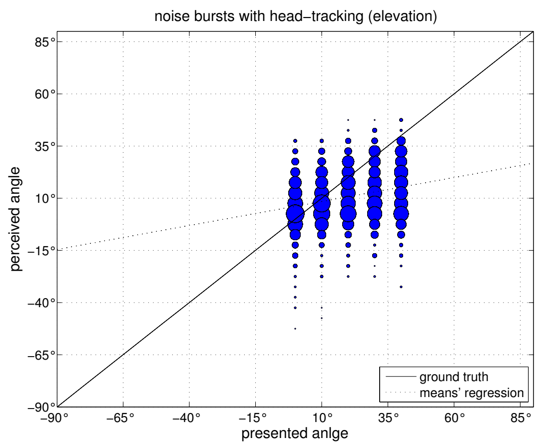


Figure B.14.: Scatterplot, elevation answers with head-tracking, noise bursts.

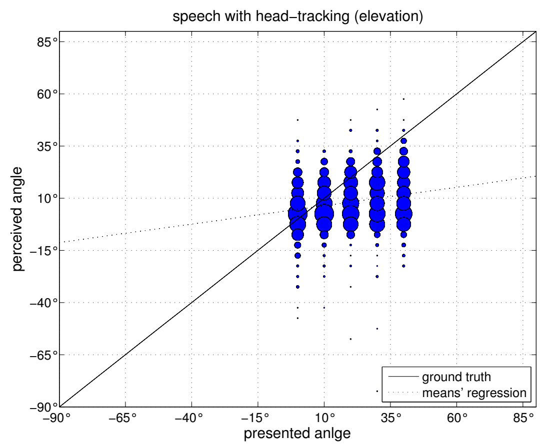


Figure B.15.: Scatterplot, elevation answers with head-tracking, speech.

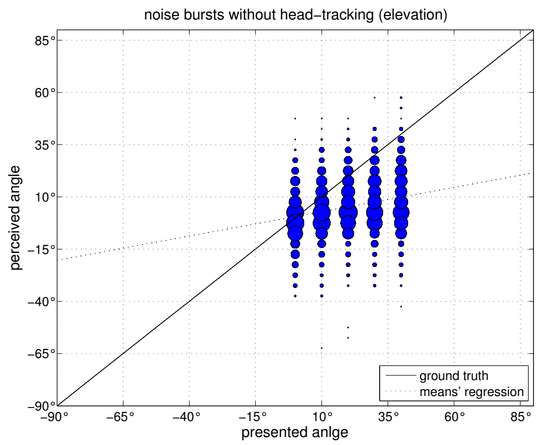


Figure B.16.: Scatterplot, elevation answers without headtracking, noise bursts.

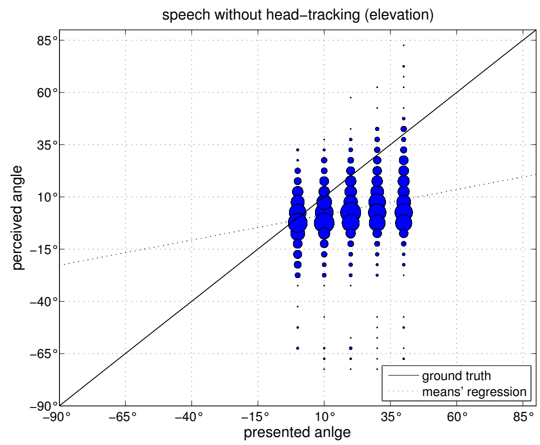
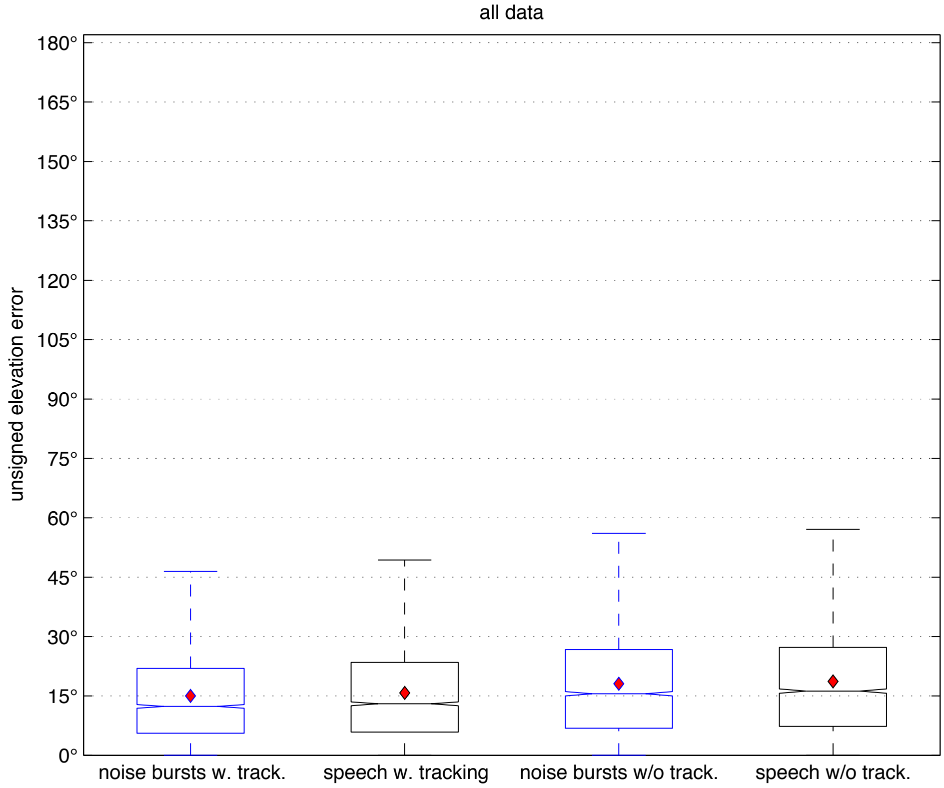


Figure B.17.: Scatterplot, elevation answers without head-tracking, speech.



	noise b. w. track.	speech w. track.	noise b. w/o track.	speech w/o track.
mean	15.02°	15.78°	18.06°	18.67°
std. dev.	11.72°	12.23°	13.63°	14.42°
median	12.35°	13.02°	15.56°	16.23°

Figure B.18.: Boxplot, elevation error.

Noise Bursts w. Tracking	Speech w. Tracking	[−1,39°, −0,12°]
Noise Bursts w. Tracking	Noise w/o Tracking	[−3,68°, −2,40°]
Noise Bursts w. Tracking	Speech w/o Tracking	[−4,29°, −3,01°]
Speech w. Tracking	Noise w/o Tracking	[−2,92°, −1,64°]
Speech w. Tracking	Speech w/o Tracking	[−3,53°, −2,25°]
Noise w/o Tracking	Speech w/o Tracking	[−1,25°, 0,03°]

Table B.2.: Elevation error: least significant difference for the stimuli with and without head-tracking.

B.6. Comparison of HRTF-Sets with and without head-tracking

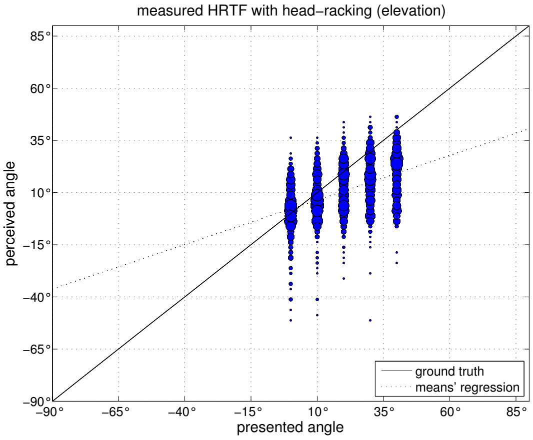


Figure B.19.: Scatterplot, elevation answers with measured HRTF with head-tracking.

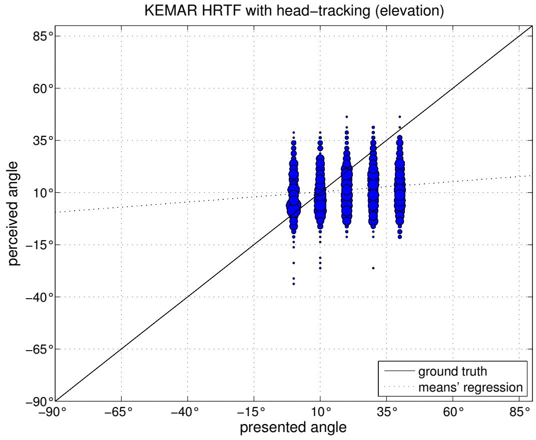


Figure B.20.: Scatterplot, elevation answers with KEMAR HRTF with head-tracking.

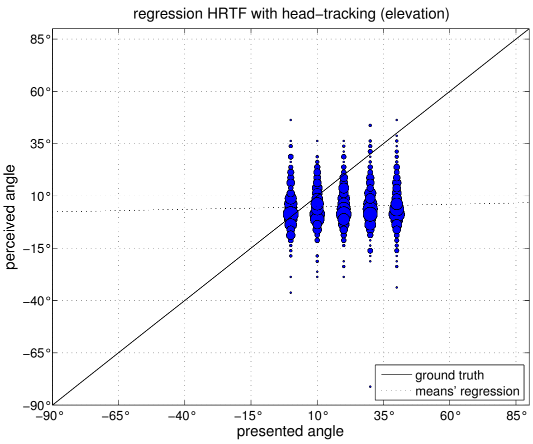


Figure B.21.: Scatterplot, elevation answers with regression HRTF with head-tracking.

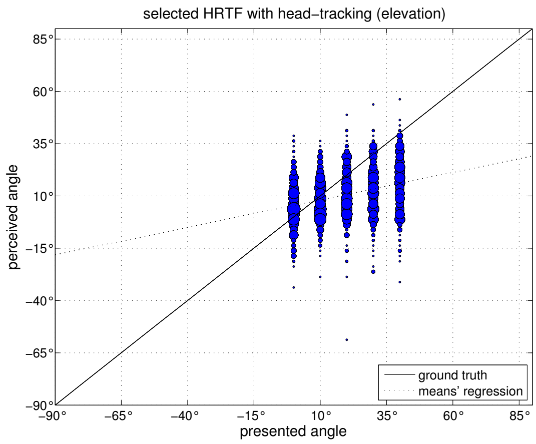
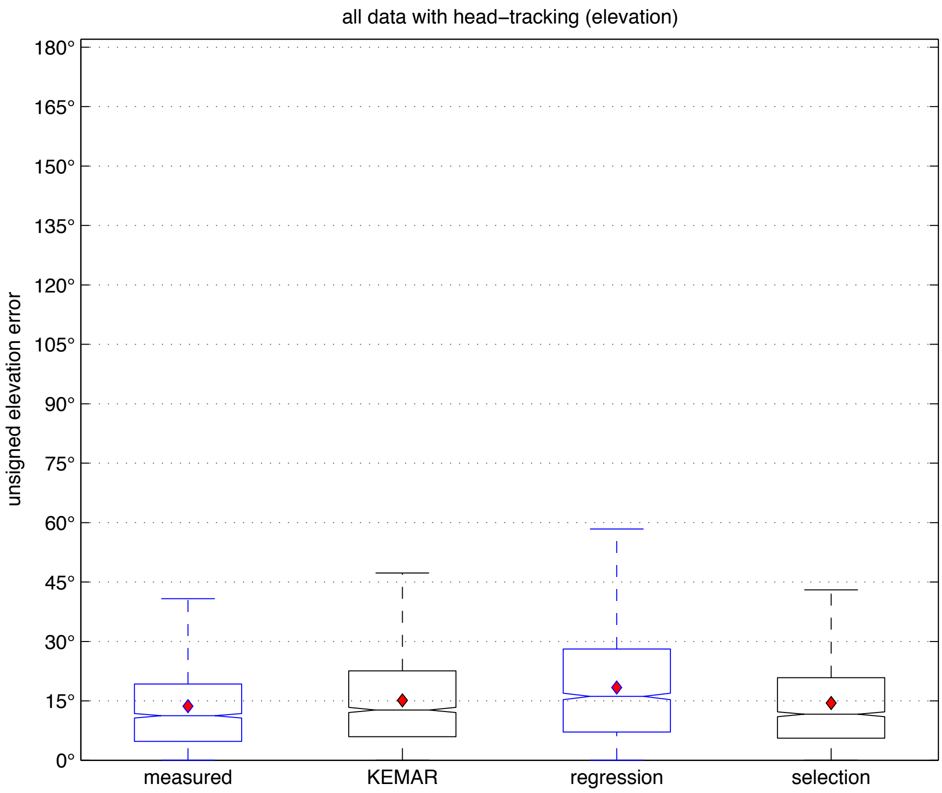


Figure B.22.: Scatterplot, elevation answers with selected HRTF with head-tracking.



	measured	KEMAR	regression	selection
mean	13.64°	15.13°	18.36°	14.46°
std. dev.	11.09°	11.22°	13.49°	11.42°
median	11.24°	12.70°	16.12°	11.62°

Figure B.23.: Boxplot, elevation error with head-tracking.

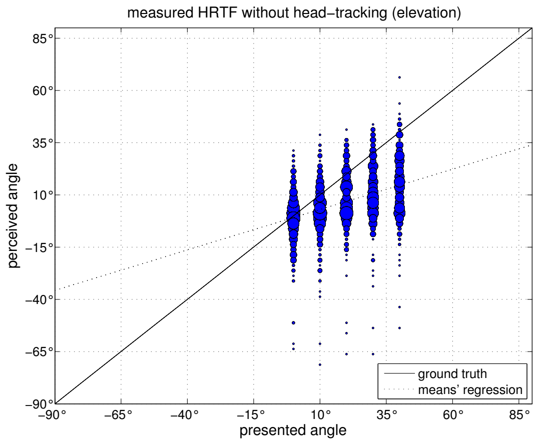


Figure B.24.: Scatterplot, elevation answers with measured HRTF without head-tracking.

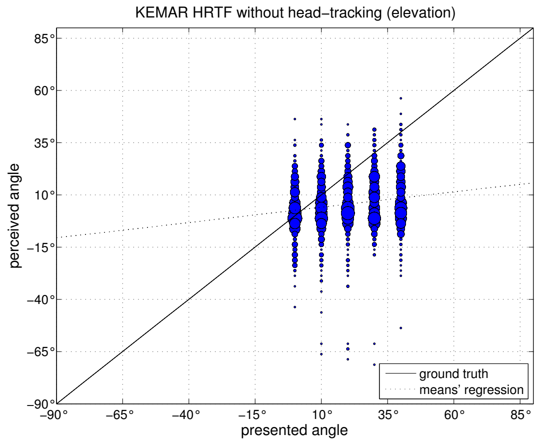


Figure B.25.: Scatterplot, elevation answers with KEMAR HRTF without head-tracking.

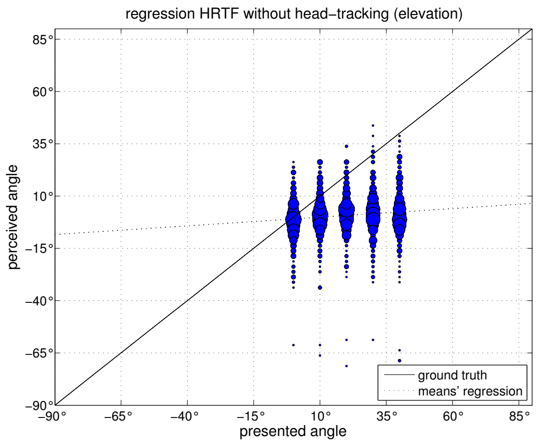


Figure B.26.: Scatterplot, elevation answers with regression HRTF without head-tracking.

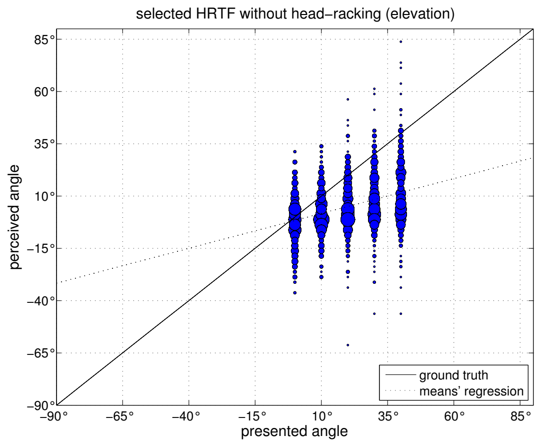
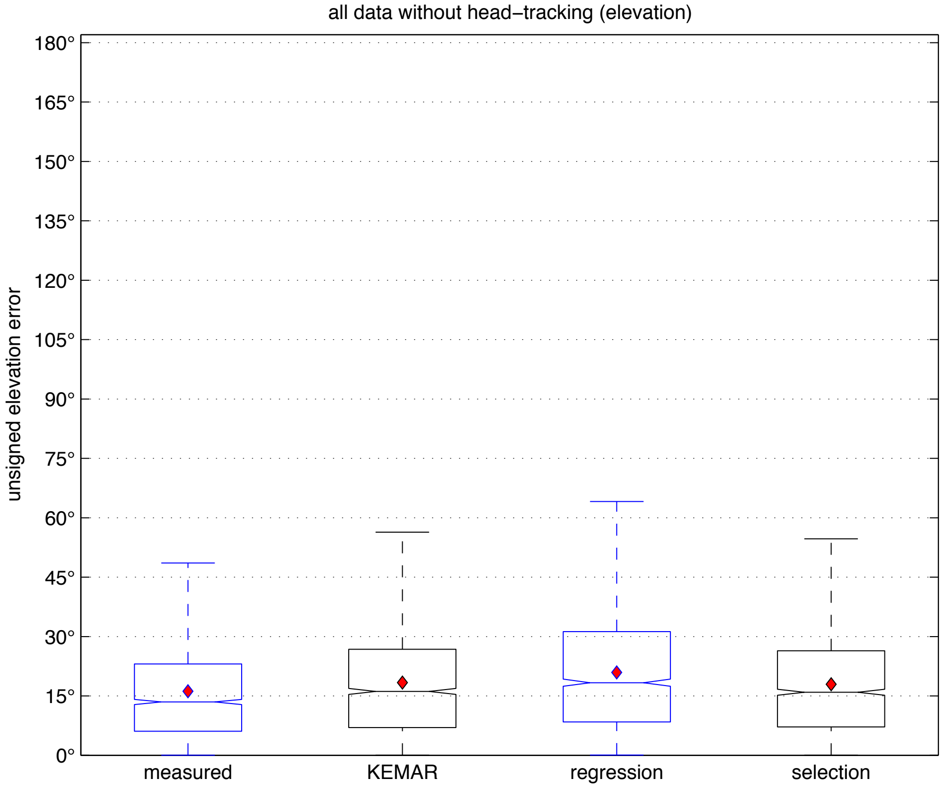


Figure B.27.: Scatterplot, elevation answers with selected HRTF without head-tracking.



	measured	KEMAR	regression	selection
mean	16.19°	18.38°	20.94°	17.93°
std. dev.	13.44°	13.96°	15.16°	13.06°
median	13.47°	16.14°	18.35°	15.92°

Figure B.28.: Boxplot, elevation error without head-tracking.

Measured HRTF w. Tracking	KEMAR HRTF w. Tracking	$[-2{,}38°, -0{,}59°]$
Measured HRTF w. Tracking	Regression HRTF w. Tracking	$[-5{,}62°, -3{,}82°]$
Measured HRTF w. Tracking	Selection HRTF w. Tracking	$[-1{,}72°, 0{,}08°]$
Measured HRTF w. Tracking	Measured HRTF w/o Tracking	$[-3{,}45°, -1{,}65°]$
Measured HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-5{,}64°, -3{,}84°]$
Measured HRTF w. Tracking	Regression HRTF w/o Tracking	$[-8{,}20°, -6{,}41°]$
Measured HRTF w. Tracking	Selection HRTF w/o Tracking	$[-5{,}18°, -3{,}39°]$
KEMAR HRTF w. Tracking	Regression HRTF w. Tracking	$[-4{,}13°, -2{,}34°]$
KEMAR HRTF w. Tracking	Selection HRTF w. Tracking	$[-0{,}23°, 1{,}56°]$
KEMAR HRTF w. Tracking	Measured HRTF w/o Tracking	$[-1{,}96°, -0{,}17°]$
KEMAR HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-4{,}15°, -2{,}36°]$
KEMAR HRTF w. Tracking	Regression HRTF w/o Tracking	$[-6{,}71°, -4{,}92°]$
KEMAR HRTF w. Tracking	Selection HRTF w/o Tracking	$[-3{,}70°, -1{,}91°]$
Regression HRTF w. Tracking	Selection HRTF w. Tracking	$[3{,}00°, 4{,}80°]$
Regression HRTF w. Tracking	Measured HRTF w/o Tracking	$[1{,}28°, 3{,}07°]$
Regression HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-0{,}92°, 0{,}88°]$
Regression HRTF w. Tracking	Regression HRTF w/o Tracking	$[-3{,}48°, -1{,}68°]$
Regression HRTF w. Tracking	Selection HRTF w/o Tracking	$[-0{,}46°, 1{,}33°]$
Selection HRTF w. Tracking	Measured HRTF w/o Tracking	$[-2{,}63°, -0{,}83°]$
Selection HRTF w. Tracking	KEMAR HRTF w/o Tracking	$[-4{,}82°, -3{,}02°]$
Selection HRTF w. Tracking	Regression HRTF w/o Tracking	$[-7{,}38°, -5{,}59°]$
Selection HRTF w. Tracking	Selection HRTF w/o Tracking	$[-4{,}37°, -2{,}57°]$
Measured HRTF w/o Tracking	KEMAR HRTF w/o Tracking	$[-3{,}09°, -1{,}29°]$
Measured HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-5{,}65°, -3{,}86°]$
Measured HRTF w/o Tracking	Selection HRTF w/o Tracking	$[-2{,}64°, -0{,}84°]$
KEMAR HRTF w/o Tracking	Regression HRTF w/o Tracking	$[-3{,}46°, -1{,}67°]$
KEMAR HRTF w/o Tracking	Selection HRTF w/o Tracking	$[-0{,}44°, 1{,}35°]$
Regression HRTF w/o Tracking	Selection HRTF w/o Tracking	$[2{,}12°, 3{,}91°]$

Table B.3.: Elevation error: least significant difference for the HRTF-datasets with and without head-tracking.

B.7. Comparison of HRTF-Sets for the Two Stimuli

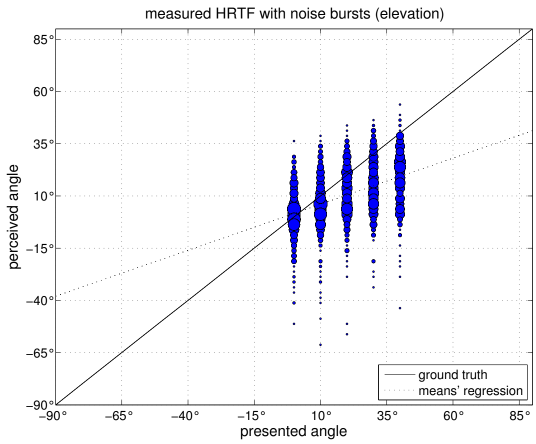


Figure B.29.: Scatterplot, elevation answers with measured HRTF with noise bursts.

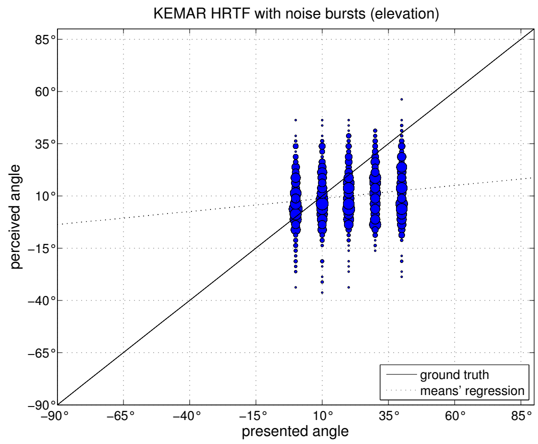


Figure B.30.: Scatterplot, elevation answers with KEMAR HRTF with noise bursts.

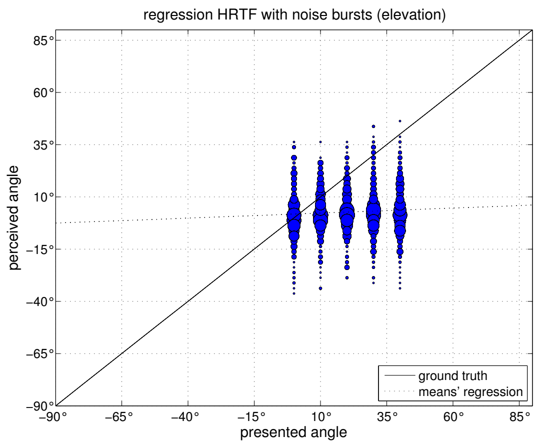


Figure B.31.: Scatterplot, elevation answers with regression HRTF with noise bursts.

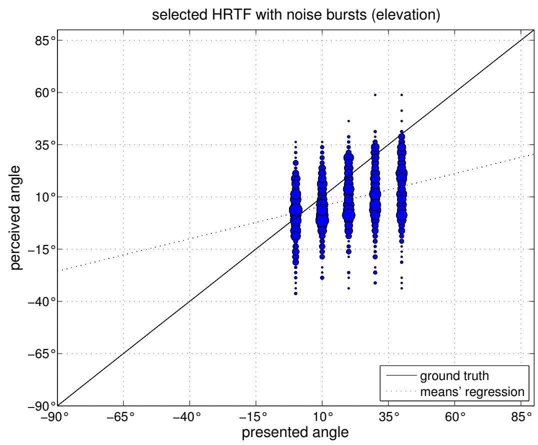
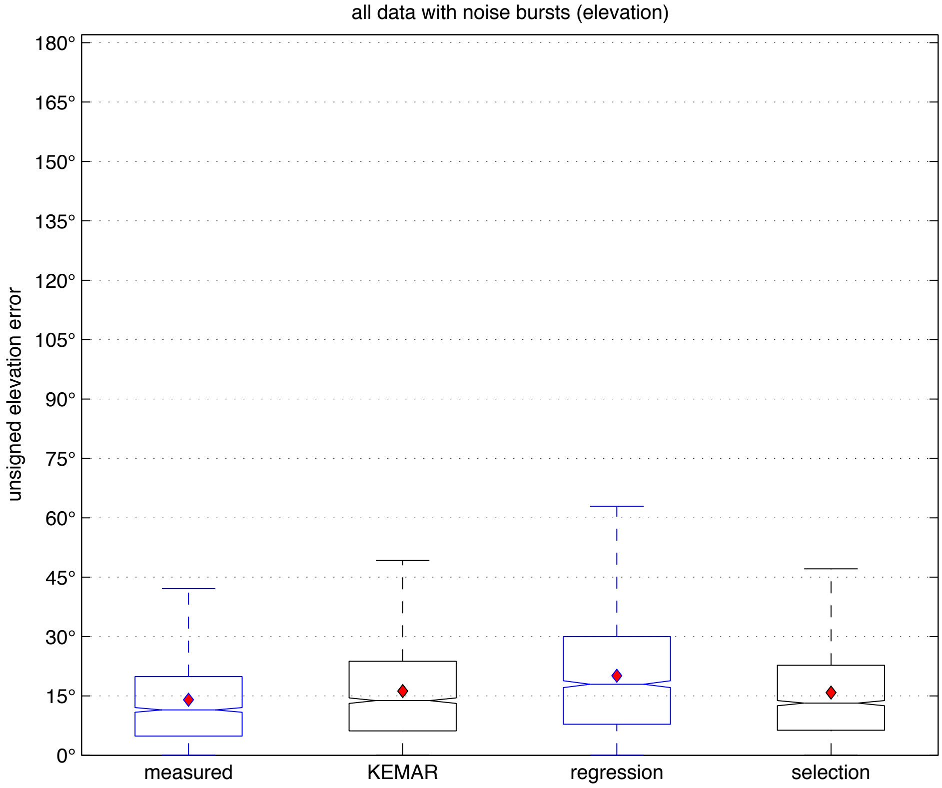


Figure B.32.: Scatterplot, elevation answers with selected HRTF with noise bursts.



	measured	KEMAR	regression	selection
mean	14.02°	16.22°	20.09°	15.84°
std. dev.	11.60°	12.10°	14.36°	12.19°
median	11.46°	13.82°	17.96°	13.18°

Figure B.33.: Boxplot, elevation error with noise bursts.

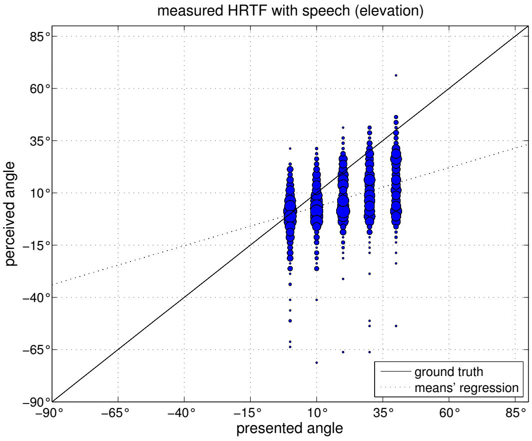


Figure B.34.: Scatterplot, elevation answers with measured HRTF with speech.

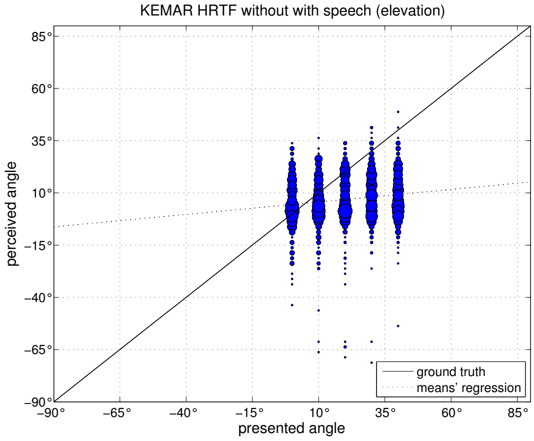


Figure B.35.: Scatterplot, elevation answers with KEMAR HRTF with speech.

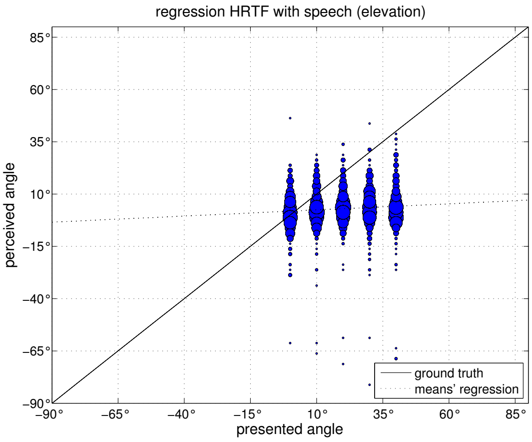


Figure B.36.: Scatterplot, elevation answers with regression HRTF with speech.

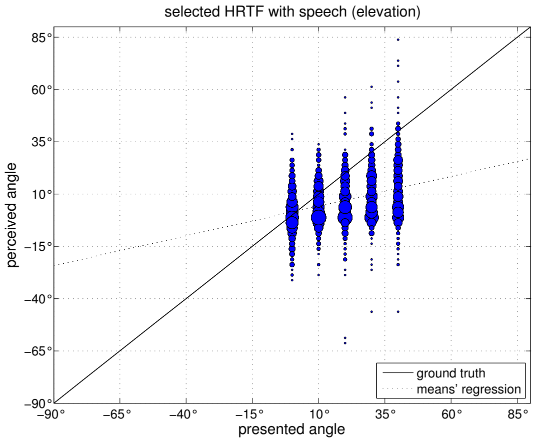
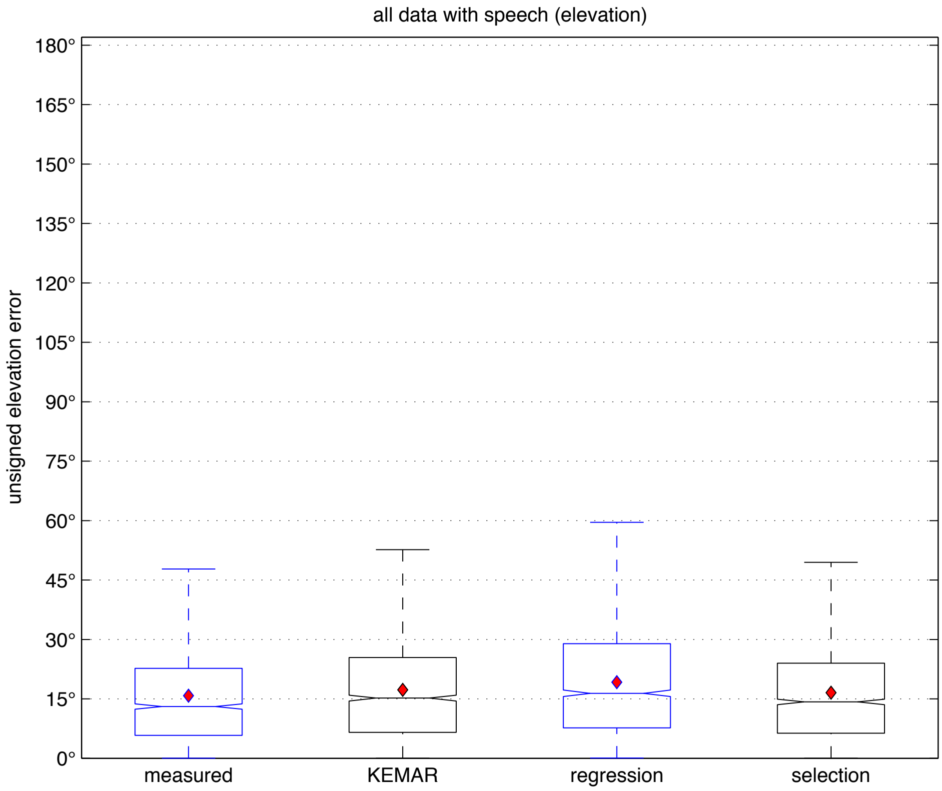


Figure B.37.: Scatterplot, elevation answers with selected HRTF with speech.



	measured	KEMAR	regression	selection
mean	15.82°	17.29°	19.22°	16.56°
std. dev.	13.07°	13.39°	14.45°	12.58°
median	13.07°	15.20°	16.41°	14.23°

Figure B.38.: Boxplot, elevation error with speech.

Noise Bursts,Measured HRTF	Noise Bursts,KEMAR HRTF	$[-3{,}10°, -1{,}30°]$
Noise Bursts,Measured HRTF	Noise Bursts, Regression HRTF	$[-6{,}97°, -5{,}17°]$
Noise Bursts,Measured HRTF	Noise Bursts, Selection HRTF	$[-2{,}72°, -0{,}92°]$
Noise Bursts,Measured HRTF	Speech Measured HRTF	$[-2{,}70°, -0{,}90°]$
Noise Bursts,Measured HRTF	Speech KEMAR HRTF	$[-4{,}18°, -2{,}37°]$
Noise Bursts,Measured HRTF	Speech Regression HRTF	$[-6{,}10°, -4{,}30°]$
Noise Bursts,Measured HRTF	Speech Selection HRTF	$[-3{,}44°, -1{,}64°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Regression HRTF	$[-4{,}77°, -2{,}97°]$
Noise Bursts,KEMAR HRTF	Noise Bursts, Selection HRTF	$[-0{,}52°, 1{,}28°]$
Noise Bursts,KEMAR HRTF	Speech Measured HRTF	$[-0{,}50°, 1{,}30°]$
Noise Bursts,KEMAR HRTF	Speech KEMAR HRTF	$[-1{,}98°, -0{,}18°]$
Noise Bursts,KEMAR HRTF	Speech Regression HRTF	$[-3{,}91°, -2{,}10°]$
Noise Bursts,KEMAR HRTF	Speech Selection HRTF	$[-1{,}24°, 0{,}56°]$
Noise Bursts, Regression HRTF	Noise Bursts, Selection HRTF	$[3{,}35°, 5{,}15°]$
Noise Bursts, Regression HRTF	Speech Measured HRTF	$[3{,}37°, 5{,}17°]$
Noise Bursts, Regression HRTF	Speech KEMAR HRTF	$[1{,}89°, 3{,}70°]$
Noise Bursts, Regression HRTF	Speech Regression HRTF	$[-0{,}03°, 1{,}77°]$
Noise Bursts, Regression HRTF	Speech Selection HRTF	$[2{,}63°, 4{,}43°]$
Noise Bursts, Selection HRTF	Speech Measured HRTF	$[-0{,}88°, 0{,}92°]$
Noise Bursts, Selection HRTF	Speech KEMAR HRTF	$[-2{,}36°, -0{,}56°]$
Noise Bursts, Selection HRTF	Speech Regression HRTF	$[-4{,}28°, -2{,}48°]$
Noise Bursts, Selection HRTF	Speech Selection HRTF	$[-1{,}62°, 0{,}18°]$
Speech Measured HRTF	Speech KEMAR HRTF	$[-2{,}38°, -0{,}58°]$
Speech Measured HRTF	Speech Regression HRTF	$[-4{,}30°, -2{,}50°]$
Speech Measured HRTF	Speech Selection HRTF	$[-1{,}64°, 0{,}16°]$
Speech KEMAR HRTF	Speech Regression HRTF	$[-2{,}83°, -1{,}02°]$
Speech KEMAR HRTF	Speech Selection HRTF	$[-0{,}16°, 1{,}64°]$
Speech Regression HRTF	Speech Selection HRTF	$[1{,}76°, 3{,}56°]$

Table B.4.: Elevation error: least significant difference for the HRTF-datasets with different stimuli.

B.8. Comparison of HRTF-Sets with Different Stimuli with and without Head-Tracking

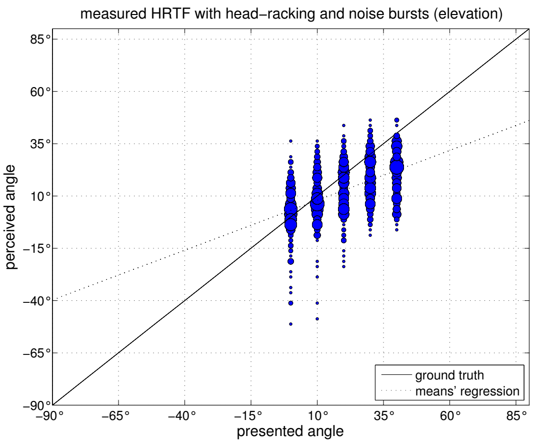


Figure B.39.: Scatterplot, elevation answers with measured HRTF with head-tracking and noise bursts.

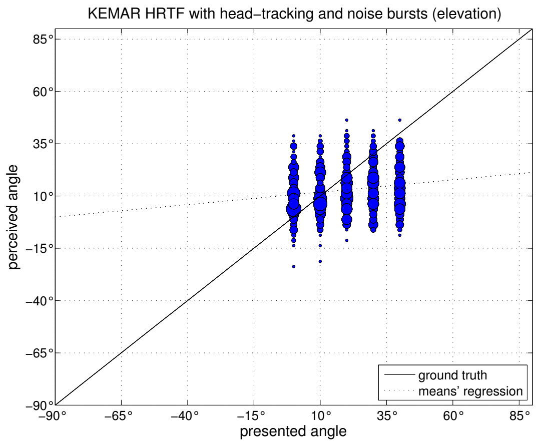


Figure B.40.: Scatterplot, elevation answers with KEMAR HRTF with head-tracking and noise bursts.

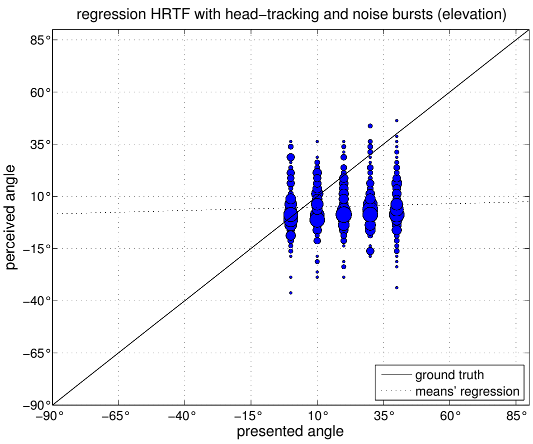


Figure B.41.: Scatterplot, elevation answers with regression HRTF with head-tracking and noise bursts.

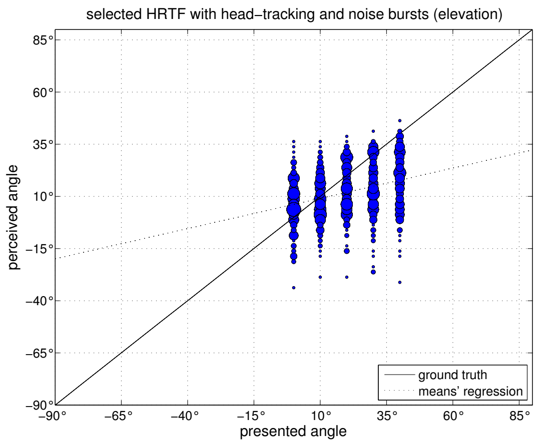
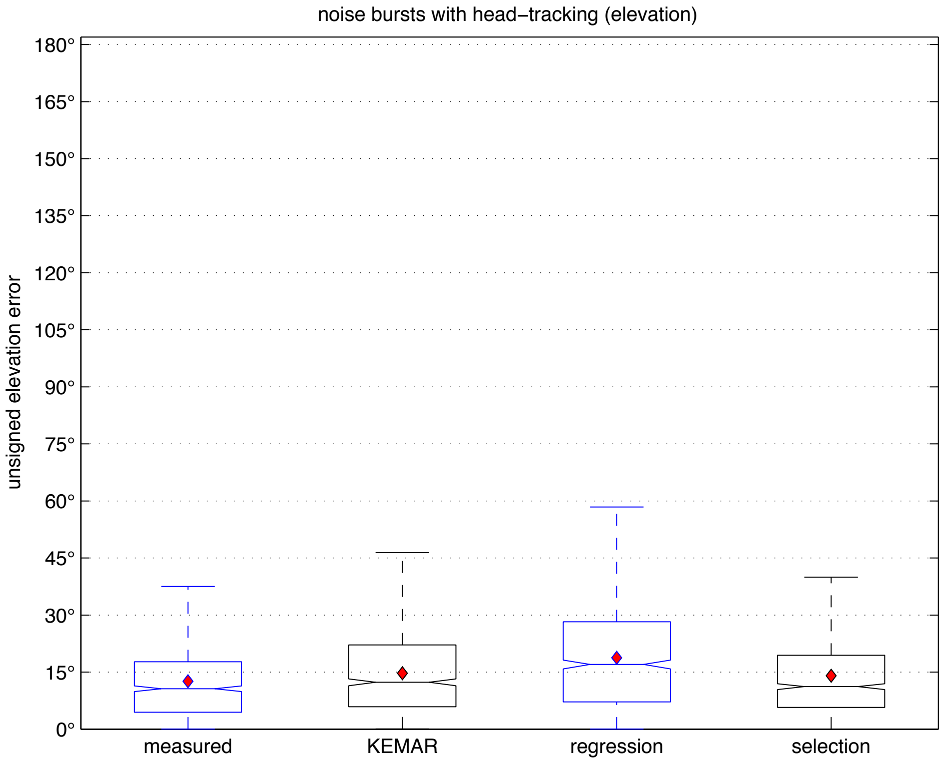


Figure B.42.: Scatterplot, elevation answers with selected HRTF with head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	12.57°	14.68°	18.78°	14.06°
std. dev.	10.08°	10.76°	13.68°	11.13°
median	10.62°	12.31°	17.00°	11.18°

Figure B.43.: Boxplot, elevation error with head-tracking and noise bursts.

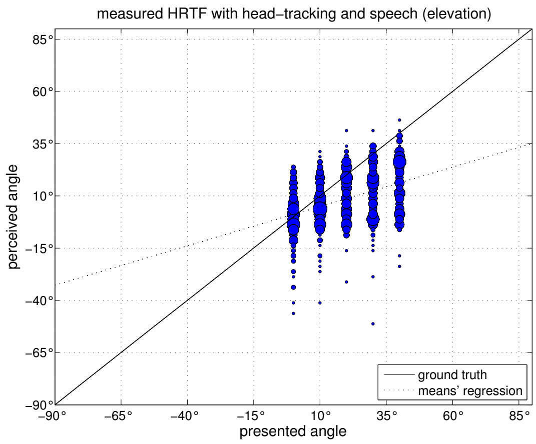


Figure B.44.: Scatterplot, elevation answers with measured HRTF with head-tracking and speech.

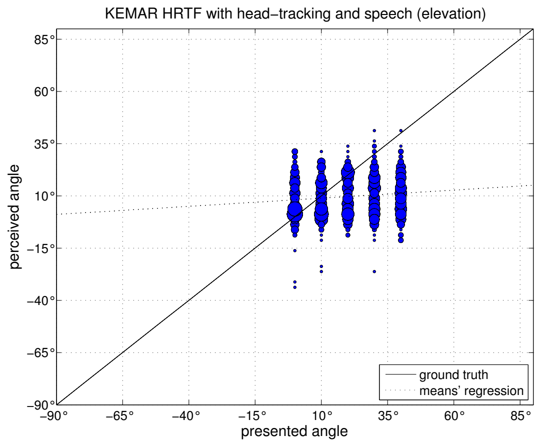


Figure B.45.: Scatterplot, elevation answers with KEMAR HRTF with head-tracking and speech.

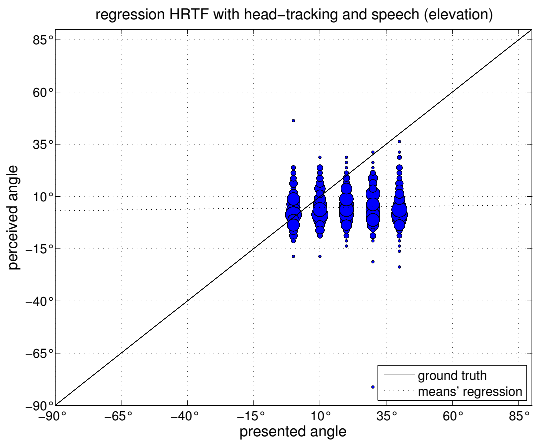


Figure B.46.: Scatterplot, elevation answers with regression HRTF with head-tracking and speech.

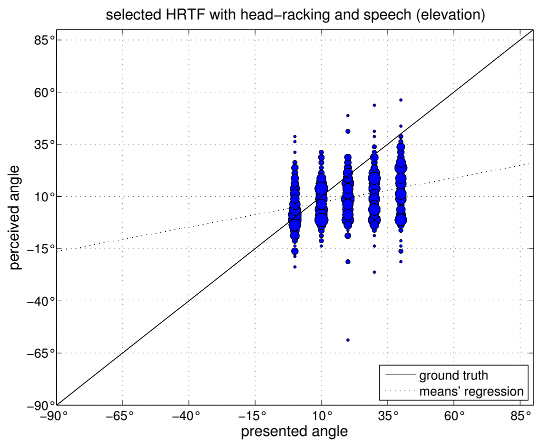
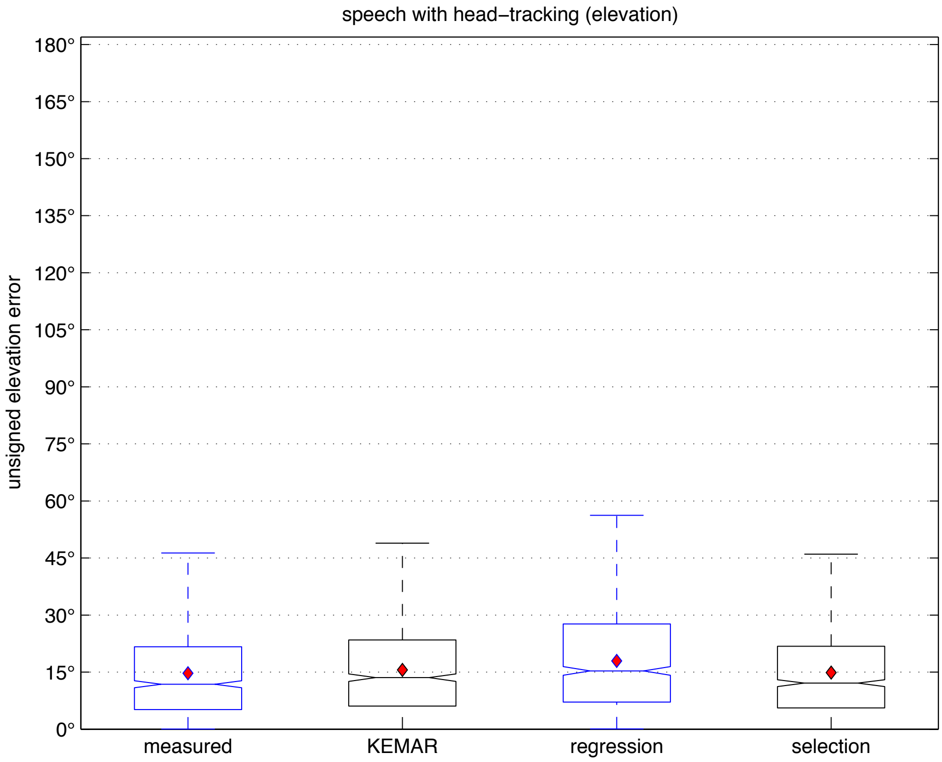


Figure B.47.: Scatterplot, elevation answers with selected HRTF with head-tracking and speech.



	measured	KEMAR	regression	selection
mean	14.71°	15.58°	17.95°	14.86°
std. dev.	11.93°	11.66°	13.30°	11.70°
median	11.80°	13.54°	15.29°	12.10°

Figure B.48.: Boxplot, elevation error with head-tracking and speech.

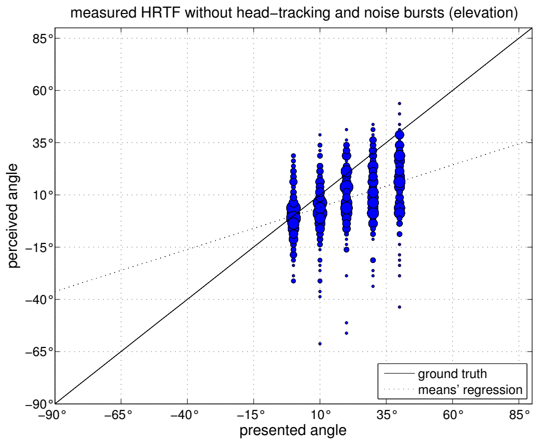


Figure B.49.: Scatterplot, elevation answers with measured HRTF without head-tracking and noise bursts.

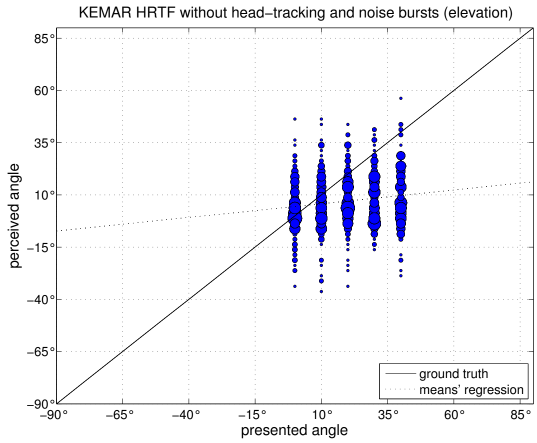


Figure B.50.: Scatterplot, elevation answers with KEMAR HRTF without head-tracking and noise bursts.

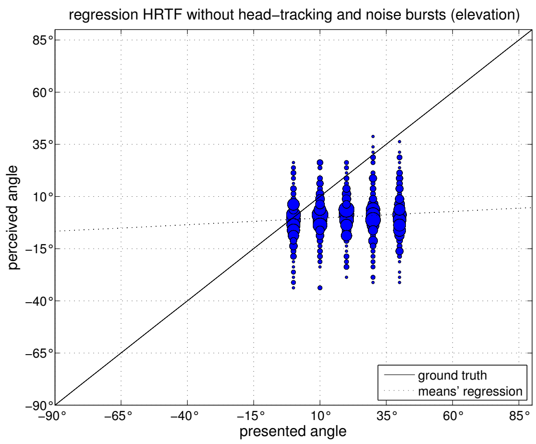


Figure B.51.: Scatterplot, elevation answers with regression HRTF without head-tracking and noise bursts.

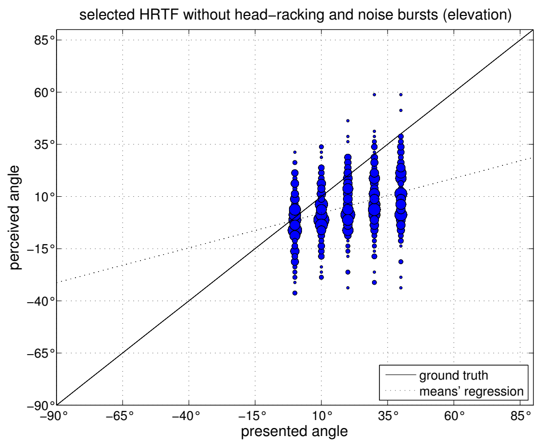
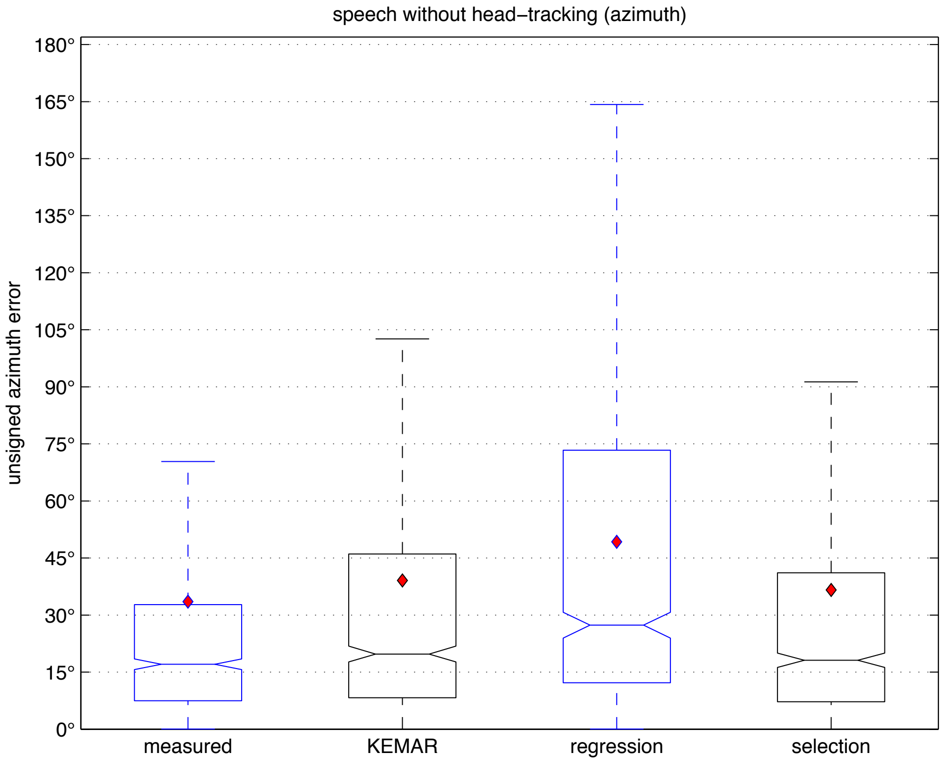
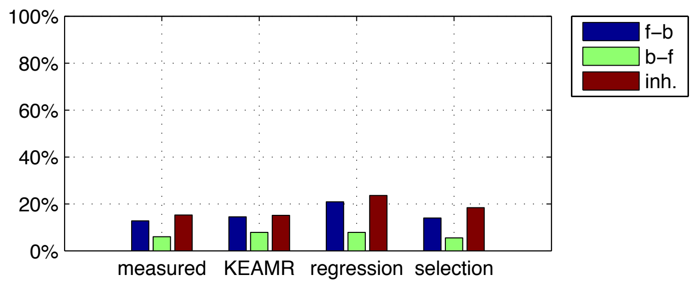


Figure B.52.: Scatterplot, elevation answers with selected HRTF without head-tracking and noise bursts.



	measured	KEMAR	regression	selection
mean	33.55°	39.07°	49.26°	36.61°
std. dev.	43.87°	47.70°	51.05°	46.88°
median	17.04°	19.75°	27.35°	18.10°



	measured			KEMAR			regression			selection		
	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f	total	f–b	b–f
conf.	18.8%	12.8%	6.0%	11.2%	14.5%	7.9%	27.5%	20.9%	6.6%	19.5%	14.5%	5.5%
inheads	15.2%			15.1%			25.0%			13.5%		

Figure B.53.: Boxplot, elevation error without head-tracking and noise bursts.

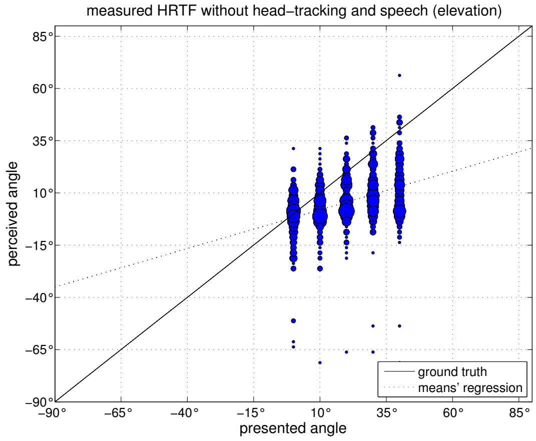


Figure B.54.: Scatterplot, elevation answers with measured HRTF without head-tracking and speech.

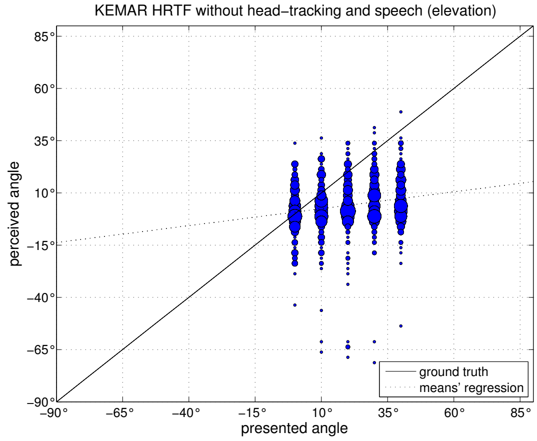


Figure B.55.: Scatterplot, elevation answers with KEMAR HRTF without head-tracking and speech.

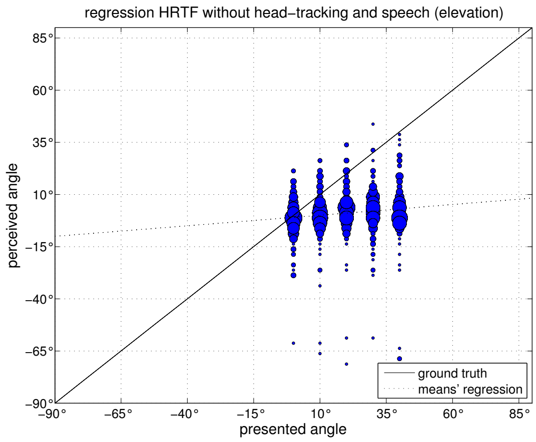


Figure B.56.: Scatterplot, elevation answers with regression HRTF without head-tracking and speech.

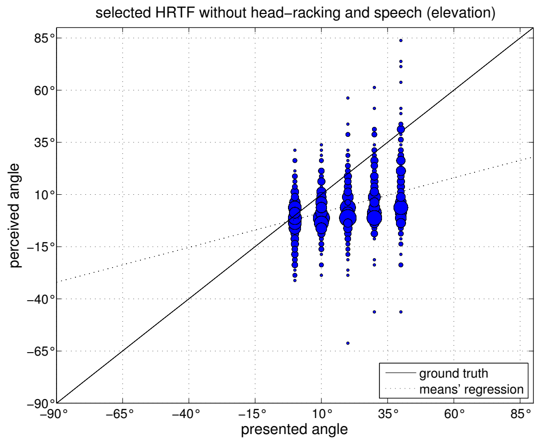
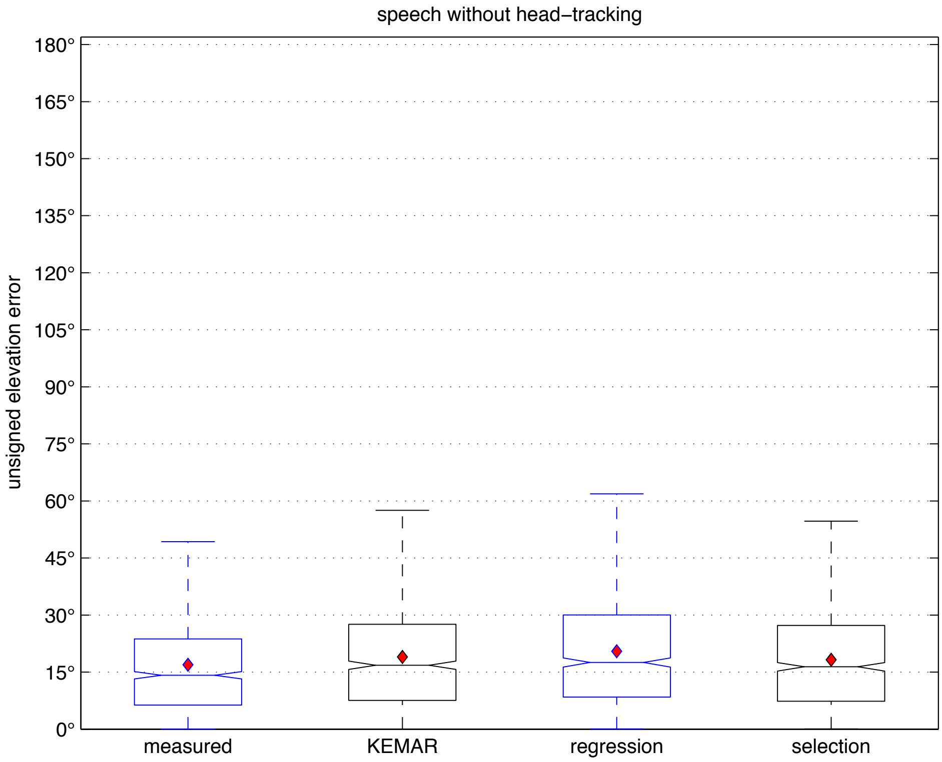


Figure B.57.: Scatterplot, elevation answers with selected HRTF without head-tracking and speech.



	measured	KEMAR	regression	selection
mean	16.92°	19.01°	20.49°	18.25°
std. dev.	14.04°	14.72°	15.41°	13.19°
median	14.16°	16.80°	17.53°	16.38°

Figure B.58.: Boxplot, elevation error without head-tracking and speech.

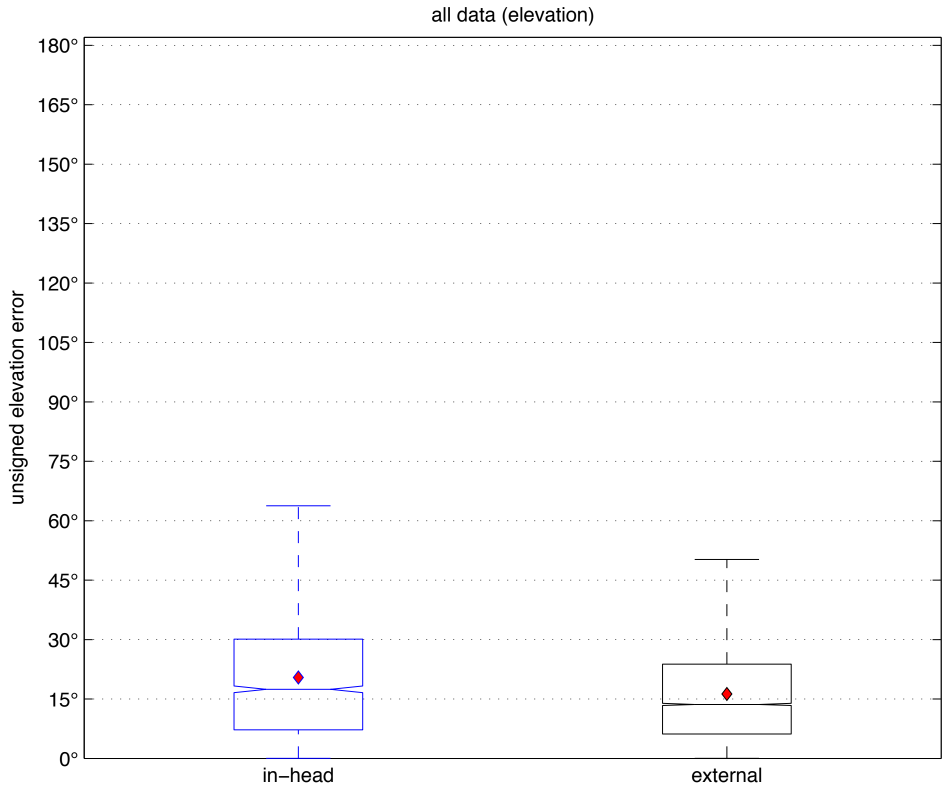
Noise B., Measured w. Track.	Noise B., KEMAR w. Track.	$[-3{,}37°, -0{,}84°]$
Noise B., Measured w. Track.	Noise B., Regr. w. Track.	$[-7{,}47°, -4{,}94°]$
Noise B., Measured w. Track.	Noise B., Selection w. Track.	$[-2{,}75°, -0{,}22°]$
Noise B., Measured w. Track.	Speech, Measured w. Track.	$[-3{,}41°, -0{,}88°]$
Noise B., Measured w. Track.	Speech, KEMAR w. Track.	$[-4{,}27°, -1{,}74°]$
Noise B., Measured w. Track.	Speech, Regr. w. Track.	$[-6{,}64°, -4{,}11°]$
Noise B., Measured w. Track.	Speech, Selection w. Track.	$[-3{,}56°, -1{,}03°]$
Noise B., Measured w. Track.	Noise B., Measured w/o Track.	$[-4{,}16°, -1{,}63°]$
Noise B., Measured w. Track.	Noise B., KEMAR w/o Track.	$[-6{,}45°, -3{,}92°]$
Noise B., Measured w. Track.	Noise B., Regr. w/o Track.	$[-10{,}09°, -7{,}56°]$
Noise B., Measured w. Track.	Noise B., Selection w/o Track.	$[-6{,}31°, -3{,}77°]$
Noise B., Measured w. Track.	Speech, Measured w/o Track.	$[-5{,}61°, -3{,}08°]$
Noise B., Measured w. Track.	Speech, KEMAR w/o Track.	$[-7{,}70°, -5{,}17°]$
Noise B., Measured w. Track.	Speech, Regr. w/o Track.	$[-9{,}19°, -6{,}65°]$
Noise B., Measured w. Track.	Speech, Selection w/o Track.	$[-6{,}94°, -4{,}41°]$
Noise B., KEMAR w. Track.	Noise B., Regr. w. Track.	$[-5{,}37°, -2{,}84°]$
Noise B., KEMAR w. Track.	Noise B., Selection w. Track.	$[-0{,}65°, 1{,}88°]$
Noise B., KEMAR w. Track.	Speech, Measured w. Track.	$[-1{,}31°, 1{,}23°]$
Noise B., KEMAR w. Track.	Speech, KEMAR w. Track.	$[-2{,}17°, 0{,}36°]$
Noise B., KEMAR w. Track.	Speech, Regr. w. Track.	$[-4{,}54°, -2{,}01°]$
Noise B., KEMAR w. Track.	Speech, Selection w. Track.	$[-1{,}46°, 1{,}08°]$
Noise B., KEMAR w. Track.	Noise B., Measured w/o Track.	$[-2{,}06°, 0{,}48°]$
Noise B., KEMAR w. Track.	Noise B., KEMAR w/o Track.	$[-4{,}35°, -1{,}81°]$
Noise B., KEMAR w. Track.	Noise B., Regr. w/o Track.	$[-7{,}99°, -5{,}46°]$
Noise B., KEMAR w. Track.	Noise B., Selection w/o Track.	$[-4{,}20°, -1{,}67°]$
Noise B., KEMAR w. Track.	Speech, Measured w/o Track.	$[-3{,}51°, -0{,}98°]$
Noise B., KEMAR w. Track.	Speech, KEMAR w/o Track.	$[-5{,}60°, -3{,}07°]$
Noise B., KEMAR w. Track.	Speech, Regr. w/o Track.	$[-7{,}08°, -4{,}55°]$
Noise B., KEMAR w. Track.	Speech, Selection w/o Track.	$[-4{,}84°, -2{,}31°]$
Noise B., Regr. w. Track.	Noise B., Selection w. Track.	$[3{,}45°, 5{,}98°]$
Noise B., Regr. w. Track.	Speech, Measured w. Track.	$[2{,}80°, 5{,}33°]$
Noise B., Regr. w. Track.	Speech, KEMAR w. Track.	$[1{,}93°, 4{,}47°]$
Noise B., Regr. w. Track.	Speech, Regr. w. Track.	$[-0{,}44°, 2{,}10°]$
Noise B., Regr. w. Track.	Speech, Selection w. Track.	$[2{,}65°, 5{,}18°]$
Noise B., Regr. w. Track.	Noise B., Measured w/o Track.	$[2{,}05°, 4{,}58°]$
Noise B., Regr. w. Track.	Noise B., KEMAR w/o Track.	$[-0{,}24°, 2{,}29°]$
Noise B., Regr. w. Track.	Noise B., Regr. w/o Track.	$[-3{,}89°, -1{,}35°]$
Noise B., Regr. w. Track.	Noise B., Selection w/o Track.	$[-0{,}10°, 2{,}43°]$
Noise B., Regr. w. Track.	Speech, Measured w/o Track.	$[0{,}59°, 3{,}12°]$
Noise B., Regr. w. Track.	Speech, KEMAR w/o Track.	$[-1{,}50°, 1{,}03°]$
Noise B., Regr. w. Track.	Speech, Regr. w/o Track.	$[-2{,}98°, -0{,}45°]$

Noise B., Regr. w. Track.	Speech, Selection w/o Track.	$[-0{,}74°, 1{,}79°]$
Noise B., Selection w. Track.	Speech, Measured w. Track.	$[-1{,}92°, 0{,}61°]$
Noise B., Selection w. Track.	Speech, KEMAR w. Track.	$[-2{,}78°, -0{,}25°]$
Noise B., Selection w. Track.	Speech, Regr. w. Track.	$[-5{,}15°, -2{,}62°]$
Noise B., Selection w. Track.	Speech, Selection w. Track.	$[-2{,}07°, 0{,}46°]$
Noise B., Selection w. Track.	Noise B., Measured w/o Track.	$[-2{,}67°, -0{,}14°]$
Noise B., Selection w. Track.	Noise B., KEMAR w/o Track.	$[-4{,}96°, -2{,}43°]$
Noise B., Selection w. Track.	Noise B., Regr. w/o Track.	$[-8{,}60°, -6{,}07°]$
Noise B., Selection w. Track.	Noise B., Selection w/o Track.	$[-4{,}82°, -2{,}29°]$
Noise B., Selection w. Track.	Speech, Measured w/o Track.	$[-4{,}13°, -1{,}59°]$
Noise B., Selection w. Track.	Speech, KEMAR w/o Track.	$[-6{,}22°, -3{,}68°]$
Noise B., Selection w. Track.	Speech, Regr. w/o Track.	$[-7{,}70°, -5{,}16°]$
Noise B., Selection w. Track.	Speech, Selection w/o Track.	$[-5{,}46°, -2{,}92°]$
Speech, Measured w. Track.	Speech, KEMAR w. Track.	$[-2{,}13°, 0{,}40°]$
Speech, Measured w. Track.	Speech, Regr. w. Track.	$[-4{,}50°, -1{,}97°]$
Speech, Measured w. Track.	Speech, Selection w. Track.	$[-1{,}42°, 1{,}12°]$
Speech, Measured w. Track.	Noise B., Measured w/o Track.	$[-2{,}02°, 0{,}52°]$
Speech, Measured w. Track.	Noise B., KEMAR w/o Track.	$[-4{,}31°, -1{,}78°]$
Speech, Measured w. Track.	Noise B., Regr. w/o Track.	$[-7{,}95°, -5{,}42°]$
Speech, Measured w. Track.	Noise B., Selection w/o Track.	$[-4{,}17°, -1{,}63°]$
Speech, Measured w. Track.	Speech, Measured w/o Track.	$[-3{,}47°, -0{,}94°]$
Speech, Measured w. Track.	Speech, KEMAR w/o Track.	$[-5{,}56°, -3{,}03°]$
Speech, Measured w. Track.	Speech, Regr. w/o Track.	$[-7{,}04°, -4{,}51°]$
Speech, Measured w. Track.	Speech, Selection w/o Track.	$[-4{,}80°, -2{,}27°]$
Speech, KEMAR w. Track.	Speech, Regr. w. Track.	$[-3{,}64°, -1{,}10°]$
Speech, KEMAR w. Track.	Speech, Selection w. Track.	$[-0{,}55°, 1{,}98°]$
Speech, KEMAR w. Track.	Noise B., Measured w/o Track.	$[-1{,}15°, 1{,}38°]$
Speech, KEMAR w. Track.	Noise B., KEMAR w/o Track.	$[-3{,}44°, -0{,}91°]$
Speech, KEMAR w. Track.	Noise B., Regr. w/o Track.	$[-7{,}09°, -4{,}55°]$
Speech, KEMAR w. Track.	Noise B., Selection w/o Track.	$[-3{,}30°, -0{,}77°]$
Speech, KEMAR w. Track.	Speech, Measured w/o Track.	$[-2{,}61°, -0{,}08°]$
Speech, KEMAR w. Track.	Speech, KEMAR w/o Track.	$[-4{,}70°, -2{,}17°]$
Speech, KEMAR w. Track.	Speech, Regr. w/o Track.	$[-6{,}18°, -3{,}65°]$
Speech, KEMAR w. Track.	Speech, Selection w/o Track.	$[-3{,}94°, -1{,}41°]$
Speech, Regr. w. Track.	Speech, Selection w. Track.	$[1{,}82°, 4{,}35°]$
Speech, Regr. w. Track.	Noise B., Measured w/o Track.	$[1{,}22°, 3{,}75°]$
Speech, Regr. w. Track.	Noise B., KEMAR w/o Track.	$[-1{,}07°, 1{,}46°]$
Speech, Regr. w. Track.	Noise B., Regr. w/o Track.	$[-4{,}72°, -2{,}18°]$
Speech, Regr. w. Track.	Noise B., Selection w/o Track.	$[-0{,}93°, 1{,}60°]$
Speech, Regr. w. Track.	Speech, Measured w/o Track.	$[-0{,}24°, 2{,}29°]$
Speech, Regr. w. Track.	Speech, KEMAR w/o Track.	$[-2{,}33°, 0{,}20°]$

Speech, Regr. w. Track.	Speech, Regr. w/o Track.	$[-3{,}81°, -1{,}28°]$
Speech, Regr. w. Track.	Speech, Selection w/o Track.	$[-1{,}57°, 0{,}96°]$
Speech, Selection w. Track.	Noise B., Measured w/o Track.	$[-1{,}87°, 0{,}67°]$
Speech, Selection w. Track.	Noise B., KEMAR w/o Track.	$[-4{,}16°, -1{,}63°]$
Speech, Selection w. Track.	Noise B., Regr. w/o Track.	$[-7{,}80°, -5{,}27°]$
Speech, Selection w. Track.	Noise B., Selection w/o Track.	$[-4{,}01°, -1{,}48°]$
Speech, Selection w. Track.	Speech, Measured w/o Track.	$[-3{,}32°, -0{,}79°]$
Speech, Selection w. Track.	Speech, KEMAR w/o Track.	$[-5{,}41°, -2{,}88°]$
Speech, Selection w. Track.	Speech, Regr. w/o Track.	$[-6{,}89°, -4{,}36°]$
Speech, Selection w. Track.	Speech, Selection w/o Track.	$[-4{,}65°, -2{,}12°]$
Noise B., Measured w/o Track.	Noise B., KEMAR w/o Track.	$[-3{,}56°, -1{,}03°]$
Noise B., Measured w/o Track.	Noise B., Regr. w/o Track.	$[-7{,}20°, -4{,}67°]$
Noise B., Measured w/o Track.	Noise B., Selection w/o Track.	$[-3{,}41°, -0{,}88°]$
Noise B., Measured w/o Track.	Speech, Measured w/o Track.	$[-2{,}72°, -0{,}19°]$
Noise B., Measured w/o Track.	Speech, KEMAR w/o Track.	$[-4{,}81°, -2{,}28°]$
Noise B., Measured w/o Track.	Speech, Regr. w/o Track.	$[-6{,}29°, -3{,}76°]$
Noise B., Measured w/o Track.	Speech, Selection w/o Track.	$[-4{,}05°, -1{,}52°]$
Noise B., KEMAR w/o Track.	Noise B., Regr. w/o Track.	$[-4{,}91°, -2{,}38°]$
Noise B., KEMAR w/o Track.	Noise B., Selection w/o Track.	$[-1{,}12°, 1{,}41°]$
Noise B., KEMAR w/o Track.	Speech, Measured w/o Track.	$[-0{,}43°, 2{,}10°]$
Noise B., KEMAR w/o Track.	Speech, KEMAR w/o Track.	$[-2{,}52°, 0{,}01°]$
Noise B., KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-4{,}00°, -1{,}47°]$
Noise B., KEMAR w/o Track.	Speech, Selection w/o Track.	$[-1{,}76°, 0{,}77°]$
Noise B., Regr. w/o Track.	Noise B., Selection w/o Track.	$[2{,}52°, 5{,}05°]$
Noise B., Regr. w/o Track.	Speech, Measured w/o Track.	$[3{,}21°, 5{,}74°]$
Noise B., Regr. w/o Track.	Speech, KEMAR w/o Track.	$[1{,}12°, 3{,}65°]$
Noise B., Regr. w/o Track.	Speech, Regr. w/o Track.	$[-0{,}36°, 2{,}17°]$
Noise B., Regr. w/o Track.	Speech, Selection w/o Track.	$[1{,}88°, 4{,}41°]$
Noise B., Selection w/o Track.	Speech, Measured w/o Track.	$[-0{,}57°, 1{,}96°]$
Noise B., Selection w/o Track.	Speech, KEMAR w/o Track.	$[-2{,}66°, -0{,}13°]$
Noise B., Selection w/o Track.	Speech, Regr. w/o Track.	$[-4{,}15°, -1{,}61°]$
Noise B., Selection w/o Track.	Speech, Selection w/o Track.	$[-1{,}90°, 0{,}63°]$
Speech, Measured w/o Track.	Speech, KEMAR w/o Track.	$[-3{,}36°, -0{,}82°]$
Speech, Measured w/o Track.	Speech, Regr. w/o Track.	$[-4{,}84°, -2{,}31°]$
Speech, Measured w/o Track.	Speech, Selection w/o Track.	$[-2{,}60°, -0{,}06°]$
Speech, KEMAR w/o Track.	Speech, Regr. w/o Track.	$[-2{,}75°, -0{,}22°]$
Speech, KEMAR w/o Track.	Speech, Selection w/o Track.	$[-0{,}51°, 2{,}03°]$
Speech, Regr. w/o Track.	Speech, Selection w/o Track.	$[0{,}97°, 3{,}51°]$

Table B.5.: Elevation error: least significant difference for the HRTF-datasets with and without head-tracking and different stimuli.

B.9. In-Head and External

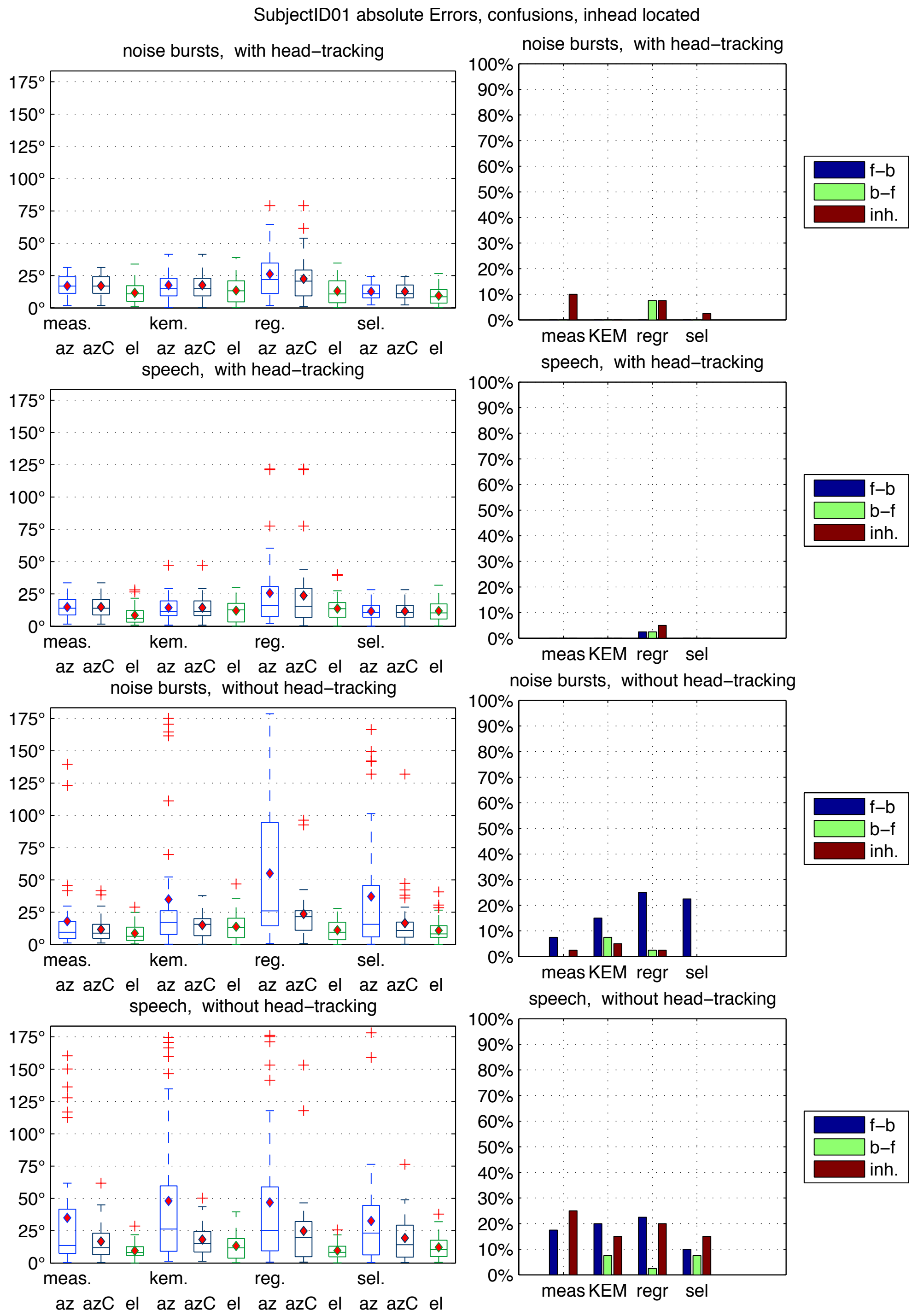


	in−head	external
mean	20.44°	16.27°
std. dev.	16.31°	12.40°
median	17.44°	13.63°

Figure B.59.: Boxplot, elevation error in-head and external.

C. Subjects

All individual data are presented. In contrast to A. and B. no scatterplots are provided and outliers are printed to the boxplots as we deal with fewer data in this case.



SubjectID01 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
speech, without head−tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f−b
b−f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	17.10°	8.29°	16.96°
	azErrC	17.10°	8.29°	16.96°
	elErr	11.75°	7.71°	10.98°
KEM.	azErr	17.67°	11.02°	15.03°
	azErrC	17.67°	11.02°	15.03°
	elErr	13.47°	9.97°	13.23°
reg.	azErr	26.21°	18.44°	21.97°
	azErrC	22.44°	16.79°	20.81°
	elErr	13.03°	9.50°	10.79°
sel.	azErr	12.66°	6.07°	11.08°
	azErrC	12.66°	6.07°	11.08°
	elErr	9.51°	6.70°	8.56°

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	14.87°	7.92°	13.97°
	azErrC	14.87°	7.92°	13.97°
	elErr	8.49°	7.22°	6.07°
KEM.	azErr	14.45°	8.89°	11.36°
	azErrC	14.45°	8.89°	11.36°
	elErr	12.15°	8.79°	12.67°
reg.	azErr	25.80°	27.77°	15.91°
	azErrC	23.80°	27.12°	15.50°
	elErr	13.70°	9.26°	13.63°
sel.	azErr	11.64°	7.14°	10.60°
	azErrC	11.64°	7.14°	10.60°
	elErr	11.89°	7.74°	10.40°

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	18.06°	28.20°	9.58°
	azErrC	11.72°	9.37°	8.80°
	elErr	8.68°	7.15°	6.37°
KEM.	azErr	34.97°	49.55°	17.16°
	azErrC	15.10°	9.44°	15.73°
	elErr	13.88°	10.67°	13.13°
reg.	azErr	55.13°	57.15°	26.08°
	azErrC	23.72°	20.03°	21.59°
	elErr	11.19°	8.11°	9.58°
sel.	azErr	37.22°	47.30°	15.69°
	azErrC	16.59°	21.86°	10.99°
	elErr	10.91°	8.94°	8.29°

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	34.99°	44.98°	13.54°
	azErrC	16.68°	13.79°	11.83°
	elErr	9.52°	6.48°	8.11°
KEM.	azErr	48.05°	53.81°	26.33°
	azErrC	18.22°	12.42°	15.14°
	elErr	13.21°	10.03°	11.69°
reg.	azErr	46.89°	52.97°	25.26°
	azErrC	24.81°	29.42°	19.56°
	elErr	9.67°	6.39°	8.33°
sel.	azErr	32.61°	38.33°	23.18°
	azErrC	19.32°	17.01°	14.15°
	elErr	12.15°	8.88°	10.34°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	7.50%	0.00%	7.50%
	inheads	7.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		

speech, with head–tracking

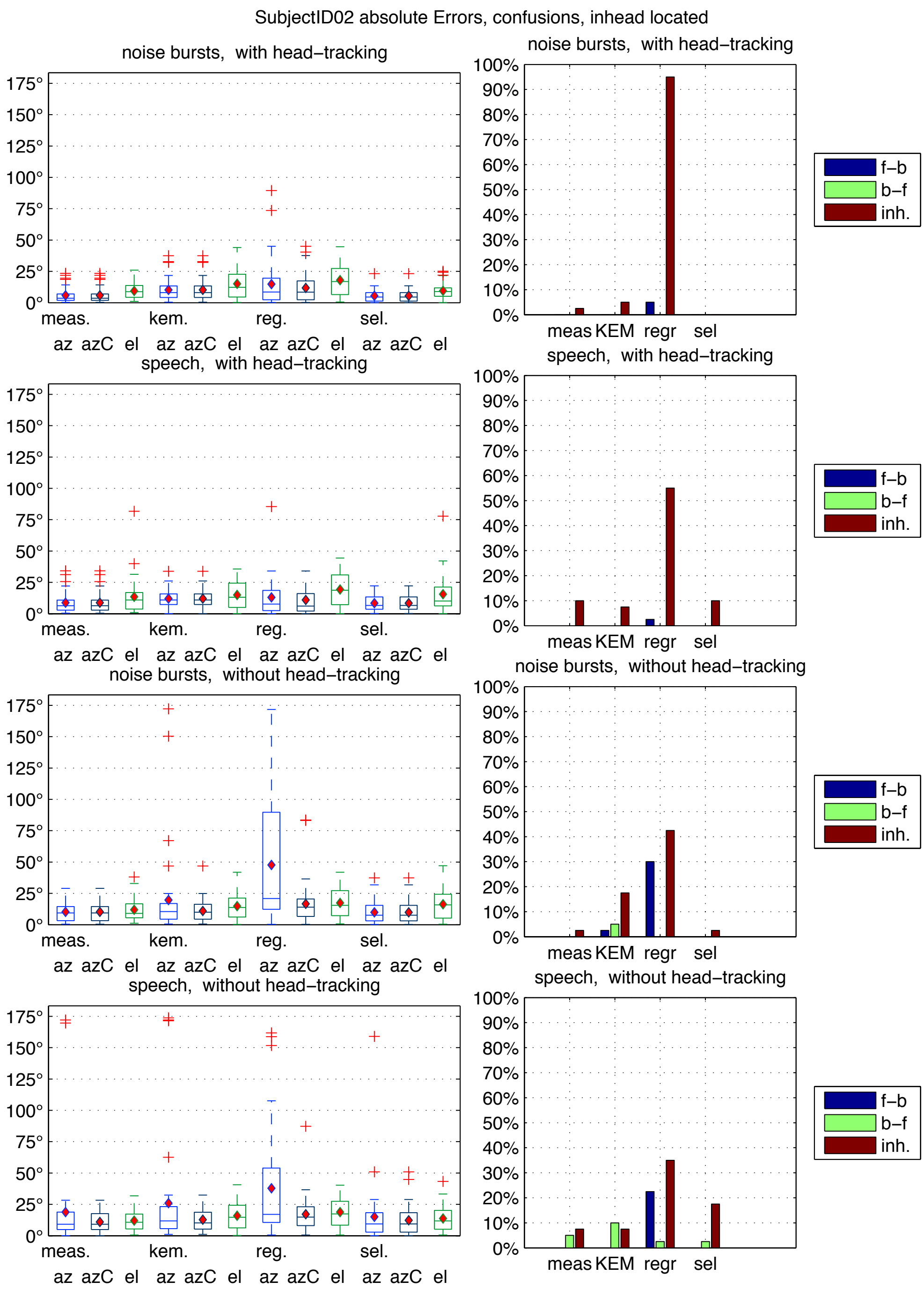
		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	5.00%	2.50%	2.50%
	inheads	5.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head–tracking

		total	front back	back front
meas.	confusions	7.50%	7.50%	0.00%
	inheads	2.5%		
KEM.	confusions	22.50%	15.00%	7.50%
	inheads	5.0%		
reg.	confusions	27.50%	25.00%	2.50%
	inheads	2.5%		
sel.	confusions	22.50%	22.50%	0.00%
	inheads	0.0%		

speech, without head–tracking

		total	front back	back front
meas.	confusions	17.50%	17.50%	0.00%
	inheads	25.0%		
KEM.	confusions	27.50%	20.00%	7.50%
	inheads	15.0%		
reg.	confusions	25.00%	22.50%	2.50%
	inheads	20.0%		
sel.	confusions	17.50%	10.00%	7.50%
	inheads	15.0%		


SubjectID02 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	5.92°	6.16°	3.52°
	azErrC	5.92°	6.16°	3.52°
	elErr	9.44°	6.16°	8.77°
KEM.	azErr	10.20°	8.56°	8.09°
	azErrC	10.20°	8.56°	8.09°
	elErr	15.14°	12.57°	12.24°
reg.	azErr	14.80°	18.82°	8.54°
	azErrC	11.80°	11.36°	8.39°
	elErr	17.99°	12.93°	16.87°
sel.	azErr	5.53°	5.03°	4.55°
	azErrC	5.53°	5.03°	4.55°
	elErr	9.53°	6.31°	8.87°

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	8.83°	8.28°	6.31°
	azErrC	8.83°	8.28°	6.31°
	elErr	13.46°	14.58°	10.93°
KEM.	azErr	12.06°	7.32°	10.99°
	azErrC	12.06°	7.32°	10.99°
	elErr	14.92°	11.25°	13.19°
reg.	azErr	13.07°	15.77°	7.74°
	azErrC	10.97°	10.65°	6.16°
	elErr	19.35°	13.46°	18.69°
sel.	azErr	8.42°	6.75°	6.57°
	azErrC	8.42°	6.75°	6.57°
	elErr	15.62°	14.83°	10.12°

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	10.25°	7.73°	9.33°
	azErrC	10.25°	7.73°	9.33°
	elErr	11.90°	8.91°	9.00°
KEM.	azErr	19.71°	35.29°	10.49°
	azErrC	11.01°	8.98°	9.98°
	elErr	14.81°	10.91°	13.74°
reg.	azErr	47.63°	49.86°	20.84°
	azErrC	16.63°	17.57°	14.01°
	elErr	17.35°	12.47°	15.50°
sel.	azErr	9.84°	8.86°	7.58°
	azErrC	9.84°	8.86°	7.58°
	elErr	16.35°	12.12°	15.79°

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	18.79°	36.22°	9.11°
	azErrC	10.99°	8.02°	9.11°
	elErr	12.10°	8.51°	10.68°
KEM.	azErr	26.03°	43.81°	11.83°
	azErrC	12.83°	8.85°	10.30°
	elErr	15.98°	10.92°	14.76°
reg.	azErr	37.89°	46.01°	16.98°
	azErrC	17.14°	14.56°	14.81°
	elErr	18.78°	11.53°	17.44°
sel.	azErr	15.11°	25.65°	9.35°
	azErrC	12.26°	11.87°	9.35°
	elErr	13.74°	10.27°	11.78°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
reg.	confusions	5.00%	5.00%	0.00%
	inheads	95.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head–tracking

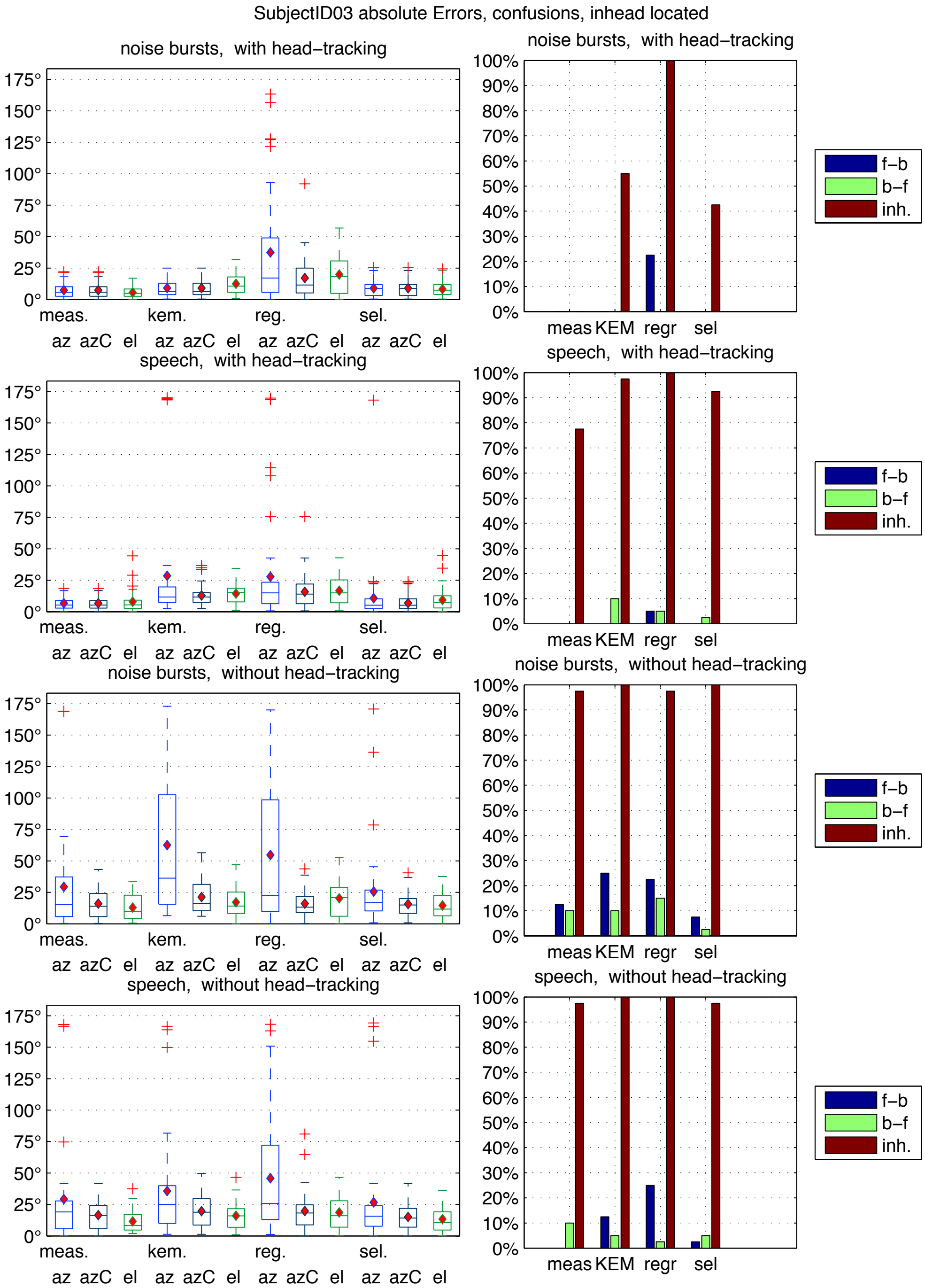
		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	7.5%		
reg.	confusions	2.50%	2.50%	0.00%
	inheads	55.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		

noise bursts, without head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	7.50%	2.50%	5.00%
	inheads	17.5%		
reg.	confusions	30.00%	30.00%	0.00%
	inheads	42.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		

speech, without head–tracking

		total	front back	back front
meas.	confusions	5.00%	0.00%	5.00%
	inheads	7.5%		
KEM.	confusions	10.00%	0.00%	10.00%
	inheads	7.5%		
reg.	confusions	25.00%	22.50%	2.50%
	inheads	35.0%		
sel.	confusions	2.50%	0.00%	2.50%
	inheads	17.5%		


SubjectID03 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
speech, without head−tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f−b
b−f
inh.

noise bursts, with head-tracking

		mean	std. dev.	median
meas.	azErr	7.42°	6.10°	5.92°
	azErrC	7.42°	6.10°	5.92°
	elErr	5.68°	4.24°	4.89°
KEM.	azErr	9.13°	7.19°	6.39°
	azErrC	9.13°	7.19°	6.39°
	elErr	12.55°	8.28°	10.74°
reg.	azErr	37.51°	46.62°	17.11°
	azErrC	17.20°	17.93°	11.56°
	elErr	19.92°	15.80°	18.32°
sel.	azErr	8.99°	6.29°	8.85°
	azErrC	8.99°	6.29°	8.85°
	elErr	8.33°	5.99°	7.42°

noise bursts, with head-tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	55.0%		
reg.	confusions	22.50%	22.50%	0.00%
	inheads	100.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	42.5%		

speech, with head-tracking

		mean	std. dev.	median
meas.	azErr	6.76°	5.03°	5.33°
	azErrC	6.76°	5.03°	5.33°
	elErr	7.99°	8.53°	5.35°
KEM.	azErr	28.52°	48.21°	11.65°
	azErrC	12.92°	8.28°	11.65°
	elErr	14.40°	8.07°	15.21°
reg.	azErr	27.77°	41.44°	14.90°
	azErrC	15.77°	14.01°	14.00°
	elErr	16.69°	11.61°	14.97°
sel.	azErr	10.73°	26.31°	5.12°
	azErrC	6.83°	6.37°	5.12°
	elErr	9.23°	9.17°	7.38°

speech, with head-tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	77.5%		
KEM.	confusions	10.00%	0.00%	10.00%
	inheads	97.5%		
reg.	confusions	10.00%	5.00%	5.00%
	inheads	100.0%		
sel.	confusions	2.50%	0.00%	2.50%
	inheads	92.5%		

noise bursts, without head-tracking

		mean	std. dev.	median
meas.	azErr	29.44°	38.34°	15.48°
	azErrC	16.06°	11.81°	13.94°
	elErr	12.96°	10.06°	9.74°
KEM.	azErr	62.55°	61.90°	36.31°
	azErrC	21.28°	12.99°	16.33°
	elErr	17.10°	11.67°	14.08°
reg.	azErr	54.67°	59.70°	22.42°
	azErrC	16.07°	10.90°	13.27°
	elErr	20.31°	14.53°	20.93°
sel.	azErr	25.60°	33.37°	16.91°
	azErrC	15.67°	10.31°	14.91°
	elErr	14.54°	9.75°	11.64°

noise bursts, without head-tracking

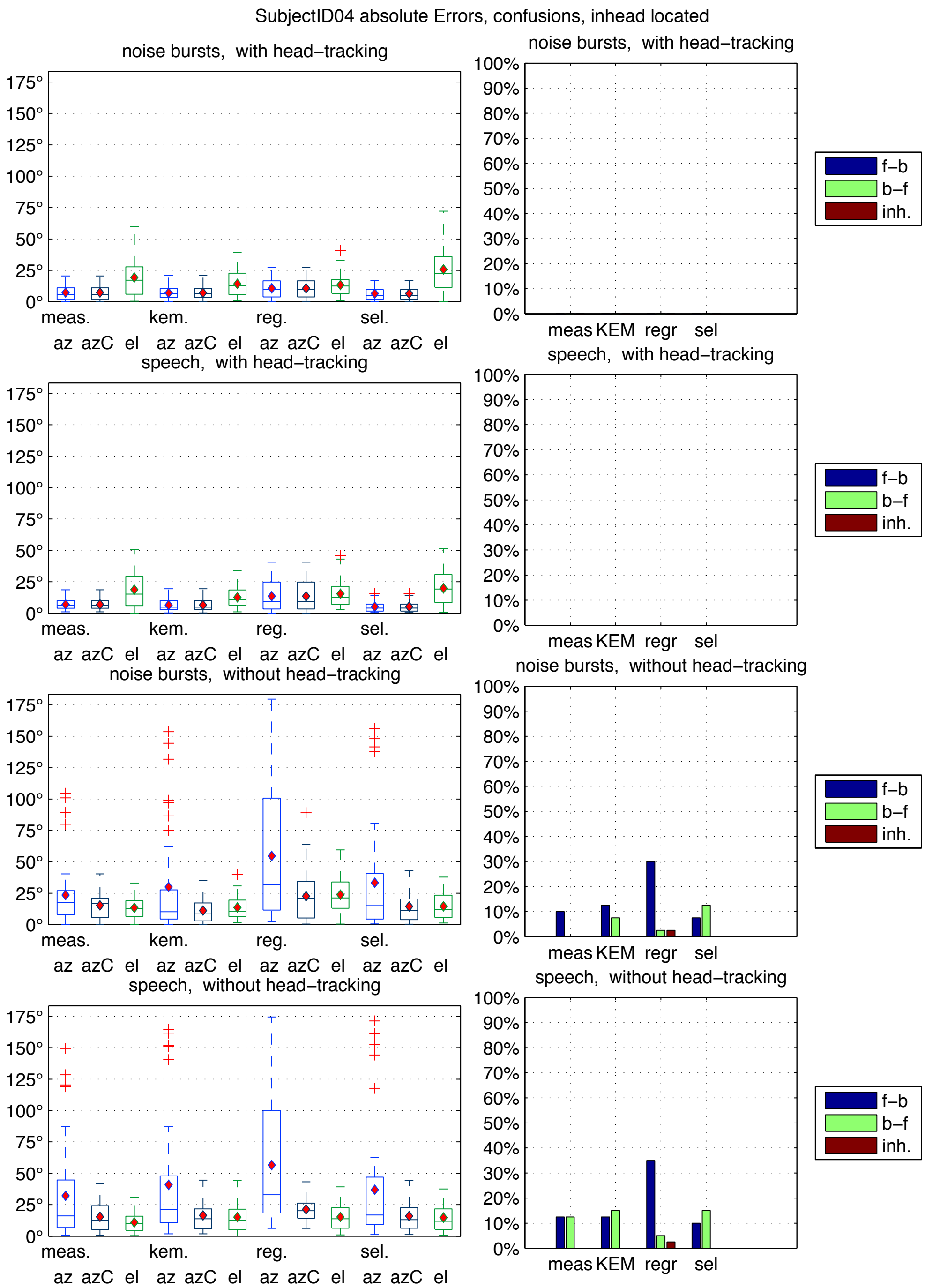
		total	front back	back front
meas.	confusions	22.50%	12.50%	10.00%
	inheads	97.5%		
KEM.	confusions	35.00%	25.00%	10.00%
	inheads	100.0%		
reg.	confusions	37.50%	22.50%	15.00%
	inheads	97.5%		
sel.	confusions	10.00%	7.50%	2.50%
	inheads	100.0%		

speech, without head-tracking

		mean	std. dev.	median
meas.	azErr	29.22°	42.51°	19.05°
	azErrC	16.48°	11.79°	16.29°
	elErr	11.62°	8.84°	8.27°
KEM.	azErr	35.67°	40.45°	25.03°
	azErrC	19.65°	13.05°	18.88°
	elErr	16.06°	10.95°	15.89°
reg.	azErr	45.91°	46.92°	25.71°
	azErrC	19.75°	16.10°	18.20°
	elErr	18.77°	13.25°	16.06°
sel.	azErr	26.68°	40.86°	15.67°
	azErrC	15.10°	10.62°	14.22°
	elErr	13.40°	10.62°	10.62°

speech, without head-tracking

		total	front back	back front
meas.	confusions	10.00%	0.00%	10.00%
	inheads	97.5%		
KEM.	confusions	17.50%	12.50%	5.00%
	inheads	100.0%		
reg.	confusions	27.50%	25.00%	2.50%
	inheads	100.0%		
sel.	confusions	7.50%	2.50%	5.00%
	inheads	97.5%		


SubjectID04 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175° 150° 125° 100° 75° 50° 25° 0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	7.37°	6.37°	5.78°
	azErrC	7.37°	6.37°	5.78°
	elErr	19.35°	15.93°	17.11°
KEM.	azErr	7.10°	5.04°	6.51°
	azErrC	7.10°	5.04°	6.51°
	elErr	14.23°	9.91°	12.87°
reg.	azErr	10.77°	7.81°	9.79°
	azErrC	10.77°	7.81°	9.79°
	elErr	13.43°	8.88°	12.49°
sel.	azErr	6.44°	5.06°	4.78°
	azErrC	6.44°	5.06°	4.78°
	elErr	25.77°	17.40°	22.33°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	6.99°	4.03°	6.35°
	azErrC	6.99°	4.03°	6.35°
	elErr	18.75°	14.66°	15.24°
KEM.	azErr	6.44°	4.76°	4.80°
	azErrC	6.44°	4.76°	4.80°
	elErr	12.61°	8.02°	10.84°
reg.	azErr	13.51°	12.51°	9.37°
	azErrC	13.51°	12.51°	9.37°
	elErr	15.46°	11.70°	12.52°
sel.	azErr	5.10°	4.16°	4.07°
	azErrC	5.10°	4.16°	4.07°
	elErr	19.77°	13.27°	19.22°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	23.53°	25.81°	17.56°
	azErrC	15.33°	10.12°	16.78°
	elErr	13.38°	9.43°	12.88°
KEM.	azErr	29.98°	42.01°	10.20°
	azErrC	11.23°	9.29°	8.54°
	elErr	13.68°	9.52°	10.74°
reg.	azErr	54.67°	54.43°	31.71°
	azErrC	22.61°	19.29°	21.16°
	elErr	23.78°	15.26°	21.28°
sel.	azErr	33.42°	43.38°	15.05°
	azErrC	14.46°	12.67°	11.16°
	elErr	14.62°	10.79°	12.03°

noise bursts, without head–tracking

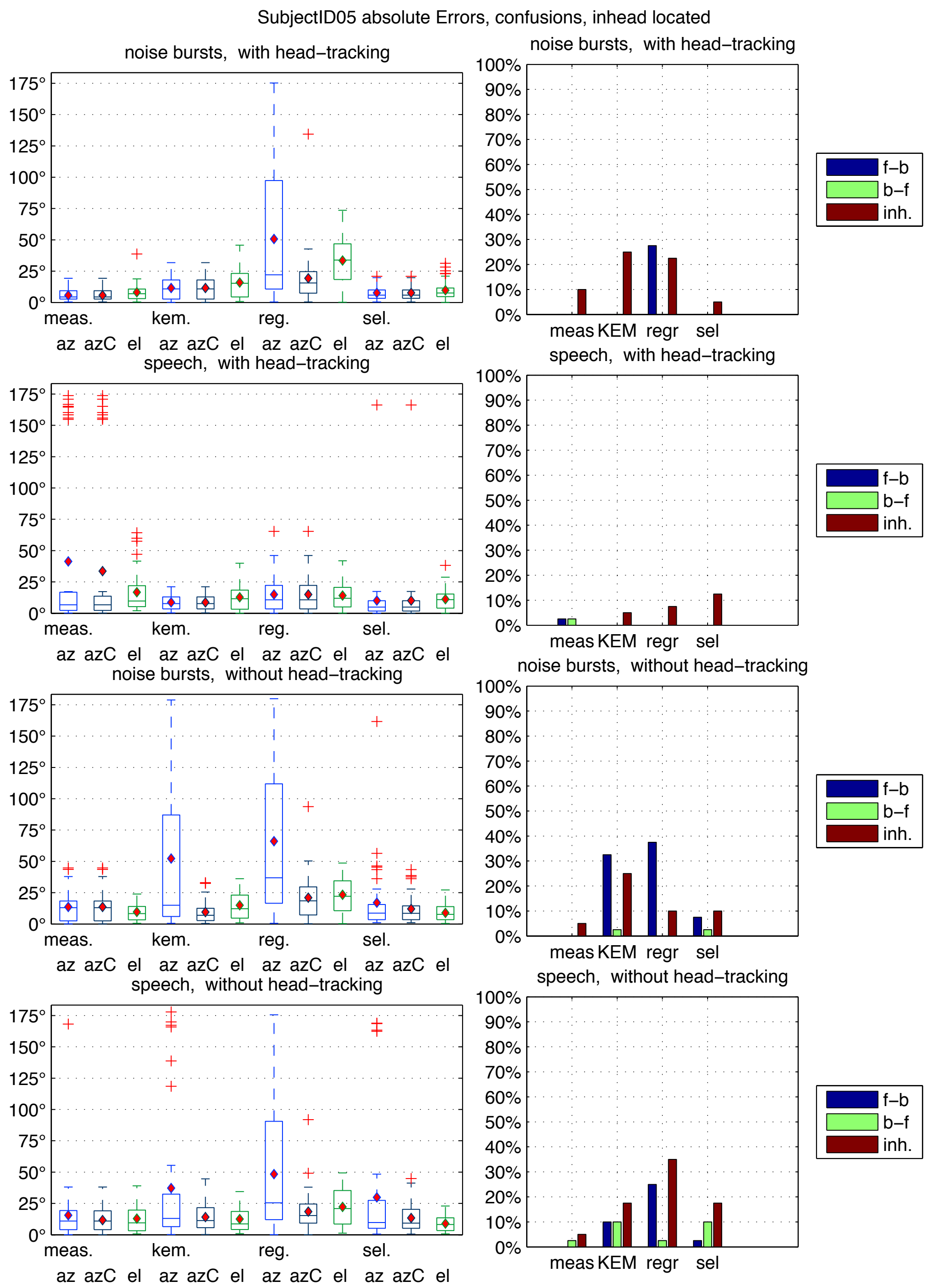
		total	front back	back front
meas.	confusions	10.00%	10.00%	0.00%
	inheads	0.0%		
KEM.	confusions	20.00%	12.50%	7.50%
	inheads	0.0%		
reg.	confusions	32.50%	30.00%	2.50%
	inheads	2.5%		
sel.	confusions	20.00%	7.50%	12.50%
	inheads	0.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	32.06°	38.79°	16.06°
	azErrC	15.35°	11.48°	12.38°
	elErr	10.81°	8.37°	10.01°
KEM.	azErr	40.76°	47.59°	21.22°
	azErrC	16.38°	11.92°	13.72°
	elErr	15.09°	11.44°	12.69°
reg.	azErr	56.56°	50.42°	32.88°
	azErrC	21.21°	9.87°	20.18°
	elErr	15.22°	10.67°	13.73°
sel.	azErr	36.95°	46.83°	16.77°
	azErrC	15.89°	12.05°	13.00°
	elErr	14.68°	10.89°	11.84°

speech, without head–tracking

		total	front back	back front
meas.	confusions	25.00%	12.50%	12.50%
	inheads	0.0%		
KEM.	confusions	27.50%	12.50%	15.00%
	inheads	0.0%		
reg.	confusions	40.00%	35.00%	5.00%
	inheads	2.5%		
sel.	confusions	25.00%	10.00%	15.00%
	inheads	0.0%		


SubjectID05 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175° 150° 125° 100° 75° 50° 25° 0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	5.77°	4.45°	4.38°
	azErrC	5.77°	4.45°	4.38°
	elErr	8.16°	7.18°	6.98°
KEM.	azErr	11.61°	9.24°	10.83°
	azErrC	11.61°	9.24°	10.83°
	elErr	15.90°	11.91°	15.33°
reg.	azErr	50.70°	57.38°	22.15°
	azErrC	19.36°	21.30°	15.57°
	elErr	33.45°	18.38°	33.91°
sel.	azErr	7.69°	5.75°	5.89°
	azErrC	7.69°	5.75°	5.89°
	elErr	9.80°	7.90°	7.62°

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	41.41°	66.78°	6.70°
	azErrC	33.67°	60.45°	6.70°
	elErr	16.78°	16.95°	9.77°
KEM.	azErr	8.67°	6.08°	7.75°
	azErrC	8.67°	6.08°	7.75°
	elErr	12.75°	10.23°	11.57°
reg.	azErr	14.93°	14.06°	10.67°
	azErrC	14.93°	14.06°	10.67°
	elErr	14.14°	11.88°	11.92°
sel.	azErr	10.07°	25.75°	4.93°
	azErrC	10.07°	25.75°	4.93°
	elErr	11.16°	8.69°	10.90°

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	13.62°	11.78°	13.08°
	azErrC	13.62°	11.78°	13.08°
	elErr	9.66°	6.93°	8.27°
KEM.	azErr	52.26°	64.43°	15.01°
	azErrC	9.54°	8.51°	6.97°
	elErr	14.99°	10.94°	12.13°
reg.	azErr	66.08°	61.80°	36.90°
	azErrC	20.97°	17.52°	18.49°
	elErr	23.36°	13.83°	22.06°
sel.	azErr	17.01°	27.33°	8.72°
	azErrC	12.00°	11.46°	8.56°
	elErr	8.88°	6.96°	7.66°

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	15.56°	26.44°	11.02°
	azErrC	11.66°	9.27°	11.02°
	elErr	12.91°	11.01°	9.54°
KEM.	azErr	37.26°	53.02°	13.03°
	azErrC	14.16°	11.36°	11.33°
	elErr	12.60°	9.65°	8.63°
reg.	azErr	48.46°	52.16°	25.48°
	azErrC	18.48°	16.29°	15.37°
	elErr	22.26°	14.65°	20.90°
sel.	azErr	29.89°	47.58°	9.75°
	azErrC	13.39°	11.42°	9.25°
	elErr	8.95°	6.00°	8.17°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	25.0%		
reg.	confusions	27.50%	27.50%	0.00%
	inheads	22.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		

speech, with head–tracking

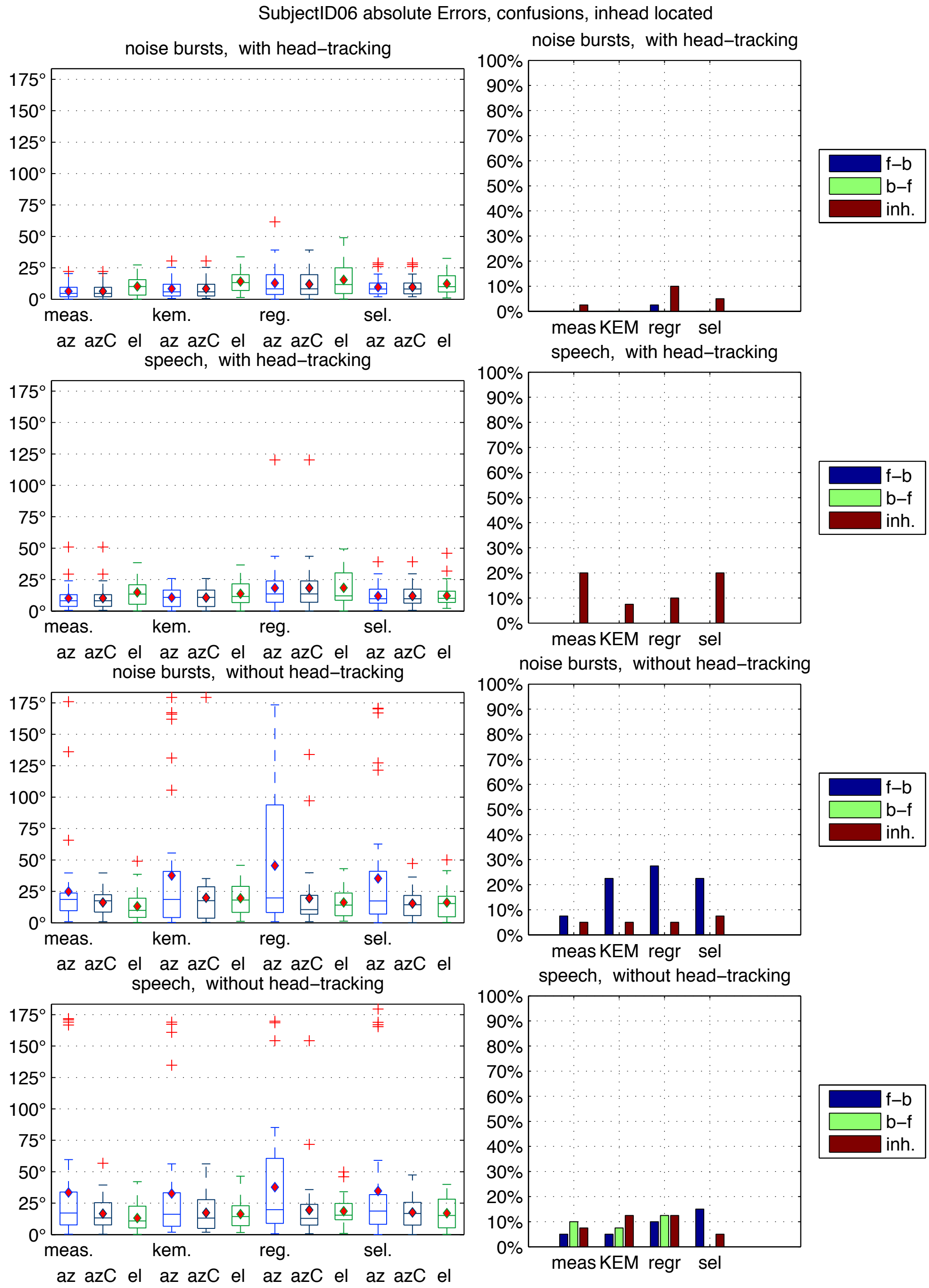
		total	front back	back front
meas.	confusions	5.00%	2.50%	2.50%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	7.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	12.5%		

noise bursts, without head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
KEM.	confusions	35.00%	32.50%	2.50%
	inheads	25.0%		
reg.	confusions	37.50%	37.50%	0.00%
	inheads	10.0%		
sel.	confusions	10.00%	7.50%	2.50%
	inheads	10.0%		

speech, without head–tracking

		total	front back	back front
meas.	confusions	2.50%	0.00%	2.50%
	inheads	5.0%		
KEM.	confusions	20.00%	10.00%	10.00%
	inheads	17.5%		
reg.	confusions	27.50%	25.00%	2.50%
	inheads	35.0%		
sel.	confusions	12.50%	2.50%	10.00%
	inheads	17.5%		


SubjectID06 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	6.33°	5.36°	4.68°
	azErrC	6.33°	5.36°	4.68°
	elErr	10.20°	7.15°	10.11°
KEM.	azErr	8.46°	7.73°	5.85°
	azErrC	8.46°	7.73°	5.85°
	elErr	14.16°	8.91°	13.30°
reg.	azErr	12.95°	12.98°	8.33°
	azErrC	11.97°	10.45°	8.33°
	elErr	15.39°	13.32°	11.67°
sel.	azErr	9.68°	6.83°	8.20°
	azErrC	9.68°	6.83°	8.20°
	elErr	12.26°	7.99°	10.04°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	2.50%	2.50%	0.00%
	inheads	10.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	10.24°	9.33°	8.18°
	azErrC	10.24°	9.33°	8.18°
	elErr	14.87°	10.66°	13.53°
KEM.	azErr	10.72°	7.59°	10.79°
	azErrC	10.72°	7.59°	10.79°
	elErr	13.77°	8.97°	11.58°
reg.	azErr	18.32°	20.14°	13.65°
	azErrC	18.32°	20.14°	13.65°
	elErr	18.47°	13.35°	12.07°
sel.	azErr	11.92°	8.26°	9.77°
	azErrC	11.92°	8.26°	9.77°
	elErr	12.19°	8.56°	10.07°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	20.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	7.5%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	20.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	24.91°	33.07°	18.65°
	azErrC	16.13°	9.66°	17.51°
	elErr	13.13°	11.54°	9.87°
KEM.	azErr	37.66°	51.96°	18.59°
	azErrC	19.98°	28.63°	17.57°
	elErr	19.61°	13.46°	18.11°
reg.	azErr	45.53°	51.15°	19.77°
	azErrC	19.56°	25.10°	10.52°
	elErr	16.21°	11.97°	14.08°
sel.	azErr	35.28°	47.70°	17.43°
	azErrC	15.35°	11.59°	14.37°
	elErr	16.13°	12.16°	15.36°

noise bursts, without head–tracking

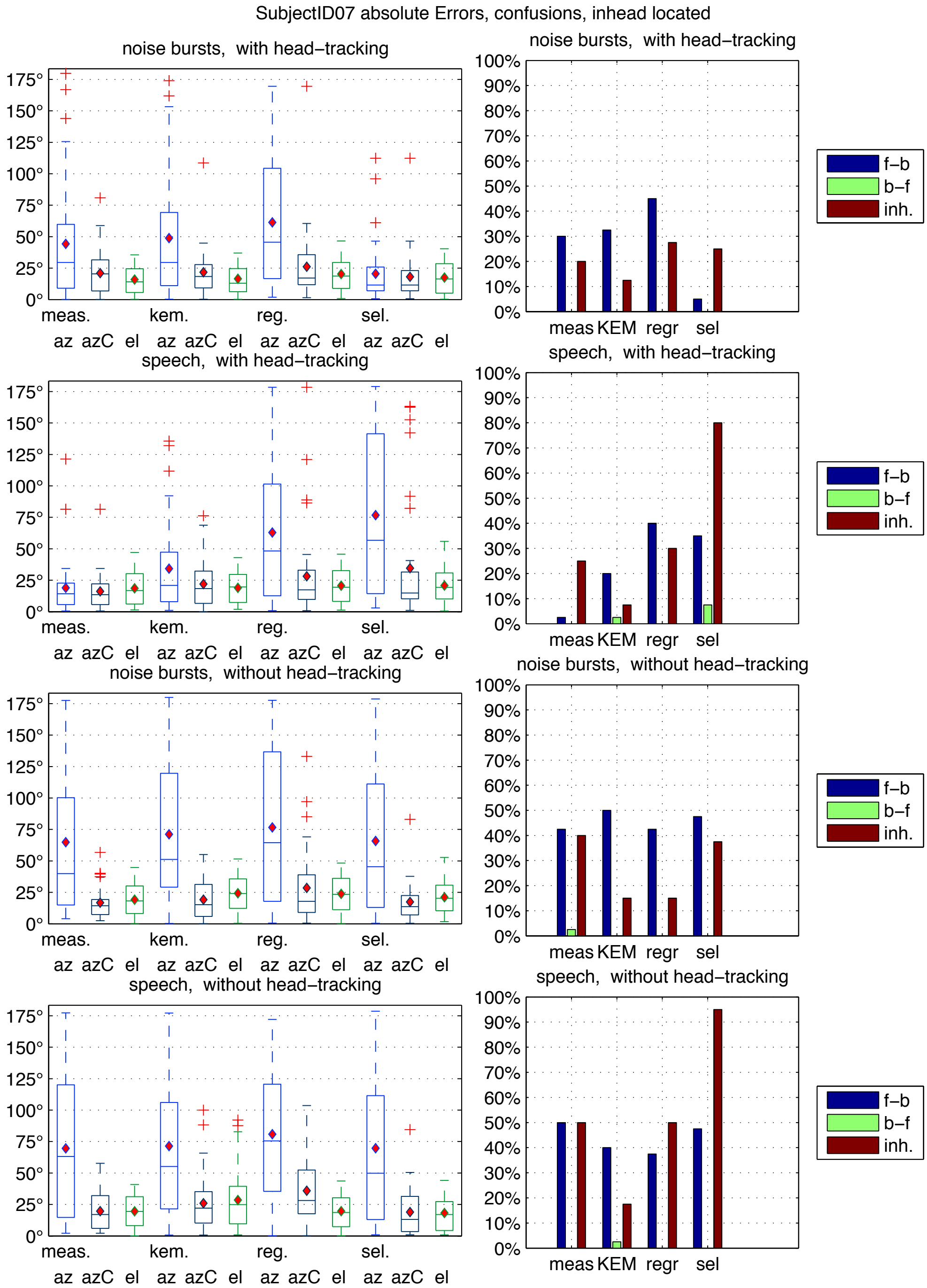
		total	front back	back front
meas.	confusions	7.50%	7.50%	0.00%
	inheads	5.0%		
KEM.	confusions	22.50%	22.50%	0.00%
	inheads	5.0%		
reg.	confusions	27.50%	27.50%	0.00%
	inheads	5.0%		
sel.	confusions	22.50%	22.50%	0.00%
	inheads	7.5%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	33.50°	48.38°	17.16°
	azErrC	16.72°	13.05°	13.26°
	elErr	13.14°	10.19°	10.84°
KEM.	azErr	32.63°	44.76°	16.17°
	azErrC	17.41°	13.84°	13.13°
	elErr	16.29°	10.56°	14.39°
reg.	azErr	37.77°	44.15°	19.79°
	azErrC	19.55°	25.82°	12.90°
	elErr	18.55°	11.47°	15.44°
sel.	azErr	34.74°	47.97°	18.72°
	azErrC	17.66°	12.12°	16.75°
	elErr	16.99°	12.52°	15.26°

speech, without head–tracking

		total	front back	back front
meas.	confusions	15.00%	5.00%	10.00%
	inheads	7.5%		
KEM.	confusions	12.50%	5.00%	7.50%
	inheads	12.5%		
reg.	confusions	22.50%	10.00%	12.50%
	inheads	12.5%		
sel.	confusions	15.00%	15.00%	0.00%
	inheads	5.0%		


SubjectID07 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
speech, without head−tracking
175° 150° 125° 100° 75° 50° 25° 0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
meas KEM regr sel
f−b
b−f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	44.30°	47.06°	29.50°
	azErrC	21.03°	17.59°	20.41°
	elErr	15.98°	11.20°	14.15°
KEM.	azErr	48.92°	49.60°	29.54°
	azErrC	21.70°	18.84°	18.41°
	elErr	16.58°	12.15°	13.06°
reg.	azErr	61.38°	52.01°	45.62°
	azErrC	26.14°	27.11°	17.19°
	elErr	20.34°	13.00°	18.66°
sel.	azErr	20.54°	23.55°	11.57°
	azErrC	18.08°	19.14°	11.57°
	elErr	17.46°	12.41°	16.44°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	30.00%	30.00%	0.00%
	inheads	20.0%		
KEM.	confusions	32.50%	32.50%	0.00%
	inheads	12.5%		
reg.	confusions	45.00%	45.00%	0.00%
	inheads	27.5%		
sel.	confusions	5.00%	5.00%	0.00%
	inheads	25.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	18.95°	21.61°	14.21°
	azErrC	16.19°	13.87°	13.46°
	elErr	18.57°	12.93°	16.75°
KEM.	azErr	34.18°	35.09°	20.95°
	azErrC	22.01°	17.94°	18.40°
	elErr	18.96°	12.58°	19.72°
reg.	azErr	62.98°	55.48°	48.33°
	azErrC	28.19°	34.93°	17.38°
	elErr	20.69°	13.46°	19.48°
sel.	azErr	76.74°	62.74°	56.74°
	azErrC	34.55°	44.70°	14.83°
	elErr	20.79°	14.11°	19.33°

speech, with head–tracking

		total	front back	back front
meas.	confusions	2.50%	2.50%	0.00%
	inheads	25.0%		
KEM.	confusions	22.50%	20.00%	2.50%
	inheads	7.5%		
reg.	confusions	40.00%	40.00%	0.00%
	inheads	30.0%		
sel.	confusions	42.50%	35.00%	7.50%
	inheads	80.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	64.85°	57.56°	39.87°
	azErrC	16.84°	12.75°	14.36°
	elErr	19.22°	13.15°	18.28°
KEM.	azErr	71.15°	58.39°	51.22°
	azErrC	19.21°	15.27°	15.22°
	elErr	24.34°	14.67°	24.06°
reg.	azErr	76.69°	61.62°	64.53°
	azErrC	28.49°	28.51°	17.86°
	elErr	23.85°	14.66°	23.45°
sel.	azErr	65.81°	57.99°	45.38°
	azErrC	17.39°	15.26°	13.61°
	elErr	21.16°	13.47°	20.25°

noise bursts, without head–tracking

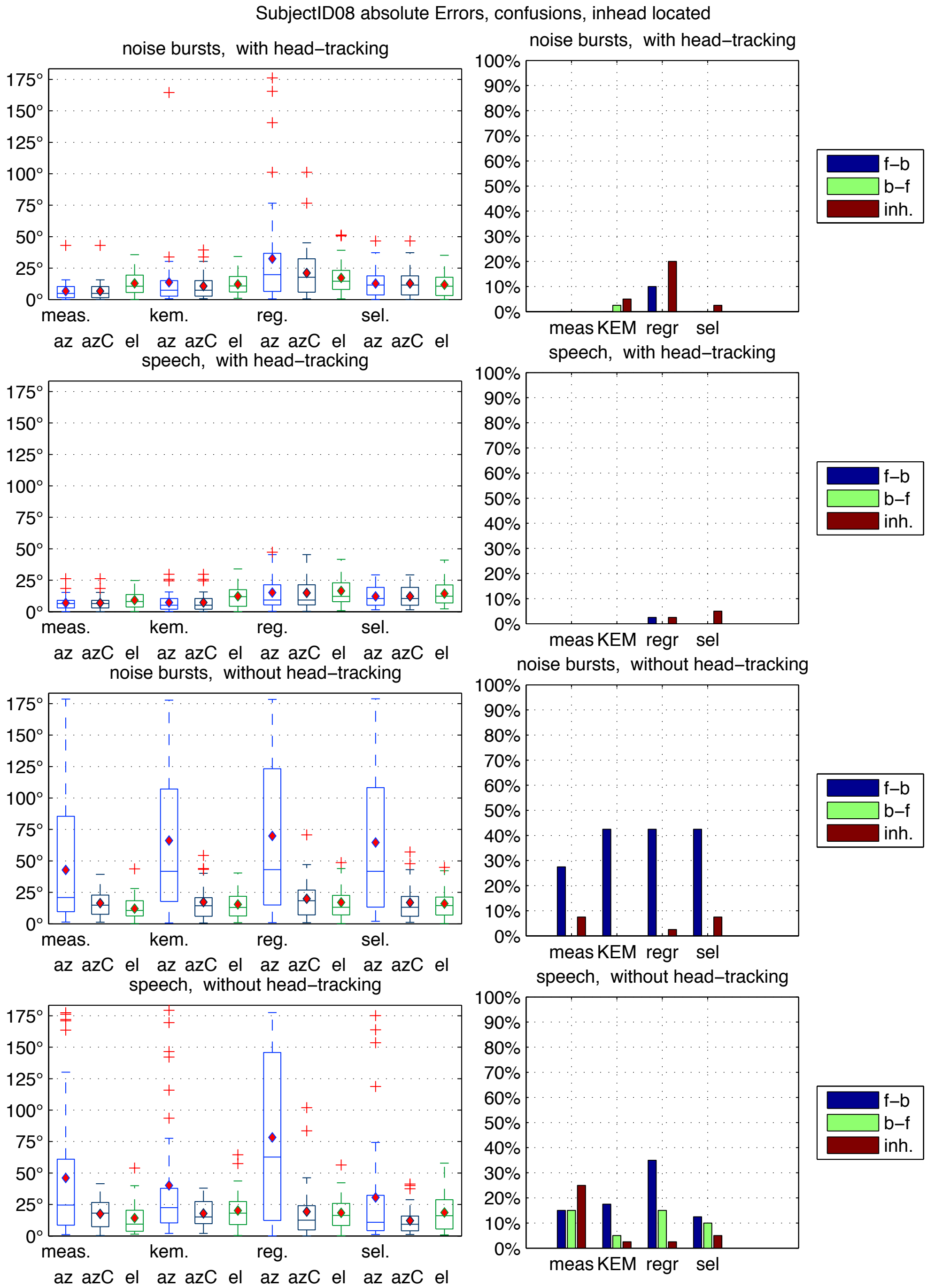
		total	front back	back front
meas.	confusions	45.00%	42.50%	2.50%
	inheads	40.0%		
KEM.	confusions	50.00%	50.00%	0.00%
	inheads	15.0%		
reg.	confusions	42.50%	42.50%	0.00%
	inheads	15.0%		
sel.	confusions	47.50%	47.50%	0.00%
	inheads	37.5%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	69.62°	57.71°	63.19°
	azErrC	19.67°	14.61°	17.03°
	elErr	19.54°	13.47°	19.41°
KEM.	azErr	71.37°	58.12°	55.18°
	azErrC	25.99°	21.98°	22.07°
	elErr	28.51°	23.63°	24.93°
reg.	azErr	80.92°	52.43°	75.54°
	azErrC	35.96°	27.30°	28.13°
	elErr	19.67°	13.51°	18.58°
sel.	azErr	69.68°	60.17°	49.89°
	azErrC	18.93°	18.74°	13.19°
	elErr	18.20°	13.47°	17.03°

speech, without head–tracking

		total	front back	back front
meas.	confusions	50.00%	50.00%	0.00%
	inheads	50.0%		
KEM.	confusions	42.50%	40.00%	2.50%
	inheads	17.5%		
reg.	confusions	37.50%	37.50%	0.00%
	inheads	50.0%		
sel.	confusions	47.50%	47.50%	0.00%
	inheads	95.0%		



SubjectID08 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175° 150° 125° 100° 75° 50° 25° 0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head−tracking

		mean	std. dev.	median
meas.	azErr	6.71°	7.40°	4.87°
	azErrC	6.71°	7.40°	4.87°
	elErr	12.86°	8.71°	10.56°
KEM.	azErr	13.79°	25.93°	7.46°
	azErrC	10.67°	9.84°	7.46°
	elErr	12.23°	7.85°	10.85°
reg.	azErr	32.51°	42.59°	19.79°
	azErrC	21.20°	20.71°	17.74°
	elErr	17.24°	12.81°	14.55°
sel.	azErr	12.73°	10.59°	11.56°
	azErrC	12.73°	10.59°	11.56°
	elErr	11.80°	9.88°	10.56°

noise bursts, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	2.50%	0.00%	2.50%
	inheads	5.0%		
reg.	confusions	10.00%	10.00%	0.00%
	inheads	20.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		

speech, with head−tracking

		mean	std. dev.	median
meas.	azErr	6.96°	5.43°	6.54°
	azErrC	6.96°	5.43°	6.54°
	elErr	9.17°	6.22°	8.02°
KEM.	azErr	7.30°	7.13°	5.13°
	azErrC	7.30°	7.13°	5.13°
	elErr	12.35°	9.76°	11.99°
reg.	azErr	15.26°	14.03°	9.28°
	azErrC	15.00°	13.49°	9.28°
	elErr	16.50°	11.23°	12.23°
sel.	azErr	12.12°	8.11°	10.44°
	azErrC	12.12°	8.11°	10.44°
	elErr	14.39°	9.51°	12.30°

speech, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	2.50%	2.50%	0.00%
	inheads	2.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		

noise bursts, without head−tracking

		mean	std. dev.	median
meas.	azErr	42.77°	46.62°	20.89°
	azErrC	16.39°	10.76°	14.87°
	elErr	12.09°	9.05°	10.56°
KEM.	azErr	66.21°	59.73°	41.69°
	azErrC	17.22°	13.99°	14.39°
	elErr	15.47°	10.98°	13.03°
reg.	azErr	69.88°	62.26°	43.09°
	azErrC	19.94°	15.99°	18.36°
	elErr	16.99°	13.67°	13.12°
sel.	azErr	64.66°	59.86°	41.72°
	azErrC	16.88°	14.31°	13.09°
	elErr	16.00°	11.53°	14.49°

noise bursts, without head−tracking

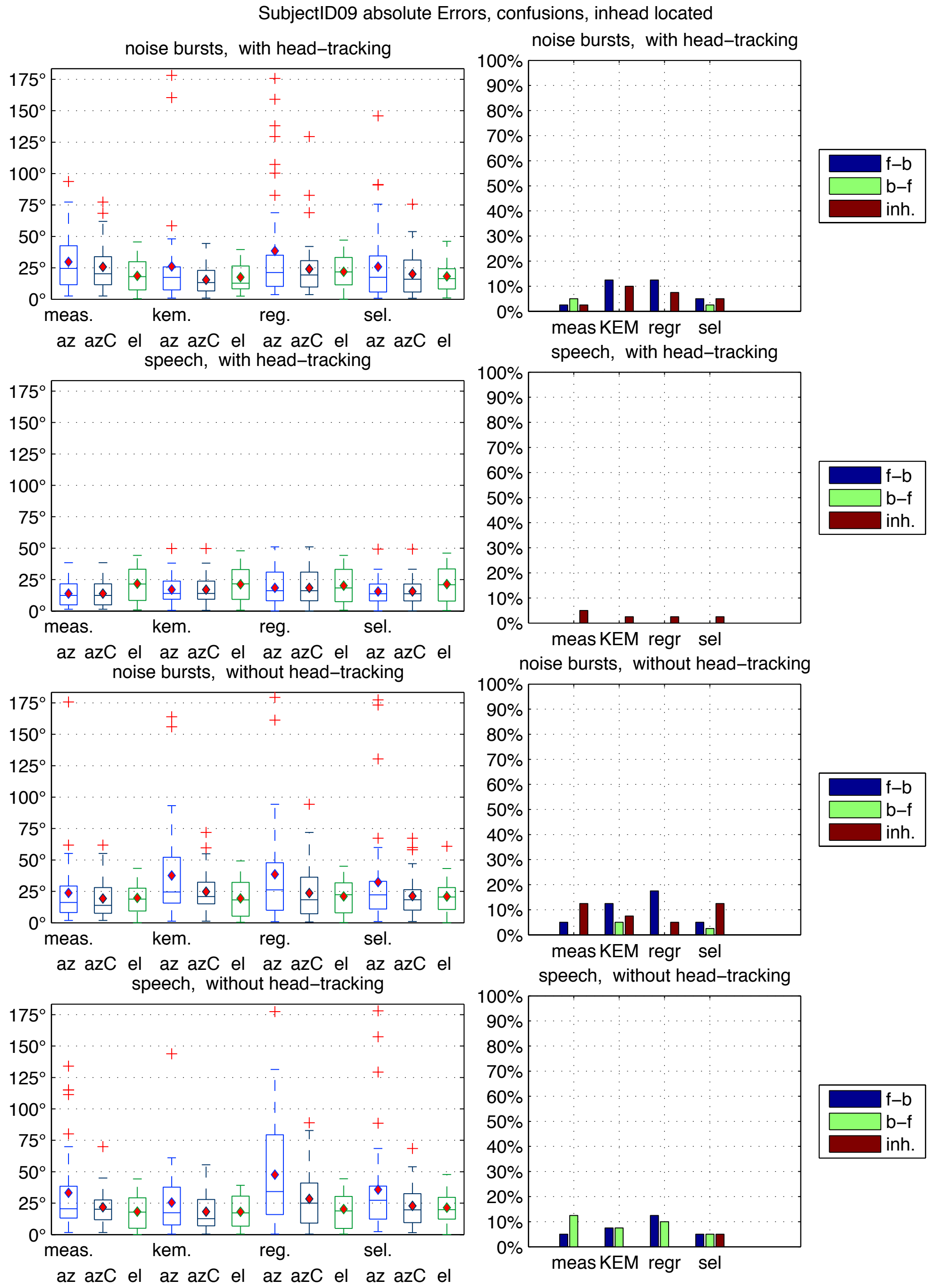
		total	front back	back front
meas.	confusions	27.50%	27.50%	0.00%
	inheads	7.5%		
KEM.	confusions	42.50%	42.50%	0.00%
	inheads	0.0%		
reg.	confusions	42.50%	42.50%	0.00%
	inheads	2.5%		
sel.	confusions	42.50%	42.50%	0.00%
	inheads	7.5%		

speech, without head−tracking

		mean	std. dev.	median
meas.	azErr	46.05°	54.76°	24.49°
	azErrC	17.45°	11.73°	18.12°
	elErr	14.26°	13.01°	9.44°
KEM.	azErr	40.19°	47.88°	22.46°
	azErrC	17.88°	11.33°	15.10°
	elErr	20.19°	14.48°	18.12°
reg.	azErr	78.35°	65.84°	62.71°
	azErrC	19.27°	21.18°	12.50°
	elErr	18.33°	13.12°	16.26°
sel.	azErr	30.65°	46.24°	10.89°
	azErrC	12.17°	10.52°	9.32°
	elErr	18.56°	13.79°	16.07°

speech, without head−tracking

		total	front back	back front
meas.	confusions	30.00%	15.00%	15.00%
	inheads	25.0%		
KEM.	confusions	22.50%	17.50%	5.00%
	inheads	2.5%		
reg.	confusions	50.00%	35.00%	15.00%
	inheads	2.5%		
sel.	confusions	22.50%	12.50%	10.00%
	inheads	5.0%		


SubjectID09 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
0° 25° 50° 75° 100° 125° 150° 175°
meas. kem. reg. sel.
az azC el
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	29.79°	22.91°	24.48°
	azErrC	25.78°	18.82°	20.31°
	elErr	18.61°	12.28°	18.01°
KEM.	azErr	26.05°	36.16°	17.35°
	azErrC	15.41°	10.62°	13.21°
	elErr	17.55°	11.75°	12.76°
reg.	azErr	38.44°	45.31°	21.30°
	azErrC	24.10°	23.83°	19.33°
	elErr	21.81°	12.90°	21.71°
sel.	azErr	25.91°	30.12°	17.56°
	azErrC	20.00°	17.38°	15.98°
	elErr	18.24°	12.49°	16.43°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	7.50%	2.50%	5.00%
	inheads	2.5%		
KEM.	confusions	12.50%	12.50%	0.00%
	inheads	10.0%		
reg.	confusions	12.50%	12.50%	0.00%
	inheads	7.5%		
sel.	confusions	7.50%	5.00%	2.50%
	inheads	5.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	13.82°	9.57°	12.36°
	azErrC	13.82°	9.57°	12.36°
	elErr	21.78°	14.00°	21.54°
KEM.	azErr	17.04°	11.71°	13.98°
	azErrC	17.04°	11.71°	13.98°
	elErr	21.28°	13.94°	21.66°
reg.	azErr	18.44°	13.42°	16.22°
	azErrC	18.44°	13.42°	16.22°
	elErr	20.14°	14.44°	18.39°
sel.	azErr	15.61°	10.59°	13.77°
	azErrC	15.61°	10.59°	13.77°
	elErr	21.40°	14.45°	20.87°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	23.86°	28.95°	16.22°
	azErrC	19.33°	15.03°	13.85°
	elErr	19.84°	12.40°	18.82°
KEM.	azErr	37.61°	36.57°	24.57°
	azErrC	24.75°	16.99°	20.90°
	elErr	19.41°	14.25°	18.24°
reg.	azErr	38.55°	39.97°	26.25°
	azErrC	23.64°	20.71°	18.36°
	elErr	20.96°	14.38°	22.32°
sel.	azErr	32.46°	40.60°	22.24°
	azErrC	21.30°	16.38°	18.35°
	elErr	20.89°	13.05°	20.54°

noise bursts, without head–tracking

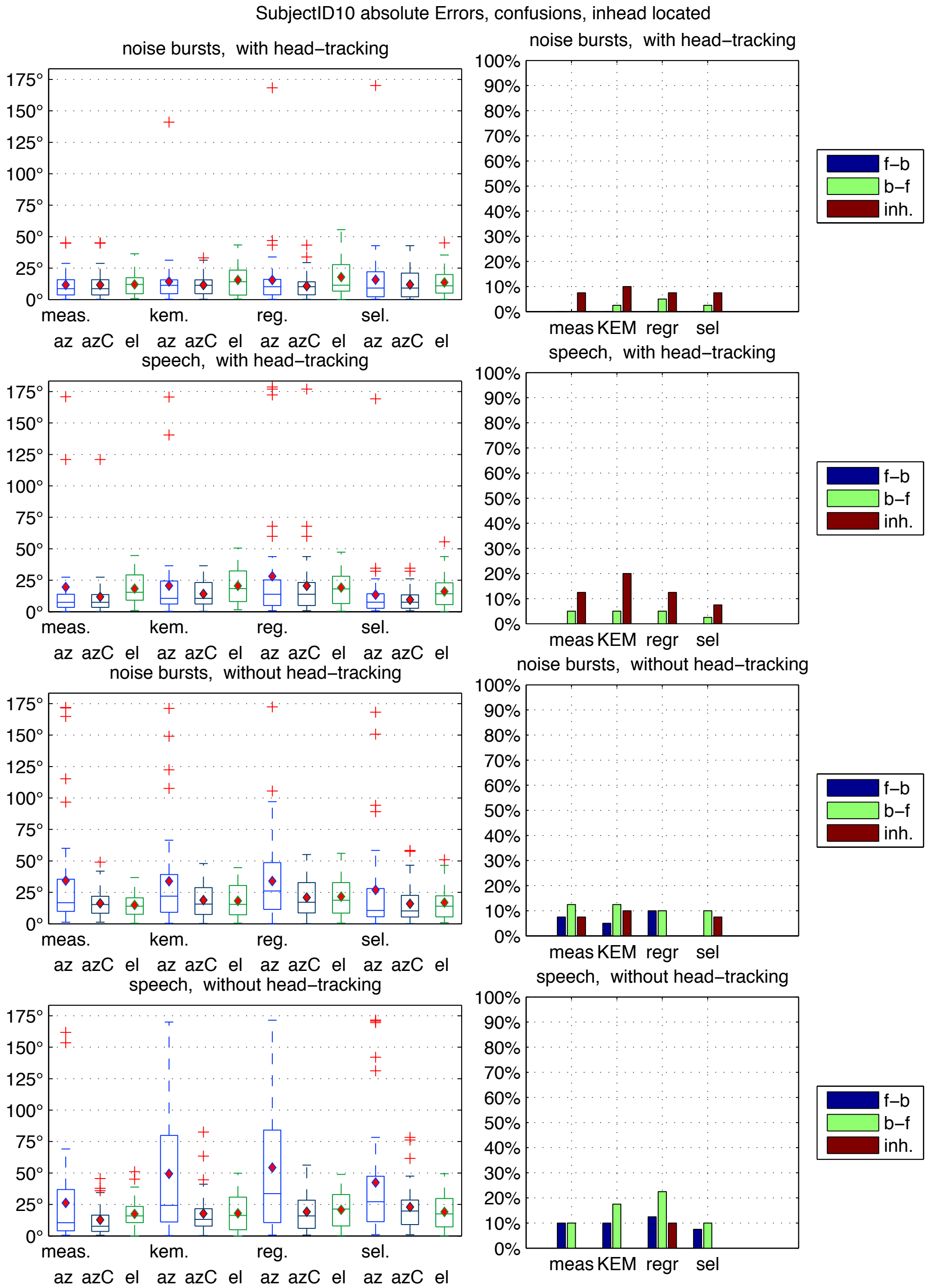
		total	front back	back front
meas.	confusions	5.00%	5.00%	0.00%
	inheads	12.5%		
KEM.	confusions	17.50%	12.50%	5.00%
	inheads	7.5%		
reg.	confusions	17.50%	17.50%	0.00%
	inheads	5.0%		
sel.	confusions	7.50%	5.00%	2.50%
	inheads	12.5%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	33.22°	33.69°	20.58°
	azErrC	21.72°	13.67°	20.21°
	elErr	18.26°	13.49°	17.87°
KEM.	azErr	25.50°	26.75°	17.39°
	azErrC	18.17°	15.22°	12.62°
	elErr	18.17°	12.40°	17.31°
reg.	azErr	47.70°	42.10°	34.17°
	azErrC	28.36°	23.34°	24.98°
	elErr	20.32°	14.39°	18.83°
sel.	azErr	35.82°	39.28°	27.29°
	azErrC	22.85°	16.22°	19.73°
	elErr	21.44°	13.00°	19.75°

speech, without head–tracking

		total	front back	back front
meas.	confusions	17.50%	5.00%	12.50%
	inheads	0.0%		
KEM.	confusions	15.00%	7.50%	7.50%
	inheads	0.0%		
reg.	confusions	22.50%	12.50%	10.00%
	inheads	0.0%		
sel.	confusions	10.00%	5.00%	5.00%
	inheads	5.0%		


SubjectID10 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	11.63°	11.02°	8.69°
	azErrC	11.63°	11.02°	8.69°
	elErr	12.00°	8.81°	12.10°
KEM.	azErr	14.32°	21.96°	11.29°
	azErrC	11.62°	8.46°	11.29°
	elErr	15.57°	12.11°	14.24°
reg.	azErr	15.53°	27.07°	10.27°
	azErrC	10.78°	9.28°	10.27°
	elErr	17.92°	15.37°	11.45°
sel.	azErr	15.84°	27.26°	9.20°
	azErrC	11.94°	10.80°	9.20°
	elErr	13.63°	10.39°	10.99°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	7.5%		
KEM.	confusions	2.50%	0.00%	2.50%
	inheads	10.0%		
reg.	confusions	5.00%	0.00%	5.00%
	inheads	7.5%		
sel.	confusions	2.50%	0.00%	2.50%
	inheads	7.5%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	19.58°	39.96°	7.47°
	azErrC	11.78°	19.01°	7.47°
	elErr	18.39°	12.27°	15.49°
KEM.	azErr	20.66°	32.98°	10.63°
	azErrC	14.06°	10.15°	10.63°
	elErr	20.52°	14.29°	18.33°
reg.	azErr	28.21°	45.26°	13.82°
	azErrC	20.48°	29.63°	13.82°
	elErr	19.20°	13.57°	18.15°
sel.	azErr	13.45°	26.64°	7.55°
	azErrC	9.55°	8.50°	7.55°
	elErr	16.09°	12.76°	14.23°

speech, with head–tracking

		total	front back	back front
meas.	confusions	5.00%	0.00%	5.00%
	inheads	12.5%		
KEM.	confusions	5.00%	0.00%	5.00%
	inheads	20.0%		
reg.	confusions	5.00%	0.00%	5.00%
	inheads	12.5%		
sel.	confusions	2.50%	0.00%	2.50%
	inheads	7.5%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	34.37°	45.66°	16.83°
	azErrC	16.30°	10.84°	15.37°
	elErr	14.93°	9.61°	14.00°
KEM.	azErr	33.81°	39.37°	21.94°
	azErrC	18.84°	13.62°	15.71°
	elErr	18.29°	13.70°	15.49°
reg.	azErr	33.94°	34.15°	26.08°
	azErrC	20.94°	15.00°	17.10°
	elErr	21.63°	16.03°	18.70°
sel.	azErr	26.98°	37.97°	10.60°
	azErrC	15.93°	14.84°	10.25°
	elErr	16.94°	13.47°	14.01°

noise bursts, without head–tracking

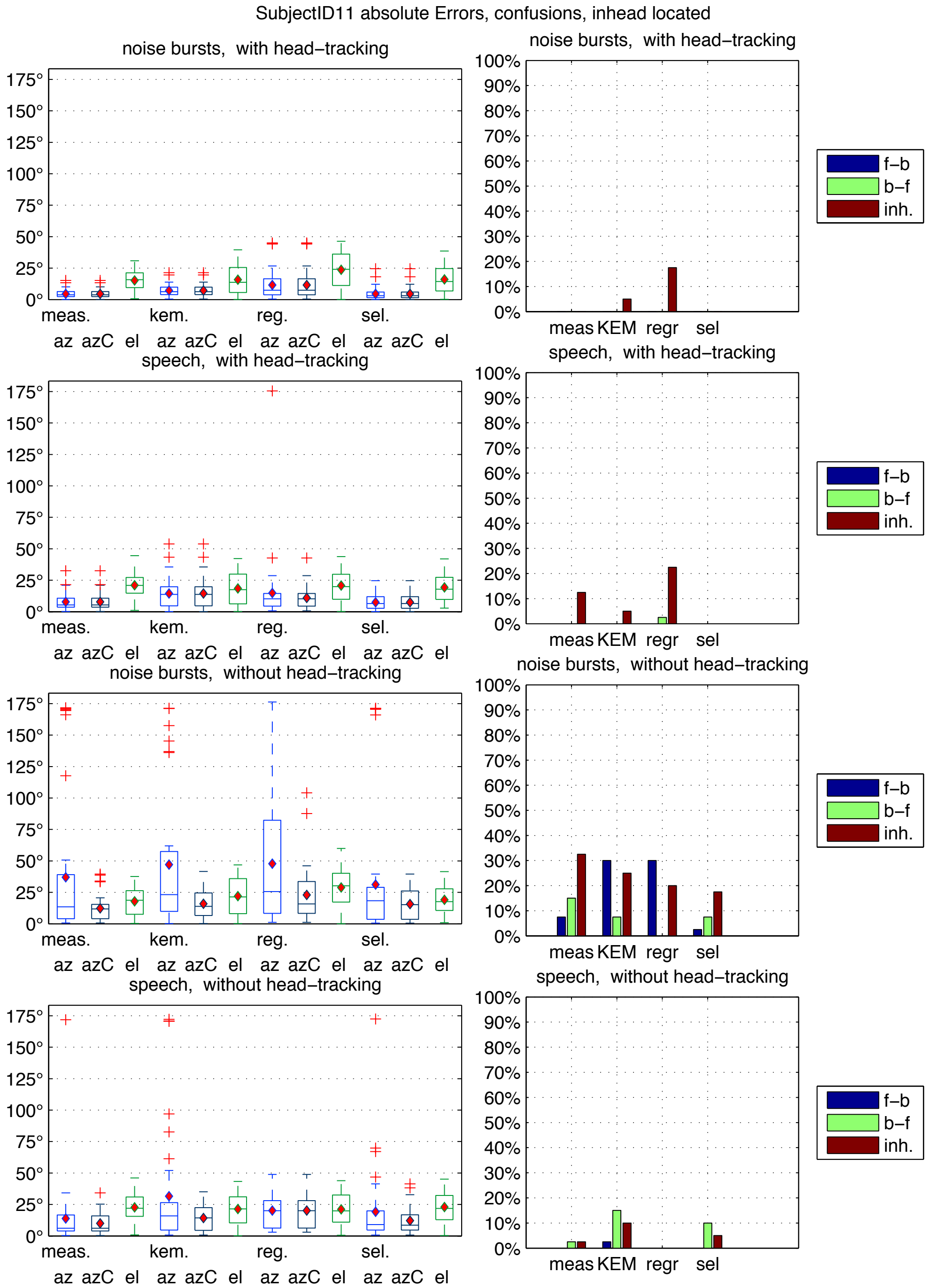
		total	front back	back front
meas.	confusions	20.00%	7.50%	12.50%
	inheads	7.5%		
KEM.	confusions	17.50%	5.00%	12.50%
	inheads	10.0%		
reg.	confusions	20.00%	10.00%	10.00%
	inheads	0.0%		
sel.	confusions	10.00%	0.00%	10.00%
	inheads	7.5%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	26.18°	36.67°	10.50°
	azErrC	12.79°	12.18°	7.72°
	elErr	17.55°	11.58°	15.98°
KEM.	azErr	49.39°	53.44°	24.30°
	azErrC	17.81°	16.87°	13.20°
	elErr	18.01°	14.47°	16.30°
reg.	azErr	54.38°	55.84°	33.64°
	azErrC	19.15°	14.74°	15.89°
	elErr	20.80°	14.03°	21.43°
sel.	azErr	42.47°	48.26°	27.24°
	azErrC	22.96°	18.72°	19.80°
	elErr	19.06°	12.97°	17.47°

speech, without head–tracking

		total	front back	back front
meas.	confusions	20.00%	10.00%	10.00%
	inheads	0.0%		
KEM.	confusions	27.50%	10.00%	17.50%
	inheads	0.0%		
reg.	confusions	35.00%	12.50%	22.50%
	inheads	10.0%		
sel.	confusions	17.50%	7.50%	10.00%
	inheads	0.0%		


SubjectID11 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	4.58°	3.29°	3.83°
	azErrC	4.58°	3.29°	3.83°
	elErr	15.25°	6.99°	15.79°
KEM.	azErr	7.27°	4.73°	6.25°
	azErrC	7.27°	4.73°	6.25°
	elErr	15.87°	11.85°	13.78°
reg.	azErr	11.61°	11.75°	7.47°
	azErrC	11.61°	11.75°	7.47°
	elErr	23.70°	13.84°	24.06°
sel.	azErr	4.52°	4.86°	3.12°
	azErrC	4.52°	4.86°	3.12°
	elErr	16.03°	10.55°	14.36°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	17.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	7.85°	6.85°	5.45°
	azErrC	7.85°	6.85°	5.45°
	elErr	21.08°	10.25°	20.91°
KEM.	azErr	14.53°	12.35°	13.72°
	azErrC	14.53°	12.35°	13.72°
	elErr	18.48°	13.07°	17.56°
reg.	azErr	14.89°	27.55°	10.24°
	azErrC	10.99°	9.10°	10.24°
	elErr	20.83°	13.52°	19.94°
sel.	azErr	7.48°	6.06°	6.44°
	azErrC	7.48°	6.06°	6.44°
	elErr	19.26°	11.29°	17.88°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	12.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
reg.	confusions	2.50%	0.00%	2.50%
	inheads	22.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	37.03°	55.10°	13.50°
	azErrC	12.30°	9.89°	11.82°
	elErr	17.83°	11.04°	18.76°
KEM.	azErr	47.09°	54.46°	23.25°
	azErrC	15.93°	10.73°	13.91°
	elErr	22.01°	14.48°	21.38°
reg.	azErr	47.74°	51.82°	25.61°
	azErrC	22.99°	21.78°	15.76°
	elErr	28.93°	14.73°	30.21°
sel.	azErr	31.19°	48.22°	18.30°
	azErrC	15.68°	11.66°	15.25°
	elErr	19.09°	10.53°	17.66°

noise bursts, without head–tracking

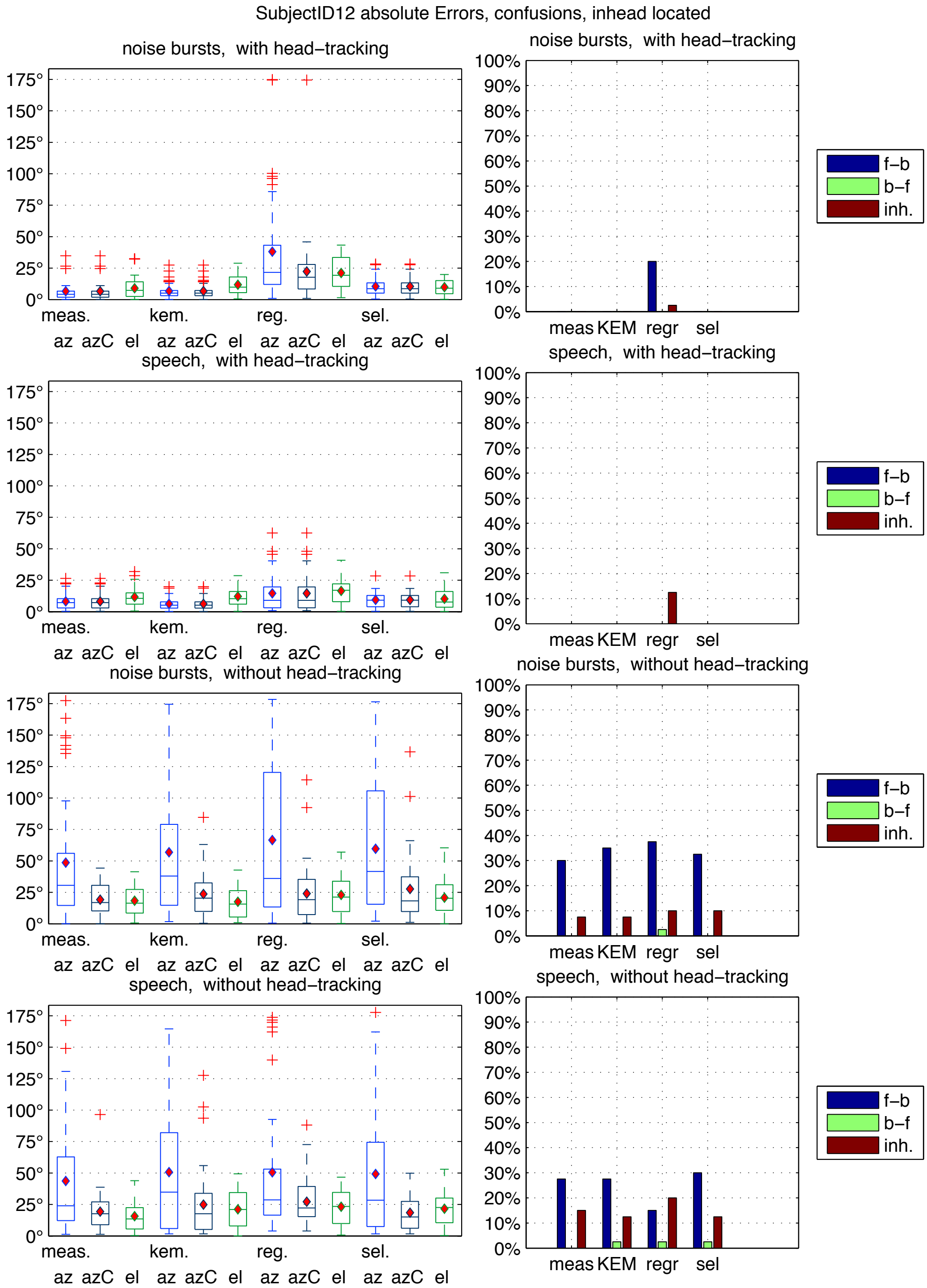
		total	front back	back front
meas.	confusions	22.50%	7.50%	15.00%
	inheads	32.5%		
KEM.	confusions	37.50%	30.00%	7.50%
	inheads	25.0%		
reg.	confusions	30.00%	30.00%	0.00%
	inheads	20.0%		
sel.	confusions	10.00%	2.50%	7.50%
	inheads	17.5%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	13.93°	26.89°	6.07°
	azErrC	10.03°	8.25°	6.07°
	elErr	22.77°	11.34°	22.01°
KEM.	azErr	31.61°	45.36°	15.93°
	azErrC	14.26°	9.97°	14.32°
	elErr	21.35°	13.79°	21.47°
reg.	azErr	20.15°	13.04°	20.04°
	azErrC	20.15°	13.04°	20.04°
	elErr	21.17°	13.72°	19.88°
sel.	azErr	19.16°	29.74°	9.05°
	azErrC	12.13°	10.03°	8.50°
	elErr	22.91°	13.10°	21.90°

speech, without head–tracking

		total	front back	back front
meas.	confusions	2.50%	0.00%	2.50%
	inheads	2.5%		
KEM.	confusions	17.50%	2.50%	15.00%
	inheads	10.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
sel.	confusions	10.00%	0.00%	10.00%
	inheads	5.0%		


SubjectID12 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
0°
25°
50°
75°
100°
125°
150°
175°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head−tracking

		mean	std. dev.	median
meas.	azErr	6.60°	7.95°	4.15°
	azErrC	6.60°	7.95°	4.15°
	elErr	9.02°	7.89°	7.36°
KEM.	azErr	6.71°	5.93°	5.17°
	azErrC	6.71°	5.93°	5.17°
	elErr	11.86°	8.33°	9.86°
reg.	azErr	38.10°	42.56°	21.58°
	azErrC	22.35°	27.37°	17.72°
	elErr	21.20°	13.01°	19.33°
sel.	azErr	10.44°	7.13°	8.63°
	azErrC	10.44°	7.13°	8.63°
	elErr	9.93°	5.87°	9.04°

speech, with head−tracking

		mean	std. dev.	median
meas.	azErr	8.13°	6.57°	7.17°
	azErrC	8.13°	6.57°	7.17°
	elErr	11.69°	7.53°	10.66°
KEM.	azErr	6.23°	4.80°	5.11°
	azErrC	6.23°	4.80°	5.11°
	elErr	12.18°	8.14°	10.34°
reg.	azErr	14.63°	15.35°	8.97°
	azErrC	14.63°	15.35°	8.97°
	elErr	16.49°	11.26°	17.03°
sel.	azErr	9.39°	6.76°	9.09°
	azErrC	9.39°	6.76°	9.09°
	elErr	10.25°	8.60°	7.65°

noise bursts, without head−tracking

		mean	std. dev.	median
meas.	azErr	48.70°	51.81°	30.54°
	azErrC	19.17°	12.92°	16.86°
	elErr	18.41°	11.77°	16.40°
KEM.	azErr	56.90°	53.51°	37.99°
	azErrC	23.68°	18.51°	20.47°
	elErr	17.50°	12.63°	15.71°
reg.	azErr	66.58°	62.26°	35.99°
	azErrC	24.06°	23.31°	19.26°
	elErr	23.02°	15.84°	21.28°
sel.	azErr	59.64°	54.14°	41.62°
	azErrC	27.72°	27.80°	18.19°
	elErr	20.80°	13.65°	20.32°

speech, without head−tracking

		mean	std. dev.	median
meas.	azErr	43.65°	46.53°	23.87°
	azErrC	19.31°	16.21°	17.59°
	elErr	15.67°	11.63°	13.48°
KEM.	azErr	50.66°	51.62°	34.87°
	azErrC	24.88°	28.01°	17.62°
	elErr	21.12°	13.88°	21.06°
reg.	azErr	50.64°	52.50°	28.65°
	azErrC	27.14°	18.74°	22.18°
	elErr	23.21°	13.70°	23.46°
sel.	azErr	49.30°	51.49°	28.38°
	azErrC	18.42°	14.02°	15.13°
	elErr	21.57°	12.56°	22.54°

noise bursts, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	20.00%	20.00%	0.00%
	inheads	2.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head−tracking

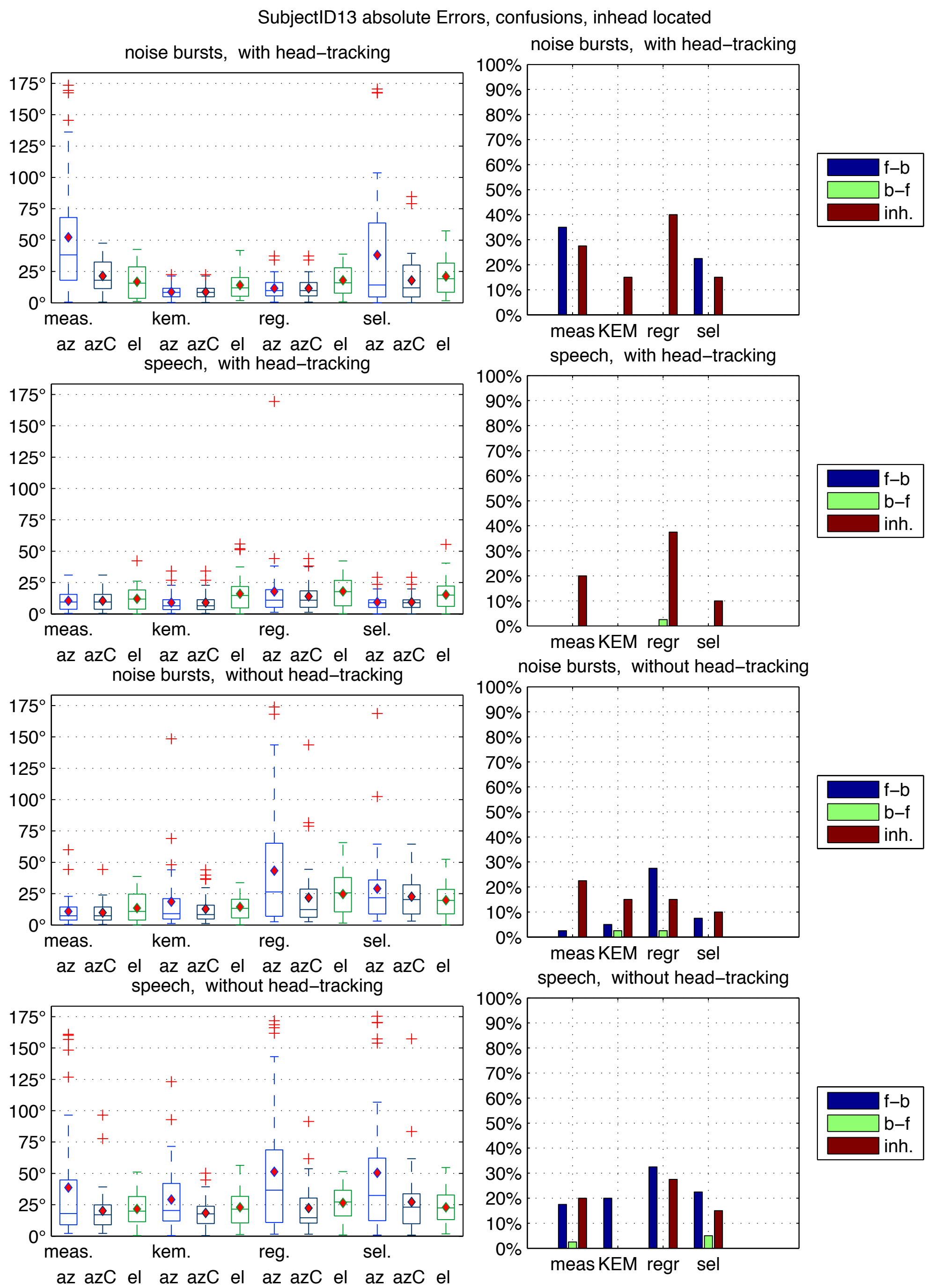
		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	12.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head−tracking

		total	front back	back front
meas.	confusions	30.00%	30.00%	0.00%
	inheads	7.5%		
KEM.	confusions	35.00%	35.00%	0.00%
	inheads	7.5%		
reg.	confusions	40.00%	37.50%	2.50%
	inheads	10.0%		
sel.	confusions	32.50%	32.50%	0.00%
	inheads	10.0%		

speech, without head−tracking

		total	front back	back front
meas.	confusions	27.50%	27.50%	0.00%
	inheads	15.0%		
KEM.	confusions	30.00%	27.50%	2.50%
	inheads	12.5%		
reg.	confusions	17.50%	15.00%	2.50%
	inheads	20.0%		
sel.	confusions	32.50%	30.00%	2.50%
	inheads	12.5%		


SubjectID13 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
speech, without head−tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f−b
b−f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	52.29°	49.51°	38.27°
	azErrC	21.36°	14.22°	17.94°
	elErr	16.76°	13.37°	15.71°
KEM.	azErr	8.63°	5.18°	8.32°
	azErrC	8.63°	5.18°	8.32°
	elErr	14.10°	9.61°	11.90°
reg.	azErr	11.62°	8.52°	9.75°
	azErrC	11.62°	8.52°	9.75°
	elErr	18.04°	11.55°	15.88°
sel.	azErr	38.16°	49.35°	14.19°
	azErrC	17.88°	19.52°	11.95°
	elErr	20.99°	14.33°	19.26°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	35.00%	35.00%	0.00%
	inheads	27.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	15.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	40.0%		
sel.	confusions	22.50%	22.50%	0.00%
	inheads	15.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	10.51°	7.36°	9.52°
	azErrC	10.51°	7.36°	9.52°
	elErr	12.08°	9.17°	11.87°
KEM.	azErr	8.97°	7.60°	6.47°
	azErrC	8.97°	7.60°	6.47°
	elErr	16.02°	14.21°	14.77°
reg.	azErr	17.84°	27.12°	11.01°
	azErrC	13.94°	11.45°	11.01°
	elErr	17.97°	12.27°	17.76°
sel.	azErr	9.35°	6.89°	8.96°
	azErrC	9.35°	6.89°	8.96°
	elErr	15.37°	12.11°	15.01°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	20.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	2.50%	0.00%	2.50%
	inheads	37.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	10.79°	11.45°	7.31°
	azErrC	9.89°	8.51°	7.31°
	elErr	13.45°	11.12°	10.82°
KEM.	azErr	18.55°	26.00°	9.00°
	azErrC	12.77°	11.22°	8.35°
	elErr	14.45°	10.57°	13.28°
reg.	azErr	43.31°	46.02°	26.40°
	azErrC	21.89°	26.80°	12.32°
	elErr	24.61°	15.99°	25.65°
sel.	azErr	29.07°	31.02°	21.74°
	azErrC	22.62°	16.47°	20.34°
	elErr	19.82°	13.99°	19.58°

noise bursts, without head–tracking

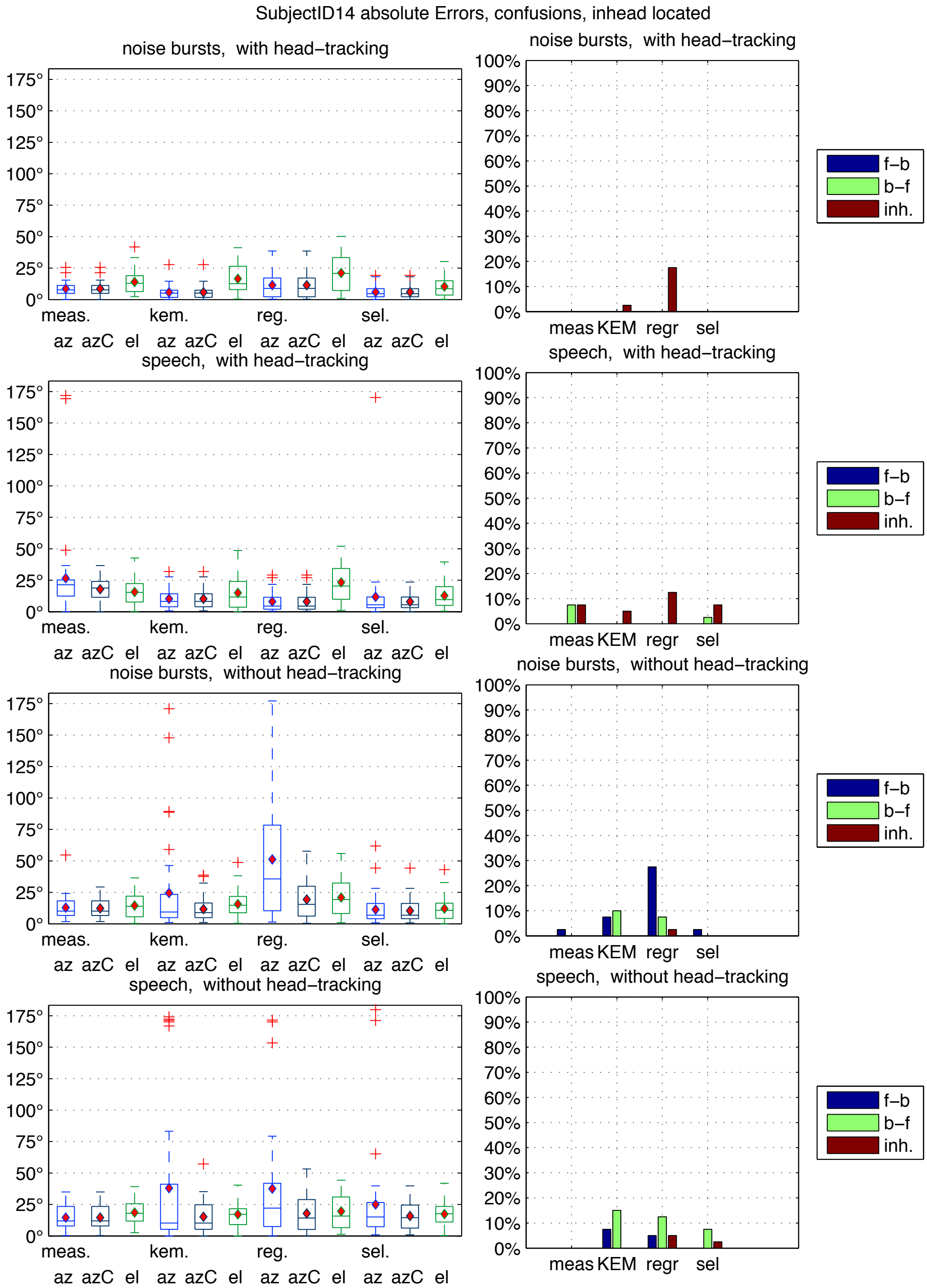
		total	front back	back front
meas.	confusions	2.50%	2.50%	0.00%
	inheads	22.5%		
KEM.	confusions	7.50%	5.00%	2.50%
	inheads	15.0%		
reg.	confusions	30.00%	27.50%	2.50%
	inheads	15.0%		
sel.	confusions	7.50%	7.50%	0.00%
	inheads	10.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	38.68°	48.36°	17.95°
	azErrC	20.20°	18.14°	16.97°
	elErr	21.59°	13.39°	19.92°
KEM.	azErr	29.16°	26.49°	20.40°
	azErrC	18.43°	11.25°	17.72°
	elErr	22.98°	15.70°	21.57°
reg.	azErr	51.35°	51.34°	36.61°
	azErrC	22.41°	19.03°	14.60°
	elErr	26.48°	14.10°	27.26°
sel.	azErr	50.42°	51.22°	32.46°
	azErrC	27.15°	27.54°	23.13°
	elErr	22.92°	12.99°	22.53°

speech, without head–tracking

		total	front back	back front
meas.	confusions	20.00%	17.50%	2.50%
	inheads	20.0%		
KEM.	confusions	20.00%	20.00%	0.00%
	inheads	0.0%		
reg.	confusions	32.50%	32.50%	0.00%
	inheads	27.5%		
sel.	confusions	27.50%	22.50%	5.00%
	inheads	15.0%		


SubjectID14 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
noise bursts, with head−tracking
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f−b
b−f
inh.
speech, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
noise bursts, without head−tracking
speech, without head−tracking
speech, without head−tracking

noise bursts, with head−tracking

		mean	std. dev.	median
meas.	azErr	8.62°	5.27°	7.71°
	azErrC	8.62°	5.27°	7.71°
	elErr	14.05°	9.46°	12.89°
KEM.	azErr	5.75°	5.10°	5.10°
	azErrC	5.75°	5.10°	5.10°
	elErr	16.57°	12.05°	12.67°
reg.	azErr	11.42°	10.50°	8.90°
	azErrC	11.42°	10.50°	8.90°
	elErr	21.19°	15.23°	20.79°
sel.	azErr	5.94°	5.00°	4.69°
	azErrC	5.94°	5.00°	4.69°
	elErr	10.31°	7.34°	8.65°

noise bursts, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	17.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head−tracking

		mean	std. dev.	median
meas.	azErr	26.65°	34.79°	21.35°
	azErrC	17.91°	8.45°	18.85°
	elErr	15.65°	9.96°	15.32°
KEM.	azErr	10.28°	7.90°	8.23°
	azErrC	10.28°	7.90°	8.23°
	elErr	14.92°	13.12°	11.64°
reg.	azErr	8.09°	8.23°	4.38°
	azErrC	8.09°	8.23°	4.38°
	elErr	23.35°	14.65°	20.47°
sel.	azErr	11.80°	26.54°	5.51°
	azErrC	7.90°	6.74°	5.51°
	elErr	12.80°	9.87°	9.69°

speech, with head−tracking

		total	front back	back front
meas.	confusions	7.50%	0.00%	7.50%
	inheads	7.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	12.5%		
sel.	confusions	2.50%	0.00%	2.50%
	inheads	7.5%		

noise bursts, without head−tracking

		mean	std. dev.	median
meas.	azErr	12.87°	9.51°	10.06°
	azErrC	12.24°	7.22°	10.06°
	elErr	14.50°	9.79°	13.86°
KEM.	azErr	24.56°	38.01°	9.36°
	azErrC	11.75°	9.56°	8.91°
	elErr	15.74°	10.92°	14.70°
reg.	azErr	51.15°	50.90°	35.73°
	azErrC	19.30°	14.50°	15.45°
	elErr	20.92°	14.72°	19.36°
sel.	azErr	11.31°	11.96°	6.84°
	azErrC	10.41°	9.06°	6.84°
	elErr	12.10°	9.67°	10.70°

noise bursts, without head−tracking

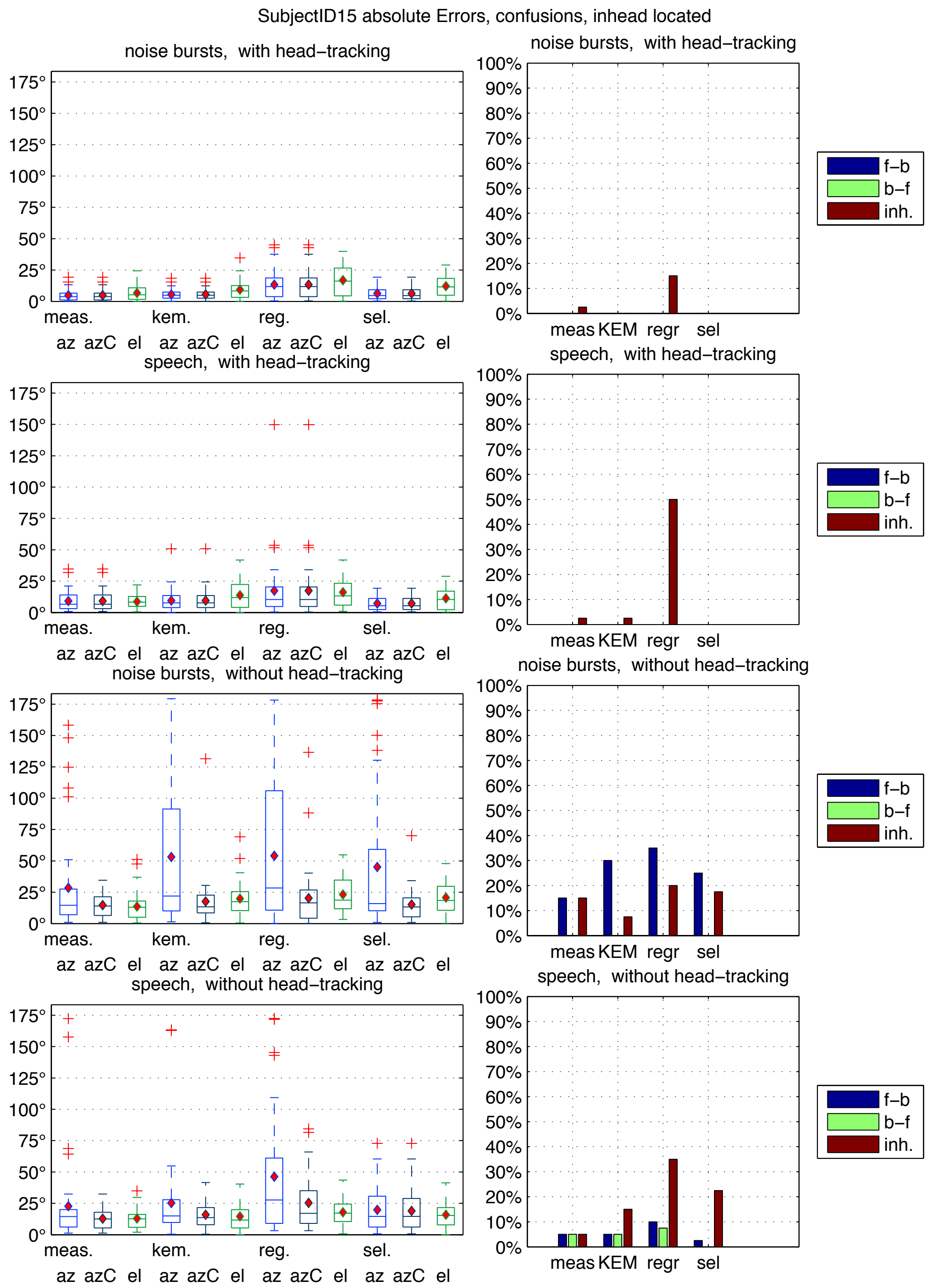
		total	front back	back front
meas.	confusions	2.50%	2.50%	0.00%
	inheads	0.0%		
KEM.	confusions	17.50%	7.50%	10.00%
	inheads	0.0%		
reg.	confusions	35.00%	27.50%	7.50%
	inheads	2.5%		
sel.	confusions	2.50%	2.50%	0.00%
	inheads	0.0%		

speech, without head−tracking

		mean	std. dev.	median
meas.	azErr	14.55°	9.57°	11.88°
	azErrC	14.55°	9.57°	11.88°
	elErr	18.56°	8.78°	17.95°
KEM.	azErr	38.02°	54.53°	10.26°
	azErrC	15.20°	12.34°	10.26°
	elErr	17.16°	11.25°	17.14°
reg.	azErr	37.63°	47.74°	22.07°
	azErrC	17.89°	14.36°	14.20°
	elErr	19.60°	14.02°	15.86°
sel.	azErr	25.07°	37.58°	15.11°
	azErrC	15.77°	11.46°	14.54°
	elErr	17.42°	10.12°	17.59°

speech, without head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	22.50%	7.50%	15.00%
	inheads	0.0%		
reg.	confusions	17.50%	5.00%	12.50%
	inheads	5.0%		
sel.	confusions	7.50%	0.00%	7.50%
	inheads	2.5%		


SubjectID15 absolute Errors, confusions, inhead located
noise bursts, with head−tracking
speech, with head−tracking
noise bursts, without head−tracking
speech, without head−tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f−b
b−f
inh.

noise bursts, with head−tracking

		mean	std. dev.	median
meas.	azErr	4.85°	4.62°	3.77°
	azErrC	4.85°	4.62°	3.77°
	elErr	6.72°	6.37°	5.27°
KEM.	azErr	5.57°	4.36°	4.86°
	azErrC	5.57°	4.36°	4.86°
	elErr	9.39°	7.56°	8.34°
reg.	azErr	13.40°	11.31°	11.83°
	azErrC	13.40°	11.31°	11.83°
	elErr	16.90°	12.31°	16.13°
sel.	azErr	6.40°	5.48°	4.65°
	azErrC	6.40°	5.48°	4.65°
	elErr	12.21°	8.14°	11.60°

noise bursts, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	15.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head−tracking

		mean	std. dev.	median
meas.	azErr	9.16°	8.18°	6.65°
	azErrC	9.16°	8.18°	6.65°
	elErr	8.71°	4.96°	8.29°
KEM.	azErr	9.51°	9.04°	7.72°
	azErrC	9.51°	9.04°	7.72°
	elErr	13.78°	10.80°	11.95°
reg.	azErr	17.42°	25.00°	10.35°
	azErrC	17.42°	25.00°	10.35°
	elErr	16.12°	12.18°	13.29°
sel.	azErr	7.20°	6.04°	5.38°
	azErrC	7.20°	6.04°	5.38°
	elErr	11.30°	9.11°	10.42°

speech, with head−tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	50.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head−tracking

		mean	std. dev.	median
meas.	azErr	28.58°	40.26°	14.65°
	azErrC	14.68°	9.80°	14.01°
	elErr	13.68°	11.33°	13.03°
KEM.	azErr	53.14°	60.08°	21.99°
	azErrC	17.68°	20.17°	13.41°
	elErr	19.99°	14.65°	17.46°
reg.	azErr	54.06°	55.63°	28.40°
	azErrC	20.26°	25.12°	16.50°
	elErr	23.17°	13.87°	18.77°
sel.	azErr	45.09°	55.40°	15.90°
	azErrC	15.21°	13.12°	13.27°
	elErr	20.80°	12.69°	18.51°

noise bursts, without head−tracking

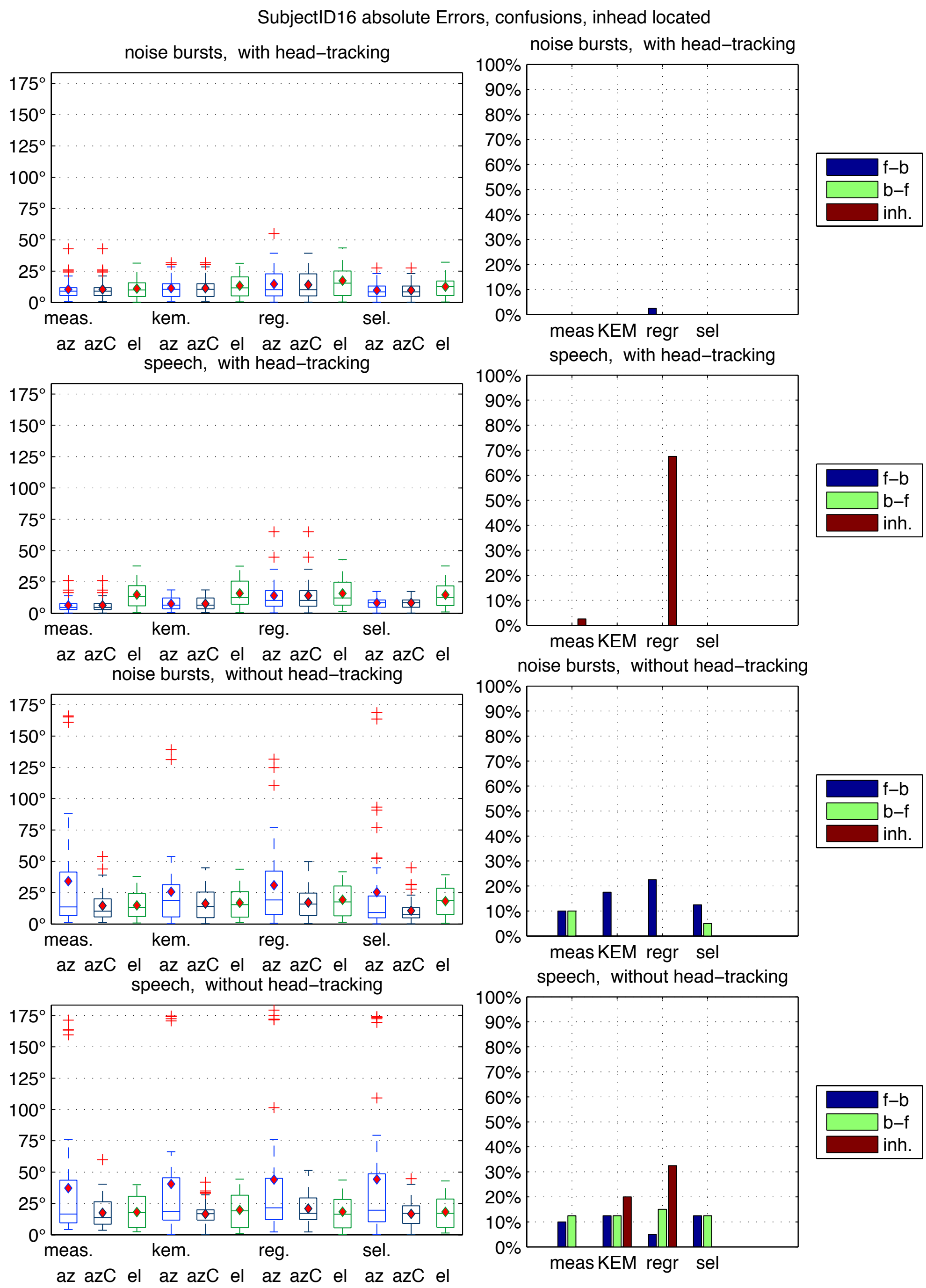
		total	front back	back front
meas.	confusions	15.00%	15.00%	0.00%
	inheads	15.0%		
KEM.	confusions	30.00%	30.00%	0.00%
	inheads	7.5%		
reg.	confusions	35.00%	35.00%	0.00%
	inheads	20.0%		
sel.	confusions	25.00%	25.00%	0.00%
	inheads	17.5%		

speech, without head−tracking

		mean	std. dev.	median
meas.	azErr	22.77°	35.97°	14.52°
	azErrC	12.74°	8.15°	12.56°
	elErr	12.90°	8.28°	12.66°
KEM.	azErr	25.31°	34.45°	14.94°
	azErrC	15.97°	10.31°	13.59°
	elErr	14.65°	11.40°	11.65°
reg.	azErr	46.27°	50.84°	27.70°
	azErrC	25.39°	21.20°	17.07°
	elErr	17.82°	10.83°	17.20°
sel.	azErr	19.85°	17.69°	14.60°
	azErrC	18.95°	16.84°	14.60°
	elErr	15.95°	10.91°	15.33°

speech, without head−tracking

		total	front back	back front
meas.	confusions	10.00%	5.00%	5.00%
	inheads	5.0%		
KEM.	confusions	10.00%	5.00%	5.00%
	inheads	15.0%		
reg.	confusions	17.50%	10.00%	7.50%
	inheads	35.0%		
sel.	confusions	2.50%	2.50%	0.00%
	inheads	22.5%		


SubjectID16 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
0° 25° 50° 75° 100° 125° 150° 175°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	10.51°	7.98°	9.04°
	azErrC	10.51°	7.98°	9.04°
	elErr	11.05°	7.25°	9.94°
KEM.	azErr	11.44°	8.50°	10.50°
	azErrC	11.44°	8.50°	10.50°
	elErr	13.39°	9.13°	11.67°
reg.	azErr	14.78°	12.37°	10.23°
	azErrC	14.12°	10.77°	10.23°
	elErr	17.39°	12.61°	15.51°
sel.	azErr	9.70°	6.52°	8.37°
	azErrC	9.70°	6.52°	8.37°
	elErr	12.69°	8.26°	12.63°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	2.50%	2.50%	0.00%
	inheads	0.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	6.37°	5.65°	4.62°
	azErrC	6.37°	5.65°	4.62°
	elErr	14.82°	10.60°	13.31°
KEM.	azErr	7.56°	4.62°	6.54°
	azErrC	7.56°	4.62°	6.54°
	elErr	15.99°	11.84°	12.71°
reg.	azErr	14.08°	12.80°	10.27°
	azErrC	14.08°	12.80°	10.27°
	elErr	15.77°	11.50°	12.19°
sel.	azErr	8.31°	4.00°	8.37°
	azErrC	8.31°	4.00°	8.37°
	elErr	14.70°	10.47°	12.78°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	67.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	34.28°	47.78°	13.63°
	azErrC	14.54°	12.91°	10.25°
	elErr	14.84°	10.49°	13.22°
KEM.	azErr	25.73°	30.06°	18.75°
	azErrC	16.33°	12.32°	14.04°
	elErr	16.96°	12.55°	15.39°
reg.	azErr	30.99°	33.21°	19.14°
	azErrC	17.14°	11.76°	15.91°
	elErr	19.31°	12.95°	17.69°
sel.	azErr	25.40°	40.44°	9.18°
	azErrC	10.60°	9.90°	7.45°
	elErr	18.21°	11.81°	18.64°

noise bursts, without head–tracking

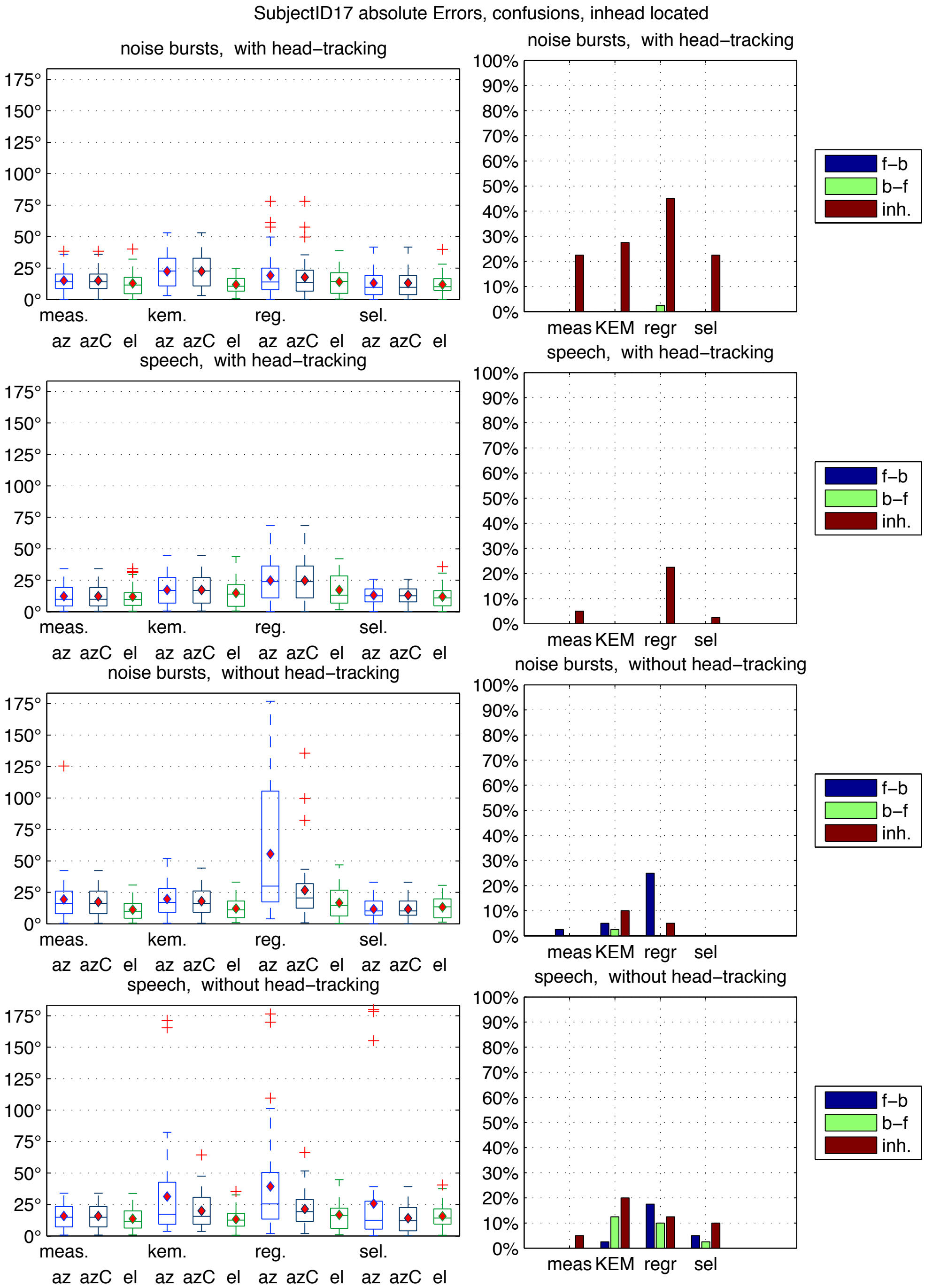
		total	front back	back front
meas.	confusions	20.00%	10.00%	10.00%
	inheads	0.0%		
KEM.	confusions	17.50%	17.50%	0.00%
	inheads	0.0%		
reg.	confusions	22.50%	22.50%	0.00%
	inheads	0.0%		
sel.	confusions	17.50%	12.50%	5.00%
	inheads	0.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	37.27°	46.66°	16.55°
	azErrC	17.56°	12.14°	13.70°
	elErr	18.10°	12.70°	17.68°
KEM.	azErr	40.48°	53.61°	18.44°
	azErrC	16.57°	9.74°	16.80°
	elErr	19.85°	13.42°	19.07°
reg.	azErr	44.04°	53.85°	21.54°
	azErrC	20.90°	12.84°	17.11°
	elErr	18.32°	13.20°	16.45°
sel.	azErr	44.22°	54.64°	19.51°
	azErrC	16.70°	10.98°	17.20°
	elErr	18.18°	12.80°	17.09°

speech, without head–tracking

		total	front back	back front
meas.	confusions	22.50%	10.00%	12.50%
	inheads	0.0%		
KEM.	confusions	25.00%	12.50%	12.50%
	inheads	20.0%		
reg.	confusions	20.00%	5.00%	15.00%
	inheads	32.5%		
sel.	confusions	25.00%	12.50%	12.50%
	inheads	0.0%		


SubjectID17 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175°
150°
125°
100°
75°
50°
25°
0°
meas.
kem.
reg.
sel.
az azC el az azC el az azC el az azC el
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	15.05°	9.14°	14.06°
	azErrC	15.05°	9.14°	14.06°
	elErr	12.95°	9.65°	11.56°
KEM.	azErr	22.50°	12.99°	22.76°
	azErrC	22.50°	12.99°	22.76°
	elErr	11.89°	6.61°	10.55°
reg.	azErr	19.25°	17.40°	13.95°
	azErrC	17.75°	16.23°	13.56°
	elErr	14.06°	9.17°	14.45°
sel.	azErr	13.11°	10.76°	9.73°
	azErrC	13.11°	10.76°	9.73°
	elErr	11.92°	7.86°	10.25°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	22.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	27.5%		
reg.	confusions	2.50%	0.00%	2.50%
	inheads	45.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	22.5%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	12.26°	9.91°	9.89°
	azErrC	12.26°	9.91°	9.89°
	elErr	11.91°	9.51°	9.78°
KEM.	azErr	17.26°	11.53°	16.89°
	azErrC	17.26°	11.53°	16.89°
	elErr	14.88°	11.33°	13.96°
reg.	azErr	24.80°	16.42°	23.91°
	azErrC	24.80°	16.42°	23.91°
	elErr	17.25°	12.59°	13.19°
sel.	azErr	13.16°	6.69°	12.72°
	azErrC	13.16°	6.69°	12.72°
	elErr	11.91°	9.04°	11.01°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	22.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	19.48°	20.56°	16.25°
	azErrC	17.38°	11.94°	16.25°
	elErr	11.15°	7.55°	9.95°
KEM.	azErr	19.70°	14.19°	17.03°
	azErrC	18.00°	11.84°	16.35°
	elErr	12.15°	8.03°	11.14°
reg.	azErr	55.55°	50.99°	30.04°
	azErrC	26.76°	26.17°	20.57°
	elErr	16.65°	12.06°	14.59°
sel.	azErr	11.69°	7.32°	10.21°
	azErrC	11.69°	7.32°	10.21°
	elErr	13.30°	8.51°	13.51°

noise bursts, without head–tracking

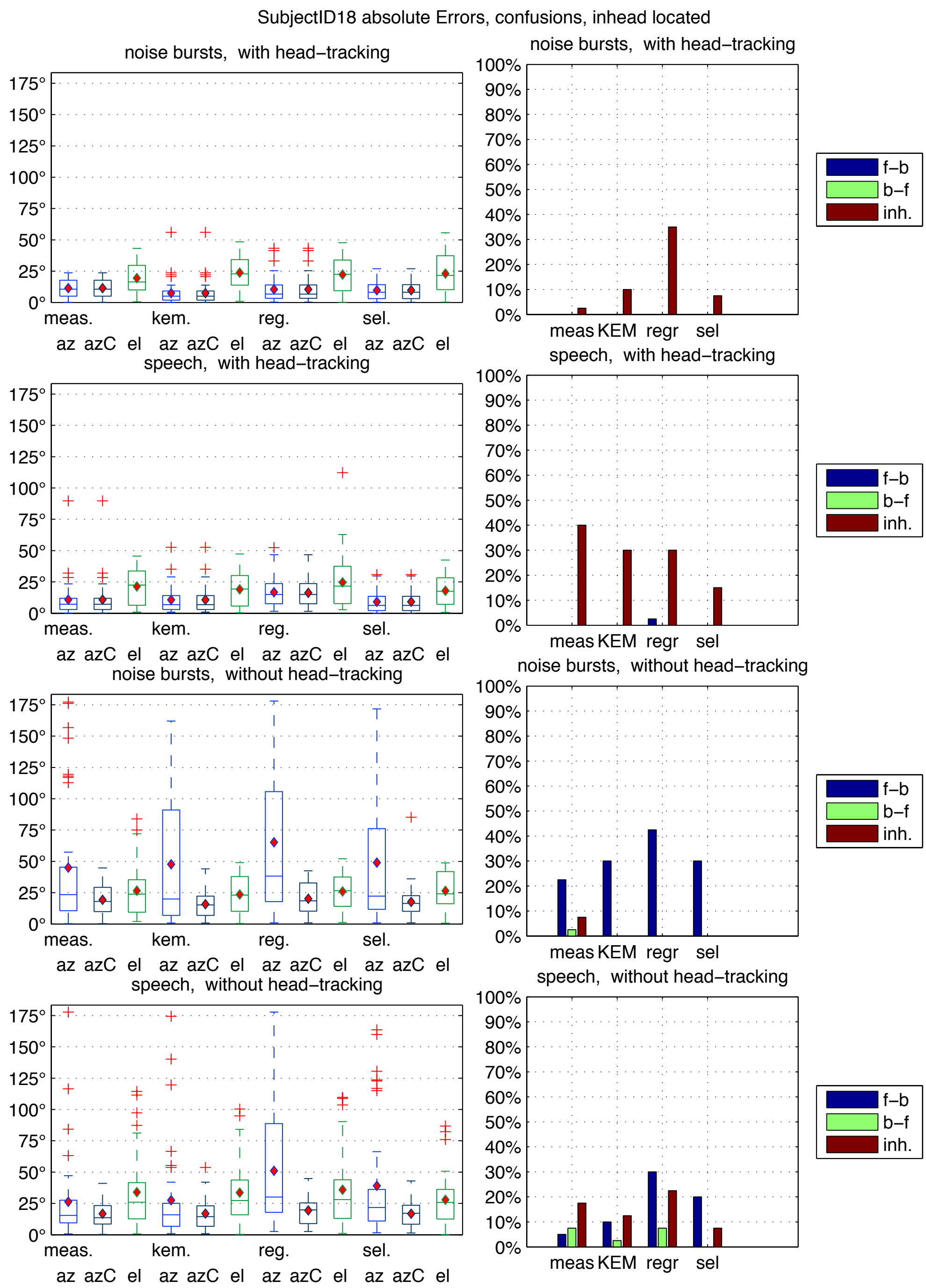
		total	front back	back front
meas.	confusions	2.50%	2.50%	0.00%
	inheads	0.0%		
KEM.	confusions	7.50%	5.00%	2.50%
	inheads	10.0%		
reg.	confusions	25.00%	25.00%	0.00%
	inheads	5.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	15.76°	9.52°	14.79°
	azErrC	15.76°	9.52°	14.79°
	elErr	13.67°	9.22°	11.37°
KEM.	azErr	31.27°	37.49°	17.29°
	azErrC	19.99°	14.90°	15.62°
	elErr	13.31°	8.50°	12.52°
reg.	azErr	39.27°	40.67°	25.49°
	azErrC	21.42°	14.52°	19.30°
	elErr	16.77°	12.09°	16.33°
sel.	azErr	25.78°	43.42°	12.42°
	azErrC	14.17°	11.25°	12.14°
	elErr	15.70°	10.40°	14.29°

speech, without head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
KEM.	confusions	15.00%	2.50%	12.50%
	inheads	20.0%		
reg.	confusions	27.50%	17.50%	10.00%
	inheads	12.5%		
sel.	confusions	7.50%	5.00%	2.50%
	inheads	10.0%		


SubjectID18 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
0° 25° 50° 75° 100° 125° 150° 175°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	11.44°	7.24°	10.57°
	azErrC	11.44°	7.24°	10.57°
	elErr	19.43°	12.45°	16.41°
KEM.	azErr	7.49°	9.86°	5.05°
	azErrC	7.49°	9.86°	5.05°
	elErr	23.80°	14.08°	22.83°
reg.	azErr	10.47°	10.44°	6.71°
	azErrC	10.47°	10.44°	6.71°
	elErr	22.23°	14.01°	22.47°
sel.	azErr	9.75°	7.20°	8.21°
	azErrC	9.75°	7.20°	8.21°
	elErr	23.12°	14.91°	21.58°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	10.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	35.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	7.5%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	10.87°	14.97°	7.25°
	azErrC	10.87°	14.97°	7.25°
	elErr	21.37°	14.32°	22.43°
KEM.	azErr	10.69°	10.94°	6.84°
	azErrC	10.69°	10.94°	6.84°
	elErr	19.06°	13.63°	19.36°
reg.	azErr	16.77°	12.47°	14.95°
	azErrC	16.25°	11.33°	14.95°
	elErr	24.61°	20.88°	21.58°
sel.	azErr	9.18°	8.93°	6.18°
	azErrC	9.18°	8.93°	6.18°
	elErr	18.01°	12.51°	17.50°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	40.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	30.0%		
reg.	confusions	2.50%	2.50%	0.00%
	inheads	30.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	15.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	44.96°	51.82°	23.41°
	azErrC	19.36°	13.04°	18.05°
	elErr	26.62°	20.91°	23.77°
KEM.	azErr	47.63°	55.00°	19.94°
	azErrC	15.81°	10.74°	15.16°
	elErr	23.62°	15.07°	23.13°
reg.	azErr	65.21°	57.50°	38.19°
	azErrC	20.18°	12.77°	18.51°
	elErr	25.97°	15.38°	26.64°
sel.	azErr	49.01°	55.28°	22.25°
	azErrC	17.69°	13.83°	16.48°
	elErr	26.53°	14.97°	24.05°

noise bursts, without head–tracking

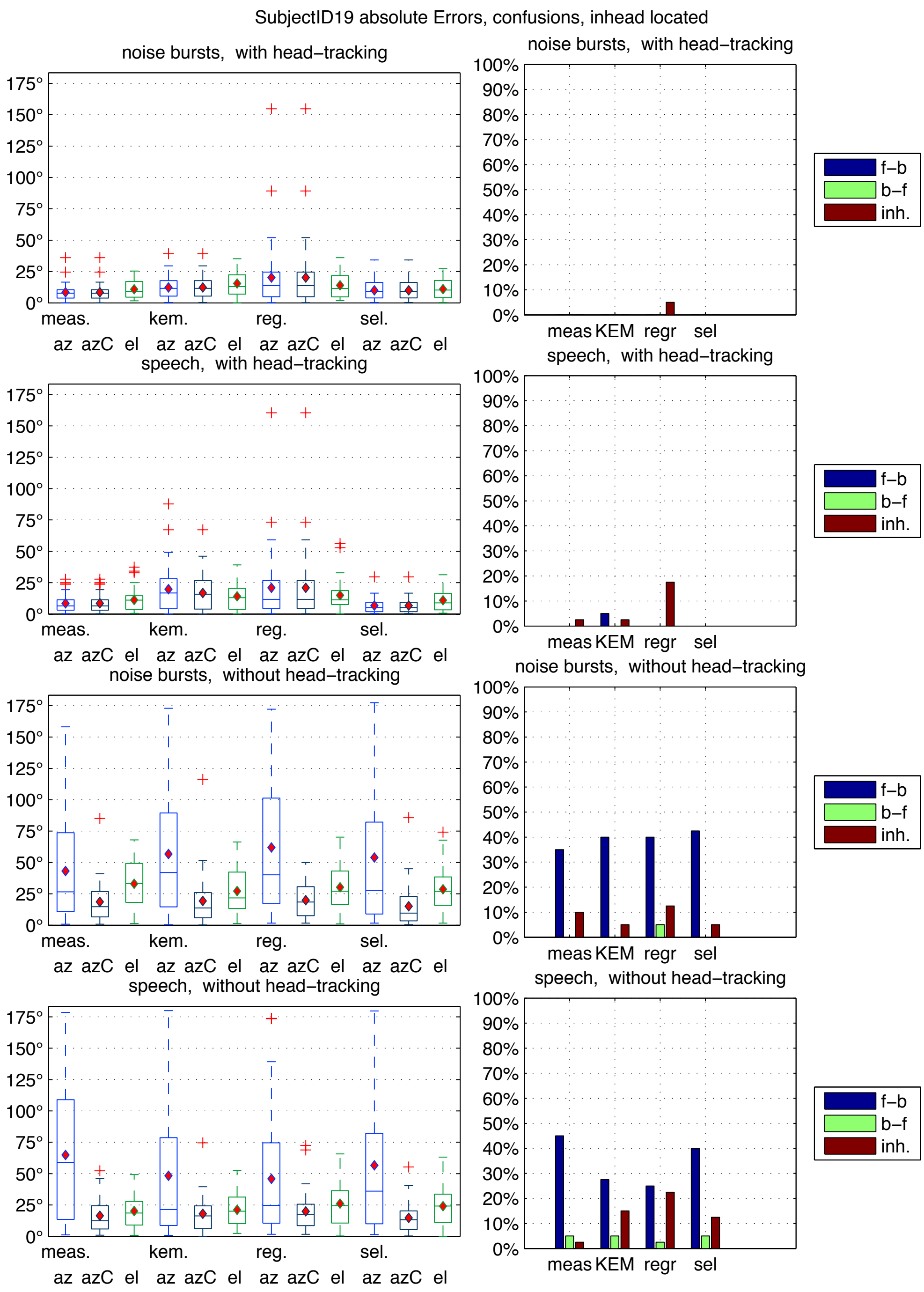
		total	front back	back front
meas.	confusions	25.00%	22.50%	2.50%
	inheads	7.5%		
KEM.	confusions	30.00%	30.00%	0.00%
	inheads	0.0%		
reg.	confusions	42.50%	42.50%	0.00%
	inheads	0.0%		
sel.	confusions	30.00%	30.00%	0.00%
	inheads	0.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	26.38°	33.35°	15.48°
	azErrC	16.82°	11.38°	13.67°
	elErr	34.03°	29.10°	26.02°
KEM.	azErr	27.57°	37.57°	15.89°
	azErrC	16.86°	12.31°	14.43°
	elErr	33.68°	25.06°	27.31°
reg.	azErr	51.03°	49.59°	30.12°
	azErrC	19.50°	10.83°	19.80°
	elErr	35.98°	31.47°	28.08°
sel.	azErr	39.09°	46.27°	21.69°
	azErrC	16.75°	10.12°	17.13°
	elErr	27.91°	20.71°	25.89°

speech, without head–tracking

		total	front back	back front
meas.	confusions	12.50%	5.00%	7.50%
	inheads	17.5%		
KEM.	confusions	12.50%	10.00%	2.50%
	inheads	12.5%		
reg.	confusions	37.50%	30.00%	7.50%
	inheads	22.5%		
sel.	confusions	20.00%	20.00%	0.00%
	inheads	7.5%		


SubjectID19 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	8.46°	6.85°	7.67°
	azErrC	8.46°	6.85°	7.67°
	elErr	10.87°	7.17°	9.12°
KEM.	azErr	12.32°	8.93°	11.59°
	azErrC	12.32°	8.93°	11.59°
	elErr	15.41°	10.03°	12.98°
reg.	azErr	20.12°	27.26°	13.73°
	azErrC	20.12°	27.26°	13.73°
	elErr	13.97°	10.35°	11.45°
sel.	azErr	9.99°	7.64°	8.92°
	azErrC	9.99°	7.64°	8.92°
	elErr	11.01°	7.87°	10.21°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
KEM.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	5.0%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	8.51°	7.34°	6.52°
	azErrC	8.51°	7.34°	6.52°
	elErr	11.21°	9.26°	11.09°
KEM.	azErr	19.80°	18.72°	16.78°
	azErrC	16.80°	14.42°	15.79°
	elErr	14.17°	10.14°	13.08°
reg.	azErr	20.93°	28.41°	11.71°
	azErrC	20.93°	28.41°	11.71°
	elErr	14.94°	12.56°	11.38°
sel.	azErr	6.78°	6.11°	5.15°
	azErrC	6.78°	6.11°	5.15°
	elErr	10.96°	8.63°	8.95°

speech, with head–tracking

		total	front back	back front
meas.	confusions	0.00%	0.00%	0.00%
	inheads	2.5%		
KEM.	confusions	5.00%	5.00%	0.00%
	inheads	2.5%		
reg.	confusions	0.00%	0.00%	0.00%
	inheads	17.5%		
sel.	confusions	0.00%	0.00%	0.00%
	inheads	0.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	43.17°	41.47°	26.59°
	azErrC	18.64°	16.20°	14.75°
	elErr	32.96°	19.51°	33.29°
KEM.	azErr	56.79°	49.54°	41.96°
	azErrC	19.29°	21.30°	13.79°
	elErr	27.16°	17.91°	21.75°
reg.	azErr	62.00°	54.96°	40.19°
	azErrC	19.95°	12.70°	18.50°
	elErr	30.22°	19.28°	27.06°
sel.	azErr	53.95°	53.71°	27.67°
	azErrC	15.14°	16.01°	9.65°
	elErr	28.62°	19.03°	26.96°

noise bursts, without head–tracking

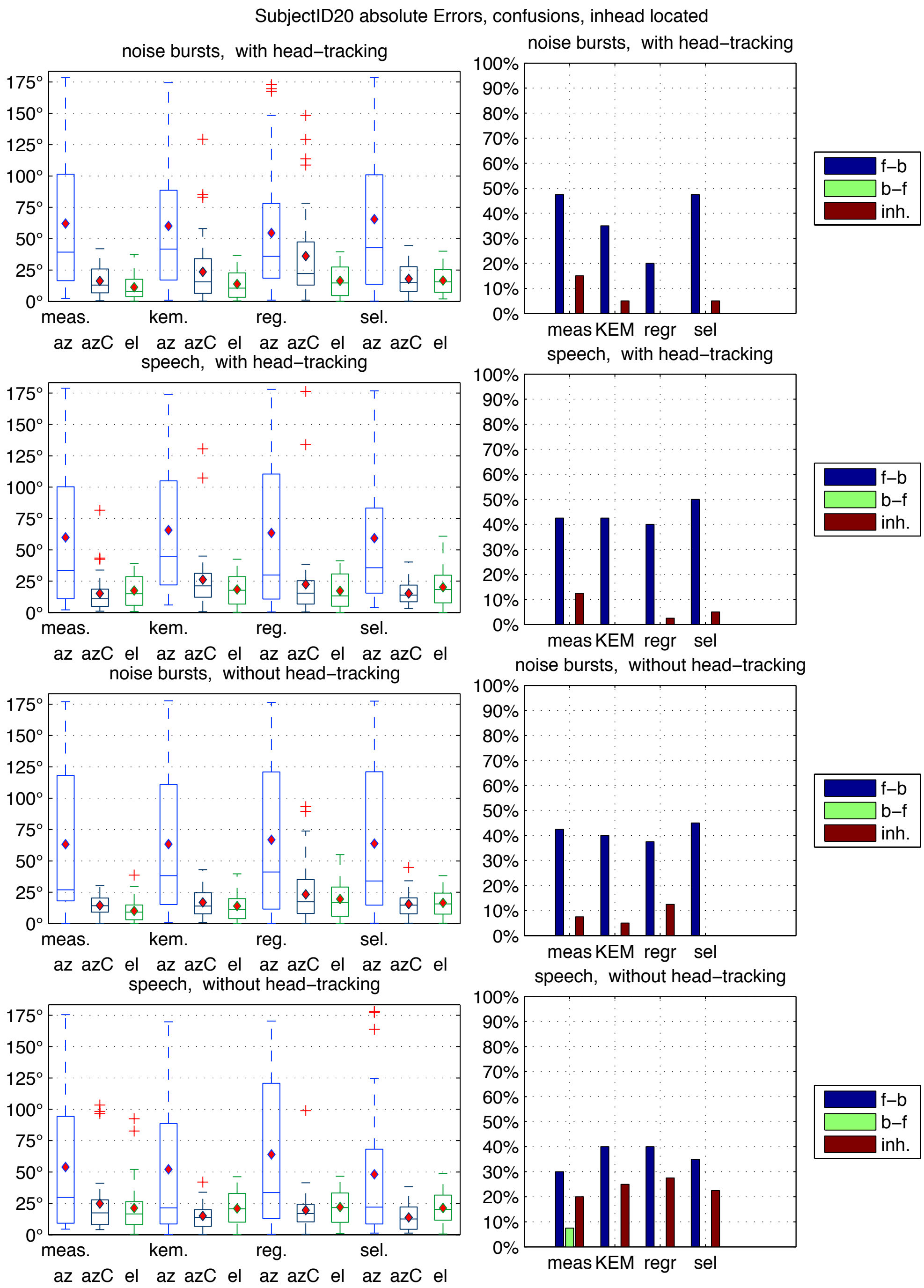
		total	front back	back front
meas.	confusions	35.00%	35.00%	0.00%
	inheads	10.0%		
KEM.	confusions	40.00%	40.00%	0.00%
	inheads	5.0%		
reg.	confusions	45.00%	40.00%	5.00%
	inheads	12.5%		
sel.	confusions	42.50%	42.50%	0.00%
	inheads	5.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	64.85°	56.41°	58.92°
	azErrC	16.44°	12.91°	12.37°
	elErr	20.13°	13.51°	18.62°
KEM.	azErr	48.33°	53.06°	21.33°
	azErrC	17.99°	14.66°	16.29°
	elErr	21.09°	12.65°	20.08°
reg.	azErr	45.91°	48.68°	24.69°
	azErrC	19.94°	15.95°	17.68°
	elErr	26.11°	19.20°	24.36°
sel.	azErr	56.61°	56.05°	36.05°
	azErrC	14.69°	11.97°	13.29°
	elErr	24.06°	15.64°	24.18°

speech, without head–tracking

		total	front back	back front
meas.	confusions	50.00%	45.00%	5.00%
	inheads	2.5%		
KEM.	confusions	32.50%	27.50%	5.00%
	inheads	15.0%		
reg.	confusions	27.50%	25.00%	2.50%
	inheads	22.5%		
sel.	confusions	45.00%	40.00%	5.00%
	inheads	12.5%		


SubjectID20 absolute Errors, confusions, inhead located
noise bursts, with head–tracking
speech, with head–tracking
noise bursts, without head–tracking
speech, without head–tracking
175° 150° 125° 100° 75° 50° 25° 0°
meas. kem. reg. sel.
az azC el az azC el az azC el az azC el
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
meas KEM regr sel
f–b
b–f
inh.

noise bursts, with head–tracking

		mean	std. dev.	median
meas.	azErr	62.06°	55.13°	39.36°
	azErrC	16.30°	11.80°	13.08°
	elErr	11.34°	9.72°	7.92°
KEM.	azErr	60.13°	55.04°	41.73°
	azErrC	23.61°	26.60°	15.63°
	elErr	13.87°	11.59°	10.55°
reg.	azErr	54.58°	48.93°	35.90°
	azErrC	36.16°	36.09°	22.23°
	elErr	16.36°	12.42°	14.75°
sel.	azErr	65.61°	58.23°	42.85°
	azErrC	17.95°	13.32°	14.79°
	elErr	16.67°	10.90°	15.57°

noise bursts, with head–tracking

		total	front back	back front
meas.	confusions	47.50%	47.50%	0.00%
	inheads	15.0%		
KEM.	confusions	35.00%	35.00%	0.00%
	inheads	5.0%		
reg.	confusions	20.00%	20.00%	0.00%
	inheads	0.0%		
sel.	confusions	47.50%	47.50%	0.00%
	inheads	5.0%		

speech, with head–tracking

		mean	std. dev.	median
meas.	azErr	59.95°	58.45°	33.46°
	azErrC	15.20°	15.62°	10.97°
	elErr	17.49°	12.46°	14.93°
KEM.	azErr	65.76°	51.97°	44.85°
	azErrC	26.18°	24.63°	21.32°
	elErr	18.38°	12.84°	17.76°
reg.	azErr	63.42°	62.97°	29.84°
	azErrC	22.52°	32.84°	15.47°
	elErr	17.32°	13.86°	13.27°
sel.	azErr	59.32°	56.82°	35.66°
	azErrC	15.18°	8.77°	13.89°
	elErr	20.20°	14.44°	18.36°

speech, with head–tracking

		total	front back	back front
meas.	confusions	42.50%	42.50%	0.00%
	inheads	12.5%		
KEM.	confusions	42.50%	42.50%	0.00%
	inheads	0.0%		
reg.	confusions	40.00%	40.00%	0.00%
	inheads	2.5%		
sel.	confusions	50.00%	50.00%	0.00%
	inheads	5.0%		

noise bursts, without head–tracking

		mean	std. dev.	median
meas.	azErr	63.27°	60.75°	26.94°
	azErrC	14.54°	8.25°	14.18°
	elErr	10.08°	9.05°	9.09°
KEM.	azErr	63.42°	59.12°	38.25°
	azErrC	16.93°	12.26°	13.98°
	elErr	13.97°	12.05°	11.17°
reg.	azErr	66.78°	61.07°	41.08°
	azErrC	23.28°	22.09°	17.34°
	elErr	19.54°	15.34°	16.88°
sel.	azErr	63.76°	60.09°	34.00°
	azErrC	15.52°	10.67°	14.76°
	elErr	16.59°	10.69°	15.67°

noise bursts, without head–tracking

		total	front back	back front
meas.	confusions	42.50%	42.50%	0.00%
	inheads	7.5%		
KEM.	confusions	40.00%	40.00%	0.00%
	inheads	5.0%		
reg.	confusions	37.50%	37.50%	0.00%
	inheads	12.5%		
sel.	confusions	45.00%	45.00%	0.00%
	inheads	0.0%		

speech, without head–tracking

		mean	std. dev.	median
meas.	azErr	53.98°	52.78°	29.78°
	azErrC	24.79°	24.15°	17.42°
	elErr	21.28°	20.13°	16.57°
KEM.	azErr	52.22°	55.77°	21.33°
	azErrC	14.96°	9.39°	13.62°
	elErr	20.92°	13.51°	20.69°
reg.	azErr	64.00°	60.08°	33.59°
	azErrC	19.57°	16.76°	16.90°
	elErr	22.00°	14.51°	21.63°
sel.	azErr	48.14°	55.93°	22.00°
	azErrC	13.77°	9.56°	12.51°
	elErr	21.24°	13.38°	20.12°

speech, without head–tracking

		total	front back	back front
meas.	confusions	37.50%	30.00%	7.50%
	inheads	20.0%		
KEM.	confusions	40.00%	40.00%	0.00%
	inheads	25.0%		
reg.	confusions	40.00%	40.00%	0.00%
	inheads	27.5%		
sel.	confusions	35.00%	35.00%	0.00%
	inheads	22.5%		