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Source: **TSG-SA WG4**

Title: Audio codec selection tests: Reports from "Global Analysis" Laboratory

Document for: **Approval**

Agenda Item: **7.4.3**

The following documents, agreed at the TSG-SA WG4 meeting #30, are presented to TSG SA #23 for approval.

S4-040172	Global Analysis Laboratory Report on 3GPP High-Rate Audio Codec Exercise	ARL
S4-040173	Global Analysis Laboratory Report on 3GPP Low-Rate Audio Codec Exercise	ARL

Note. The spreadsheets containing all raw data utilised for the Global Analysis Laboratory Report of 3GPP High-Rate and Low-Rate Audio Codec Exercises are available as attachments to the documents S4-040172 and S4-040173 at http://www.3gpp.org/ftp/tsg_sa/WG4_CODEC/TSGS4_30/Docs/

TSG-SA4#30 meeting **Tdoc S4 (04)0172**
February 23-27, 2004, Malaga, Spain

Source: **S. R. Quackenbush, Audio Research Labs**
Title: **Global Analysis Laboratory Report on 3GPP High-Rate Audio Codec Exercises**
Status: **Approved**
Revision: **March 5, 2004**

Executive Summary

A series of three subjective listening tests were conducted as part of the 3GPP Audio codec exercise, as specified in document S4-030821, "PSS/MMS High-Rate Audio Selection Test and Processing Plan Version 2.2.0." This documents reports the results of those tests.

The following table summarizes the performance of the codecs in the highest-rate of the Low-Rate tests for stereo signals on unimpaired channels (test A3 and A4, see S4-030824 [2] and S4-040173 [8]), and in each of the three High-Rate tests. In this table the two candidate codecs are AAC+ and CT. For each test, the codec with the best subjective score is highlighted in green, where "best" is in the statistical sense that the codec estimated mean score is better than that of the other codec at the 95% level of significance.

Tests	Operating condition	AAC+	CT
LR-A3	24 kbps, mono	74.9	75.8
LR-A4	24 kbps, stereo	55.3	67.1
1	32 kbps, stereo	75.8	84.9
2	48 kbps, stereo	82.0	81.5
3-1	32 kbps, stereo, 1% FER	66.2	72.9
3-2	32 kbps, stereo, 3% FER	56.3	62.3

As the table shows, candidate CT appears to have consistently strong performance, having an estimated mean score at the 95% level of significance that is higher than that of candidate AAC+ in 4 of the 6 tests, and an estimated mean score that is not different from that of AAC+ in the remaining test.

The data support the following statements:

- Candidate CT had a mean score that was better than that of candidate AAC+ at the 95% level of significance in 4 of the 6 tests (LR-A4, 1, 2, 3-1, 3-2), and a mean score that is not different from that of AAC+ in the remaining tests (LR-A3, A2).

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1 Introduction

The European Telecommunications Standards Institute (ETSI) has conducting a series of subjective listening tests as part of the 3GPP Audio codec exercise. 3GPP desires to use the tests to evaluate candidate codecs for their needs, as set forth in documents S4-030821, "PSS/MMS High-Rate Audio Selection Test and Processing Plan Version 2.2.0" [1] and S4-030824, "AMR-WB+ and PSS/MMS Low-Rate Audio Selection Test and Processing Plan Version 2.2" [2]. This documents reports the results of those tests.

2 Overview of experiments

The High-Rate tests were comprised of three experiments defined in [1]. The Selection Rules (Section 9) uses the results of two additional experiments defined in [2].

Exp.	Operational mode	#Codecs in test	# reference codecs	#Anchors in test	#References	#items	Total
1	32 kbps, stereo	2(use case B encoder)	2, incl. RealAudio @ 32 kbit/s stereo	2	1	12	84
2	48 kbps, stereo	2(use case B encoder)	2, incl. RealAudio @ 48 kbit/s stereo	2	1	12	84
3	32 kbps, stereo, 1% and 3% random frame loss	4 (2 candidates at 2 frame loss rates each)	2 (AAC-LC at 2 frame loss rates)	2	1	12	108

3 Systems under test

3.1 Candidate codecs

The candidate codec participating in the PSS/MMS high-rate audio selection tests are listed in the following table.

#	Codec name	Providing Organization(s)
1	AAC+	Coding Technologies/ NEC
2	CT	Coding Technologies

3.2 Reference codecs

The reference codecs are listed in the following table.

#	Codec name	Providing Organization(s)
3	AAC	Fraunhofer
4	RealAudio	RealNetworks

3.3 Anchors and references

Besides the items encoded with the candidate and reference codecs, anchor and reference items were included in the tests. In the experiments, two anchors will be used with lowpass filtered original signal.
Also included is the uncoded original signal, once as open and once as hidden reference.

#	Type	Specification	Channel type
1	Anchor	3.5 kHz Lowpass	Mono and Stereo
2	Anchor	7.0 kHz Lowpass	Mono and Stereo
6	Hidden Reference	Original signal	Mono and Stereo
7	Open Reference	Original signal	Mono and Stereo

4 Experimental design

The following tables show the parameters, candidate codes, reference codecs and anchors and references for each experiment. The row labels in the first column (headed "Parameter") are explained as follows:

- The row labeled "Experiment" indicates the experiment. Each experiment is specified in a separate table.
- The row labeled "Bit Rate" indicates the bitrate for the experiment.
- The row labeled "Signal" indicates the number of distinct channels in the test material (i.e. mono or stereo).
- The row labeled "Candidate codecs" lists each candidate codec tested in the experiment in sub-divisions of that row. All Candidate codecs process 48 kHz sampling rate test material and code at bit rate indicated for each experiment unless explicitly indicated otherwise.
- The row labeled "Reference codecs" lists each reference codec tested in the experiment in sub-divisions of that row. All Reference codecs process 48 kHz sampling rate test material and code at bit rate indicated for each experiment unless explicitly indicated otherwise (e.g. RealAudio in experiment 1).
- The row labeled "Anchors and references" lists each anchor and reference condition tested in the experiment in sub-divisions of the main row.

4.1 High-Rate Experiments

Parameter	Value	Additional Constraints
Experiment	1	
Bit Rate	32 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	CT	
Reference codecs	AAC	
	RealAudio	22.05 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	2	
Bit Rate	48 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	CT	
Reference codecs	AAC	
	RealAudio	44.1 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Experiment 3 simulated errored channels using two conditions, 1 percent frame error rate (FER) and 3 percent FER. The application of the two error conditions doubled the number of systems under test. Note, however, that the RealAudio reference codec was not present in this experiment.

Parameter	Value	Additional Constraints
Experiment	3	
Bit Rate	32 kbps	
Signal	Stereo	
Candidate codecs	AAC+ FER 1%	
	AAC+ FER 3%	
	CT FER 1%	
	CT FER 3%	
Reference codecs	AAC FER 1%	
	AAC FER 3%	
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

4.2 Low-Rate Experiments applied to High-Rate Selection

For more details on these experiments see [2].

Parameter	Value	Additional Constraints
Experiment	A3a and A3b	
Bit Rate	24 kbps	
Signal	Mono	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	23.85 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	A4a and A4b	
Bit Rate	24 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	23.85 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	6 dB attenuated side channel
	7.0 kHz Lowpass	2 dB attenuated side channel
	3.5 kHz Lowpass	12 dB attenuated side channel

5 Test Material

5.1 Signal categories

The test material was selected so as to be representative of the following signal categories:

- Classic, with and/or without vocals
- Pop, with and/or without vocals
- Single instruments
- Mixed speech and music
- Speech with and/or without background noise
- a capella vocals, solo and/or choir

5.2 Test Items

A single set of twelve test items were used for the three experiments. They are:

```
c_01_org.wav
c_02_org.wav
p_01_org.wav
p_02_org.wav
si_01_org.wav
si_02_org.wav
sm_01_org.wav
sm_02_org.wav
sp_01_org.wav
sp_02_org.wav
sp_03_org.wav
v_01_org.wav
```

Original material was in stereo, and for mono experiments it was downmixed.

5.3 Training Items

A single set of four training items are used for the three tests. They are:

```
c_09_org.wav
p_09_org.wav
si_09_org.wav
sp_09_org.wav
```

6 Test sites

The experiments for each candidate codec are run by two listening laboratories in parallel, as shown in Table 6-1.

Table 6-1: Allocation of sub-experiments to the Listening Laboratories

Exp.	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Total
LL ID	TS	NT	FT	DY	NK	ER	Per Exp.
1	X			X			2
2		x			x		2
3			x			x	2
Totals:	1	1	1	1	1	1	6

(Legend: T-Systems (TS), NTT-AT (NT), France Telecom R&D (FT), Dynastat (DY), Nokia (NK), Ericsson (ER)

7 Statistical analysis

7.1 Overview

7.1.1 Standard Pivot Table Analysis

The Pivot Table statistical analysis followed the standard MUSHRA procedure [3].

The calculation of the averages of the scores of all listeners remaining after post-screening will result in the Mean Subjective Scores (MSS).

The first step of the analysis of the results is the calculation of the mean score $\overline{u}_{jk}$, for each of the presentations:

$$\overline{u}_{jk} = \frac{1}{N}\sum_{i=1}^{N} u_{ijk}$$

where:

u_i is the score of observer i for a given test condition j and sequence k
N is the number of observers

Confidence intervals are calculated which are derived from the standard deviation and the size of each sample. The 95% confidence interval is given by:

$$\left[\overline{u}_{jk} - \delta_{jk}, \overline{u}_{jk} + \delta_{jk}\right]$$

where:

$$\delta_{jk} = 1.96\frac{S_{jkl}}{\sqrt{N}}$$

and the standard deviation S_{jk} is given by: $S_{jk} = \sqrt{\sum_{i=1}^{N} \frac{\left(\overline{u}_{jk} - u_{ijk}\right)^2}{\left(N-1\right)}}$

With a probability of 95%, the absolute value of the difference between the experimental mean score and the “true” mean score (for a large number of observations) is smaller than the 95% confidence interval, on condition that the distribution of the individual scores meets certain requirements.

Similarly, a standard deviation is calculated for each test condition. It is noted however that this standard deviation may be influenced more by differences associated with the test sequences than by differences associated with the listeners participating in the assessment.

7.2 Statistical Model Based on the Experimental Design

The basic model of a score can be thought of as the sum of “effects”. A particular score may depend on which codec was involved, which audio selection is being played, which laboratory is conducting the test, and which subject is listening.

We anticipate, *a priori*, that there may also be an interaction between the audio selection and the codec under test. In other words, some codecs may perform better with some types of audio selections than with others. Further, we anticipate, *a priori*, that there may also be an interaction between the codecs under test and the testing laboratory. The proposed analysis evaluates whether these interactions exist and compensates for them, if necessary.

Further, in statistical terminology, subjects are “nested” within laboratories. In other words, subject 1 in laboratory A is a different person, with different characteristics, from subject 1 in laboratory B.

Using a simple notation, the proposed basic model for the high-rate experiments as described above is

Score = Codec (c = 1, …, 7 or 9)
+ Signal Category (SigCat = 1, … 6)
+ Signal (Signal = 1, …, 12)
+ Codec by Signal Category interaction
(Codec:SigCat, Codec = 1, …, 7 or 9, SigCat = 1, …, 6)
+ Laboratory (Site = 1, …, 2)
+ Codec by Laboratory interaction (Codec:Site, Codec = 1, …, 7 or 9, Site = 1, …, 2)
+ Subjects (s = 1, …, 15 for each Site)
+ Experimental error

In other words, the score is the sum of a number of factors plus random "error." Just the codec main effects, and possibly the codec by signal category interaction are of real interest. The main effects are analogues of the Pivot Table averages. The interaction term for, say, the codec by signal category interaction takes into account that a response might not be predictable simply by adding an effect for the codec and an effect for the signal category. Some codecs may be "winners" for some signal category, while other codecs may be "winners" for other signal categories. The statistical significance and the size of these effects will be a measure of how important the interaction terms are

There will be one instance of this model for each of the 3 high-rate experiments.

The experimental design is balanced, in that there are equal numbers of each factor level involved with each codec, with the exception that the signal categories are not equally represented. This balance has the advantage that the mean score for each codec is an appropriate statistic for estimating the quality of that codec, assuming that the signal categories are close to balanced. As discussed below, it is the estimates of the standard deviations (or equivalently, the widths of the confidence intervals) that are different depending on the method of analysis. It would be best to use the analysis method that yields the narrowest confidence intervals, thereby giving the most information for the money spent.

Further, as mentioned in the Analysis Process section below, some Subject-Signal judgments of the codecs will be eliminated because they appear to be inconsistent with *a priori* expectations. To the extent that this happens, the analysis of variance will have to compensate for this imbalance.

7.3 Pivot Table and ANOVA Analysis

Data from experiments such of these have been analyzed in the past using the Pivot Table facilities of MS Excel spreadsheets. For simple experiments, this is probably adequate. However, the experiments being analyzed in these tests are far from simple. The pivot table is used to calculate for each codec a grand average (across all signals, subjects, etc.) and the standard deviation of that average. From these, confidence intervals can be constructed, and differences between codecs can be evaluated.

The problem from a statistical viewpoint with this analysis for the experiments described here is that the standard deviations are inflated by the variability of the other factors. This results in a test with less statistical resolving power. In other words, for a given confidence interval width, the Pivot Table method of analysis requires more listeners than the analysis method described here, or, for a given number of listeners, the proposed analysis of variance method yields narrower confidence intervals than the Pivot Table method. The reason for this is that, for example, although each codec is rated for each signal, and therefore the signal differences cancel out when comparing averages, the difference between signals will make the numbers gathered into

that average more variable than they would be if the average signal effects were subtracted out first.

The statistical technique called Analysis of Variance or ANOVA will perform the appropriate analysis, better estimating the standard deviations and confidence intervals for the differences between codecs. A detailed description of ANOVA is beyond the scope of this document, but references are given in Section 7.5

7.4 Post-Processing of Listener Data

The MUSHRA test methodology provides very limited ability to assess the reliability of individual listeners. In this analysis, listener reliability was assessed by observing the extent to which the listener scored the hidden reference at 100 and gave monotonically decreasing scores to each of the hidden reference, the 7.5 kHz lowpass anchor and the 3.6 kHz lowpass anchor. An interval for modest listener error was allowed in applying this rule, e.g. that the hidden reference must be scored higher than 85 rather than exactly 100. Similarly, scores may depart from strict monotonicity by 10 points and still be allowed. These values (85 and 10) were chosen to allow for more listener error than in the low rate experiments because the differences in quality of the high rate signals appeared to be harder to judge than with the low rate signals.

7.5 Analysis Process

The analysis will proceed through the following steps

1. The MS Excel data templates are prepared in the approved format.
2. The data arrives from the testing laboratories in the MS Excel data template.
3. The data from the both labs is compiled into a single workbook for each experiment.
4. A Visual Basic program is used to unstack the data so that each row will have only one listener response.
5. The condition labels are replaced by the correct, unrandomized codec names.
6. A consistency check is performed. Listener-signal combinations are eliminated (given a Weight of 0) if
    - the hidden reference does not receive a rating of at least 85 or
    - the lp3500 anchor rating is not more than 10 units greater than the lp7000 anchor rating.
7. A Pivot Table analysis is performed to obtain simple, benchmark results, from which appropriate presentation charts are created. As described above, the more complex ANOVA analysis should produce codec means which are very close to the pivot table means, differing only in the effect of any missing or eliminated data. The main difference in results will be that the ANOVA confidence intervals will be narrower than the Pivot Table confidence intervals.
8. The data is exported to a text file and entered into “R” [4], a gnu version of the statistical analysis system called “S” [5]. A script is used to fit the model. In particular, the function aov() [6] is used to fit a linear model (the ANOVA model above) to the data. The fitted codec effects and interactions, estimated standard errors of the effects, and the estimated standard error of the residuals are used to create the appropriate confidence intervals. The output from R is captured in a text file.
9. The Visual Basic programs used to compile and screen the data, Excel workbook with all received data and the Pivot Table analysis, the R analysis script, and the text file of R output are all available as part of this report.

8 Test Results

In this section the candidate codecs are named only in the initial table showing test parameters. In all subsequent data analysis they are referred to using the labels Codec1 and Codec2 such that their identity is concealed.

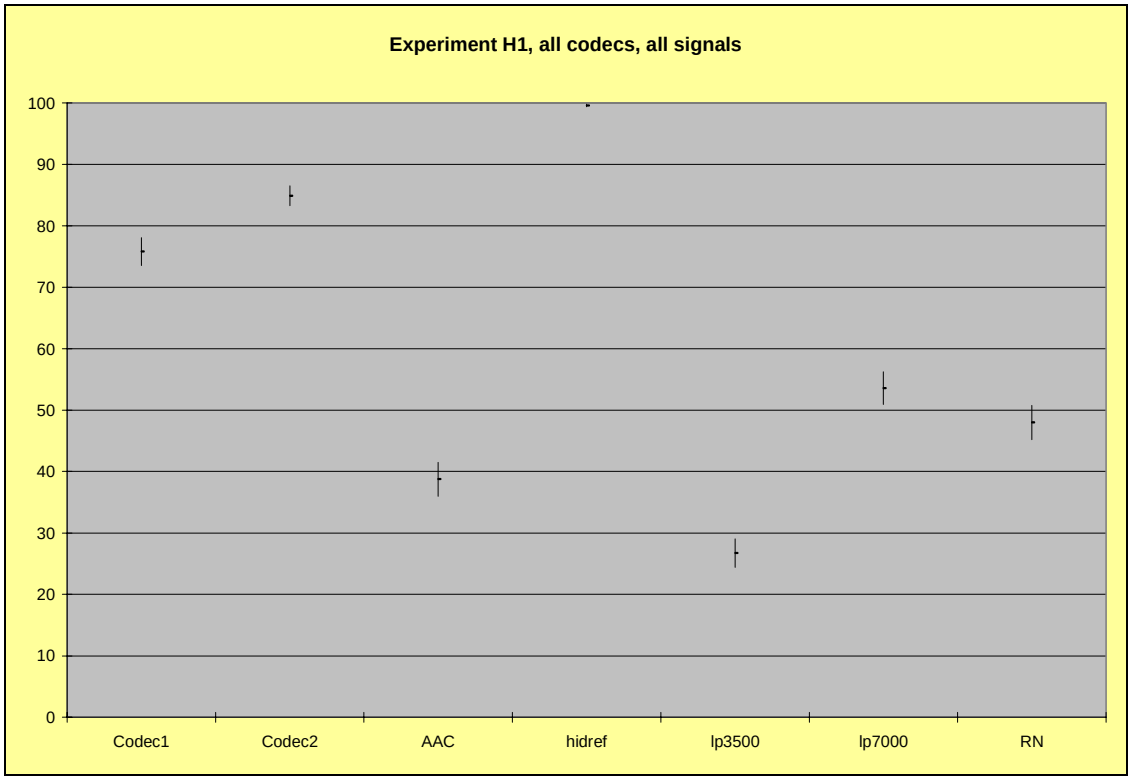
8.1 Test 1

8.1.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	1	
Bit Rate	32 kbps	
Signal	Stereo	
Candidate codecs	AAC+	Codec1
	CT	Codec2
Reference codecs	AAC	AAC
	RealAudio@32 kbit/s stereo	RN
Anchors and references	Open Reference	
	Hidden Reference	hidref
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.1.2 Pivot Table Results

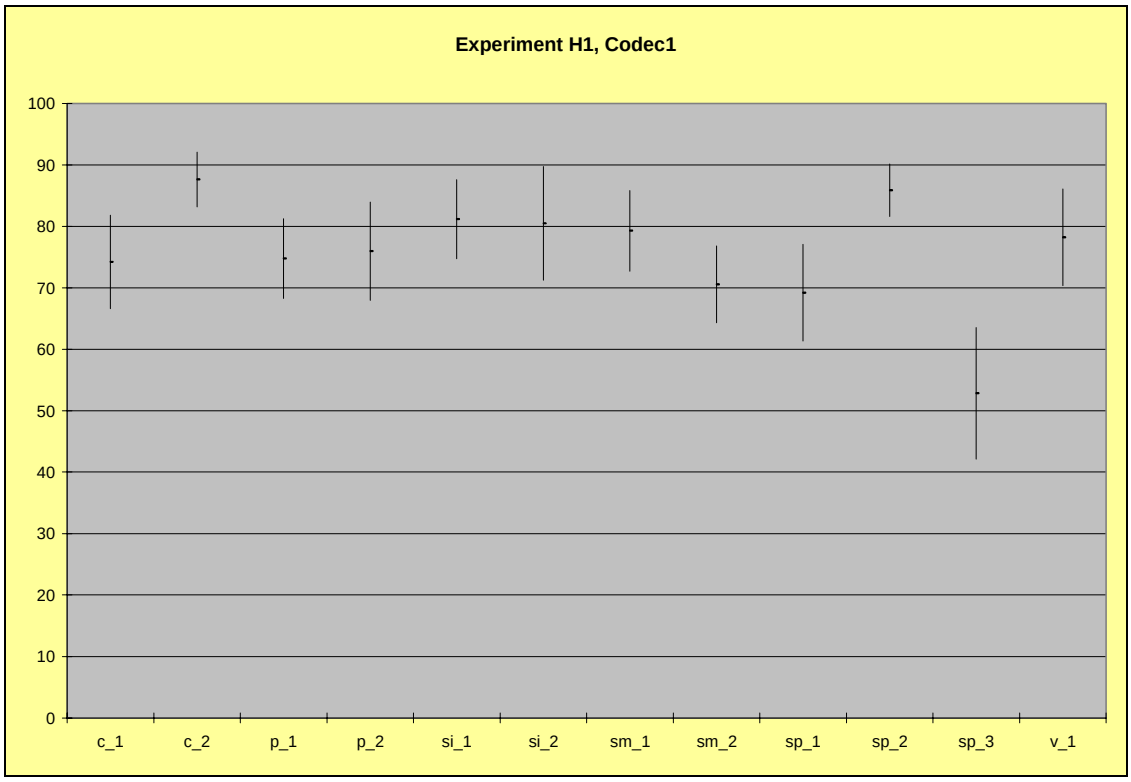
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

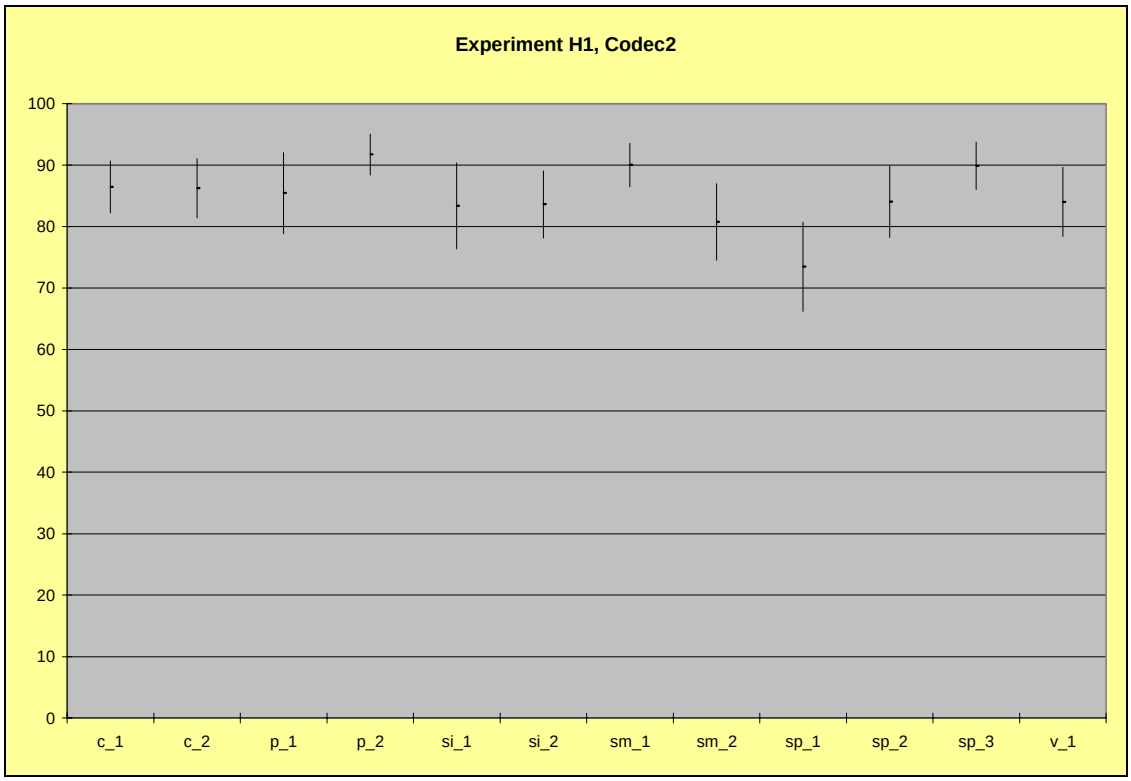


Each of the candidate codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	AAC	hidref	lp3500	lp7000	RN
Average	75.8	84.9	38.7	99.6	26.7	53.6	48.0
Lower Bound	73.5	83.2	36.0	99.4	24.4	50.9	45.2
Upper Bound	78.1	86.5	41.5	99.8	29.1	56.2	50.8

The following 2 charts show the performance of each of the candidate codecs for each of the test signals.





The following table presents the data used to create the previous charts.

	Codec 1			Codec 2		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
c_1	81.8	66.6	74.2	90.7	82.2	86.4
c_2	92.1	83.2	87.6	91.0	81.4	86.2
p_1	81.3	68.3	74.8	92.0	78.8	85.4
p_2	84.0	68.0	76.0	95.1	88.4	91.7
si_1	87.6	74.7	81.2	90.3	76.4	83.3
si_2	89.7	71.2	80.5	89.1	78.1	83.6
sm_1	85.9	72.7	79.3	93.6	86.4	90.0
sm_2	76.8	64.3	70.6	87.0	74.5	80.7
sp_1	77.1	61.3	69.2	80.7	66.2	73.5
sp_2	90.1	81.6	85.9	89.8	78.2	84.0
sp_3	63.5	42.1	52.8	93.8	86.0	89.9
v_1	86.1	70.4	78.2	89.6	78.4	84.0

8.1.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	1326938	165867	856.4	< 2.2e-16 ***
SigCat	5	15238	3048	15.7	2.50E-15 ***
Signal	6	40742	6790	35.1	< 2.2e-16 ***
Site	1	109184	109184	563.7	< 2.2e-16 ***
Subject	28	182687	6525	33.7	< 2.2e-16 ***
Codec:Signal	40	36003	900	4.6	< 2.2e-16 ***
Codec:Site	8	20330	2541	13.1	< 2.2e-16 ***
Residuals	3125	605265	194		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	AAC	RN	hidref	lp3500	lp7000
mean	75.8	84.9	38.7	48.0	99.6	26.7	53.6
N	354	354	354	354	354	354	354
Lower Bound	74.4	83.5	37.3	46.6	98.2	25.3	52.2
Upper Bound	77.2	86.3	40.1	49.4	101.0	28.1	55.0

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Signal Category main effect

	c	p	si	sm	sp	v
mean	61.1	58.9	64.7	60.8	60.1	61.5
N	413	413	406	413	623	210

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec		SigCat					
		c	p	si	sm	sp	v
Codec1	mean	81.1	75.4	80.8	74.9	69.1	78.2
rep	N	59	59	58	59	89	30
Codec2	mean	86.3	88.5	83.5	85.3	82.5	84.0
rep	N	59	59	58	59	89	30
AAC	mean	38.9	36.0	47.5	39.1	32.3	45.3
rep	N	59	59	58	59	89	30
RN	mean	43.6	43.5	47.8	50.1	54.9	40.8
rep	N	59	59	58	59	89	30
hidref	mean	99.2	99.6	99.5	100.0	99.6	99.8
rep	N	59	59	58	59	89	30
lp3500	mean	27.5	23.9	31.1	24.7	26.3	27.7
rep	N	59	59	58	59	89	30
lp7000	mean	51.0	45.2	62.5	51.2	56.2	54.9
	N	59	59	58	59	89	30

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of “interaction.” The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the sp category is ±2.8, while the width of the 95% confidence intervals for the v category is ±4.8, and the width of the 95% confidence intervals for the other categories is ±3.4.

Signal main effect

	c_1	c_2	p_1	p_2	si_1	si_2
mean	57.5	64.5	58.6	63.6	57.0	65.1
N	203	210	210	203	203	203
	sm_1	sm_2	sp_1	sp_2	sp_3	v_1
mean	63.9	58.3	59.5	66.3	57.5	61.04
N	203	210	210	203	210	210

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	DY	T-Sys
mean	74.6	47.7
N	1232	1246

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.1.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others.

8.1.5 Post-screening of data

Of the 360 sets of 7 judgments (one for each codec, reference codec, and anchor) in this experiment, 6 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense.

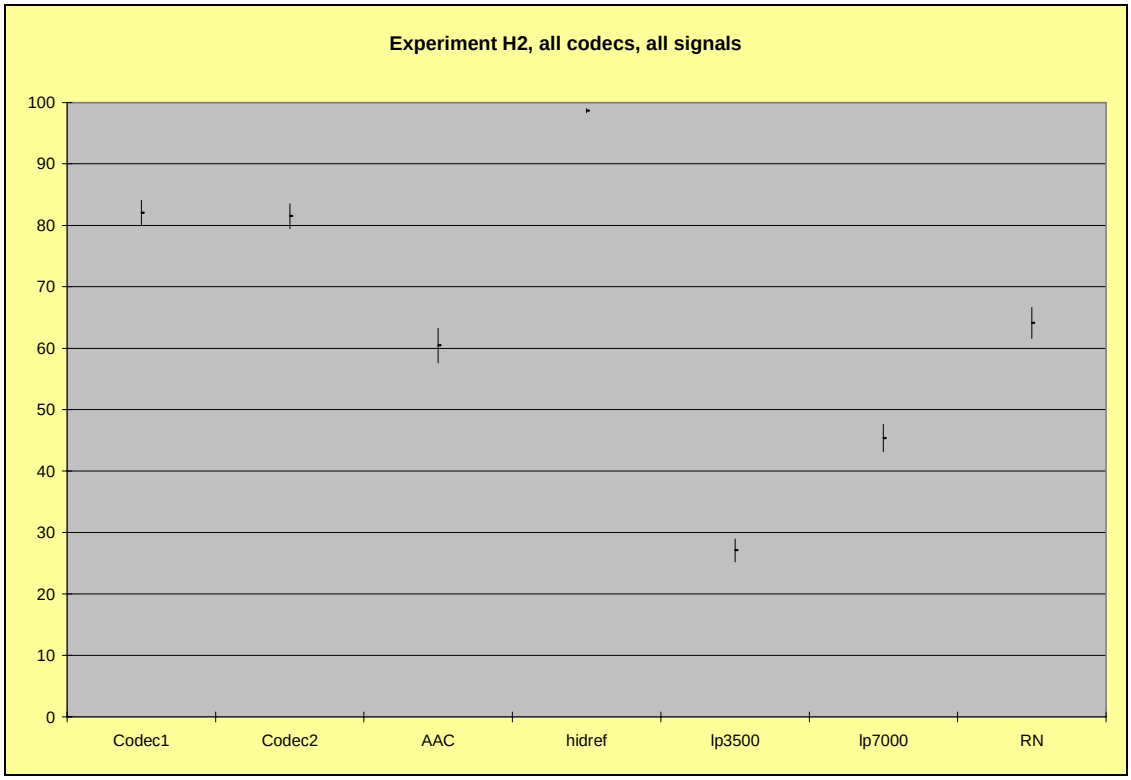
8.2 Test 2

8.2.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	2	
Bit Rate	48 kbps	
Signal	Stereo	
Candidate codecs	AAC+	Codec1
	CT	Codec2
Reference codecs	AAC	AAC
	RealAudio@48 kbit/s stereo	RN
Anchors and references	Open Reference	
	Hidden Reference	hidref
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.2.2 Pivot Table Results

The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

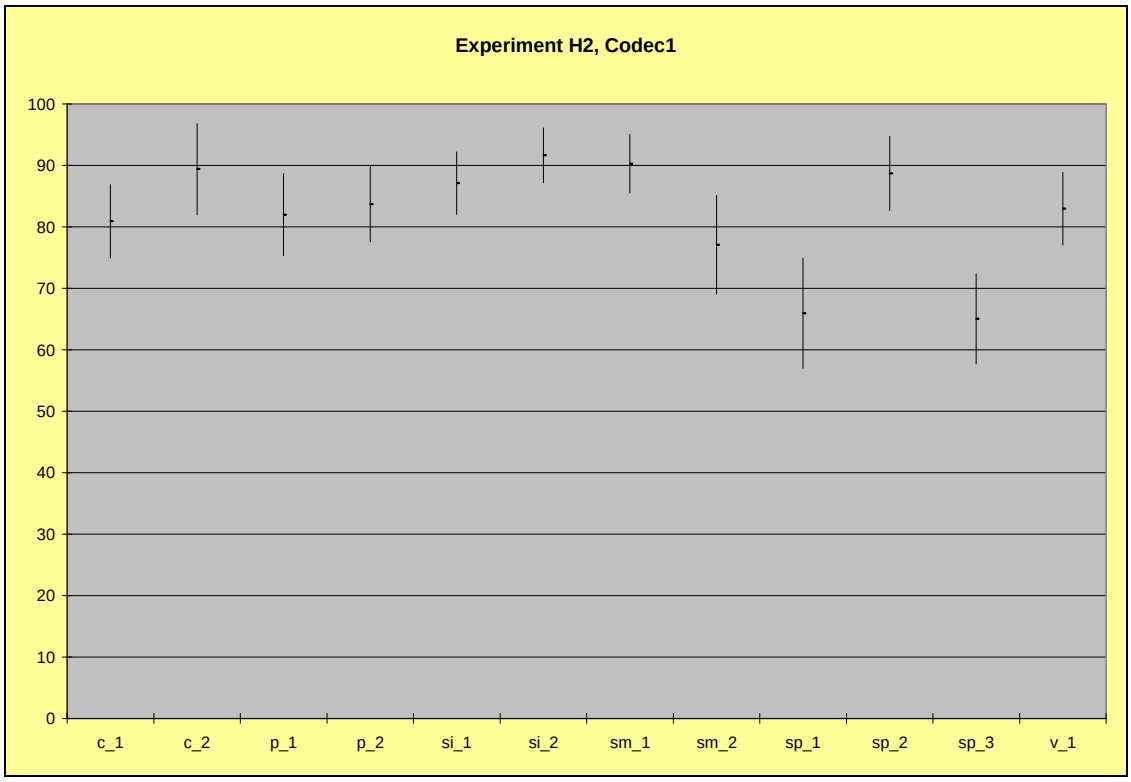


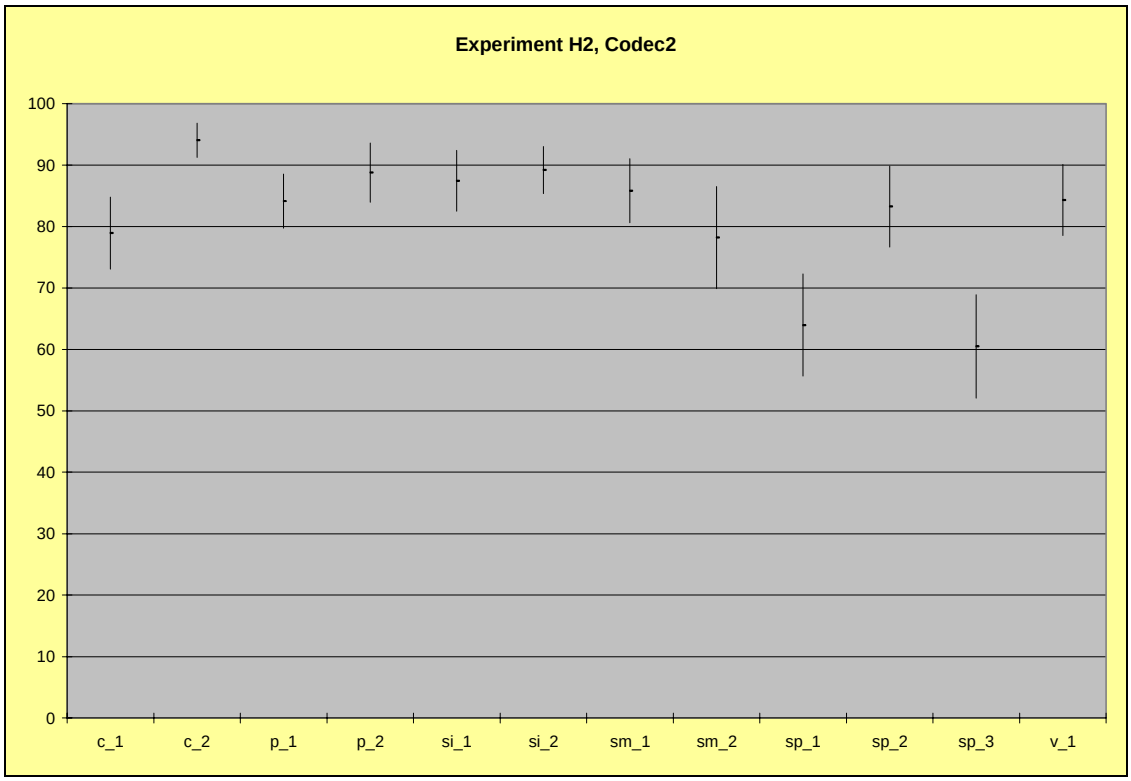
Each of the candidate codecs out-performs both of the reference codecs.

The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	AAC	hidref	lp3500	lp7000	RN
Average	82.0	81.5	60.5	98.7	27.1	45.4	64.1
Lower Bound	80.0	79.5	57.7	98.3	25.2	43.2	61.6
Upper Bound	84.1	83.5	63.3	99.0	29.0	47.6	66.7

The following 2 charts show the performance of each of the candidate codecs for each of the test signals.





The following table presents the data used to create the previous charts.

	Codec 1			Codec 2		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
c_1	86.9	74.9	80.9	84.8	73.0	78.9
c_2	96.8	82.0	89.4	96.8	91.2	94.0
p_1	88.6	75.3	82.0	88.5	79.7	84.1
p_2	89.8	77.5	83.7	93.6	84.0	88.8
si_1	92.2	82.0	87.1	92.4	82.5	87.4
si_2	96.1	87.2	91.6	93.0	85.4	89.2
sm_1	95.0	85.5	90.3	91.0	80.6	85.8
sm_2	85.1	69.1	77.1	86.5	69.9	78.2
sp_1	74.9	57.0	65.9	72.3	55.6	64.0
sp_2	94.8	82.7	88.7	89.8	76.7	83.3
sp_3	72.4	57.7	65.0	68.9	52.1	60.5
v_1	88.9	77.0	83.0	90.1	78.6	84.3

8.2.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	6	1148537	191423	785.6	< 2.2e-16 ***
SigCat	5	13303	2661	10.9	2.13e-10 ***
Signal	6	28346	4724	19.4	< 2.2e-16 ***
Site	1	1	1	0.0	0.96
Subject	28	216419	7729	31.7	< 2.2e-16 ***
Codec:Signal	30	62531	2084	8.6	< 2.2e-16 ***
Codec:Site	6	4127	688	2.8	0.01 **
Residuals	2192	534086	244		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level except Site, which is not significant, and the Codec by Site interaction, which is statistically significant at the 99% level. This means that each of the aspects of the experimental design, except possibly Site, was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	AAC	RN	hidref	lp3500	lp7000
mean	82.0	81.5	60.5	64.1	98.7	27.1	45.4
N	325	325	325	325	325	325	325
Lower Bound	80.3	79.8	58.8	62.4	97.0	25.4	43.7
Upper Bound	83.7	83.2	62.2	65.8	100.4	28.8	47.1

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Signal Category main effect

	c	p	si	sm	sp	v
mean	67.3	66.8	67.7	66.7	61.5	66.2
N	364	371	385	378	581	196

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec		SigCat					
		c	p	si	sm	sp	v
Codec1	mean	85.3	82.8	89.4	83.9	73.1	83.0
	N	52	53	55	54	83	28
Codec2	mean	86.8	86.5	88.3	82.2	69.1	84.3
	N	52	53	55	54	83	28
AAC	mean	78.2	60.5	52.5	62.8	49.3	71.5
	N	52	53	55	54	83	28
RN	mean	56.3	67.6	63.0	69.0	67.5	54.6
	N	52	53	55	54	83	28
hidref	mean	98.0	98.8	98.4	98.5	99.4	98.5
	N	52	53	55	54	83	28
lp3500	mean	25.3	27.4	29.9	27.2	26.0	27.9
	N	52	53	55	54	83	28
lp7000	mean	41.4	44.1	51.9	43.3	46.4	43.6
	N	52	53	55	54	83	28

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the sp category is ±3.4, while the width of the 95% confidence intervals for the v category is ±5.8, and the width of the 95% confidence intervals for the other categories is ±4.2.

Signal main effect

	c_1	c_2	p_1	p_2	si_1	si_2
mean	64.7	66.5	64.1	67.1	61.2	69.9
N	175	189	182	189	189	196
	sm_1	sm_2	sp_1	sp_2	sp_3	v_1
mean	68.5	62.6	63.8	73.0	60.2	65.61
N	196	182	203	189	189	196

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Nokia	NTT-AT
mean	65.63	65.6
N	1183	1092

The sites are not statistically significantly different, although the interaction between sites and codecs is statistically significant at the 99% level.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.2.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others.

8.2.5 Post-screening of data

Of the 360 sets of 7 judgments (one for each codec, reference codec, and anchor) in this experiment, 35 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means change less than 1 unit, which is not much in a practical sense.

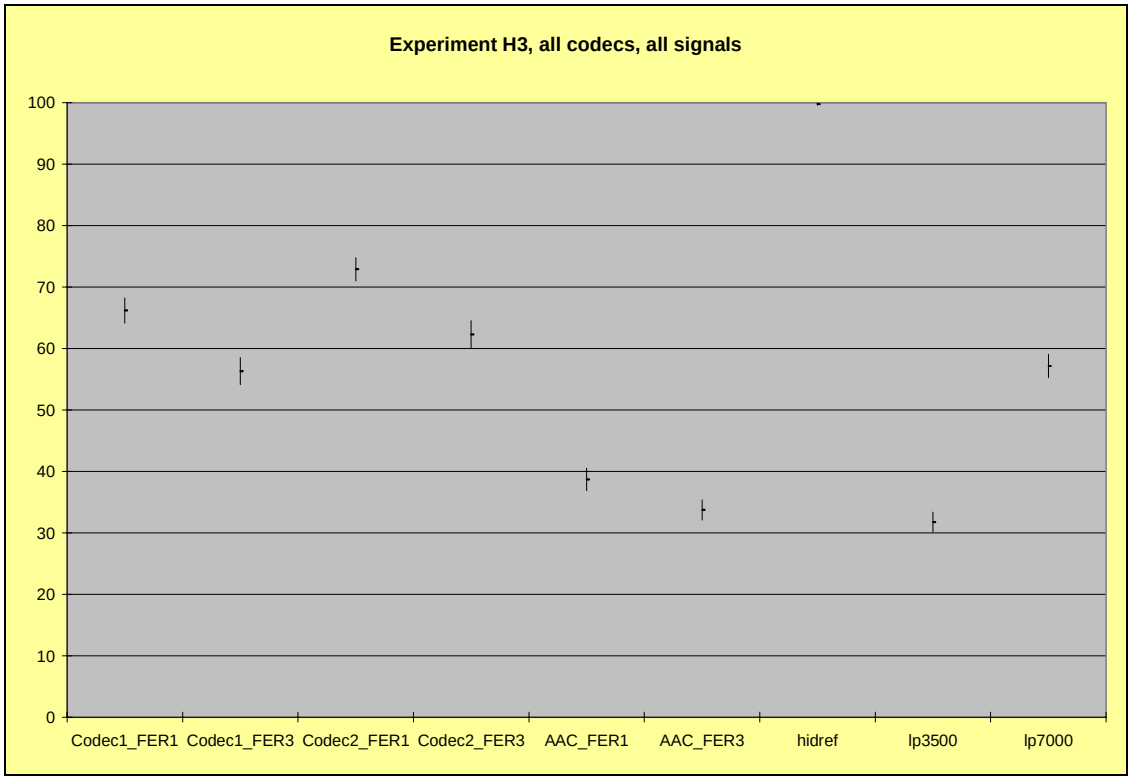
8.3 Test 3

8.3.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	3	
Bit Rate	32 kbps, 1% and 3% random frame loss	
Signal	Stereo	
Candidate codecs	AAC+, 1% random frame loss	Codec1_FER1
	AAC+, 3% random frame loss	Codec1_FER3
	CT, 1% random frame loss	Codec2_FER1
	CT, 3% random frame loss	Codec2_FER3
Reference codecs	AAC, 1% random frame loss	AAC_FER1
	AAC, 3% random frame loss	AAC_FER3
Anchors and references	Open Reference	
	Hidden Reference	hidref
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.3.2 Pivot Table Results

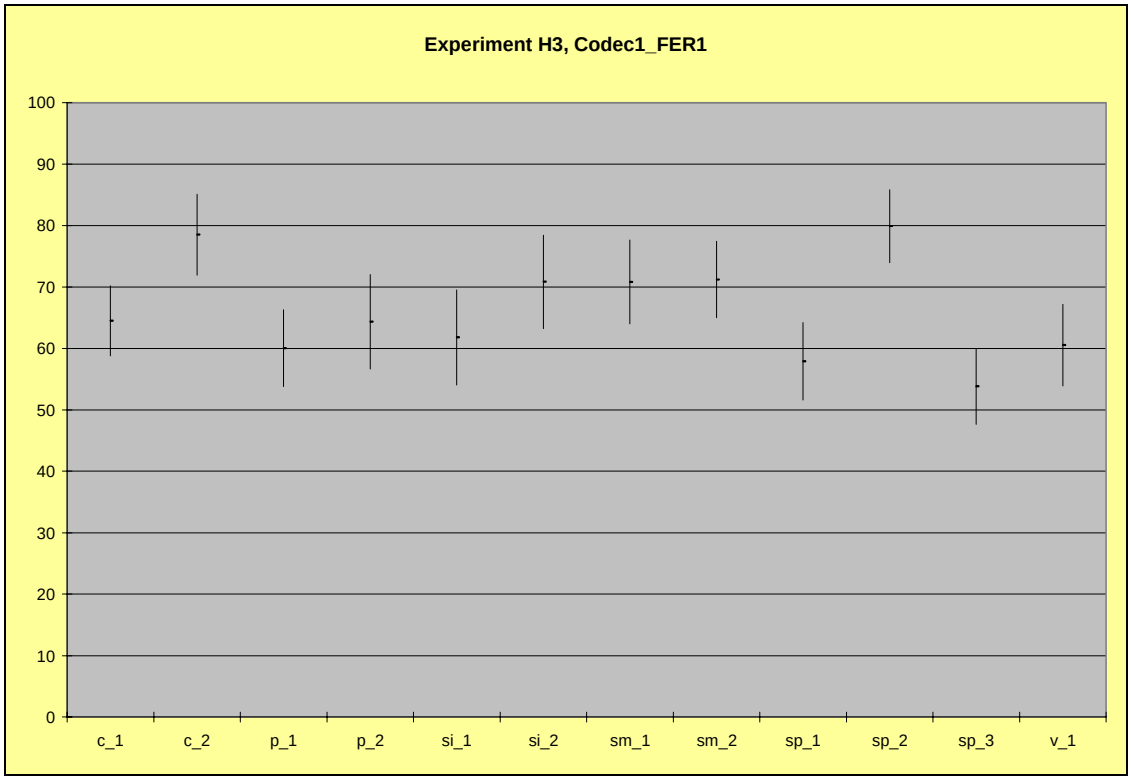
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

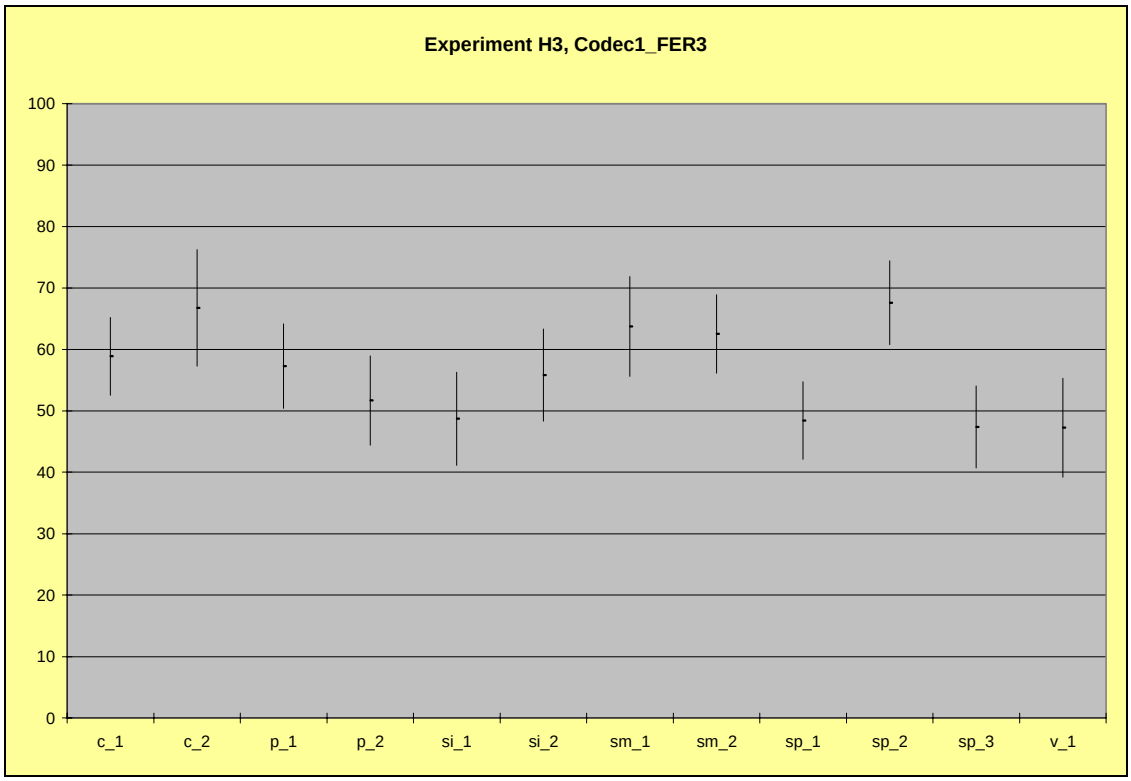


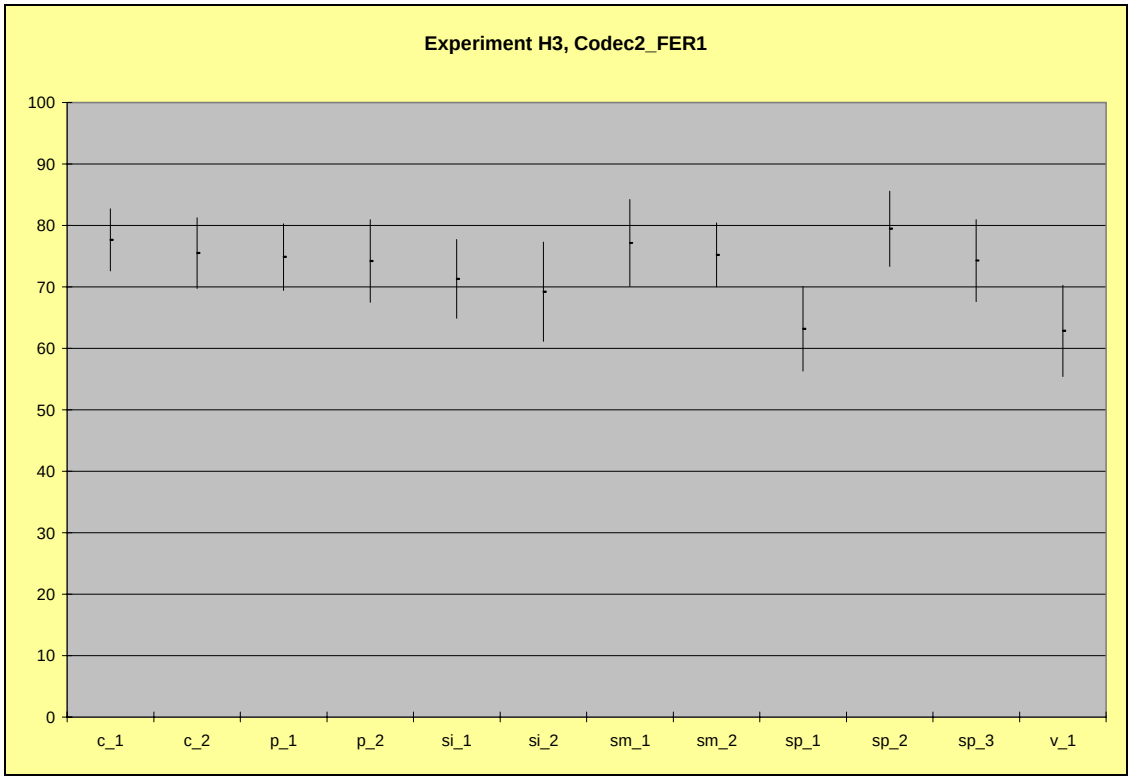
Each of the candidate codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

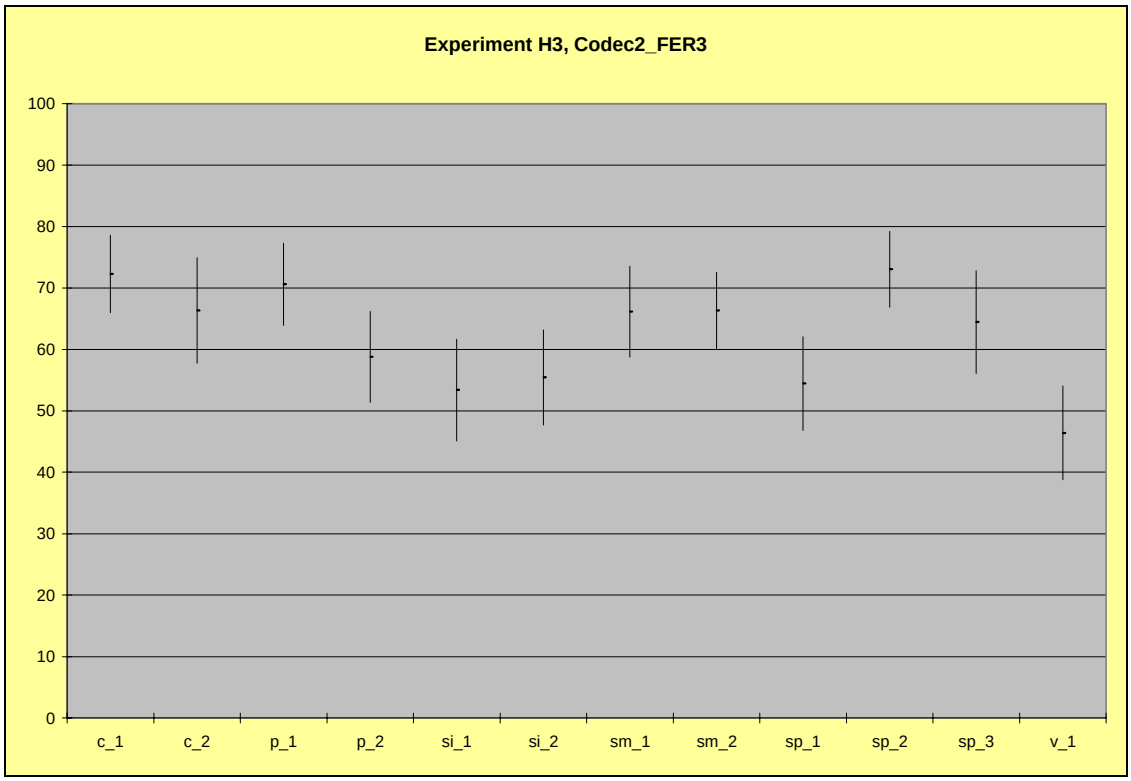
	Codec1_ FER1	Codec1_ FER3	Codec2 _FER1	Codec2 _FER3	AAC_ FER1	AAC_ FER3	hidref	lp3500	lp7000
Average	66.2	56.3	72.9	62.3	38.7	33.7	99.8	31.7	57.2
Lower Bound	64.1	54.1	71.0	60.0	36.8	32.1	99.6	30.1	55.3
Upper Bound	68.2	58.5	74.8	64.6	40.5	35.4	100.0	33.4	59.1

The following 4 charts show the performance of each of the candidate codecs for each of the test signals.




Experiment H3, Codec1_FER3
100
90
80
70
60
50
40
30
20
10
0
c_1
c_2
p_1
p_2
si_1
si_2
sm_1
sm_2
sp_1
sp_2
sp_3
v_1


Experiment H3, Codec2_FER1
100
90
80
70
60
50
40
30
20
10
0
c_1
c_2
p_1
p_2
si_1
si_2
sm_1
sm_2
sp_1
sp_2
sp_3
v_1



The following table presents the data used to create the previous charts.

	Codec1_FER1			Codec1_FER3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
c_1	70.2	58.8	64.5	65.2	52.6	58.9
c_2	85.1	71.9	78.5	76.2	57.3	66.8
p_1	66.3	53.8	60.0	64.2	50.4	57.3
p_2	72.0	56.7	64.3	58.9	44.4	51.7
si_1	69.5	54.1	61.8	56.3	41.1	48.7
si_2	78.4	63.2	70.8	63.3	48.3	55.8
sm_1	77.7	64.0	70.8	71.8	55.6	63.7
sm_2	77.4	65.0	71.2	68.9	56.1	62.5
sp_1	64.2	51.6	57.9	54.7	42.1	48.4
sp_2	85.8	74.0	79.9	74.4	60.8	67.6
sp_3	60.0	47.7	53.8	54.1	40.7	47.4
v_1	67.2	53.9	60.5	55.3	39.2	47.3

	Codec2_FER1			Codec2_FER3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
c_1	82.7	72.6	77.7	78.6	66.0	72.3
c_2	81.2	69.8	75.5	74.9	57.7	66.3
p_1	80.3	69.5	74.9	77.3	63.9	70.6
p_2	80.9	67.5	74.2	66.2	51.4	58.8
si_1	77.7	64.9	71.3	61.6	45.1	53.4
si_2	77.3	61.2	69.2	63.1	47.7	55.4
sm_1	84.2	70.1	77.2	73.5	58.7	66.1
sm_2	80.4	70.0	75.2	72.5	60.2	66.3
sp_1	70.0	56.3	63.2	62.1	46.8	54.4
sp_2	85.6	73.3	79.5	79.2	66.9	73.0
sp_3	81.0	67.6	74.3	72.8	56.0	64.4
v_1	70.3	55.5	62.9	54.0	38.8	46.4

8.3.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	1326938	165867	856.4	< 2.2e-16 ***
SigCat	5	15238	3048	15.7	2.50E-15 ***
Signal	6	40742	6790	35.1	< 2.2e-16 ***
Site	1	109184	109184	563.7	< 2.2e-16 ***
Subject	28	182687	6525	33.7	< 2.2e-16 ***
Codec:Signal	40	36003	900	4.6	< 2.2e-16 ***
Codec:Site	8	20330	2541	13.1	< 2.2e-16 ***
Residuals	3125	605265	194		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1_FER1	Codec1_FER3	Codec2_FER1	Codec2_FER3	AAC_FER1	AAC_FER3	hidref	lp3500	lp7000
mean	66.2	56.3	72.9	62.3	38.7	33.7	99.8	31.8	57.2
N	358	358	358	358	358	358	358	358	358
Lower Bound	64.7	54.9	71.5	60.9	37.2	32.3	98.3	30.3	55.7
Upper Bound	67.6	57.8	74.3	63.7	40.1	35.2	101.2	33.2	58.6

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Signal Category main effect

	c	p	si	sm	sp	v
mean	60.3	56.3	58.3	59.2	57.2	52.0
N	540	531	540	531	810	270

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec		SigCat					
		c	p	si	sm	sp	v
Codec1_FER1	mean	71.5	62.2	66.3	71.0	63.9	60.5
rep	N	60	59	60	59	90	30
Codec1_FER3	mean	62.8	54.5	52.3	63.1	54.5	47.3
rep	N	60	59	60	59	90	30
Codec2_FER1	mean	76.6	74.5	70.3	76.2	72.3	62.9
rep	N	60	59	60	59	90	30
Codec2_FER3	mean	69.3	64.8	54.4	66.2	64.0	46.4
rep	N	60	59	60	59	90	30
AAC_FER1	mean	39.8	36.4	44.3	38.4	36.1	37.9
rep	N	60	59	60	59	90	30
AAC_FER3	mean	37.6	31.9	39.3	32.6	32.3	24.9
rep	N	60	59	60	59	90	30
hidref	mean	99.8	99.6	99.8	100.0	99.7	100.0
rep	N	60	59	60	59	90	30
lp3500	mean	32.6	29.7	33.6	31.1	32.3	30.3
rep	N	60	59	60	59	90	30
lp7000	mean	52.9	52.6	64.7	54.5	59.5	57.8
rep	N	60	59	60	59	90	30

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of “interaction.” The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the sp category is ±2.9, while the width of the 95% confidence intervals for the v category is ±5.0, and the width of the 95% confidence intervals for the other categories is ±3.6.

Signal main effect

	c_1	c_2	p_1	p_2	si_1	si_2
mean	54.3	61.0	58.0	57.3	53.6	61.7
N	270	270	270	261	270	270
	sm_1	sm_2	sp_1	sp_2	sp_3	v_1
mean	58.5	56.8	53.6	65.6	53.8	57.6
N	261	270	270	270	270	270

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Ericsson	FT
mean	63.4	51.8
N	1620	1602

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect
The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.3.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others.

8.3.5 Post-screening of data

Of the 360 sets of 7 judgments (one for each codec, reference codec, and anchor) in this experiment, 2 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense.

9 Application of Selection Rules

The Selection Rules as defined in S4-(03)0837 [7] have been applied using the data collected in the experiments being analyzed here. The following are the results.

9.1 Selection Rule 1

These rules are design criteria, and we assume for the purposes of this document that all three candidate codecs pass these rules.

9.2 Selection Rule 2

This rule ensures that each candidate codec outperforms the better of the reference codecs in each test case. Inspecting the 3 charts above showing "all data" with confidence intervals, it is easy to verify that both candidate codecs performed better than the reference codecs. The average results from the charts above for each test case have been assembled in the following chart for easy reference.

Operating condition	AAC+	CT	AAC	RN
32 kbit/s, stereo	75.8	84.9	38.7	48.0
48 kbps, stereo	82.0	81.5	60.5	64.1
32 kbps, stereo, 1% FER	66.2	72.9	38.7	n/a
32 kbps, stereo, 3% FER	56.3	62.3	33.7	n/a

9.3 Selection Rule 3

As described in the Selection Rules document, and clarified in document [9] the Preferred and Informative Figure of Merit (FoM) calculations were performed and are presented in the table below. The AAC reference is referred to as the "preferred quality FoM" and the RN reference is referred to as the "informative quality FoM.

AAC+

Preferred FoM

	Mean	min	max
LR-A3	21.02	-14.47	42.50
LR-A4	6.23	-31.70	35.14
HR-1	37.05	22.52	44.24
HR-2	21.51	-0.44	47.74
HR-3-1%	27.49	18.10	37.10
HR-3-3%	12.13	-4.37	28.13
average	20.90	13.39	43.03
min	-31.70		
max	47.74		

FoM L1 6

FoM L2 0

CT

Preferred FoM

	Mean	min	max
LR-A3	21.87	-15.40	42.00
LR-A4	17.91	-13.80	44.24
HR-1	46.10	25.62	70.40
HR-2	20.99	-2.44	48.07
HR-3-1%	34.22	16.50	49.17
HR-3-3%	8.71	-15.70	24.10
average	24.97	13.23	55.88
min	-15.70		
max	70.40		

FoM L1 6

FoM L2 0

AAC+

Informative FoM

	Mean	min	max
HR-1	27.84	4.00	43.57
HR-2	18.02	-0.15	33.04
average	22.93	1.93	38.30
min	-0.15		
max	43.57		

FoM L1 2

FoM L2 0

CT

Informative FoM

	Mean	min	max
HR-1	36.90	20.47	54.23
HR-2	17.50	-4.70	37.67
average	27.20	7.88	45.95
min	-4.70		
max	54.23		

FoM L1 2

FoM L2 0

Reference Documents

1. Tdoc S4-(03)0821, PSS/MMS High-Rate Audio Selection Test and Processing Plan Version 2.2.0.
2. Tdoc S4-(03)0824, AMR-WB+ and PSS/MMS Low-Rate Audio Selection Test and Processing Plan Version 2.2.
3. RECOMMENDATION ITU-R BS.1534, Method for the subjective assessment of intermediate quality level of coding systems.
4. An Introduction to R, Notes on R: A Programming Environment for Data Analysis and Graphics, Version 1.4.1, by W.N. Venables, D.M. Smith and the R Development Core Team (2001) Network Theory Limited.
5. Modern Applied Statistics with S, by W.N. Venables and B.D. Ripley (2002) Springer. Known colloquially as MASS.
6. MASS, p 140ff describe lm(). p 165ff describe aov(), which is a “wrapper” for lm().
7. Tdoc S4-(03)0837. PSS/MMS Audio Codec and Extended AMR-WB Selection Rules, Version 2.0.
8. Tdoc S4-(04)0173, Global Analysis Laboratory Report on 3GPP Low-Rate Audio Codec Exercises
9. Tdoc S4-040117 Implementation of the preferred FOM of PSS/MMS low-rate audio codec selection rule 3.

TSG-SA4#30 meeting Tdoc S4 (04)0173
February 23-27, 2004, Malaga, Spain

Source: S. R. Quackenbush, Audio Research Labs
Title: Global Analysis Laboratory Report on 3GPP Low-Rate Audio Codec Exercises
Status: Approved
Revision: March 5, 2004

Executive Summary

A series of eight experiments were conducted in the 3GPP Audio codec exercise, as specified in S4-030824, "AMR-WB+ and PSS/MMS Low-Rate Audio Selection Test and Processing Plan Version 2.2." This documents reports the results of those tests.
The following table summarizes the performance of the candidate codecs in each of the eight tests. For each test, the codec with the best subjective score is highlighted in green, where "best" is in the statistical sense that the codec estimated mean score is better than that of the other codecs at the 95% level of significance (based on ANOVA results). In the case that two codecs are "best" (e.g. test A3) it indicates that the two codecs do not differ from each other in a statistically significant sense, but that both are better than the third codec the 95% level of significance.

Test	Operating condition	AAC+	AMR-WB+	CT
A1	14 kbps, mono, use case A (PSS)	50.8	62.6	51.5
A2	18 kbps, stereo, use case A (PSS)	37.5	55.6	53.3
A3	24 kbps, mono, use case A (PSS)	75.0	67.4	75.8
A4	24 kbps, stereo, use case A (PSS)	55.3	61.3	67.1
B1	14 kbps, mono, use case B (MMS), 16 kHz inp. and outp. sampling rate	45.5	50.7	44.4
B2	18 kbps, stereo, use case B (MMS)	43.3	50.7	55.7
B3	14 kbps, mono, use case A (PSS), 3% FER	43.1	52.5	44.3
B4	24 kbps, stereo, use case A (PSS), 3% FER	48.9	53.3	58.0

As the table shows, AMR-WB+ and CT each have operating points at which they have strong performance. It appears that bit rate (i.e. lower or higher) and number of channels (i.e. mono or stereo) are significant factors in determining the performance of these two codecs.
The data support the following statements:

- In all three tests at 14 kb/s (B1, A1, B3), candidate AMR-WB+ had a mean score that was better than candidate CT in a statistical sense at the 95% confidence level.
- In one test at 18 kb/s (A2), candidate AMR-WB+ had a mean score that was better than candidate CT, while in the other test at 18 kb/s (B2), CT had a mean score that was better than AMR-WB+, where "better" is in a statistical sense at the 95% confidence level.
- In all three tests at 24 kb/s (A3, A4, B4), candidate CT had a mean score that was better than candidate AMR-WB+ in a statistical sense at the 95% confidence level.
- In all tests (A1-B4) candicate AMR-WB+ is better than reference codecs AAC and AMR-WB in a statistical sense at the 95% confidence level.
- In both tests at 18 kb/s (A2, B3), candicate CT is better than the reference codecs AAC and AMR-WB in a statistical sense at the 95% confidence level.
- In all three tests at 24 kb/s (A3, A4, B4), all candidate codecs are better than the reference codecs (AAC and AMR-WB) in a statistical sense at the 95% confidence level.

Table of Contents

1 Introduction

The European Telecommunications Standards Institute (ETSI) has conducted a series of eight experiments in the 3GPP Audio codec exercise. 3GPP desires to use the test to evaluate candidate codecs for their needs, as set forth in document S4-030824, "**AMR-WB+ and PSS/MMS Low-Rate Audio Selection Test and Processing Plan Version 2.2**" [1]. This documents reports the results of those tests.

In this report, Section 2 presents an overview of the test design, Section 3 describes the systems under test, and Section 4 describes the experimental design in greater detail. Section 5 describes the test material used. For a detailed report on processing of the test material, see the Host and Mirror Laboratory Reports. Section 6 documents the test laboratories used for each component of the test. Section 7 presents an overview of the statistical analysis used in the data reduction, and Section 8 presents the test results for each of the experiments. Section 9 presents the results of applying the Selection Rules.

2 Overview of experiments

There were eight experiments conducted, which were divided into two main blocks, "A" and "B", each of which tested different operating conditions:

- A: Intrinsic quality comparison of candidate codecs
- B: Quality comparison under stressed operating conditions

Each of experiment block A and B were further divided into four experiments that tested the candidate codecs at different bitrates and operational conditions.

Experiments in block A tested the candidate codecs at the following bitrates and operating conditions:

- A1: 14 kbps, mono, use case A (PSS)
- A2: 18 kbps, stereo, use case A (PSS)
- A3: 24 kbps, mono, use case A (PSS)
- A4: 24 kbps, stereo, use case A (PSS)

Experiments in block B tested the candidate codecs at the following bitrates and operating conditions:

- B1: 14 kbps, mono, use case B (MMS), 16 kHz input and output sampling rate.
- B2: 18 kbps, stereo, use case B (MMS),
- B3: 14 kbps, mono, use case A (PSS), 3% frame error rate (FER)
- B4: 24 kbps, stereo, use case A (PSS), 3% FER

Each of experiments 1-4 in blocks A and B was further divided into two sub-experiments, designated "a" and "b". This division made the magnitude of the resulting listening task of reasonable size and also permitted added diversity in the test material. Two listening labs participated in each sub-experiment (for a total of four per experiment), and a different set of test material was used for each sub-experiment.

- A1a Test material set A1a, Listening Lab 1 and 5
- A1b Test material set A1b, Listening Lab 2 and 6
- A2a Test material set A2a, Listening Lab 3 and 7
- A2b Test material set A2b, Listening Lab 4 and 8
- A3a Test material set A3a, Listening Lab 5 and 1
- A3b Test material set A3b, Listening Lab 6 and 2
- A4a Test material set A4a, Listening Lab 7 and 3
- A4b Test material set A4b, Listening Lab 8 and 4
- B1a Test material set B1a, Listening Lab 1 and 5
- B1b Test material set B1b, Listening Lab 2 and 6

- B2a Test material set B2a, Listening Lab 3 and 7
- B2b Test material set B2b, Listening Lab 4 and 8
- B3a Test material set B3a, Listening Lab 5 and 1
- B3b Test material set B3b, Listening Lab 6 and 2
- B4a Test material set B4a, Listening Lab 7 and 3
- B4b Test material set B4b, Listening Lab 8 and 4

3 Systems under test

3.1 Candidate codecs

The candidate codecs participating in the AMR-WB+ and PSS/MMS low-rate audio selection tests are listed in the following table.

Codec	AMR-WB+ candidate	PSS/MMS low-rate audio candidate	Providing Organization(s)
AAC+	No	Yes	Coding Technologies/ NEC
AMR-WB+	Yes	Yes	Ericsson/ Nokia/ VoiceAge
CT	No	Yes	Coding Technologies

3.2 Reference codecs

The reference codecs are listed in the following table.

Codec name	AMR-WB+ candidate	PSS/MMS low-rate audio candidate	Providing Organization(s)
AAC	No	No	Fraunhofer
AMR-WB	No	No	3GPP

3.3 Anchors and references

Besides the items encoded with the candidate and reference codecs, anchor and reference items were included in the tests. In the experiments testing mono signals, two anchors were used, those being lowpass filtered versions of the original signal. In the experiments testing stereo signals, three anchors were used, those being lowpass filtered versions of the original signal with, additionally, a reduced stereo image. The designation “side channel attenuated by 12dB” indicates that the sum and difference signals are constructed from the stereo signal, the difference signal is attenuated by 12dB, and the stereo signal is reconstructed. A similar process is followed for 6dB attenuation. One of the references is the uncoded original signal, designated the “Hidden Reference.” The other reference signal is also uncoded original signal, but it is designated the “Open Reference.” The MUSHRA test methodology [2], requires not only 3.5 kHz and 7.0 kHz Lowpass anchors, but also both Open and Hidden references.

Type	Specification	Channels
Anchor	3.5 kHz Lowpass	Mono
Anchor	7.0 kHz Lowpass	Mono
Anchor	3.5 kHz Lowpass significantly reduced stereo image (side channel attenuated by 12dB)	Stereo

Anchor	7.0 kHz Lowpass significantly reduced stereo image (side channel attenuated by 12dB)	Stereo
Anchor	7.0 kHz Lowpass slightly reduced stereo image (side channel attenuated by 6dB)	Stereo
Hidden Reference	Original signal	Mono and Stereo
Open Reference	Original signal	Mono and Stereo

4 Experimental design

The following tables show the parameters, candidate codes, reference codecs and anchors and references for each experiment. The row labels in the first column (headed "Parameter") are explained as follows:

- The row labeled "Experiment" indicates the experiment (composed of two sub-experiments). Each experiment is specified in a separate table.
- The row labeled "Bit Rate" indicates the bitrate for the experiment. All candidate and reference codecs run at this bitrate unless explicitly noted in the "Additional Constraints" column (e.g. as with AMR-WB in experiment A1a and A1b).
- The row labeled "Signal" indicates the number of distinct channels in the test material (i.e. mono or stereo). All signals are 48 kHz sampling rate unless explicitly noted in the "Additional Constraints" column. If noted in the "Signal" row (e.g. as in experiment B1a and B1b) this indicates that all codecs processed a sampling rate other than 48 kHz. If indicated in a "codec" row (e.g. as with AMR-WB in experiment A1a and A1b), it indicates that that codec processed a sampling rate other than 48 kHz.
- The row labeled "Candidate codecs" lists each candidate codec tested in the experiment in sub-divisions of that row. All Candidate codecs process 48 kHz sampling rate test material and code at bit rate indicated for each experiment unless explicitly indicated otherwise.
- The row labeled "Reference codecs" lists each reference codec tested in the experiment in sub-divisions of that row. All Reference codecs process 48 kHz sampling rate test material and code at bit rate indicated for each experiment unless explicitly indicated otherwise.
- The row labeled "Anchors and references" lists each anchor and reference condition tested in the experiment in sub-divisions of the main row.

4.1 Experiment block A

All experiments in block A are use case A (PSS) and the test material used in each experiment is described in Section 5.

Parameter	**Value**	**Additional Constraints**
Experiment	A1a and A1b	
Bit Rate	14 kbps	
Signal	Mono	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	14.25 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	A2a and A2b	
Bit Rate	18 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	18.25 kbps, 16 kHz sampling rate, mono
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	6 dB attenuated side channel
	7.0 kHz Lowpass	12 dB attenuated side channel
	3.5 kHz Lowpass	12 dB attenuated side channel

Parameter	Value	Additional Constraints
Experiment	A3a and A3b	
Bit Rate	24 kbps	
Signal	Mono	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	23.85 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	A4a and A4b	
Bit Rate	24 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	23.85 kbps, 16 kHz sampling rate, mono
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	6 dB attenuated side channel
	7.0 kHz Lowpass	2 dB attenuated side channel
	3.5 kHz Lowpass	12 dB attenuated side channel

4.2 Experiment Block B

In block B, experiments B1a, B1b, B2a and B2b are use case B (MMS) while experiments B3a, B3b, B4a and B4b are use case A (PSS). Test Material used in each experiment is described in Section 5. This table for Experiments B3a, B3b, B4a and B4b have a new row that indicates "Channel Error Condition." These experiments are tested under simulated errored channel conditions, such that on average three percent of the codec frames are errored.

Parameter	Value	Additional Constraints
Experiment	B1a and B1b	
Bit Rate	14 kbps	
Signal	Mono	16 kHz input and output sampling rate
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	14.25 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	B2a and B2b	
Bit Rate	18 kbps	
Signal	Stereo	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	18.25 kbps, 16 kHz sampling rate, mono
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	6 dB attenuated side channel
	7.0 kHz Lowpass	12 dB attenuated side channel
	3.5 kHz Lowpass	12 dB attenuated side channel

Parameter	Value	Additional Constraints
Experiment	B3a and B3b	
Bit Rate	14 kbps	
Signal	Mono	
Channel Error Condition	3% FER	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	14.25 kbps, 16 kHz sampling rate
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	
	3.5 kHz Lowpass	

Parameter	Value	Additional Constraints
Experiment	B4a and B4b	
Bit Rate	24 kbps	
Signal	Stereo	
Channel Error Condition	3% FER	
Candidate codecs	AAC+	
	AMR-WB+	
	CT	
Reference codecs	AAC	
	AMR-WB	23.85 kbps, 16 kHz sampling rate, mono
Anchors and references	Open Reference	
	Hidden Reference	
	7.0 kHz Lowpass	6 dB attenuated side channel
	7.0 kHz Lowpass	12 dB attenuated side channel
	3.5 kHz Lowpass	12 dB attenuated side channel

5 Test Material

5.1 Signal categories

The test material was selected so as to be representative of the following four signal categories:

- Music
- Speech
- Speech over music (i.e. speech with background music)
- Speech between music (i.e. alternating speech and music segments)

Original material was in stereo, and for mono experiments it was downmixed.

5.2 Training Items

A single set of four training items were used for the eight tests, one item selected from each of the four stimulus categories. The four training items are shown in Annex I.

5.3 Test Items

Eight sets of test items were used, one for each experiment. The four signal categories were represented within each set, specifically with four Music items, four Speech items, two Speech between Music items and two Speech over Music items. Due to limitations in the availability of test material, some individual items appeared in more than one set. The eight sets are shown in Annex I.

6 Test sites

Individual experiments use two listening laboratories, as shown in Table 7-1. The abbreviation for the listening labs are as follows: Fraunhofer Geselschaft (FhG), France Telecom (FT) , T-Systems (TS), NTT-AT, Dynastat (D), Nokia (N), Ericsson (E), Coding Technologies (CT).

Table 7-1: Allocation of sub-experiments to the Listening Laboratories

Exp.	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Lab7	Lab8
LL ID	FhG	CT	E	N	D	FT	TS	NTT_AT
A1a	x				X			
A1b		x				X		
A2a			x				x	
A2b				x				x
A3a	x				X			
A3b		x				X		
A4a			x				x	
A4b				x				x
B1a	x				X			
B1b		x				X		
B2a			x				x	
B2b				x				x
B3a	x				X			
B3b		x				X		
B4a			x				x	
B4b				x				x
Totals:	4	4	4	4	4	4	4	4

7 Statistical analysis

7.1 Overview

7.1.1 Standard Pivot Table Analysis

The Pivot Table statistical analysis followed the standard MUSHRA procedure [2].

The calculation of the averages of the scores of all listeners remaining after post-screening will result in the Mean Subjective Scores (MSS).

The mean score $\bar{u}_j$, is calculated as:

$$\bar{u}_j = \frac{1}{\sum_k w_k} \sum_{ik} w_k u_{ijk}$$

where:

u_{ijk} is the score of observer *i* for a test condition *j* and sequence *k*

w_k is the weight for test sequence *k*

Note that in this test, signal categories Speech over Music and Speech between Music had a weight of 2, with all other categories having a weight of 1.

Confidence intervals are calculated which are derived from the standard deviation and the size of each sample. The 95% confidence interval is given by:

$$[\bar{u}_j - \delta_j, \bar{u}_j + \delta_j]$$

where:

$$\delta_j = 1.96 \frac{S_j}{\sqrt{N}}$$

where *N* is the number of independent observations (typically number of observers times number of sequences) and the standard deviation S_j is given by:

$$S_j^2 = \frac{\sum_{ik} w_k (u_{ijk} - \bar{u}_j)}{(\sum_k w_k) - 1}$$

With a probability of 95%, the absolute value of the difference between the experimental mean score and the "true" mean score (for a large number of observations) is smaller than the 95% confidence interval, on condition that the distribution of the individual scores meets certain requirements.

7.2 Statistical Model Based on the Experimental Design

The basic model of a score can be thought of as the sum of "effects". A particular score may depend on which codec was involved, which sub-experiment was involved, which audio selection is being played, which laboratory is conducting the test, and which subject is listening.

We anticipate, *a priori*, that there may also be an interaction between the audio selection and the codec under test. In other words, some codecs may perform better with some types of audio selections than with others. Further, we anticipate, *a priori*, that there may also be an interaction between the codecs under test and the testing laboratory. The proposed analysis evaluates whether these interactions exist and compensates for them, if necessary.

Further, in statistical terminology, subjects are "nested" within laboratories. In other words, subject 1 in laboratory A is a different person, with different characteristics, from subject 1 in laboratory B. Similarly, laboratories are nested within sub-experiments for the low-rate experiments. And, for the low-rate experiments, audio selections are also nested within sub-experiments.

Using a simple notation, the proposed basic model for the low-rate experiments as described above is

Score = Codec (c = 1, …, 8 or 9)
+ Sub-experiment (Sub = a or b)
+ Signal Category (SigCat = 1, … 4)
+ Signal (Signal = 1, …, 24)
+ Codec by Signal Category interaction
(Codec:SigCat, Codec = 1, …, 8 or 9, SigCat = 1, …, 4)
+ Laboratory (Site = 1, …, 4)
+ Codec by Laboratory interaction (Codec:Site, Codec = 1, …, 8 or 9, Site = 1, …, 4)
+ Subjects (s = 1, …, 15 for each Site)
+ Experimental error

In other words, the score is the sum of a number of factors plus random "error." Just the codec main effects, and possibly the codec by signal category interaction are of real interest. The main effects are analogues of the Pivot Table averages. The interaction term for, say, the codec by signal category interaction takes into account that a response might not be predictable simply by adding an effect for the codec and an effect for the signal category. Some codecs may be "winners" for some signal category, while other codecs may be "winners" for other signal categories. The statistical significance and the size of these effects will be a measure of how important the interaction terms are

There will be one instance of this model for each of the 8 low-rate experiments.

The experimental design is balanced, in that there are equal numbers of each factor level involved with each codec, with the exception that the signal categories are not equally represented. This balance has the advantage that the mean score for each codec is an appropriate statistic for estimating the quality of that codec, assuming that the signal categories

are close to balanced. As discussed below, it is the estimates of the standard deviations (or equivalently, the widths of the confidence intervals) that are different depending on the method of analysis. It would be best to use the analysis method that yields the narrowest confidence intervals, thereby giving the most information for the money spent.

Further, as mentioned in the Analysis Process section below, some Subject-Signal judgments of the codecs will be eliminated because they appear to be inconsistent with *a priori* expectations. To the extent that this happens, the analysis of variance will have to compensate for this imbalance.

7.3 Pivot Table and ANOVA Analysis

Data from experiments such of these have been analyzed in the past using the Pivot Table facilities of MS Excel spreadsheets. For simple experiments, this is probably adequate. However, the experiments being analyzed in these tests are far from simple. The pivot table is used to calculate for each codec a grand average (across all signals, subjects, etc.) and the standard deviation of that average. From these, confidence intervals can be constructed, and differences between codecs can be evaluated.

The problem from a statistical viewpoint with this analysis for the experiments described here is that the standard deviations are inflated by the variability of the other factors. This results in a test with less statistical resolving power. In other words, for a given confidence interval width, the Pivot Table method of analysis requires more listeners than the analysis method described here, or, for a given number of listeners, the proposed analysis of variance method yields narrower confidence intervals than the Pivot Table method. The reason for this is that, for example, although each codec is rated for each signal, and therefore the signal differences cancel out when comparing averages, the difference between signals will make the numbers gathered into that average more variable than they would be if the average signal effects were subtracted out first.

The statistical technique called Analysis of Variance or ANOVA will perform the appropriate analysis, better estimating the standard deviations and confidence intervals for the differences between codecs. A detailed description of ANOVA is beyond the scope of this document, but references are given in Section 9.

7.4 Post-Processing of Listener Data

The MUSHRA test methodology provides very limited ability to assess the reliability of individual listeners. In this analysis, listener reliability was assessed by observing the extent to which the listener scored the hidden reference at 100 and gave monotonically decreasing scores to each of the hidden reference, the 7.5 kHz lowpass anchor and the 3.6 kHz lowpass anchor. An interval for modest listener error was allowed in applying this rule, e.g. that the hidden reference must be scored higher than 95 rather than exactly 100. Similarly, scores may depart from strict monotonicity by 5 points and still be allowed.

7.5 Analysis Process

The analysis will proceed through the following steps

1. The MS Excel data templates are prepared in the approved format.
2. The data arrives from the testing laboratories in the MS Excel data template.
3. The data from the multiple labs is compiled into a single workbook for each experiment.
4. A Visual Basic program is used to unstack the data so that each row will have only one listener response.

5. The condition labels are replaced by the correct, unrandomized codec names.
6. A consistency check is performed. Listener-signal combinations are eliminated (given a Weight of 0) if
    - the hidden reference does not receive a rating of at least 95 or
    - the lp3500 anchor rating is not more than 5 units greater than the lp7000 anchor rating. In some experiments there are two lp3500 anchors or two lp700 anchors. In those cases, the two ratings are averaged before the comparison.
7. Data is weighted according to the "relative values" given in Table 3.2 of [7].
8. A Pivot Table analysis is performed to obtain simple, benchmark results, from which appropriate presentation charts are created. As described above, the more complex ANOVA analysis should produce codec means which are very close to the pivot table means, differing only in the effect of any missing or eliminated data. The main difference in results will be that the ANOVA confidence intervals will be narrower than the Pivot Table confidence intervals.
9. The data is exported to a text file and entered into "R" [3], a gnu version of the statistical analysis system called "S" [4]. A script is used to fit the model. In particular, the function aov() [5]is used to fit a linear model (the ANOVA model above) to the data. The fitted codec effects and interactions, estimated standard errors of the effects, and the estimated standard error of the residuals are used to create the appropriate confidence intervals. The output from R is captured in a text file.
10. The Visual Basic programs used to compile and screen the data, Excel workbook with all received data and the Pivot Table analysis, the R analysis script, and the text file of R output are all available as part of this report.

8 Test Results

In this section the candidate codecs are named only in the initial table showing test parameters. In all subsequent data analysis they are referred to using the labels Codec1, Codec2 and Codec3 such that their identity is concealed.

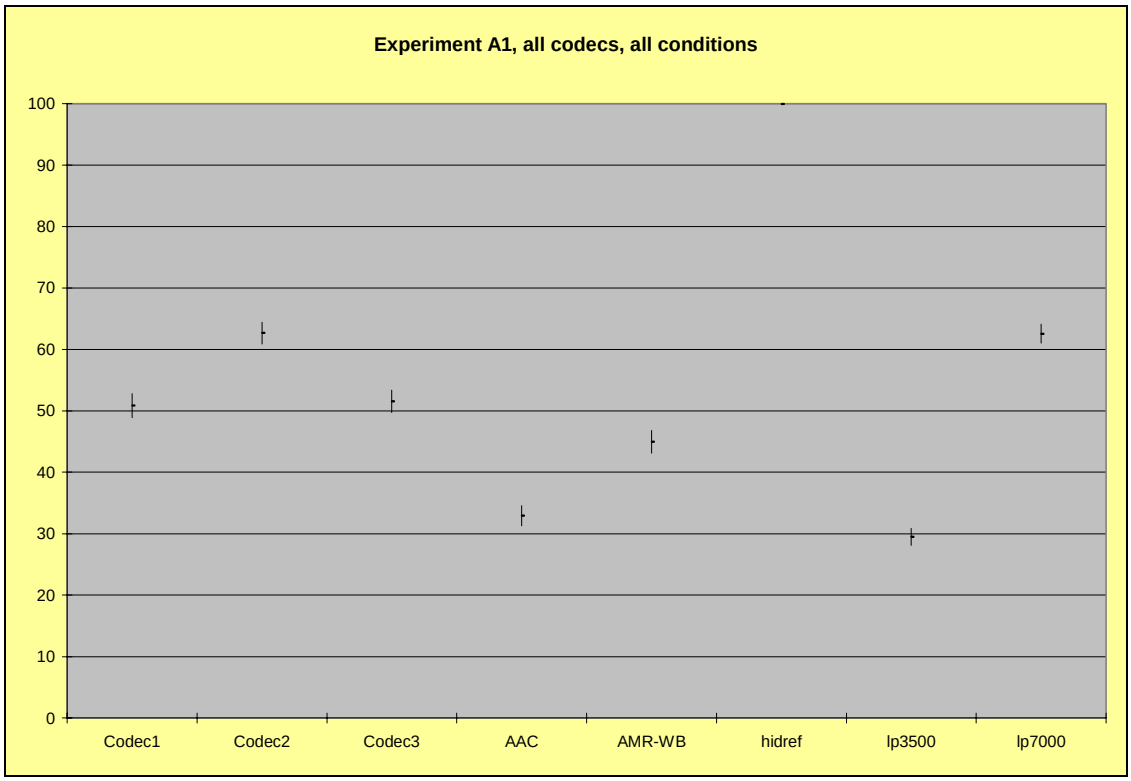
8.1 Test A1a and A1b

8.1.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	A1a and A1b	
Bit Rate	14 kbps	
Signal	Mono	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 14.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	hidref
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.1.2 Pivot Table Results

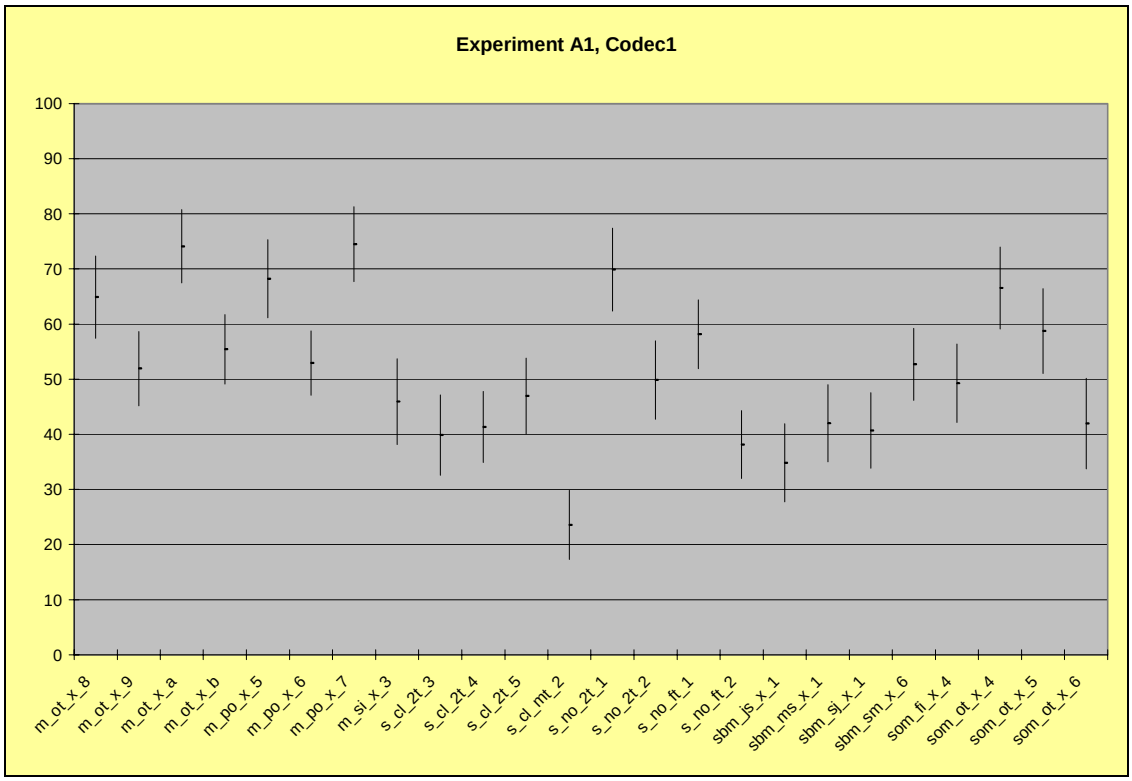
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

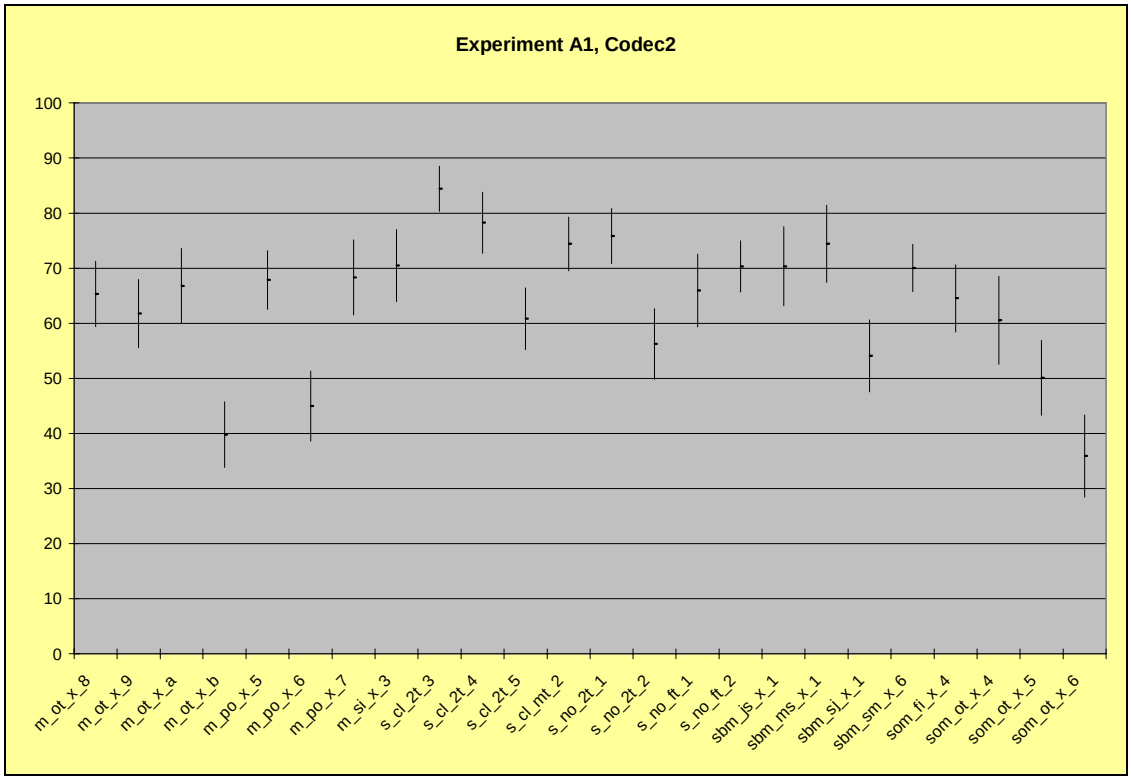


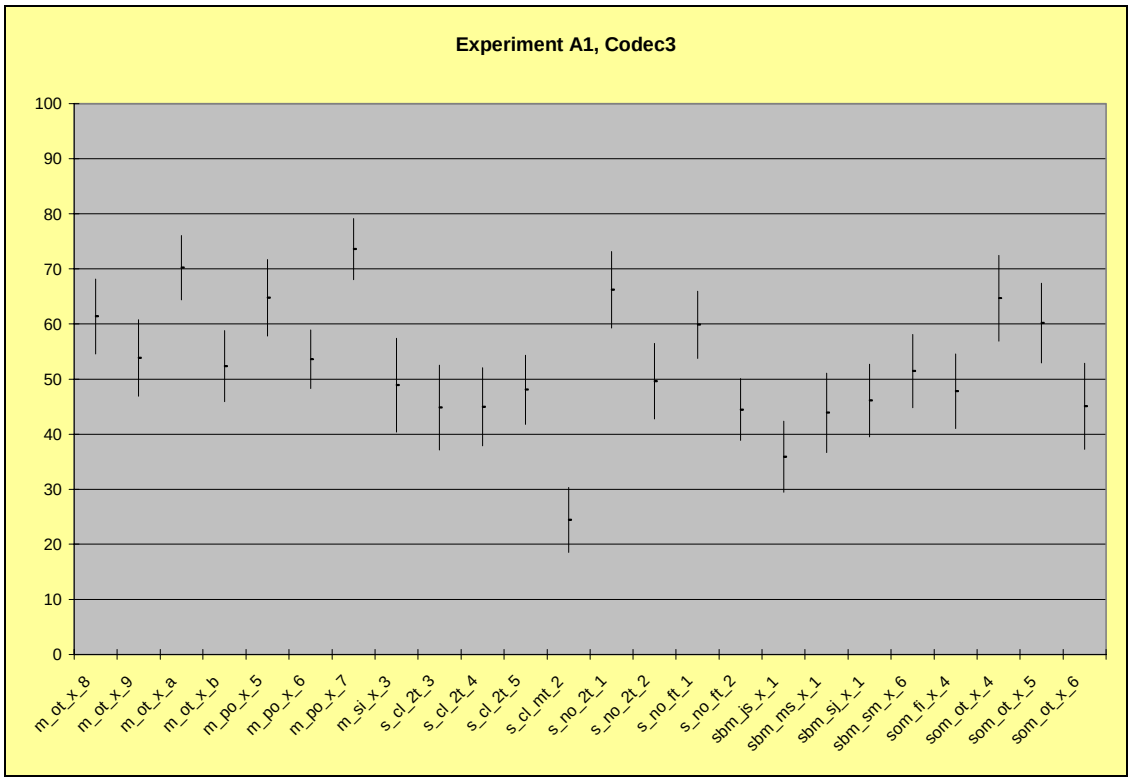
Each of the candidates codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
Average	50.8	62.6	51.5	32.9	44.9	99.9	29.5	62.5
Lower Bound	48.9	60.9	49.7	31.3	43.1	99.9	28.1	61.0
Upper Bound	52.8	64.4	53.4	34.5	46.8	100.0	30.9	64.1

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.


Experiment A1, Codec1
100
90
80
70
60
50
40
30
20
10
0
m_ot_x_8
m_ot_x_9
m_ot_x_a
m_ot_x_b
m_po_x_5
m_po_x_6
m_po_x_7
m_si_x_3
s_cl_2t_3
s_cl_2t_4
s_cl_2t_5
s_cl_mt_2
s_no_2t_1
s_no_2t_2
s_no_ft_1
s_no_ft_2
sbm_js_x_1
sbm_ms_x_1
sbm_sj_x_1
sbm_sm_x_6
som_fi_x_4
som_ot_x_4
som_ot_x_5
som_ot_x_6


Experiment A1, Codec2
100
90
80
70
60
50
40
30
20
10
0
m_ot_x_8
m_ot_x_9
m_ot_x_a
m_ot_x_b
m_po_x_5
m_po_x_6
m_po_x_7
m_si_x_3
s_cl_2t_3
s_cl_2t_4
s_cl_2t_5
s_cl_mt_2
s_no_2t_1
s_no_2t_2
s_no_ft_1
s_no_ft_2
sbm_js_x_1
sbm_ms_x_1
sbm_sj_x_1
sbm_sm_x_6
som_fi_x_4
som_ot_x_4
som_ot_x_5
som_ot_x_6



The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ot_x_8	72.4	57.4	64.9	71.3	59.4	65.3	68.1	54.6	61.4
m_ot_x_9	58.7	45.2	51.9	68.0	55.6	61.8	60.8	46.9	53.8
m_ot_x_a	80.7	67.5	74.1	73.6	60.0	66.8	76.1	64.4	70.2
m_ot_x_b	61.7	49.1	55.4	45.7	33.8	39.8	58.8	45.9	52.4
m_po_x_5	75.3	61.1	68.2	73.2	62.5	67.9	71.7	57.8	64.8
m_po_x_6	58.8	47.1	52.9	51.4	38.6	45.0	58.9	48.3	53.6
m_po_x_7	81.3	67.7	74.5	75.1	61.5	68.3	79.1	68.0	73.6
m_si_x_3	53.7	38.2	45.9	77.0	63.9	70.5	57.4	40.4	48.9
s_cl_2t_3	47.2	32.6	39.9	88.5	80.3	84.4	52.5	37.1	44.8
s_cl_2t_4	47.8	34.9	41.3	83.8	72.7	78.3	52.1	37.9	45.0
s_cl_2t_5	53.8	40.0	46.9	66.4	55.2	60.8	54.3	41.8	48.1
s_cl_mt_2	29.8	17.3	23.6	79.3	69.5	74.4	30.3	18.5	24.4
s_no_2t_1	77.4	62.4	69.9	80.9	70.9	75.9	73.2	59.3	66.2
s_no_2t_2	57.0	42.7	49.8	62.6	49.8	56.2	56.5	42.8	49.6
s_no_ft_1	64.4	51.9	58.1	72.5	59.3	65.9	66.0	53.8	59.9
s_no_ft_2	44.3	32.0	38.2	75.0	65.7	70.3	50.1	38.8	44.5
sbm_js_x_1	41.9	27.7	34.8	77.5	63.2	70.3	42.3	29.4	35.9
sbm_ms_x_1	49.0	35.0	42.0	81.4	67.4	74.4	51.1	36.7	43.9
sbm_sj_x_1	47.6	33.8	40.7	60.6	47.6	54.1	52.7	39.5	46.1
sbm_sm_x_6	59.2	46.2	52.7	74.3	65.7	70.0	58.1	44.8	51.5
som_fi_x_4	56.4	42.1	49.3	70.7	58.4	64.5	54.6	41.0	47.8

som_ot_x_4	74.0	59.1	66.6	68.5	52.6	60.6	72.5	56.9	64.7
som_ot_x_5	66.4	51.0	58.7	56.9	43.3	50.1	67.4	52.9	60.2
som_ot_x_6	50.2	33.7	42.0	43.4	28.4	35.9	52.9	37.2	45.1

8.1.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	7	3176083	453726	2213.8	< 2.2e-16 ***
Sub	1	174779	174779	852.8	< 2.2e-16 ***
SigCat	3	8119	2706	13.2	1.36e-08 ***
Signal	19	49926	2628	12.8	< 2.2e-16 ***
Site	2	140772	70386	343.4	< 2.2e-16 ***
Subject	57	435998	7649	37.3	< 2.2e-16 ***
Codec:Signal	21	227576	10837	52.9	< 2.2e-16 ***
Codec:Site	21	95383	4542	22.2	< 2.2e-16 ***
Residuals	7340	1504370	205		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
mean	50.8	62.7	51.6	32.9	45.0	99.9	29.5	62.6
N	701	701	701	701	701	701	701	701
Lower Bound	49.8	61.6	50.5	31.9	43.9	98.9	28.4	61.5
Upper Bound	51.9	63.7	52.6	34.0	46.0	101.0	30.5	63.6

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	59.4	49.7
N	2706	2898

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	54.8	55.8	53.1	53.7
N	1896	1896	920	920

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	60.8	45.6	42.8	53.9
	N	237	237	115	115
Codec2	mean	60.3	70.7	67.1	52.4
	N	237	237	115	115
Codec3	mean	59.7	47.5	44.6	54.3
	N	237	237	115	115
AAC	mean	40.8	30.1	28.0	32.7
	N	237	237	115	115
AMR-WB	mean	31.0	55.6	50.3	43.0
	N	237	237	115	115
hidref	mean	99.8	100.0	100.0	100.0
	N	237	237	115	115
lp3500	mean	27.2	32.2	29.3	29.2
	N	237	237	115	115
lp7000	mean	58.7	65.0	62.7	64.0
	N	237	237	115	115

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of “interaction.” The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±1.8, while the width of the 95% confidence intervals for the som and sbm categories is ±2.6.

Signal main effect

	m_ot_x_8	m_ot_x_9	m_ot_x_a	m_ot_x_b	m_po_x_5	m_po_x_6
mean	55.1	55.8	56.8	49.4	53.6	51.2
N	224	232	240	248	240	248
	m_po_x_7	m_si_x_3	s_cl_2t_3	s_cl_2t_4	s_cl_2t_5	s_cl_mt_2
mean	56.5	57.1	52.5	54.3	55.4	53.1
N	232	232	232	232	240	248
	s_no_2t_1	s_no_2t_2	s_no_ft_1	s_no_ft_2	sbm_js_x_1	sbm_ms_x_1
mean	59.1	53.4	52.5	54.8	51.4	52.3
N	224	248	224	248	216	224
	sbm_sj_x_1	sbm_sm_x_6	som_fi_x_4	som_ot_x_4	som_ot_x_5	som_ot_x_6
mean	54.5	58.8	52.6	58.4	55.5	51.2
N	240	240	224	216	240	240

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	CT	DY	FhG	FT
mean	56.3	60.6	48.9	52.1
N	1536	1266	1440	1362

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect
The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.1.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 4% larger.

8.1.5 Post-screening of data

Of the 732 sets of 8 judgments (one for each codec, reference codec, and anchor) in this experiment, 28 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 5%.

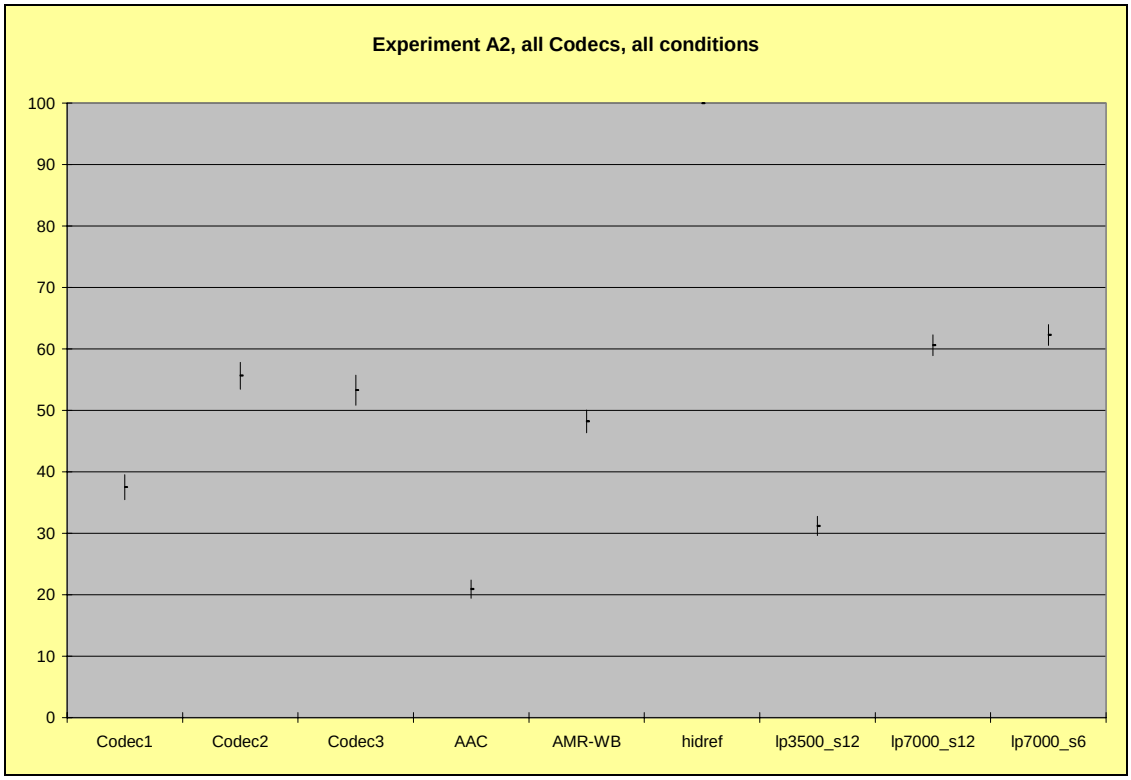
8.2 Test A2a and A2b

8.2.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	A2a and A2b	
Bit Rate	18 kbps	
Signal	Stereo	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 18.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass, 6 dB attenuated side channel	LP7.0-S6
	7.0 kHz Lowpass,12 dB attenuated side channel	LP7.0-S12
	3.5 kHz Lowpass, 12 dB attenuated side channel	LP3.5-S12

8.2.2 Pivot Table Results

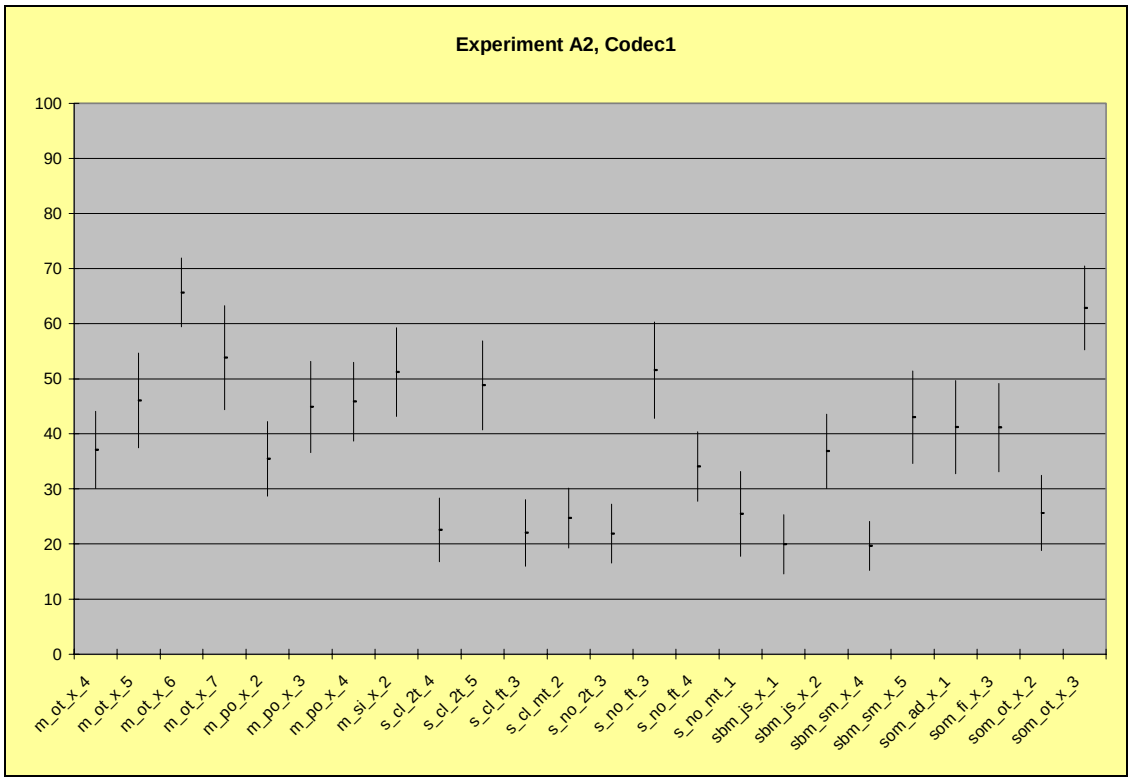
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

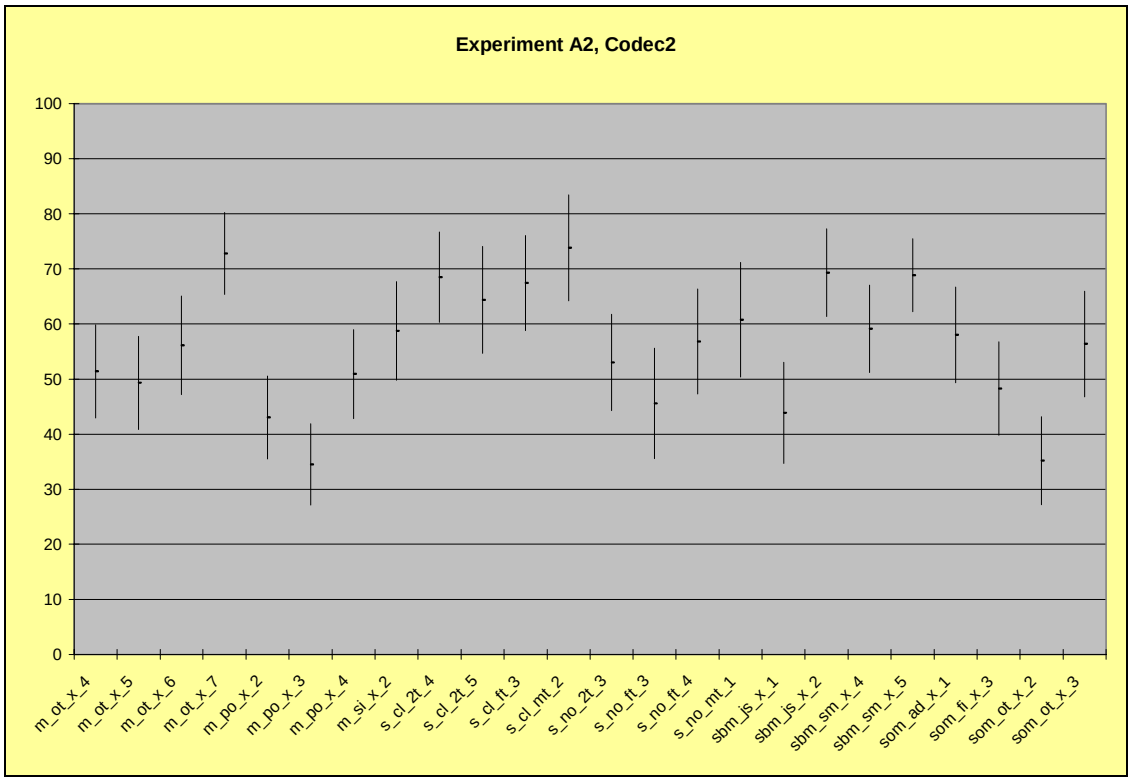


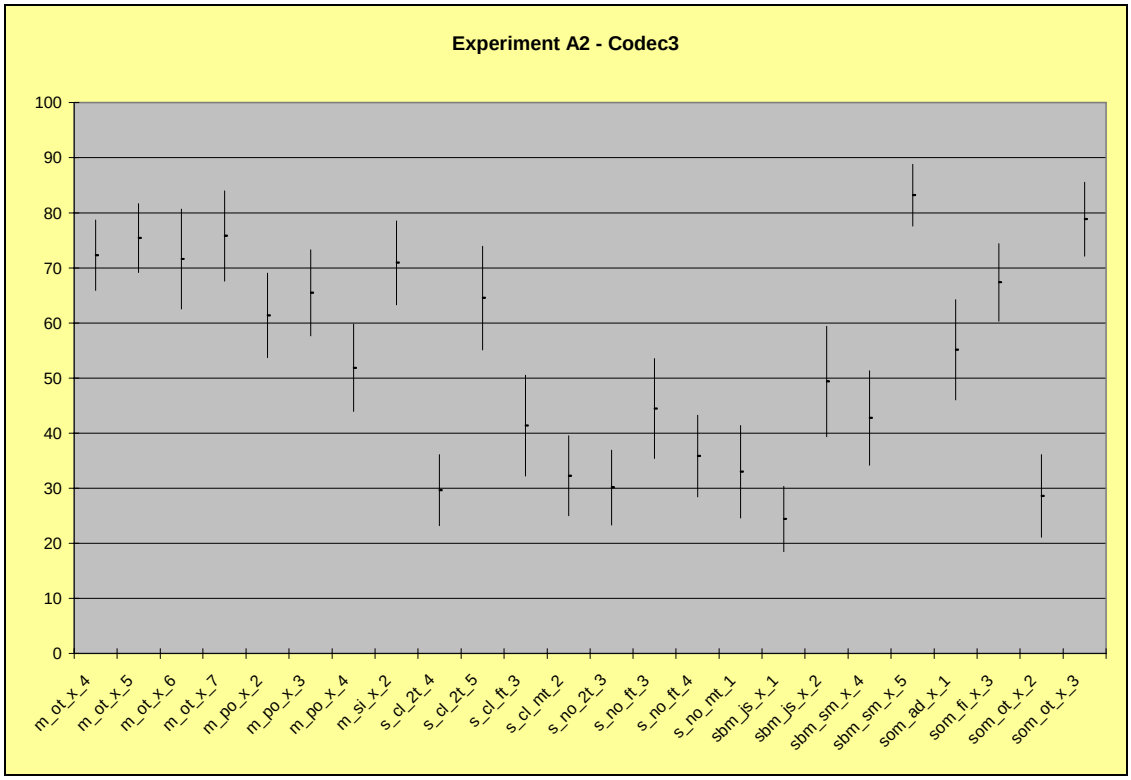
Codec1 did not perform better than AMR-WB. The other two candidate codecs out-perform both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
Average	37.5	55.6	53.3	20.9	48.2	100.0	31.2	60.6	62.3
Lower Bound	35.5	53.4	50.8	19.4	46.4	99.9	29.6	58.9	60.6
Upper Bound	39.5	57.8	55.7	22.4	50.1	100.0	32.8	62.3	64.0

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ot_x_4	44.1	30.1	37.1	59.9	42.9	51.4	78.7	65.9	72.3
m_ot_x_5	54.7	37.5	46.1	57.8	40.9	49.3	81.7	69.2	75.4
m_ot_x_6	71.9	59.4	65.7	65.1	47.2	56.1	80.7	62.6	71.6
m_ot_x_7	63.3	44.4	53.8	80.2	65.4	72.8	84.0	67.6	75.8
m_po_x_2	42.2	28.7	35.5	50.5	35.5	43.0	69.0	53.7	61.4
m_po_x_3	53.2	36.6	44.9	41.9	27.1	34.5	73.3	57.7	65.5
m_po_x_4	53.0	38.7	45.8	59.0	42.8	50.9	59.8	44.0	51.9
m_si_x_2	59.3	43.1	51.2	67.7	49.8	58.7	78.5	63.3	70.9
s_cl_2t_4	28.4	16.8	22.6	76.7	60.3	68.5	36.1	23.2	29.6
s_cl_2t_5	56.9	40.8	48.8	74.1	54.6	64.4	74.0	55.1	64.5
s_cl_ft_3	28.1	16.0	22.0	76.1	58.8	67.4	50.5	32.2	41.4
s_cl_mt_2	30.1	19.3	24.7	83.4	64.2	73.8	39.5	25.0	32.3
s_no_2t_3	27.2	16.6	21.9	61.7	44.3	53.0	36.9	23.3	30.1
s_no_ft_3	60.3	42.8	51.6	55.6	35.6	45.6	53.5	35.4	44.5
s_no_ft_4	40.4	27.8	34.1	66.4	47.3	56.8	43.3	28.4	35.9
s_no_mt_1	33.2	17.8	25.5	71.2	50.4	60.8	41.4	24.6	33.0
sbm_js_x_1	25.3	14.6	19.9	53.0	34.7	43.9	30.4	18.5	24.4
sbm_js_x_2	43.6	30.1	36.9	77.3	61.3	69.3	59.4	39.4	49.4
sbm_sm_x_4	24.1	15.2	19.7	67.1	51.2	59.1	51.3	34.2	42.8
sbm_sm_x_5	51.4	34.6	43.0	75.5	62.2	68.9	88.8	77.6	83.2
som_ad_x_1	49.7	32.7	41.2	66.7	49.3	58.0	64.2	46.0	55.1
som_fi_x_3	49.1	33.1	41.1	56.8	39.8	48.3	74.4	60.3	67.4
som_ot_x_2	32.5	18.8	25.6	43.1	27.2	35.2	36.1	21.1	28.6
som_ot_x_3	70.5	55.2	62.8	66.0	46.8	56.4	85.6	72.1	78.8

8.2.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	3800935	475117	2281.9	< 2.2e-16 ***
Sub	1	197314	197314	947.7	< 2.2e-16 ***
SigCat	3	1212	404	1.9	0.1207
Signal	19	35863	1888	9.1	< 2.2e-16 ***
Site	2	653224	326612	1568.6	< 2.2e-16 ***
Subject	56	541981	9678	46.5	< 2.2e-16 ***
Codec:Signal	24	295401	12308	59.1	< 2.2e-16 ***
Codec:Site	24	151884	6329	30.4	< 2.2e-16 ***
Residuals	8169	1700890	208		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level, except signal category (SigCat). This means that each of the aspects of the experimental design, except SigCat was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this

experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
mean	37.5	55.6	53.3	20.9	48.2	100.0	31.2	60.6	62.3
N	695	695	695	695	695	695	695	695	695
Lower Bound	36.4	54.6	52.2	19.8	47.1	98.9	30.1	59.5	61.2
Upper Bound	38.6	56.7	54.4	22.0	49.3	101.0	32.3	61.7	63.3

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	47.5	57.2
N	3231	3024

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	52.2	52.5	51.6	52.5
N	2124	2079	1044	1008

This variable is not statistically significant. The signal categories have means that do not differ statistically.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	47.1	31.2	29.5	42.3
	N	236	231	116	112
Codec2	mean	51.9	61.3	60.0	49.2
	N	236	231	116	112
Codec3	mean	68.0	38.8	49.1	57.1
	N	236	231	116	112
AAC	mean	27.6	15.1	19.1	21.7
	N	236	231	116	112
AMR-WB	mean	36.6	58.4	50.4	47.7
	N	236	231	116	112
hidref	mean	99.9	100.0	100.0	100.0
	N	236	231	116	112

lp3500_s12	mean	28.5	34.4	32.2	29.7
	N	236	231	116	112
lp7000_s12	mean	54.0	65.7	61.1	61.7
	N	236	231	116	112
lp7000_s6	mean	55.7	67.5	62.8	63.3
	N	236	231	116	112

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±1.9, while the width of the 95% confidence intervals for the som and sbm categories is ±2.6.

Signal main effect

	m_ot_x_4	m_ot_x_5	m_ot_x_6	m_ot_x_7	m_po_x_2	m_po_x_3
mean	52.8	54.4	54.7	56.8	48.0	51.6
N	270	270	234	270	270	270
	m_po_x_4	m_si_x_2	s_cl_2t_4	s_cl_2t_5	s_cl_ft_3	s_cl_mt_2
mean	49.5	50.0	52.2	54.2	55.0	51.1
N	270	270	270	252	270	243
	s_no_2t_3	s_no_ft_3	s_no_ft_4	s_no_mt_1	sbm_js_x_1	sbm_js_x_2
mean	51.9	49.0	51.7	52.1	50.9	50.6
N	270	252	252	270	270	261
	sbm_sm_x_4	sbm_sm_x_5	som_ad_x_1	som_fi_x_3	som_ot_x_2	som_ot_x_3
mean	52.1	55.3	49.9	54.1	51.2	53.4
N	270	243	243	270	261	234

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Ericsson	Nokia	NTT-AT	T-Sys
mean	63.9	56.0	48.0	40.5
N	1611	1584	1440	1620

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.2.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal

differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 9% larger.

8.2.5 Post-screening of data

Of the 720 sets of 9 judgments (one for each codec, reference codec, and anchor) in this experiment, 25 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 2%.

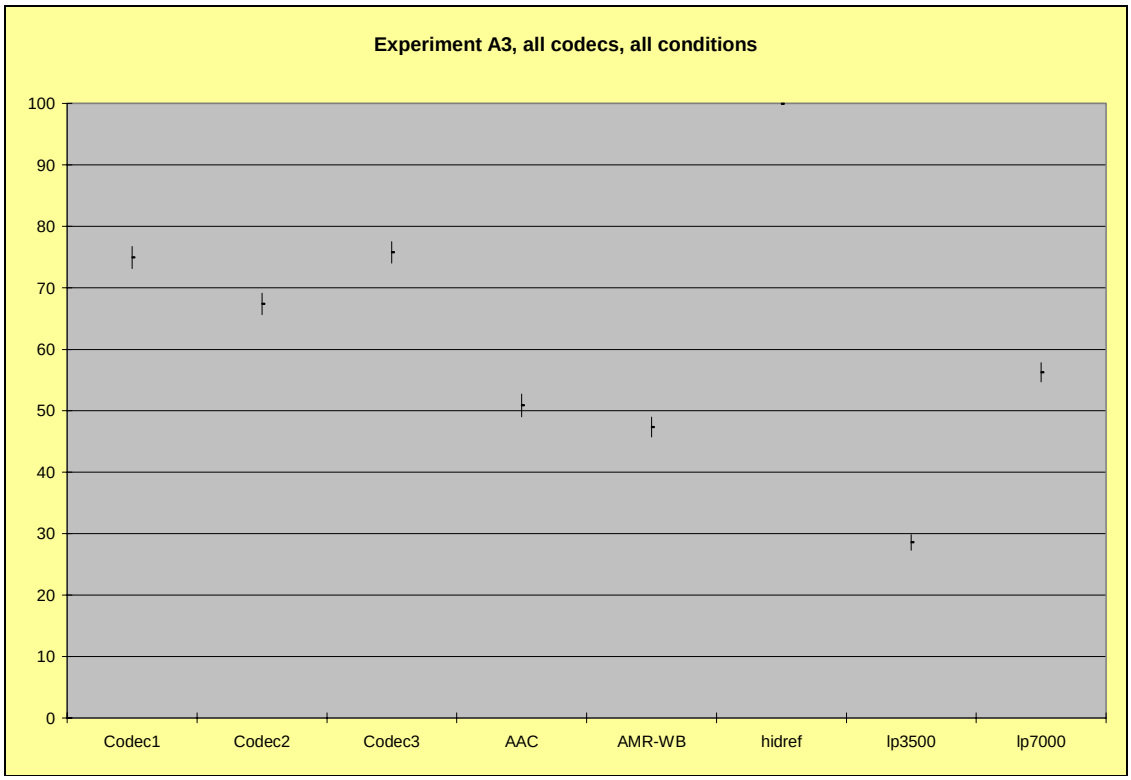
8.3 Test A3a and A3b

8.3.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	A3a and A3b	
Bit Rate	24 kbps	
Signal	Mono	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 23.85 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.3.2 Pivot Table Results

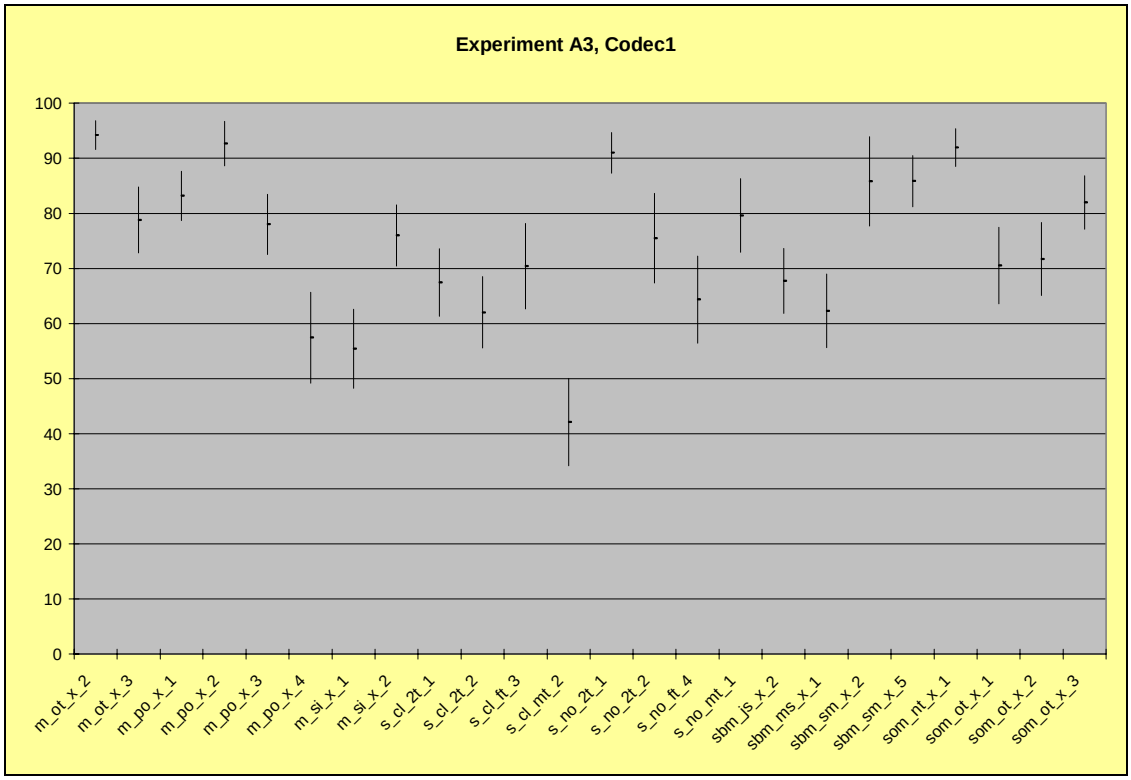
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

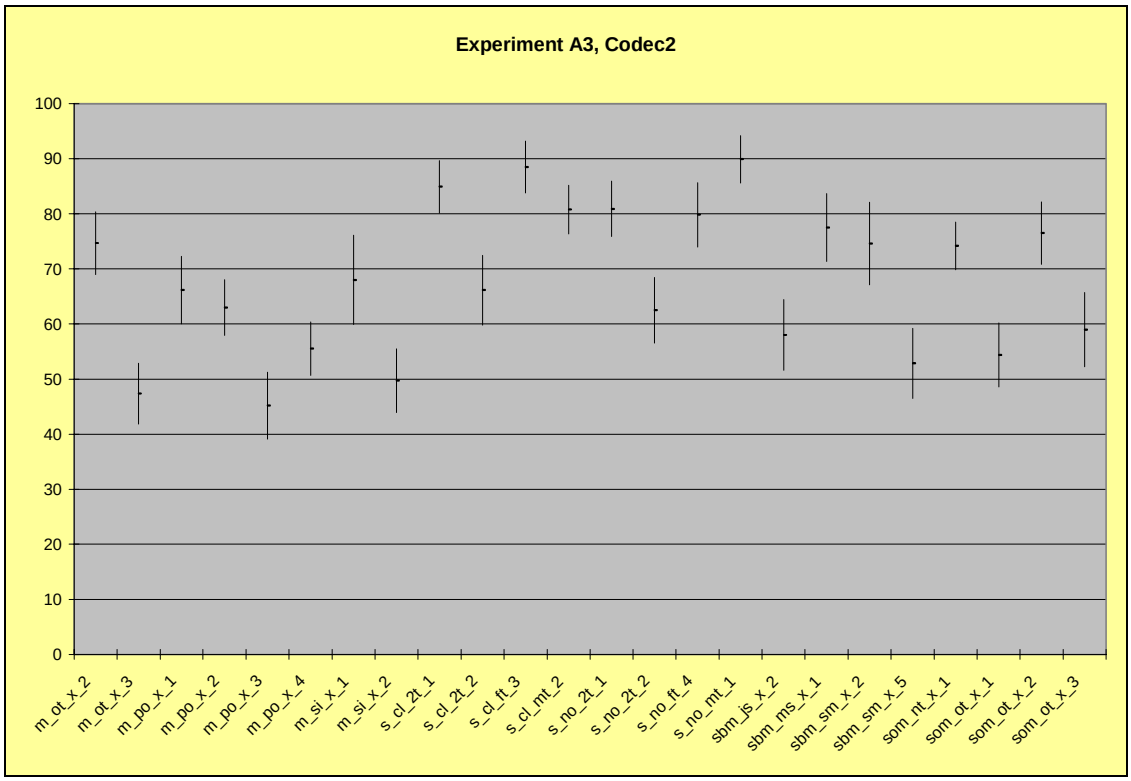


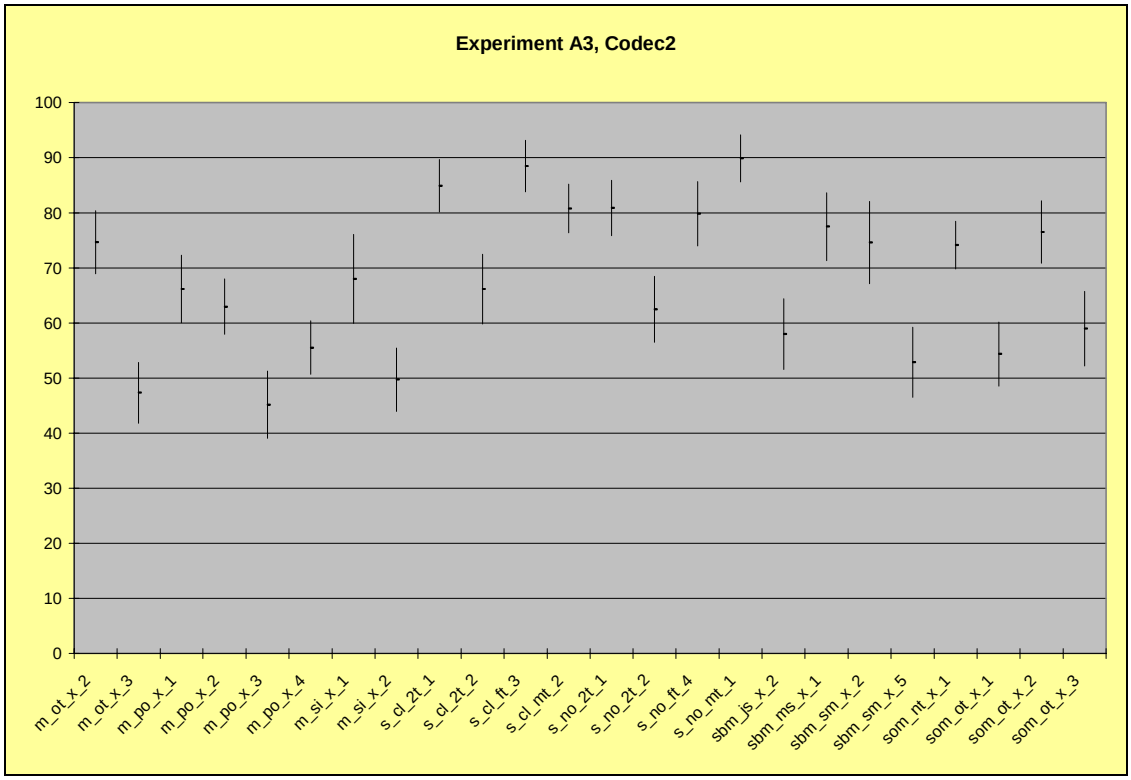
Each of the candidates codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
Average	74.9	67.4	75.8	50.9	47.4	99.9	28.6	56.2
Lower Bound	73.2	65.6	74.1	49.0	45.7	99.9	27.3	54.7
Upper Bound	76.7	69.1	77.5	52.7	49.0	100.0	29.9	57.8

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ot_x_2	96.8	91.6	94.2	80.4	68.9	74.7	94.6	87.1	90.9
m_ot_x_3	84.8	72.8	78.8	52.9	41.8	47.3	84.8	74.3	79.5
m_po_x_1	87.7	78.7	83.2	72.3	60.0	66.2	89.4	78.1	83.7
m_po_x_2	96.7	88.6	92.7	68.0	57.9	63.0	93.2	86.8	90.0
m_po_x_3	83.5	72.5	78.0	51.2	39.1	45.2	87.6	77.9	82.7
m_po_x_4	65.9	49.9	57.9	59.8	50.1	55.0	70.2	56.2	63.2
m_si_x_1	62.6	48.2	55.4	76.1	59.9	68.0	62.3	47.7	55.0
m_si_x_2	81.6	70.4	76.0	55.5	43.9	49.7	79.6	66.6	73.1
s_cl_2t_1	73.6	61.3	67.5	89.7	80.1	84.9	75.3	62.7	69.0
s_cl_2t_2	68.5	55.5	62.0	72.5	59.8	66.1	78.2	66.6	72.4
s_cl_ft_3	78.2	62.7	70.4	93.2	83.8	88.5	79.6	66.5	73.0
s_cl_mt_2	50.0	34.2	42.1	85.2	76.3	80.8	48.9	33.5	41.2
s_no_2t_1	94.7	87.3	91.0	85.9	75.9	80.9	94.8	87.8	91.3
s_no_2t_2	83.6	67.4	75.5	68.5	56.5	62.5	84.7	72.7	78.7
s_no_ft_4	72.2	56.5	64.3	85.7	74.0	79.8	73.4	58.3	65.9
s_no_mt_1	86.3	72.9	79.6	94.2	85.6	89.9	88.0	75.7	81.8
sbm_js_x_2	73.6	61.8	67.7	64.4	51.6	58.0	76.0	62.8	69.4
sbm_ms_x_1	69.0	55.6	62.3	83.7	71.3	77.5	71.9	57.3	64.6
sbm_sm_x_2	93.9	77.7	85.8	82.1	67.1	74.6	93.5	77.4	85.4
sbm_sm_x_5	90.5	81.2	85.9	59.2	46.5	52.9	88.9	80.0	84.4
som_nt_x_1	95.4	88.5	92.0	78.5	69.8	74.1	95.5	88.6	92.0
som_ot_x_1	77.5	63.6	70.5	60.2	48.6	54.4	77.3	61.2	69.3
som_ot_x_2	78.3	65.1	71.7	82.2	70.8	76.5	79.2	65.9	72.6
som_ot_x_3	86.9	77.1	82.0	65.7	52.2	59.0	86.3	77.7	82.0

8.3.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	7	3099551	442793	2411.5	< 2.2e-16 ***
Sub	1	243230	243230	1324.6	< 2.2e-16 ***
SigCat	3	40927	13642	74.3	< 2.2e-16 ***
Signal	19	87161	4587	25.0	< 2.2e-16 ***
Site	2	194847	97423	530.6	< 2.2e-16 ***
Subject	56	312996	5589	30.4	< 2.2e-16 ***
Codec:Signal	21	106306	5062	27.6	< 2.2e-16 ***
Codec:Site	21	145639	6935	37.8	< 2.2e-16 ***
Residuals	7357	1350893	184		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
mean	75.0	67.4	75.8	50.9	47.4	99.9	28.6	56.2
N	703	703	703	703	703	703	703	703
Lower Bound	73.9	66.4	74.8	49.9	46.4	98.9	27.6	55.2
Upper Bound	76.0	68.4	76.8	51.9	48.4	100.9	29.6	57.2

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	68.4	57.0
N	2816	2801

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	58.8	65.0	62.9	63.9
N	1873	1880	936	928

This variable is highly statistically significant. Further, the signal categories do have means that do differ somewhat and so there may be some practical difference between the signal categories in this experiment.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec		SigCat			
		m	s	sbm	som
Codec1	mean	76.9	68.9	75.3	78.8
	N	235	235	117	116
Codec2	mean	58.7	79.2	65.6	65.9
	N	235	235	117	116
Codec3	mean	77.2	71.5	75.9	78.7
	N	235	235	117	116
AAC	mean	47.6	51.6	52.3	51.9
	N	235	235	117	116
AMR-WB	mean	37.0	57.0	46.8	48.6
	N	235	235	117	116
hidref	mean	99.8	99.9	100.1	100.0
	N	235	235	117	116
lp3500	mean	23.7	29.9	30.1	30.7
	N	235	235	117	116

lp7000	mean	49.6	61.7	57.0	56.7
	N	235	235	117	116

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±1.8, while the width of the 95% confidence intervals for the som and sbm categories is ±2.5.

Signal main effect

	m_ot_x_2	m_ot_x_3	m_po_x_1	m_po_x_2	m_po_x_3	m_po_x_4
mean	69.4	64.7	64.1	62.5	65.5	61.6
N	240	232	240	240	224	240
	m_si_x_1	m_si_x_2	s_cl_2t_1	s_cl_2t_2	s_cl_ft_3	s_cl_mt_2
mean	51.5	62.0	58.7	61.9	61.7	58.7
N	240	224	240	232	232	240
	s_no_2t_1	s_no_2t_2	s_no_ft_4	s_no_mt_1	sbm_js_x_2	sbm_ms_x_1
mean	66.2	62.9	65.0	66.2	61.6	58.1
N	232	232	232	240	240	240
	sbm_sm_x_2	sbm_sm_x_5	som_nt_x_1	som_ot_x_1	som_ot_x_2	som_ot_x_3
mean	66.7	64.5	65.8	60.1	61.2	63.8
N	216	240	216	240	240	232

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	CT	DY	FhG	FT
mean	64.4	69.7	55.7	60.8
N	1440	1392	1424	1368

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.3.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 10% larger.

8.3.5 Post-screening of data

Of the 720 sets of 8 judgments (one for each codec, reference codec, and anchor) in this experiment, 17 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by less than 1%.

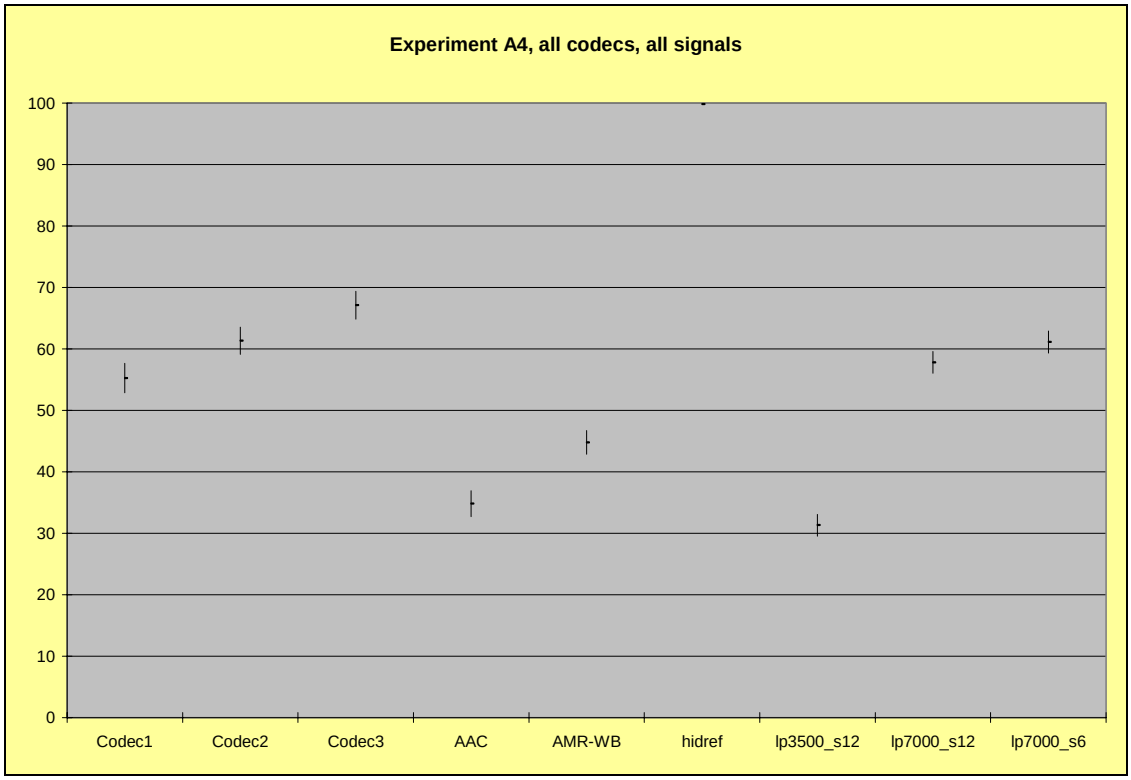
8.4 Test A4a and A4b

8.4.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	A4a and A4b	
Bit Rate	24 kbps	
Signal	Stereo	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 18.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass, 6 dB attenuated side channel	LP7.0-S6
	7.0 kHz Lowpass,12 dB attenuated side channel	LP7.0-S12
	3.5 kHz Lowpass, 12 dB attenuated side channel	LP3.5-S12

8.4.2 Pivot Table Results

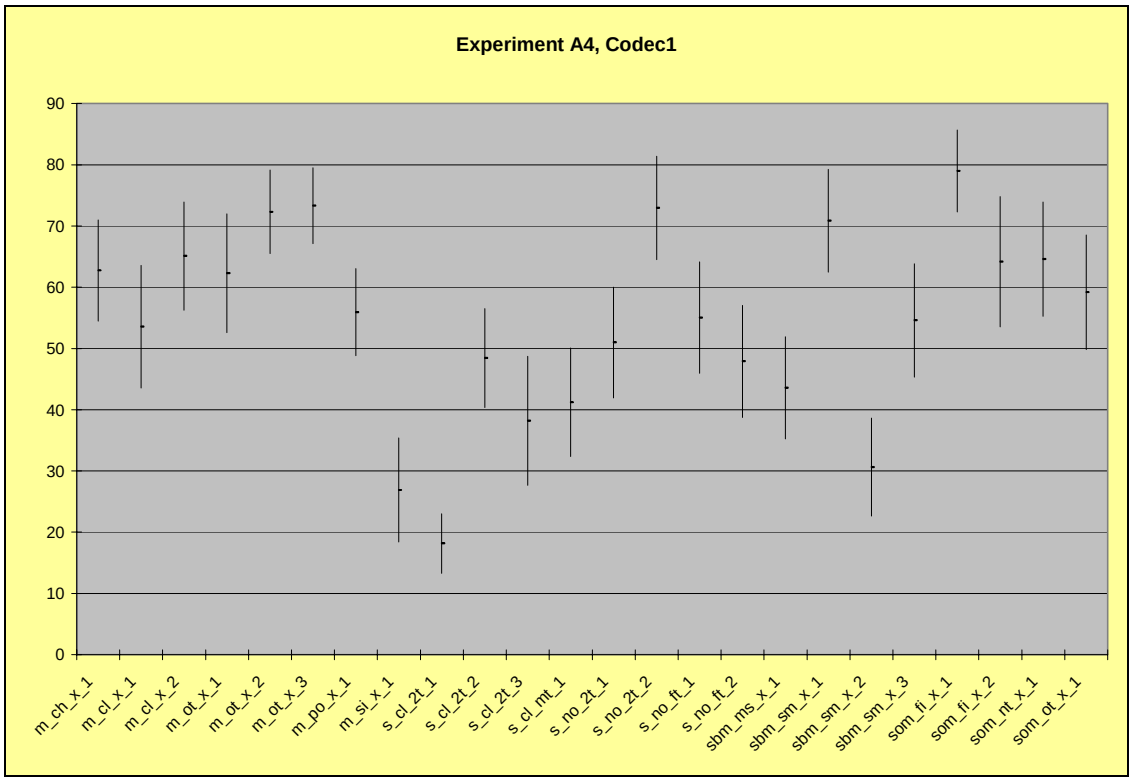
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

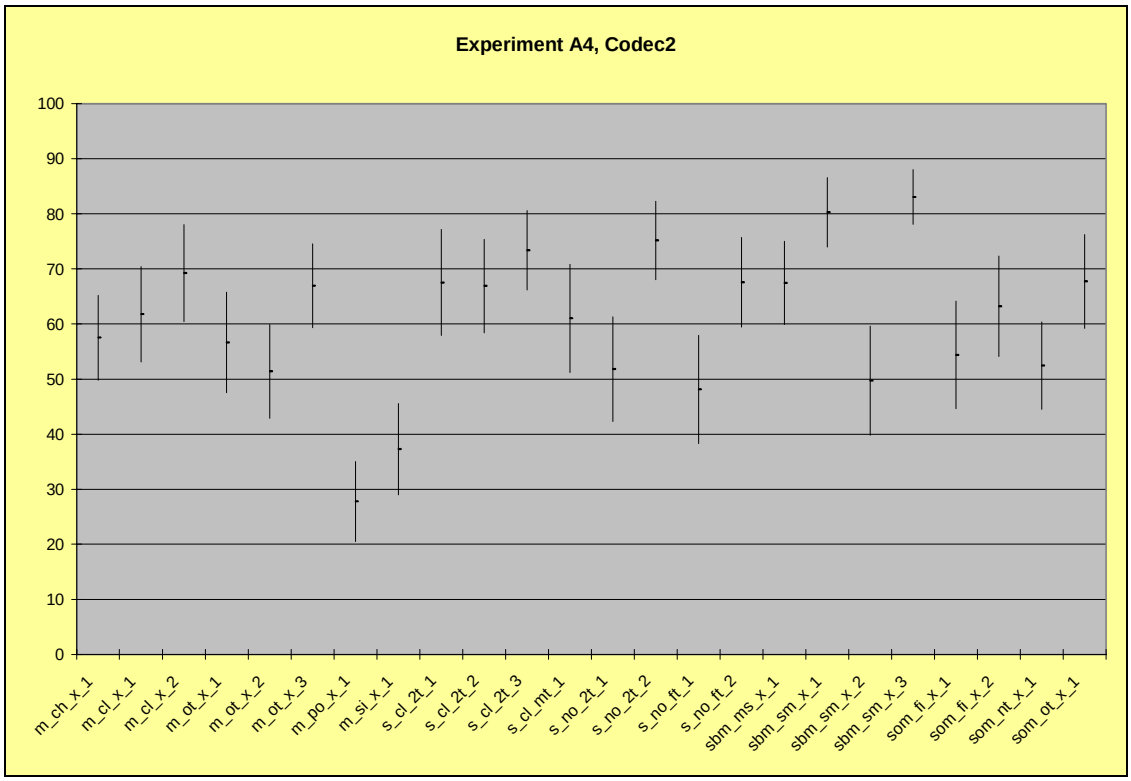


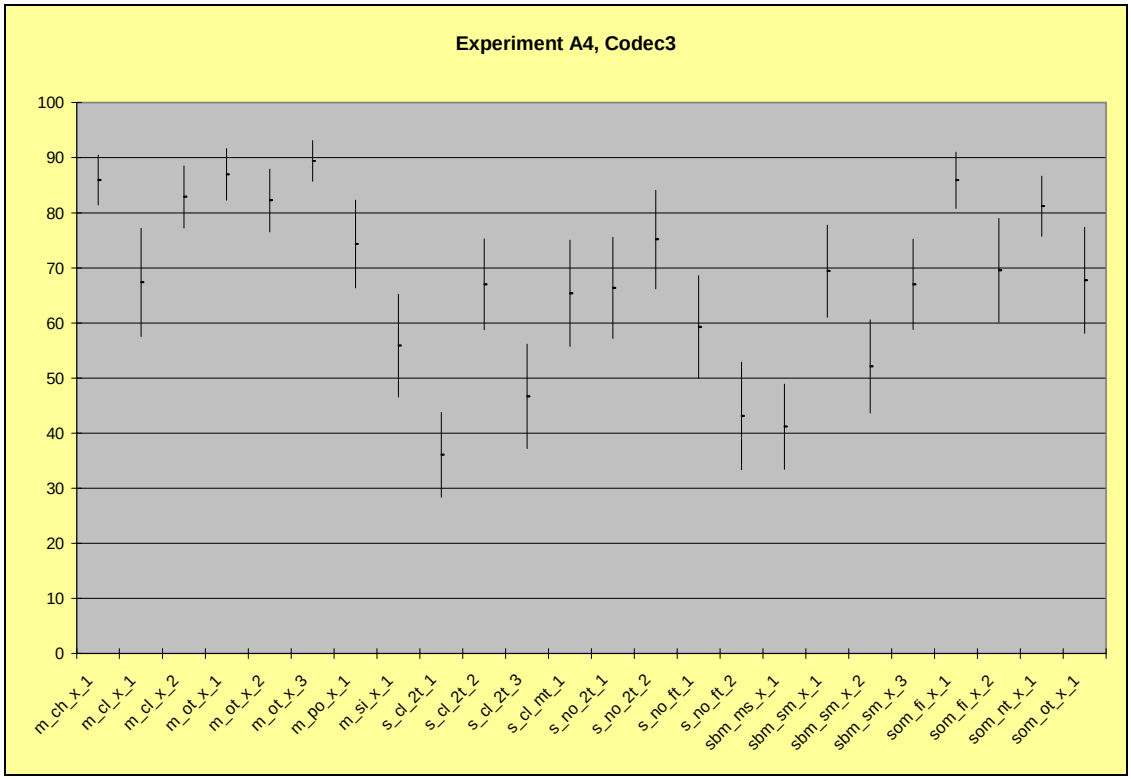
Each of the candidates codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
Average	55.3	61.3	67.1	34.8	44.8	99.8	31.3	57.8	61.1
Lower Bound	52.9	59.1	64.9	32.7	42.9	99.8	29.6	56.0	59.3
Upper Bound	57.7	63.6	69.4	36.9	46.7	99.9	33.0	59.6	62.9

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ch_x_1	71.0	54.5	62.8	65.2	49.8	57.5	90.5	81.4	86.0
m_cl_x_1	63.6	43.5	53.6	70.4	53.1	61.8	77.2	57.6	67.4
m_cl_x_2	73.9	56.3	65.1	78.0	60.5	69.2	88.5	77.3	82.9
m_ot_x_1	72.0	52.6	62.3	65.8	47.5	56.6	91.7	82.3	87.0
m_ot_x_2	79.1	65.5	72.3	59.9	42.9	51.4	88.0	76.6	82.3
m_ot_x_3	79.5	67.1	73.3	74.5	59.3	66.9	93.1	85.7	89.4
m_po_x_1	63.0	48.8	55.9	35.0	20.5	27.8	82.3	66.4	74.3
m_si_x_1	35.4	18.4	26.9	45.5	29.0	37.3	65.2	46.6	55.9
s_cl_2t_1	23.0	13.3	18.2	77.1	57.9	67.5	43.8	28.4	36.1
s_cl_2t_2	56.5	40.4	48.5	75.4	58.4	66.9	75.3	58.7	67.0
s_cl_2t_3	48.7	27.7	38.2	80.6	66.2	73.4	56.1	37.2	46.7
s_cl_mt_1	50.1	32.4	41.2	70.8	51.2	61.0	75.0	55.7	65.4
s_no_2t_1	60.0	42.0	51.0	61.3	42.3	51.8	75.5	57.2	66.4
s_no_2t_2	81.4	64.5	73.0	82.3	68.0	75.2	84.1	66.2	75.2
s_no_ft_1	64.1	45.9	55.0	57.9	38.3	48.1	68.6	49.9	59.3
s_no_ft_2	57.1	38.7	47.9	75.7	59.4	67.6	52.9	33.4	43.1
sbm_ms_x_1	51.9	35.3	43.6	75.0	59.9	67.4	48.9	33.5	41.2
sbm_sm_x_1	79.3	62.5	70.9	86.5	74.0	80.3	77.8	61.1	69.4
sbm_sm_x_2	38.6	22.6	30.6	59.6	39.8	49.7	60.6	43.6	52.1
sbm_sm_x_3	63.8	45.3	54.6	88.0	78.1	83.0	75.2	58.8	67.0
som_fi_x_1	85.7	72.3	79.0	64.1	44.6	54.4	91.0	80.8	85.9
som_fi_x_2	74.8	53.6	64.2	72.3	54.1	63.2	79.0	60.2	69.6
som_nt_x_1	73.9	55.3	64.6	60.4	44.5	52.4	86.7	75.7	81.2
som_ot_x_1	68.5	49.9	59.2	76.2	59.2	67.7	77.4	58.1	67.7

8.4.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	2993494	374187	1493.3	< 2.2e-16 ***
Sub	1	185315	185315	739.6	< 2.2e-16 ***
SigCat	3	17435	5812	23.2	6.07e-15 ***
Signal	19	80881	4257	17.0	< 2.2e-16 ***
Site	2	601061	300531	1199.4	< 2.2e-16 ***
Subject	56	697285	12452	49.7	< 2.2e-16 ***
Codec:Signal	24	277209	11550	46.1	< 2.2e-16 ***
Codec:Site	24	181124	7547	30.1	< 2.2e-16 ***
Residuals	8079	2024414	251		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
mean	55.3	61.3	67.1	34.8	44.8	99.8	31.3	57.8	61.1
N	686	686	686	686	686	686	686	686	686
Lower Bound	54.1	60.2	65.9	33.6	43.6	98.7	30.1	56.6	59.9
Upper Bound	56.4	62.5	68.3	36.0	46.0	101.0	32.5	59.0	62.3

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	52.5	62.0
N	3213	2961

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	56.1	55.2	58.2	58.7
N	2079	2052	1026	1017

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	58.7	46.2	49.3	67.0
	N	231	228	114	113
Codec2	mean	53.1	63.7	69.6	59.1
	N	231	228	114	113
Codec3	mean	77.8	57.3	56.9	76.4
	N	231	228	114	113
AAC	mean	38.6	22.3	43.4	34.9
	N	231	228	114	113
AMR-WB	mean	34.2	51.1	46.5	47.6
	N	231	228	114	113
hidref	mean	99.8	99.9	99.9	99.8

	N	231	228	114	113
lp3500_s12		29.7	32.7	33.7	29.1
		231	228	114	113
lp7000_s12	mean	55.4	59.7	59.8	56.4
	N	231	228	114	113
lp7000_s6	mean	57.8	63.7	64.8	58.3
	N	231	228	114	113

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±2.1, while the width of the 95% confidence intervals for the som and sbm categories is ±2.9.

Signal main effect

	m_ch_x_1	m_cl_x_1	m_cl_x_2	m_ot_x_1	m_ot_x_2	m_ot_x_3
mean	61.4	56.2	59.0	57.2	61.5	58.7
N	261	270	234	252	261	261
	m_po_x_1	m_si_x_1	s_cl_2t_1	s_cl_2t_2	s_cl_2t_3	s_cl_mt_1
mean	53.2	49.9	53.8	58.1	54.6	57.6
N	270	270	270	270	225	270
	s_no_2t_1	s_no_2t_2	s_no_ft_1	s_no_ft_2	sbm_ms_x_1	sbm_sm_x_1
mean	58.7	60.0	53.1	60.3	55.2	60.6
N	270	225	252	270	270	243
	sbm_sm_x_2	sbm_sm_x_3	som_fi_x_1	som_fi_x_2	som_nt_x_1	som_ot_x_1
mean	53.6	59.4	60.8	55.4	58.8	52.5
N	270	243	261	252	270	234

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Ericsson	Nokia	NTT-AT	T-Sys
mean	68.5	60.4	53.5	45.7
N	1602	1503	1458	1611

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.4.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However,

the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 9% larger.

8.4.5 Post-screening of data

Of the 720 sets of 9 judgments (one for each codec, reference codec, and anchor) in this experiment, 34 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 1%.

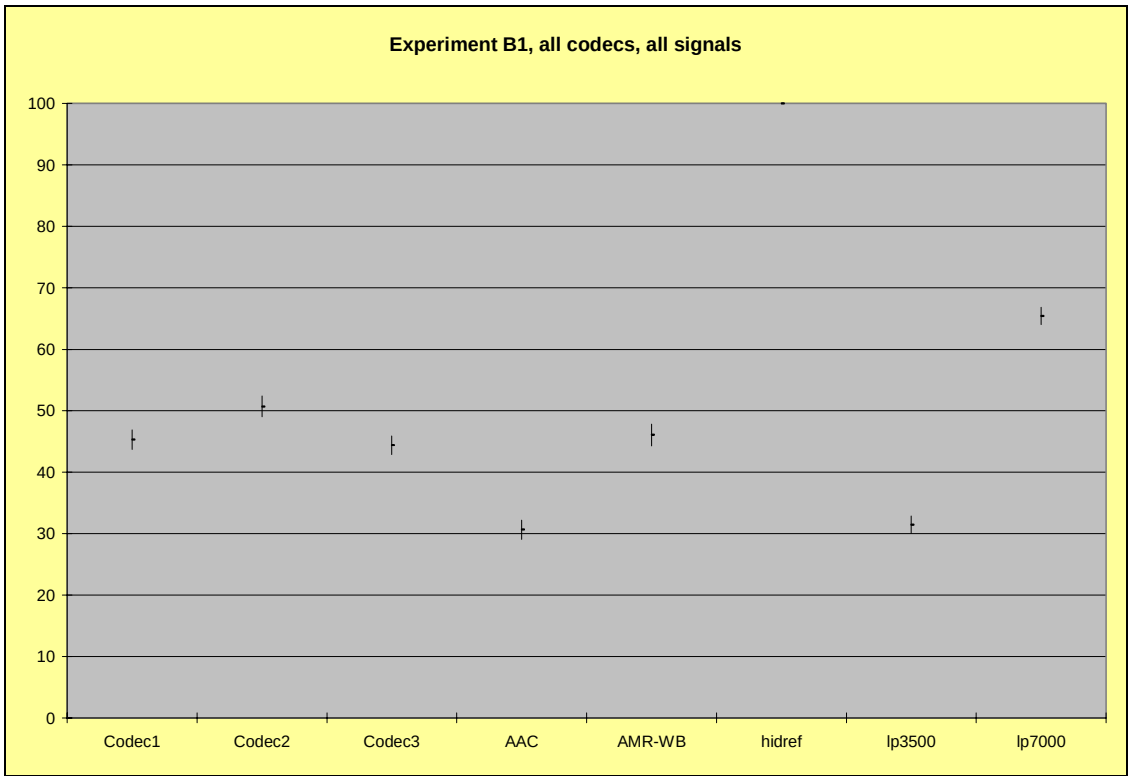
8.5 Test B1a and B1b

8.5.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	B1a and B1b	
Bit Rate	14 kbps	
Signal	Mono, 16 kHz input and output sampling rate	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 14.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.5.2 Pivot Table Results

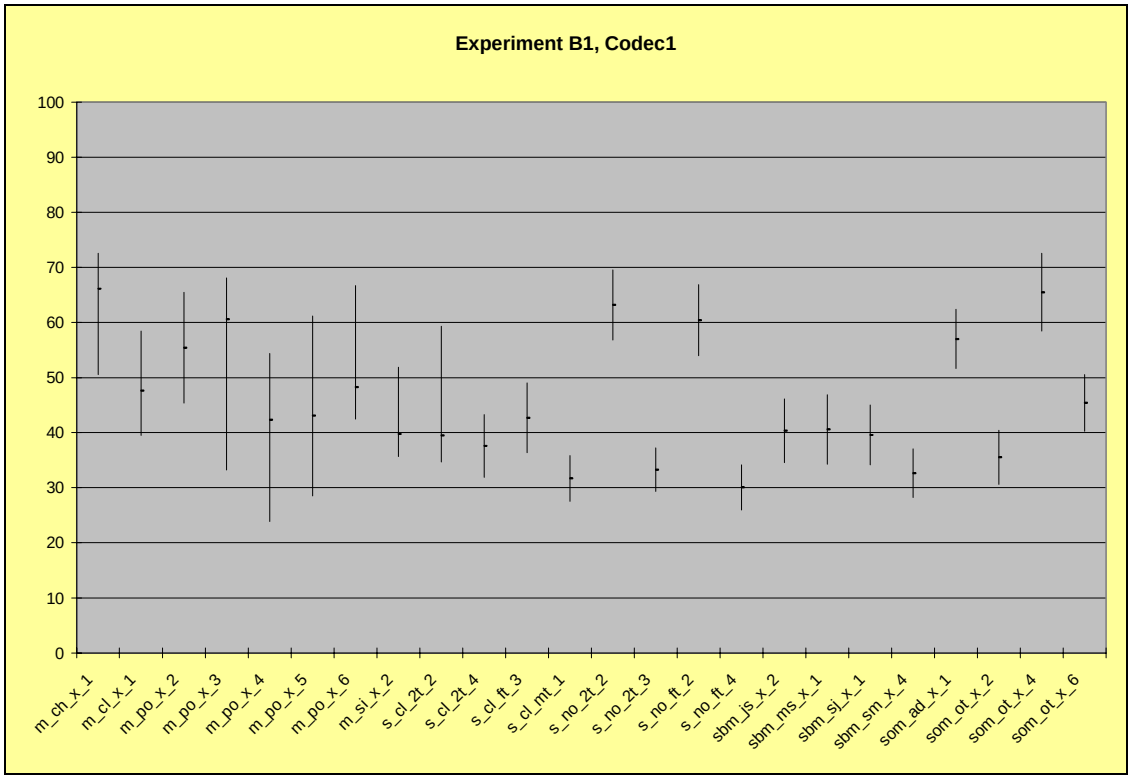
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

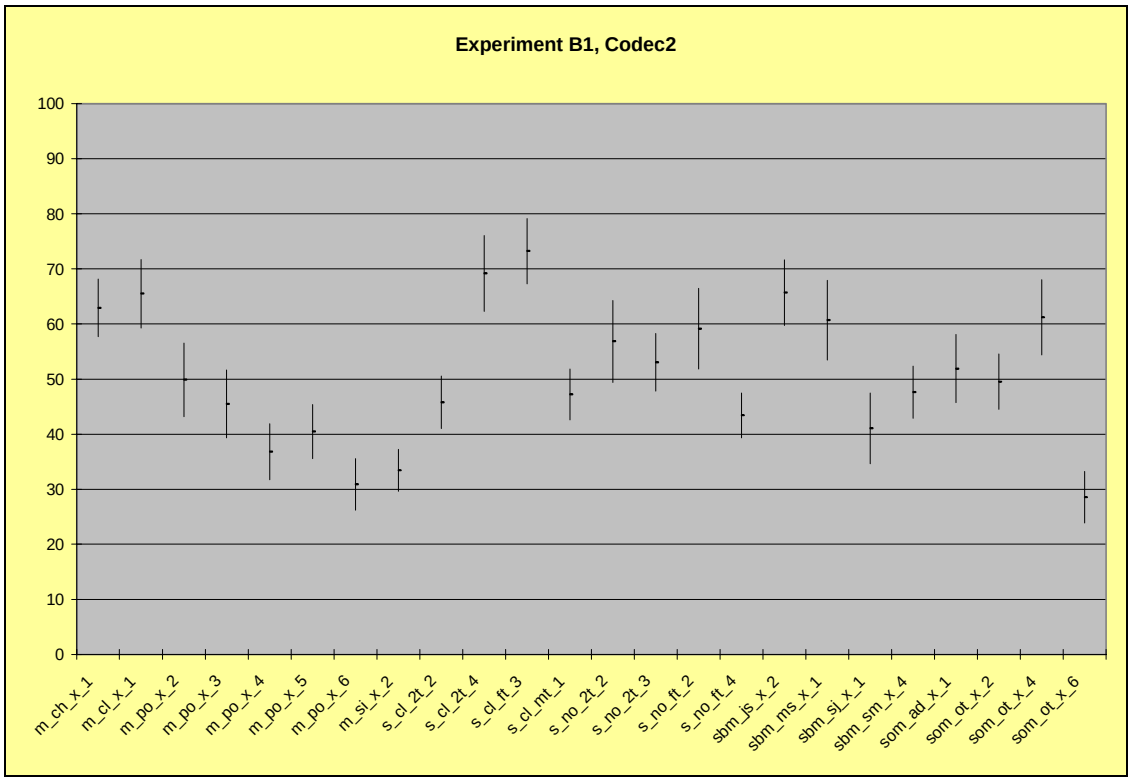


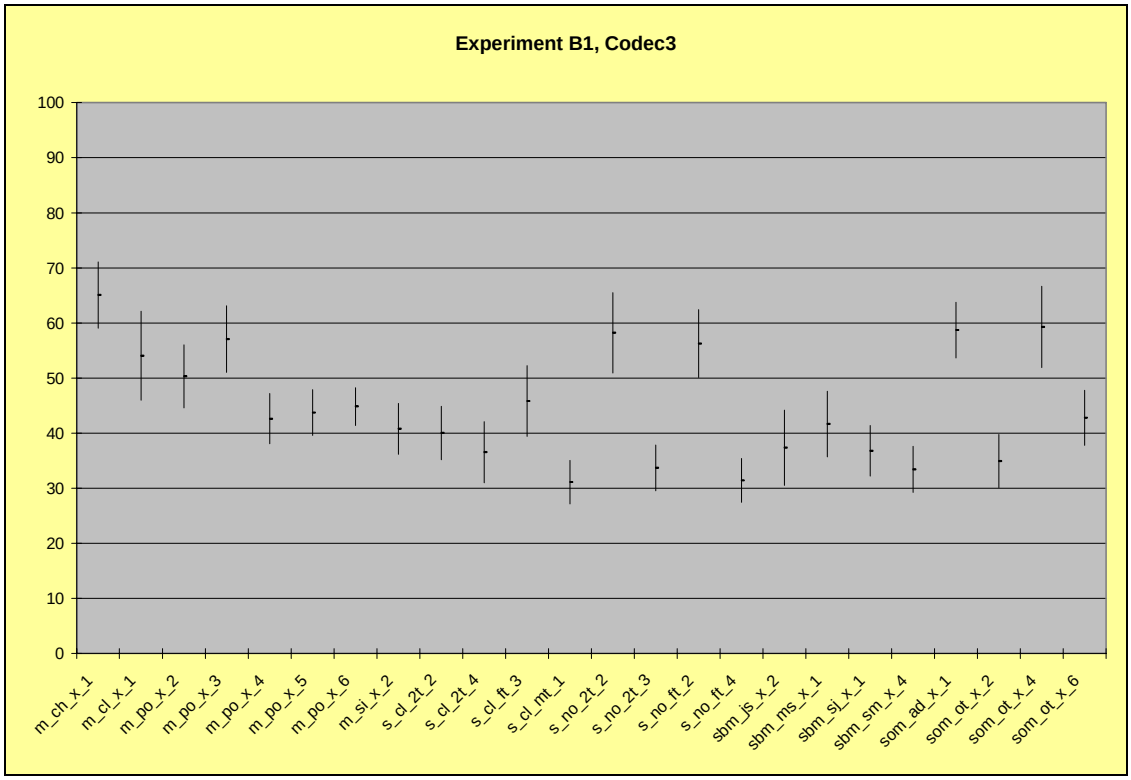
Only Codec2 out-performs both reference codecs in this experiment. Although Codec1 and Codec3 both out-perform AAC, they perform not statistically different from AMR-WB. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
Average	45.4	50.7	44.4	30.7	46.2	100.0	31.7	65.3
Lower Bound	43.9	49.0	42.9	29.2	44.4	100.0	30.3	63.9
Upper Bound	47.0	52.4	46.0	32.3	47.9	100.0	33.1	66.7

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ch_x_1	71.5	60.8	66.1	68.2	57.7	62.9	71.1	59.1	65.1
m_cl_x_1	55.7	39.5	47.6	71.7	59.3	65.5	62.1	46.0	54.0
m_po_x_2	61.8	49.0	55.4	56.5	43.2	49.9	56.1	44.6	50.3
m_po_x_3	66.7	54.3	60.5	51.6	39.4	45.5	63.1	51.0	57.1
m_po_x_4	46.9	37.8	42.3	41.9	31.7	36.8	47.2	38.1	42.6
m_po_x_5	47.4	38.8	43.1	45.4	35.6	40.5	47.9	39.6	43.7
m_po_x_6	54.1	42.5	48.3	35.5	26.2	30.9	48.3	41.4	44.8
m_si_x_2	43.8	35.7	39.7	37.3	29.6	33.4	45.4	36.2	40.8
s_cl_2t_2	44.3	34.7	39.5	50.6	41.0	45.8	44.9	35.2	40.0
s_cl_2t_4	43.3	31.9	37.6	76.1	62.3	69.2	42.1	31.0	36.6
s_cl_ft_3	49.0	36.4	42.7	79.2	67.3	73.2	52.2	39.4	45.8
s_cl_mt_1	35.9	27.5	31.7	51.8	42.6	47.2	35.1	27.1	31.1
s_no_2t_2	69.5	56.8	63.2	64.3	49.4	56.8	65.5	50.9	58.2
s_no_2t_3	37.2	29.3	33.3	58.3	47.8	53.0	37.9	29.5	33.7
s_no_ft_2	66.8	54.0	60.4	66.5	51.8	59.1	62.5	50.1	56.3
s_no_ft_4	34.2	26.0	30.1	47.5	39.3	43.4	35.4	27.4	31.4
sbm_js_x_2	46.1	34.6	40.3	71.6	59.8	65.7	44.2	30.6	37.4
sbm_ms_x_1	46.8	34.3	40.6	67.9	53.5	60.7	47.6	35.7	41.7
sbm_sj_x_1	45.0	34.1	39.6	47.5	34.6	41.0	41.4	32.2	36.8
sbm_sm_x_4	37.0	28.2	32.6	52.4	42.9	47.6	37.6	29.3	33.4
som_ad_x_1	62.4	51.6	57.0	58.1	45.7	51.9	63.7	53.7	58.7
som_ot_x_2	40.4	30.6	35.5	54.5	44.5	49.5	39.8	30.1	34.9
som_ot_x_4	72.5	58.4	65.5	68.1	54.4	61.2	66.7	51.9	59.3
som_ot_x_6	50.5	40.3	45.4	33.2	23.9	28.5	47.8	37.8	42.8

8.5.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	7	3303832	471976	3463.3	< 2.2e-16 ***
Sub	1	282871	282871	2075.7	< 2.2e-16 ***
SigCat	3	13911	4637	34.0	< 2.2e-16 ***
Signal	19	32501	1711	12.6	< 2.2e-16 ***
Site	2	233235	116617	855.7	< 2.2e-16 ***
Subject	56	404146	7217	53.0	< 2.2e-16 ***
Codec:Signal	21	181389	8638	63.4	< 2.2e-16 ***
Codec:Site	21	96737	4607	33.8	< 2.2e-16 ***
Residuals	7461	1016783	136		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
mean	45.5	50.7	44.4	30.7	46.2	100.0	31.7	65.3
N	713	713	713	713	713	713	713	713
Lower Bound	44.6	49.9	43.6	29.9	45.2	99.1	30.8	64.6
Upper Bound	46.3	51.6	45.3	31.6	47.0	100.9	32.5	66.2

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	57.8	45.8
N	2824	2880

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	50.5	53.3	50.5	53.1
N	1920	1896	944	944

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec		SigCat			
		m	s	sbm	som
Codec1	mean	50.4	42.3	38.2	50.8
	N	240	237	118	118
Codec2	mean	45.7	55.9	53.8	47.6
	N	240	237	118	118
Codec3	mean	49.8	41.6	37.3	48.9
	N	240	237	118	118
AAC	mean	38.0	28.6	26.5	29.7
	N	240	237	118	118
AMR-WB	mean	29.7	57.5	48.5	49.3
	N	240	237	118	118
hidref	mean	99.9	100.0	100.0	100.0
	N	240	237	118	118

lp3500	mean	28.2	33.1	33.5	32.0
	N	240	237	118	118
lp7000	mean	62.0	67.0	66.1	66.2
	N	240	237	118	118

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±1.5, while the width of the 95% confidence intervals for the som and sbm categories is ±2.1.

Signal main effect

	m_ch_x_1	m_cl_x_1	m_po_x_2	m_po_x_3	m_po_x_4	m_po_x_5
mean	55.9	53.9	46.3	50.8	52.4	53.0
N	240	240	240	240	240	240
	m_po_x_6	m_si_x_2	s_cl_2t_2	s_cl_2t_4	s_cl_ft_3	s_cl_mt_1
mean	52.6	49.5	52.3	50.4	52.2	49.1
N	240	240	240	232	232	240
	s_no_2t_2	s_no_2t_3	s_no_ft_2	s_no_ft_4	sbm_js_x_2	sbm_ms_x_1
mean	52.8	53.4	53.7	50.7	51.1	50.3
N	232	240	240	240	232	240
	sbm_sj_x_1	sbm_sm_x_4	som_ad_x_1	som_ot_x_2	som_ot_x_4	som_ot_x_6
mean	53.3	52.6	49.8	52.7	55.5	49.5
N	232	240	240	232	232	240

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	CT	DY	FhG	FT
mean	52.2	59.8	44.1	51.4
N	1440	1416	1440	1424

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect
The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets.

8.5.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not

been included in the statistical model, the residual standard error would have been about 10% larger.

8.5.5 Post-screening of data

Of the 720 sets of 8 judgments (one for each codec, reference codec, and anchor) in this experiment, 7 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by less than 1%.

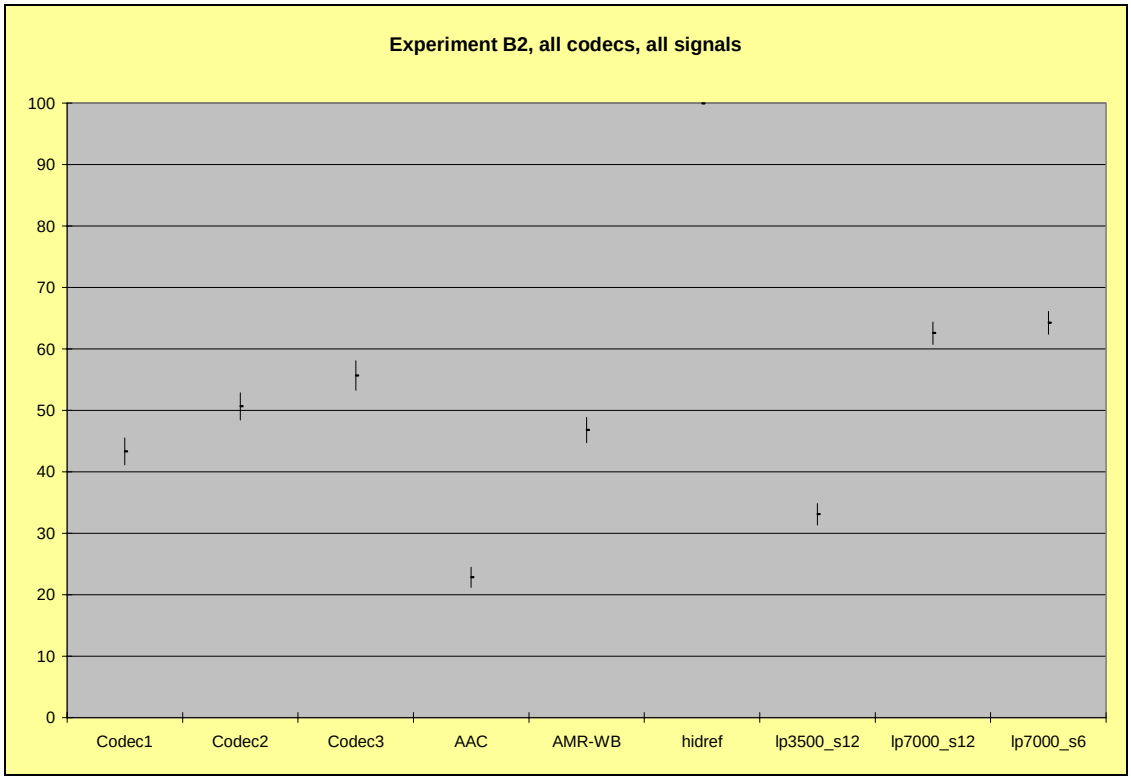
8.6 Test B2a and B2b

8.6.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	B2a and B2b	
Bit Rate	18 kbps	
Signal	Stereo	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 18.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass, 6 dB attenuated side channel	LP7.0-S6
	7.0 kHz Lowpass,12 dB attenuated side channel	LP7.0-S12
	3.5 kHz Lowpass, 12 dB attenuated side channel	LP3.5-S12

8.6.2 Pivot Table Results

The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

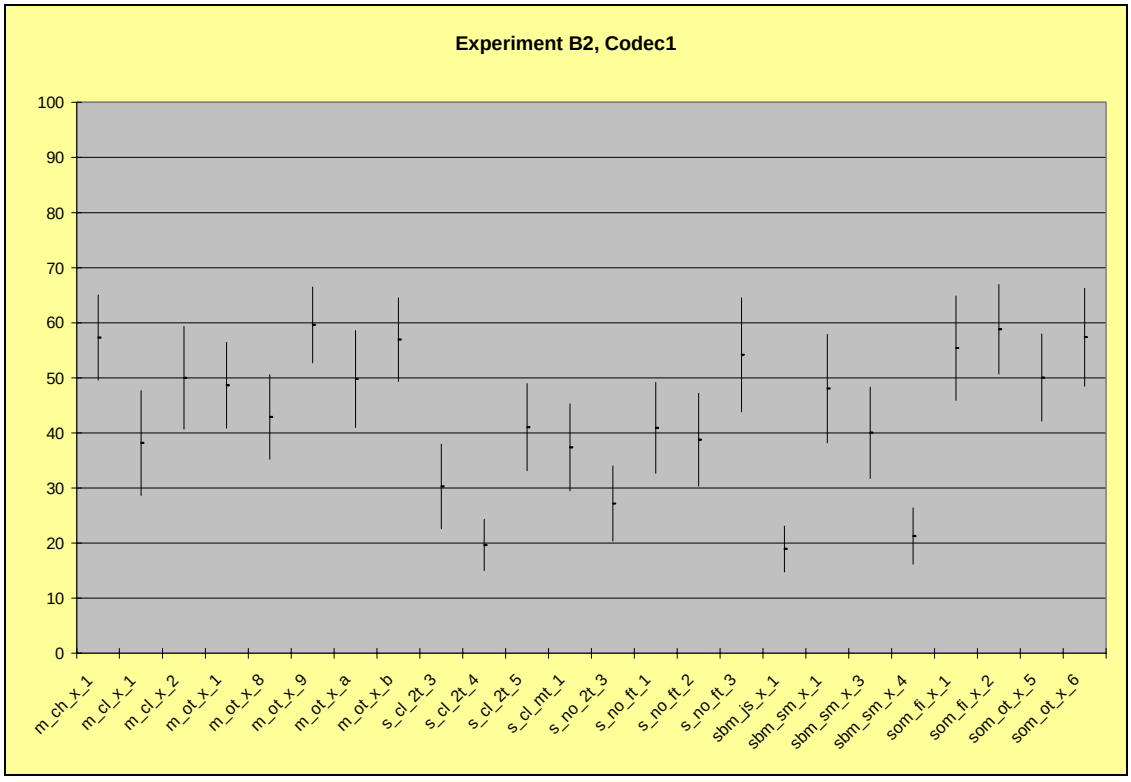


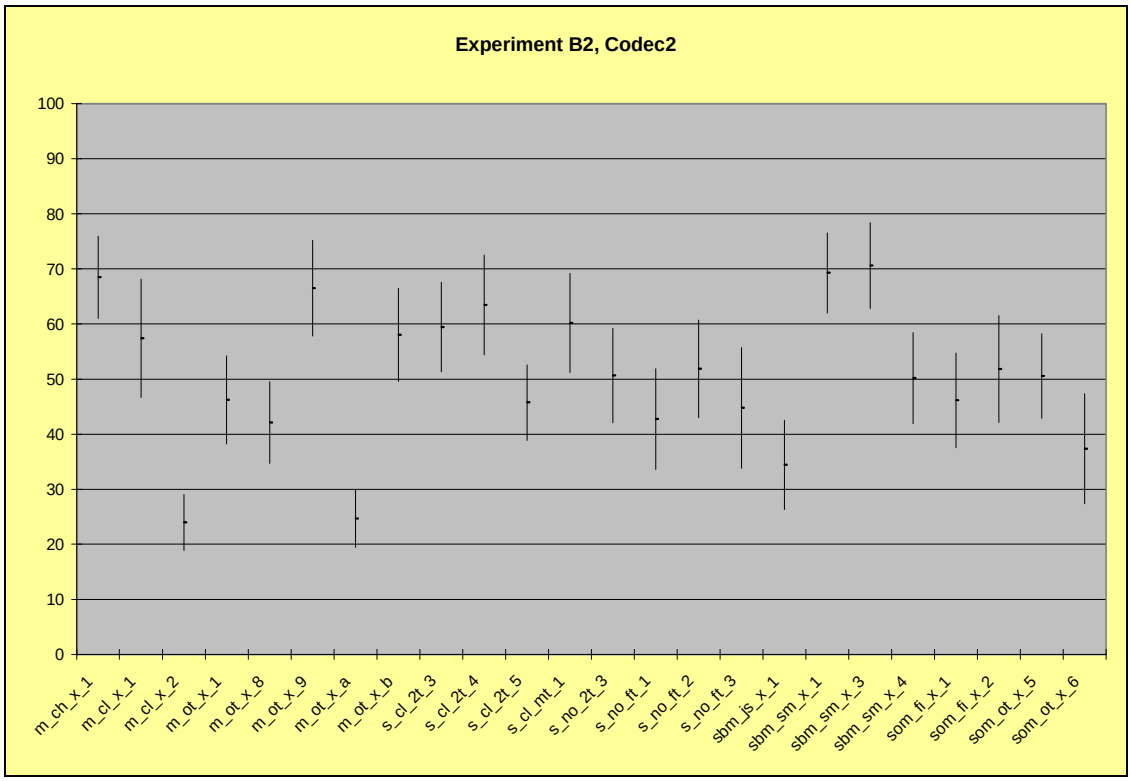
While all of the candidates codecs out-perform the AAC reference codec, Codec1 fails to outperform AMR-WB, and a more sensitive analysis (section 8.6.3) is needed to

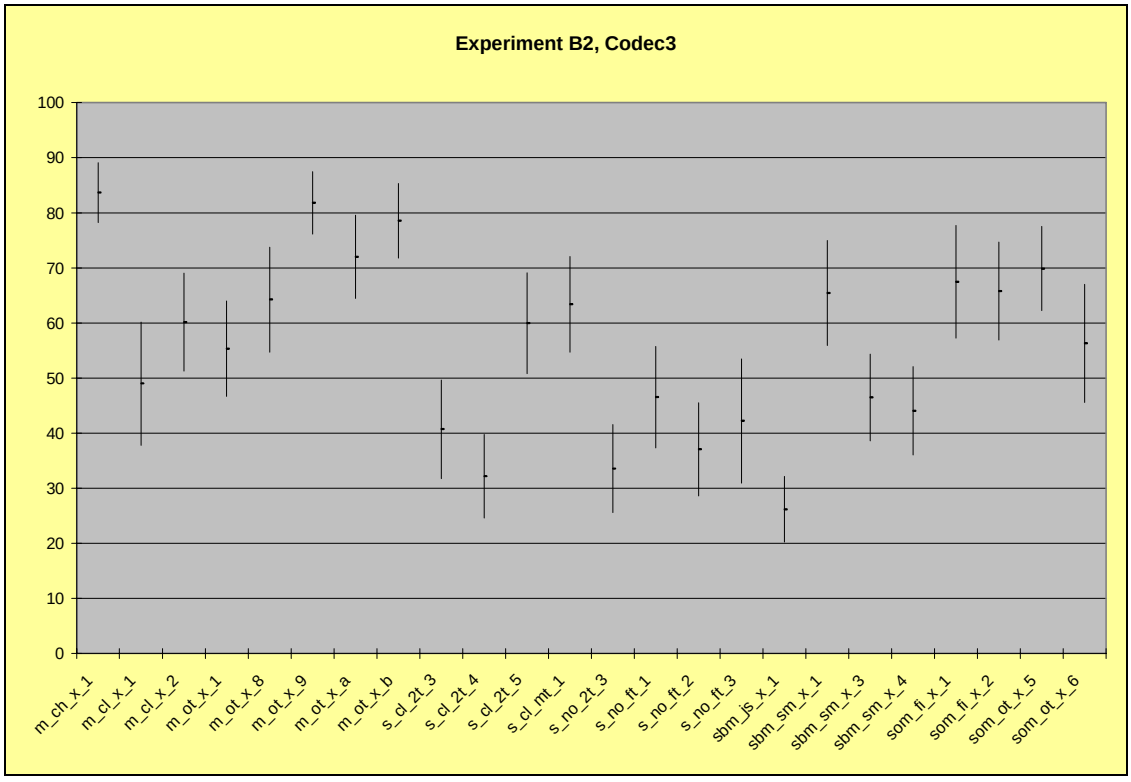
determine that Codec2 does indeed out-perform AMR-WB. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
Average	43.3	50.7	55.7	22.8	46.8	99.9	33.1	62.6	64.2
Lower Bound	41.1	48.4	53.3	21.2	44.8	99.9	31.3	60.7	62.4
Upper Bound	45.5	52.9	58.1	24.5	48.8	100.0	34.8	64.4	66.1

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ch_x_1	65.0	49.6	57.3	75.9	61.0	68.5	89.1	78.2	83.7
m_cl_x_1	47.6	28.6	38.1	68.2	46.6	57.4	60.2	37.8	49.0
m_cl_x_2	59.3	40.7	50.0	29.1	18.9	24.0	69.1	51.3	60.2
m_ot_x_1	56.4	40.8	48.6	54.2	38.2	46.2	64.0	46.7	55.3
m_ot_x_8	50.6	35.2	42.9	49.5	34.7	42.1	73.7	54.7	64.2
m_ot_x_9	66.5	52.7	59.6	75.2	57.8	66.5	87.5	76.1	81.8
m_ot_x_a	58.6	41.0	49.8	30.0	19.4	24.7	79.6	64.4	72.0
m_ot_x_b	64.5	49.4	57.0	66.5	49.6	58.0	85.3	71.8	78.6
s_cl_2t_3	38.0	22.6	30.3	67.5	51.3	59.4	49.7	31.8	40.7
s_cl_2t_4	24.3	15.0	19.6	72.5	54.4	63.5	39.7	24.6	32.2
s_cl_2t_5	49.0	33.1	41.0	52.6	38.8	45.7	69.1	50.8	60.0
s_cl_mt_1	45.3	29.4	37.4	69.2	51.2	60.2	72.0	54.7	63.4
s_no_2t_3	34.0	20.4	27.2	59.2	42.0	50.6	41.5	25.6	33.6
s_no_ft_1	49.2	32.7	40.9	51.9	33.6	42.7	55.7	37.3	46.5
s_no_ft_2	47.2	30.3	38.8	60.7	43.0	51.9	45.5	28.6	37.1
s_no_ft_3	64.5	43.8	54.2	55.7	33.8	44.8	53.5	30.9	42.2
sbm_js_x_1	23.1	14.8	18.9	42.5	26.3	34.4	32.1	20.2	26.2
sbm_sm_x_1	57.9	38.2	48.0	76.5	62.0	69.3	74.9	55.9	65.4
sbm_sm_x_3	48.3	31.7	40.0	78.4	62.8	70.6	54.4	38.6	46.5
sbm_sm_x_4	26.4	16.2	21.3	58.4	41.9	50.2	52.1	36.1	44.1
som_fi_x_1	64.9	45.9	55.4	54.7	37.6	46.1	77.7	57.2	67.5
som_fi_x_2	66.9	50.7	58.8	61.5	42.1	51.8	74.7	56.9	65.8
som_ot_x_5	57.9	42.1	50.0	58.2	42.9	50.6	77.5	62.2	69.9
som_ot_x_6	66.3	48.5	57.4	47.3	27.4	37.3	67.0	45.6	56.3

8.6.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	3584309	448039	1942.8	< 2.2e-16 ***
Sub	1	169861	169861	736.6	< 2.2e-16 ***
SigCat	3	8504	2835	12.3	5.09e-08 ***
Signal	19	42875	2257	9.8	< 2.2e-16 ***
Site	2	622804	311402	1350.3	< 2.2e-16 ***
Subject	56	810238	14469	62.7	< 2.2e-16 ***
Codec:Signal	24	347422	14476	62.8	< 2.2e-16 ***
Codec:Site	24	134199	5592	24.2	< 2.2e-16 ***
Residuals	8196	1890101	231		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
mean	43.3	50.7	55.7	22.9	46.8	99.9	33.1	62.6	64.2
N	696	696	696	696	696	696	696	696	696
Lower Bound	42.2	49.5	54.5	21.7	45.7	98.8	32.0	61.4	63.1
Upper Bound	44.4	51.8	56.8	24.0	47.9	101.1	34.2	63.7	65.4

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals. *In fact, as shown here, the confidence intervals for Codec2 and AMR-WB do not overlap.*

Sub Experiment main effect

	a	b
mean	48.9	57.9
N	3231	3033

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	53.3	51.7	53.4	54.6
N	2097	2097	1035	1035

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	50.4	36.0	31.6	55.3
	N	233	233	115	115
Codec2	mean	48.1	52.4	55.6	46.6
	N	233	233	115	115
Codec3	mean	68.0	44.4	45.2	65.0
	N	233	233	115	115
AAC	mean	30.6	15.2	20.7	24.9
	N	233	233	115	115
AMR-WB	mean	31.5	53.0	59.0	43.8
	N	233	233	115	115
hidref	mean	99.9	99.9	100.0	99.9

	N	233	233	115	115
lp3500_s12	mean	31.3	34.8	33.9	32.3
	N	233	233	115	115
lp7000_s12	mean	58.8	64.0	66.2	61.3
	N	233	233	115	115
lp7000_s6	mean	61.1	65.9	68.0	61.9
	N	233	233	115	115

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±2.0, while the width of the 95% confidence intervals for the som and sbm categories is ±2.8.

Signal main effect

	m_ch_x_1	m_cl_x_1	m_cl_x_2	m_ot_x_1	m_ot_x_8	m_ot_x_9
mean	54.3	48.3	53.0	52.9	54.2	57.1
N	261	252	270	270	270	261
	m_ot_x_a	m_ot_x_b	s_cl_2t_3	s_cl_2t_4	s_cl_2t_5	s_cl_mt_1
mean	53.9	51.8	53.6	52.8	57.3	52.6
N	270	243	252	270	270	261
	s_no_2t_3	s_no_ft_1	s_no_ft_2	s_no_ft_3	sbm_js_x_1	sbm_sm_x_1
mean	53.8	49.0	55.2	51.2	50.4	56.0
N	270	261	270	243	540	504
	sbm_sm_x_3	sbm_sm_x_4	som_fi_x_1	som_fi_x_2	som_ot_x_5	som_ot_x_6
mean	56.0	51.1	54.6	54.5	53.2	50.4
N	486	540	522	522	540	486

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Ericsson	Nokia	NTT-AT	T-Sys
mean	64.8	56.5	49.7	41.6
N	1620	1575	1458	1611

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.6.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However,

the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 7% larger.

8.6.5 Post-screening of data

Of the 720 sets of 9 judgments (one for each codec, reference codec, and anchor) in this experiment, 24 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 1%.

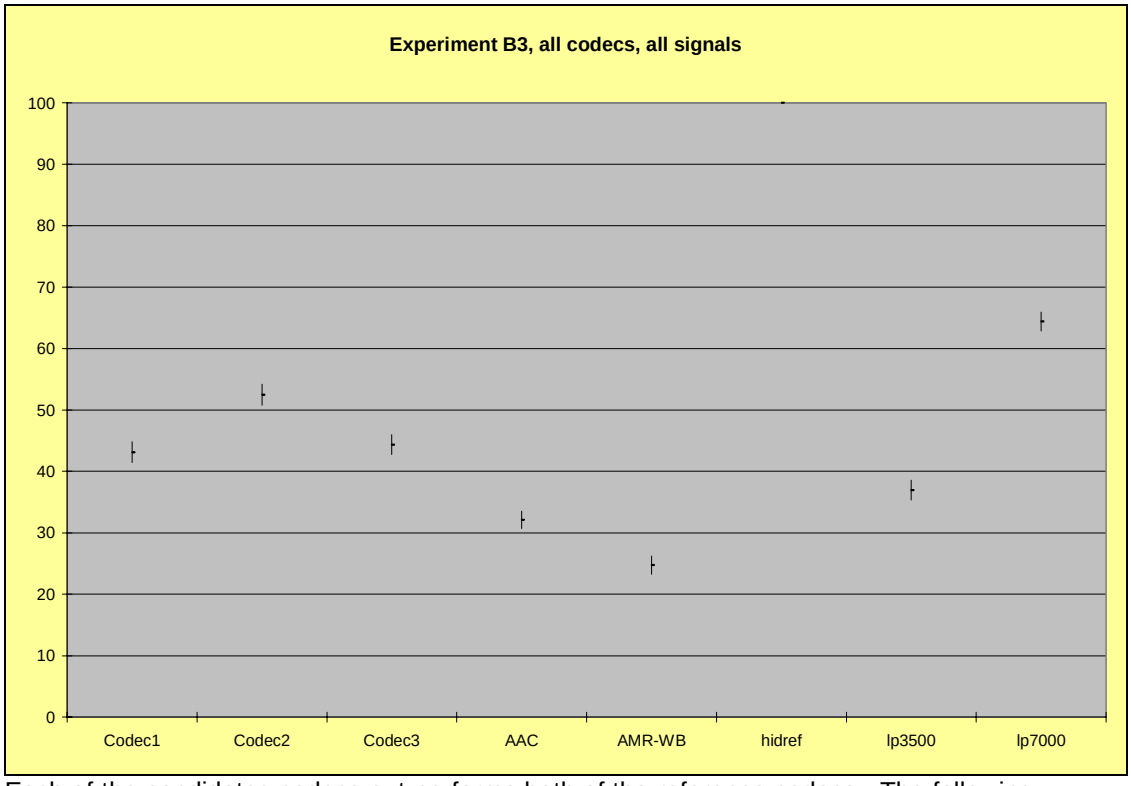
8.7 Test B3a and B3b

8.7.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	B3a and B3b	
Bit Rate	14 kbps	
Signal	Mono	
Channel Error Condition	3% FER	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 14.25 kbps, 16 kHz sampling rate	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass	LP7.0
	3.5 kHz Lowpass	LP3.5

8.7.2 Pivot Table Results

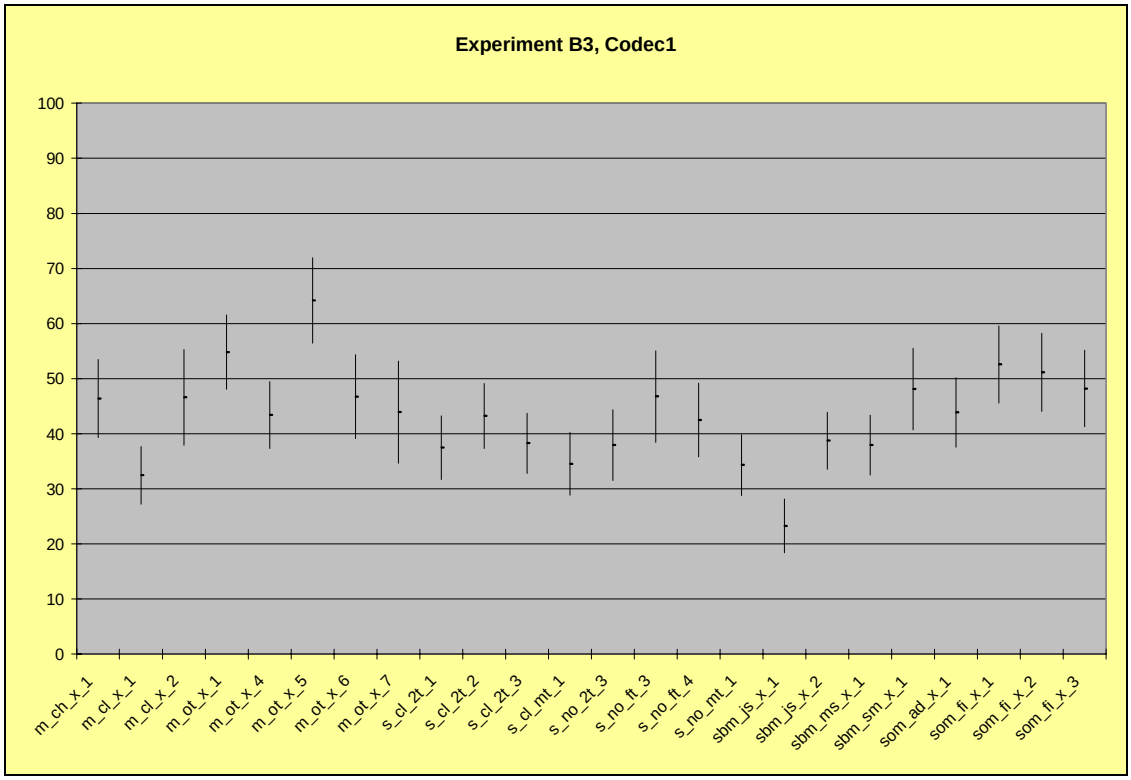
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

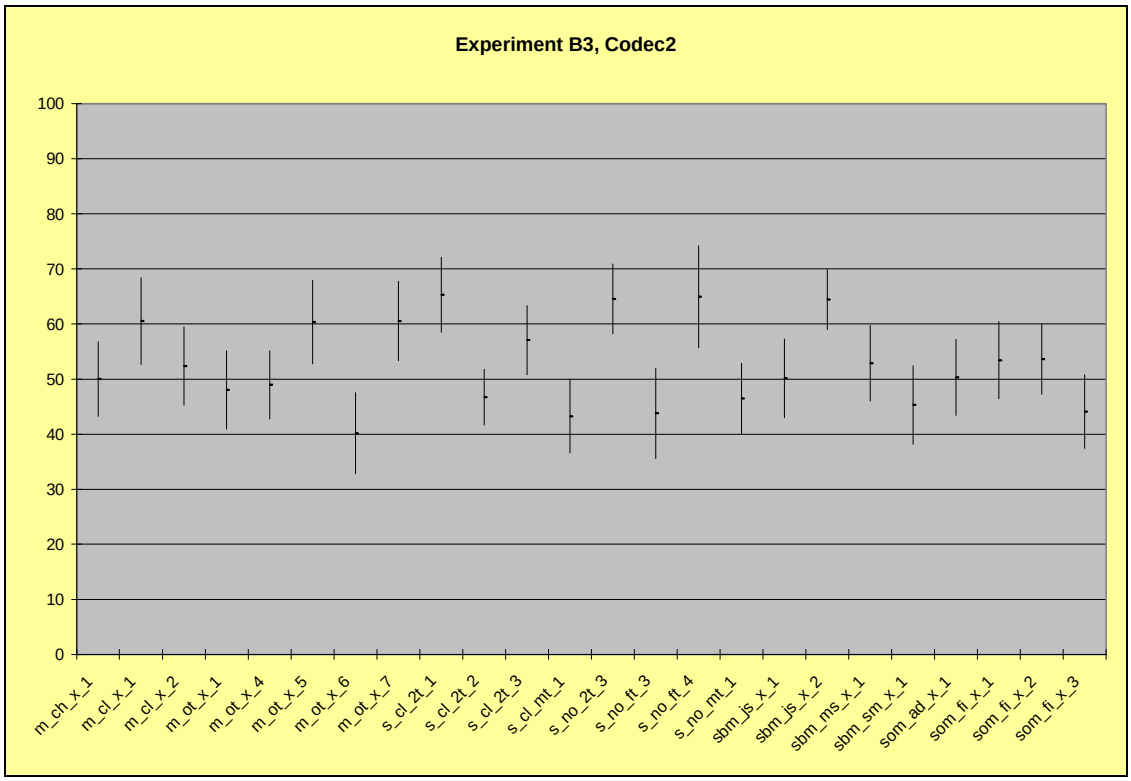


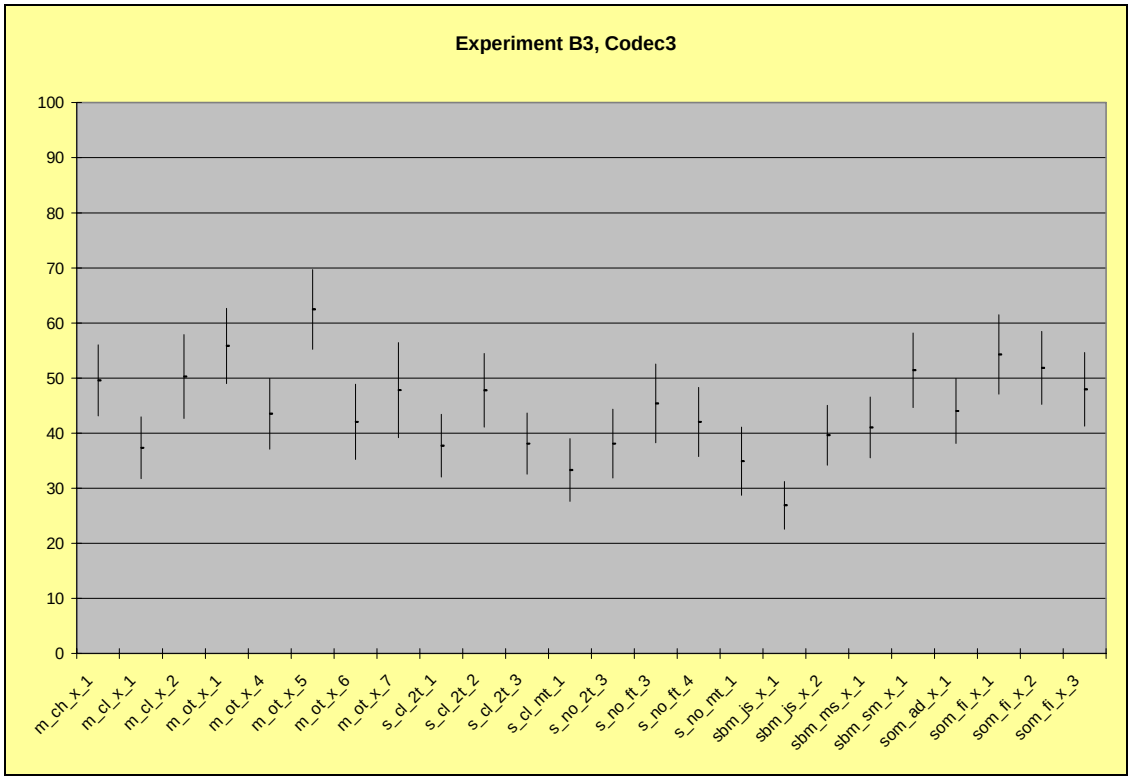
Each of the candidates codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
Average	43.1	52.5	44.3	32.1	24.7	100.0	37.0	64.4
Lower Bound	41.4	50.8	42.7	30.7	23.2	100.0	35.3	62.9
Upper Bound	44.8	54.2	46.0	33.6	26.2	100.0	38.6	65.9

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.







The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ch_x_1	53.5	39.3	46.4	56.8	43.2	50.0	56.0	43.1	49.6
m_cl_x_1	37.7	27.2	32.4	68.4	52.6	60.5	42.9	31.7	37.3
m_cl_x_2	55.3	37.9	46.6	59.4	45.2	52.3	57.9	42.6	50.3
m_ot_x_1	61.5	48.0	54.8	55.2	40.9	48.0	62.7	49.0	55.8
m_ot_x_4	49.5	37.3	43.4	55.1	42.8	48.9	49.9	37.1	43.5
m_ot_x_5	72.0	56.4	64.2	67.9	52.7	60.3	69.7	55.2	62.4
m_ot_x_6	54.3	39.1	46.7	47.5	32.8	40.1	48.9	35.2	42.0
m_ot_x_7	53.2	34.7	43.9	67.7	53.4	60.5	56.4	39.2	47.8
s_cl_2t_1	43.3	31.7	37.5	72.1	58.5	65.3	43.4	32.0	37.7
s_cl_2t_2	49.1	37.3	43.2	51.8	41.7	46.7	54.4	41.1	47.8
s_cl_2t_3	43.7	32.8	38.3	63.4	50.8	57.1	43.7	32.5	38.1
s_cl_mt_1	40.2	28.8	34.5	49.9	36.6	43.2	39.0	27.6	33.3
s_no_2t_3	44.4	31.5	37.9	70.9	58.2	64.6	44.4	31.8	38.1
s_no_ft_3	55.0	38.4	46.7	52.0	35.6	43.8	52.5	38.3	45.4
s_no_ft_4	49.2	35.8	42.5	74.2	55.7	64.9	48.3	35.8	42.0
s_no_mt_1	39.8	28.8	34.3	52.8	40.1	46.5	41.1	28.7	34.9
sbm_js_x_1	28.1	18.4	23.2	57.3	43.0	50.1	31.2	22.6	26.9
sbm_js_x_2	43.9	33.5	38.7	69.8	59.0	64.4	45.0	34.2	39.6
sbm_ms_x_1	43.4	32.5	37.9	59.7	46.0	52.9	46.6	35.5	41.0
sbm_sm_x_1	55.5	40.7	48.1	52.4	38.2	45.3	58.2	44.7	51.4
som_ad_x_1	50.2	37.5	43.9	57.2	43.4	50.3	49.9	38.1	44.0
som_fi_x_1	59.6	45.6	52.6	60.4	46.4	53.4	61.5	47.1	54.3
som_fi_x_2	58.2	44.0	51.1	60.0	47.2	53.6	58.5	45.2	51.9
som_fi_x_3	55.2	41.2	48.2	50.8	37.4	44.1	54.6	41.2	47.9

8.7.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	7	3681304	525901	3009.3	< 2.2e-16 ***
Sub	1	101718	101718	582.0	< 2.2e-16 ***
SigCat	3	7139	2380	13.6	7.43e-09 ***
Signal	19	22274	1172	6.7	< 2.2e-16 ***
Site	2	22730	11365	65.0	< 2.2e-16 ***
Subject	56	526486	9402	53.8	< 2.2e-16 ***
Codec:Signal	21	136860	6517	37.3	< 2.2e-16 ***
Codec:Site	21	173159	8246	47.2	< 2.2e-16 ***
Residuals	7381	1289904	175		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500	lp7000
mean	43.1	52.5	44.4	32.1	24.7	100.0	37.0	64.4
N	702	702	702	702	702	702	702	702
Lower Bound	42.1	51.5	43.4	31.1	23.8	99.0	36.0	63.4
Upper Bound	44.1	53.5	45.3	33.1	25.7	101.0	37.9	65.4

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	53.5	46.1
N	2768	2848

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	50.9	49.8	48.2	50.2
N	1824	1896	944	952

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	47.2	39.3	37.1	49.0
	N	228	237	118	119
Codec2	mean	52.5	53.9	53.2	50.3
	N	228	237	118	119
Codec3	mean	48.5	39.6	39.8	49.6
	N	228	237	118	119
AAC	mean	45.5	26.0	27.5	30.0
	N	228	237	118	119
AMR-WB	mean	16.1	32.2	24.4	26.0
	N	228	237	118	119
hidref	mean	100.1	100.0	100.0	100.0

	N	228	237	118	119
lp3500	mean	35.5	38.9	38.8	34.6
	N	228	237	118	119
lp7000	mean	61.6	68.6	65.1	62.1
	N	228	237	118	119

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±1.7, while the width of the 95% confidence intervals for the som and sbm categories is ±2.4.

Signal main effect

	m_ch_x_1	m_cl_x_1	m_cl_x_2	m_ot_x_1	m_ot_x_4	m_ot_x_5
mean	48.3	48.8	52.5	48.9	49.3	52.9
N	232	232	240	224	240	216
	m_ot_x_6	m_ot_x_7	s_cl_2t_1	s_cl_2t_2	s_cl_2t_3	s_cl_mt_1
mean	47.5	50.3	50.9	51.2	49.0	46.0
N	232	208	240	232	240	240
	s_no_2t_3	s_no_ft_3	s_no_ft_4	s_no_mt_1	sbm_js_x_1	sbm_js_x_2
mean	51.1	50.0	50.9	49.1	47.2	50.7
N	232	240	232	240	232	240
	sbm_ms_x_1	sbm_sm_x_1	som_ad_x_1	som_fi_x_1	som_fi_x_2	som_fi_x_3
mean	48.6	52.4	47.5	51.2	50.0	50.3
N	232	240	232	240	240	240

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	CT	DY	FhG	FT
mean	50.1	52.3	47.4	49.4
N	1424	1328	1440	1424

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect

The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.7.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not

been included in the statistical model, the residual standard error would have been about 13% larger.

8.7.5 Post-screening of data

Of the 720 sets of 8 judgments (one for each codec, reference codec, and anchor) in this experiment, 18 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 2%.

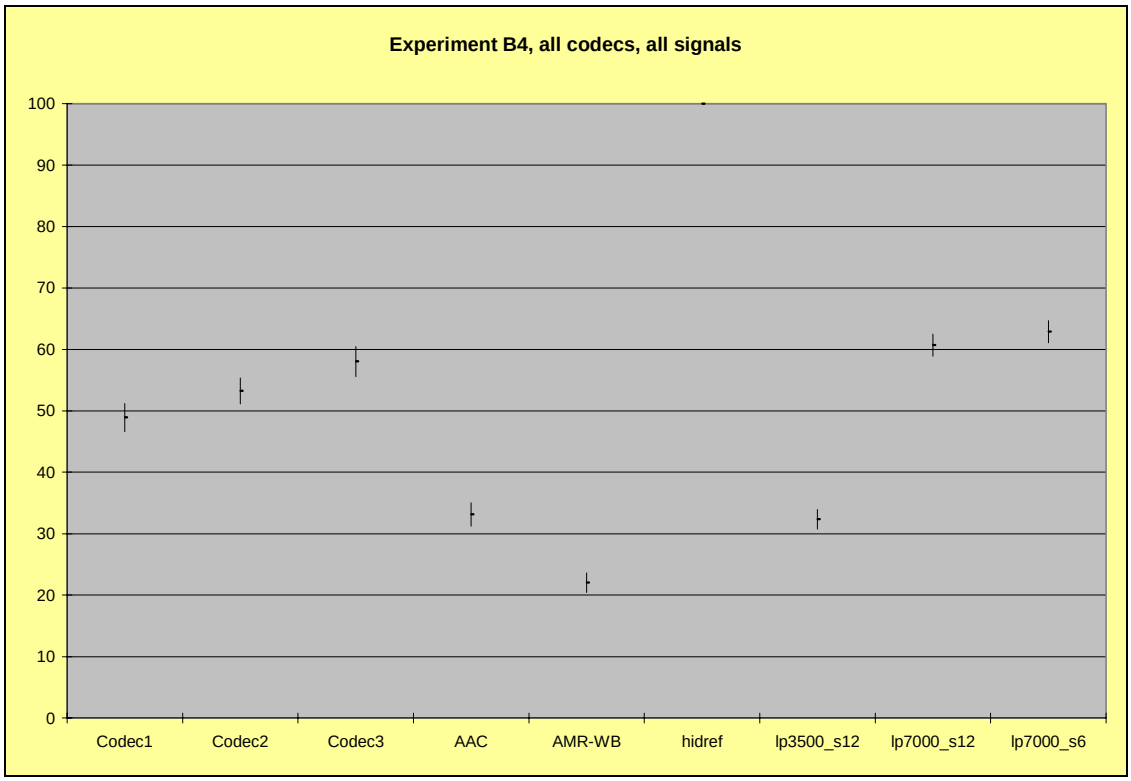
8.8 Test B4a and B4b

8.8.1 Test parameters and systems under test

Parameter	Value	Symbol
Experiment	B4a and B4b	
Bit Rate	24 kbps	
Signal	Stereo	
Channel Error Condition	3% FER	
Candidate codecs	AAC+	Codec 1
	AMR-WB+	Codec 2
	CT	Codec 3
Reference codecs	AAC	AAC
	AMR-WB, 23.85 kbps, 16 kHz sampling rate, mono	AMR-WB
Anchors and references	Open Reference	
	Hidden Reference	HR
	7.0 kHz Lowpass, 6 dB attenuated side channel	LP7.0-S6
	7.0 kHz Lowpass,12 dB attenuated side channel	LP7.0-S12
	3.5 kHz Lowpass, 12 dB attenuated side channel	LP3.5-S12

8.8.2 Pivot Table Results

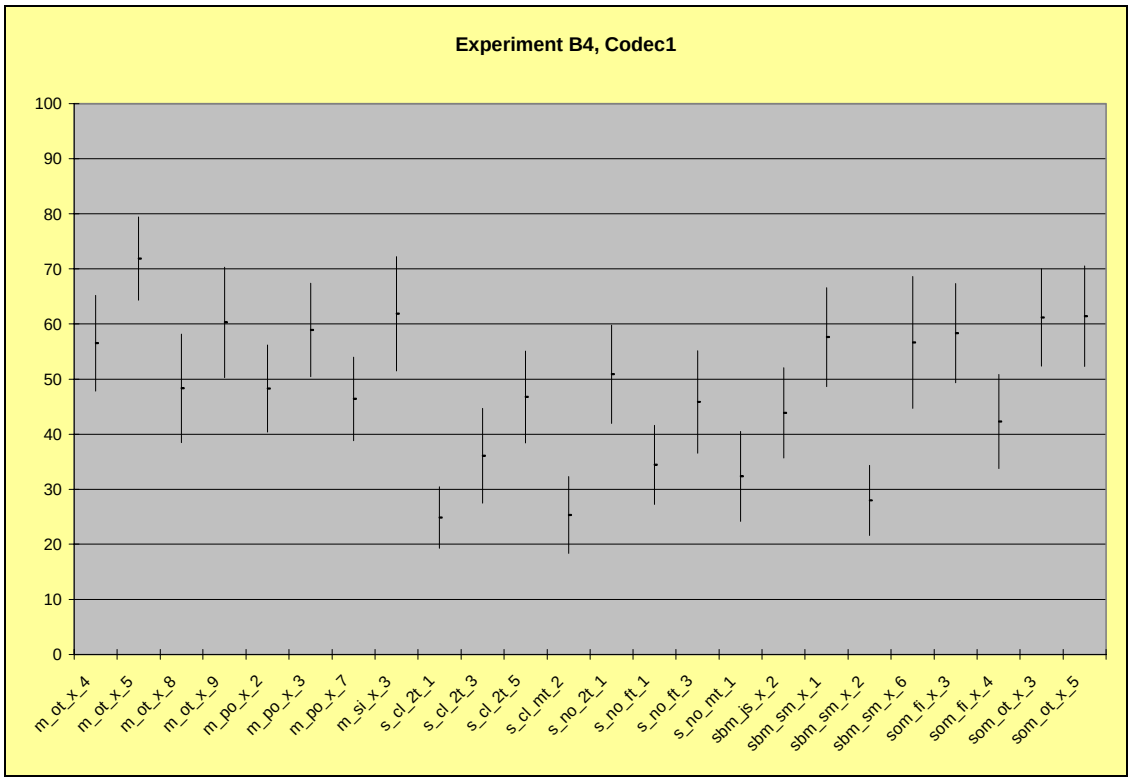
The following chart shows the overall relative performance of the codecs in this experiment. The means and 95% confidence intervals shown are from the standard Pivot Table analysis in which the summary statistics are computed over all signals listeners, and laboratories.

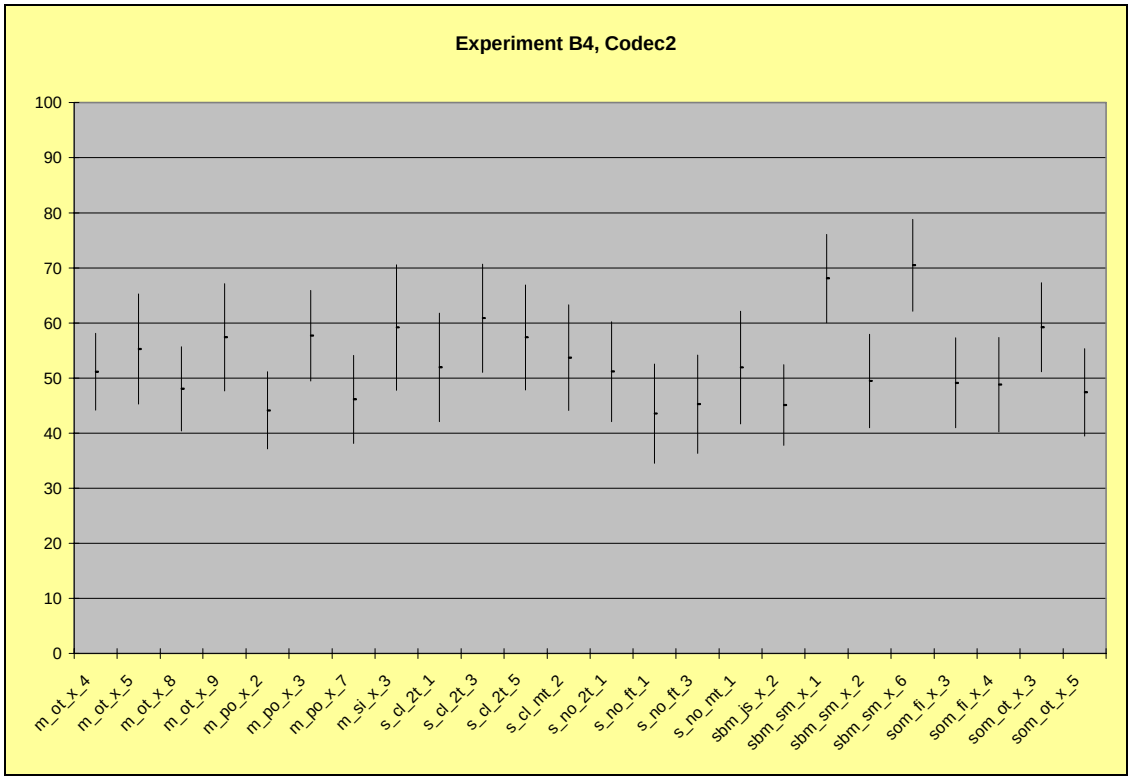


Each of the candidates codecs out-performs both of the reference codecs. The following table shows the numerical values plotted in the chart above.

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
Average	48.9	53.3	58.0	33.1	22.0	100.0	32.4	60.7	62.9
Lower Bound	46.6	51.1	55.6	31.2	20.5	99.9	30.8	58.9	61.1
Upper Bound	51.2	55.4	60.4	35.1	23.6	100.0	34.0	62.5	64.7

The following 3 charts show the performance of each of the candidate codecs for each of the test signals.


Experiment B4, Codec1
100
90
80
70
60
50
40
30
20
10
0
m_ot_x_4
m_ot_x_5
m_ot_x_8
m_ot_x_9
m_po_x_2
m_po_x_3
m_po_x_7
m_si_x_3
s_cl_2t_1
s_cl_2t_3
s_cl_2t_5
s_cl_mt_2
s_no_2t_1
s_no_ft_1
s_no_ft_3
s_no_mt_1
sbm_js_x_2
sbm_sm_x_1
sbm_sm_x_2
sbm_sm_x_6
som_fi_x_3
som_fi_x_4
som_ot_x_3
som_ot_x_5


Experiment B4, Codec2
100
90
80
70
60
50
40
30
20
10
0
m_ot_x_4
m_ot_x_5
m_ot_x_8
m_ot_x_9
m_po_x_2
m_po_x_3
m_po_x_7
m_si_x_3
s_cl_2t_1
s_cl_2t_3
s_cl_2t_5
s_cl_mt_2
s_no_2t_1
s_no_ft_1
s_no_ft_3
s_no_mt_1
sbm_js_x_2
sbm_sm_x_1
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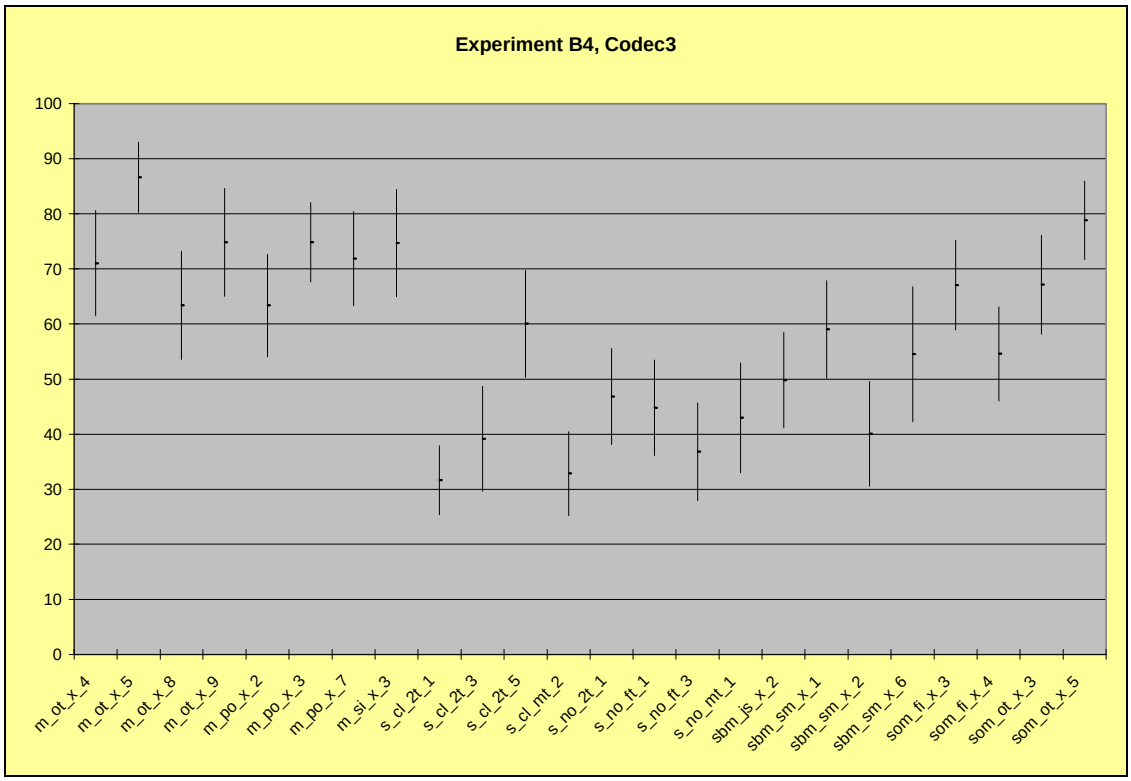
sbm_sm_x_6
som_fi_x_3
som_fi_x_4
som_ot_x_3
som_ot_x_5



The following table presents the data used to create the previous charts.

	Codec 1			Codec 2			Codec 3		
	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean	Upper Bound	Lower Bound	Mean
m_ot_x_4	65.2	47.8	56.5	58.1	44.2	51.1	80.6	61.4	71.0
m_ot_x_5	79.4	64.3	71.9	65.3	45.3	55.3	93.0	80.2	86.6
m_ot_x_8	58.2	38.5	48.3	55.7	40.4	48.0	73.2	53.6	63.4
m_ot_x_9	70.3	50.3	60.3	67.2	47.6	57.4	84.6	65.0	74.8
m_po_x_2	56.1	40.4	48.3	51.1	37.1	44.1	72.6	54.1	63.3
m_po_x_3	67.4	50.4	58.9	65.9	49.5	57.7	82.0	67.6	74.8
m_po_x_7	54.0	38.8	46.4	54.1	38.2	46.1	80.4	63.3	71.9
m_si_x_3	72.2	51.5	61.9	70.6	47.8	59.2	84.4	64.9	74.7
s_cl_2t_1	30.4	19.3	24.9	61.8	42.1	52.0	37.9	25.4	31.6
s_cl_2t_3	44.7	27.5	36.1	70.7	51.0	60.9	48.7	29.6	39.1
s_cl_2t_5	55.1	38.4	46.7	66.9	47.8	57.4	69.7	50.4	60.0
s_cl_mt_2	32.3	18.4	25.3	63.3	44.1	53.7	40.5	25.2	32.8
s_no_2t_1	59.8	41.9	50.9	60.2	42.1	51.2	55.5	38.1	46.8
s_no_ft_1	41.6	27.3	34.4	52.5	34.5	43.5	53.4	36.2	44.8
s_no_ft_3	55.1	36.5	45.8	54.2	36.4	45.3	45.7	27.9	36.8
s_no_mt_1	40.5	24.2	32.3	62.2	41.7	51.9	52.9	33.0	43.0
sbm_js_x_2	52.0	35.6	43.8	52.4	37.8	45.1	58.4	41.1	49.8
sbm_sm_x_1	66.6	48.6	57.6	76.1	60.1	68.1	67.9	50.1	59.0
sbm_sm_x_2	34.3	21.6	28.0	57.9	41.0	49.5	49.5	30.6	40.1
sbm_sm_x_6	68.6	44.7	56.6	78.8	62.1	70.5	66.7	42.3	54.5
som_fi_x_3	67.3	49.3	58.3	57.3	41.0	49.1	75.2	58.9	67.0

som_fi_x_4	50.8	33.8	42.3	57.4	40.2	48.8	63.1	46.0	54.6
som_ot_x_3	70.0	52.3	61.2	67.3	51.2	59.2	76.1	58.2	67.1
som_ot_x_5	70.5	52.3	61.4	55.4	39.4	47.4	85.9	71.7	78.8

8.8.3 Analysis of Variance Results

The data were analyzed using Analysis of Variance techniques. The following are the overall basic results from the Analysis of Variance:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Codec	8	3887175	485897	1959.7	< 2.2e-16 ***
Sub	1	144206	144206	581.6	< 2.2e-16 ***
SigCat	3	15192	5064	20.4	3.51e-13 ***
Signal	19	48865	2572	10.4	< 2.2e-16 ***
Site	2	603654	301827	1217.3	< 2.2e-16 ***
Subject	56	576837	10301	41.5	< 2.2e-16 ***
Codec:Signal	24	300923	12538	50.6	< 2.2e-16 ***
Codec:Site	24	162969	6790	27.4	< 2.2e-16 ***
Residuals	8232	2041092	248		

Signif. codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < • < 0.1 < ‘ ‘ < 1

All components of the model are highly statistically significant at greater than the 99.9% level. This means that each of the aspects of the experimental design was important and rightfully included in the model, so that the effect of that component can be compensated for when analyzing the variable of interest, the difference between the codecs. However, it should be kept in mind that this experiment resulted in much data being collected, and small differences can be statistically significant, while their practical effect is minimal.

The following are the main effects (the estimated mean of each level of each variable) as determined by this analysis.

Codec main effect

	Codec1	Codec2	Codec3	AAC	AMR-WB	hidref	lp3500_s12	lp7000_s12	lp7000_s6
mean	48.9	53.3	58.0	33.1	22.0	100.0	32.4	60.7	62.9
N	930	930	930	930	930	930	930	930	930
Lower Bound	47.7	52.1	56.8	32.0	20.9	98.8	31.2	59.5	61.7
Upper Bound	50.1	54.4	59.2	34.3	23.2	101.1	33.5	61.9	64.1

As can be seen by comparing this table with the Pivot Table analysis means above, the two analyses give almost identical results. As mentioned, the difference between the analyses is in the width of the confidence intervals.

Sub Experiment main effect

	a	b
mean	48.3	56.6
N	3231	3051

The two sub experiments have surprisingly different means. This difference is not only statistically significant, it may lead to insight about the differences between the signal sets or the laboratories employed in the two sub-experiments.

Signal Category main effect

	m	s	sbm	som
mean	53.5	50.2	52.4	53.4
N	2088	2106	1026	1062

Although this variable is highly statistically significant, the signal categories have means that do not differ too much. The practical differences may not be too great. The statistical significance here means that the largest mean is definitely statistically significantly different from the smallest, but other differences would require a more in-depth analysis.

Codec by Signal Category (Codec:SigCat) interaction effect

Codec	SigCat				
		m	s	sbm	som
Codec1	mean	56.4	37.1	46.0	56.0
rep	N	232	234	228	236
Codec2	mean	52.2	52.0	57.8	51.1
rep	N	232	234	228	236
Codec3	mean	72.4	41.8	50.6	67.0
rep	N	232	234	228	236
AAC	mean	41.1	21.2	38.8	31.7
rep	N	232	234	228	236
AMR-WB	mean	16.6	29.7	21.8	20.0
rep	N	232	234	228	236
hidref	mean	99.8	100.0	100.1	99.9
rep	N	232	234	228	236
lp3500_s12	mean	30.3	36.4	30.9	31.9
rep	N	232	234	228	236
lp7000_s12	mean	55.0	65.3	61.7	60.7
rep	N	232	234	228	236
lp7000_s6	mean	57.4	67.8	64.0	62.4
rep	N	232	234	228	236

As can be seen in the above table, some codecs perform relatively better in some signal categories, while other codecs perform better in other signal categories. This is the meaning of "interaction." The set of codec by signal category interactions above are statistically significant. Without presenting all the confidence intervals, the width of the 95% confidence intervals for the m and s categories is ±2.0, while the width of the 95% confidence intervals for the som and sbm categories is ±2.9.

Signal main effect

	m_ot_x_4	m_ot_x_5	m_ot_x_8	m_ot_x_9	m_po_x_2	m_po_x_3
mean	53.4	54.0	53.3	53.6	48.1	51.1
N	261	261	270	243	270	261
	m_po_x_7	m_si_x_3	s_cl_2t_1	s_cl_2t_3	s_cl_2t_5	s_cl_mt_2
mean	51.5	54.2	51.0	52.5	59.1	50.6
N	270	252	270	261	270	270
	s_no_2t_1	s_no_ft_1	s_no_ft_3	s_no_mt_1	sbm_js_x_2	sbm_sm_x_1
mean	55.0	46.9	52.6	50.8	49.8	56.0
N	270	252	270	243	270	234
	sbm_sm_x_2	sbm_sm_x_6	som_fi_x_3	som_fi_x_4	som_ot_x_3	som_ot_x_5

mean	50.4	53.8	52.5	50.2	52.4	54.2
N	270	252	270	252	270	270

The signal main effects are shown here for completeness. The differences are statistically significant, but since the each signal is a unique item, it is not clear what use can be made of these individual means.

Site main effect

	Ericsson	Nokia	NTT-AT	T-Sys
mean	63.3	56.7	47.6	41.3
N	1620	1584	1467	1611

The sites are statistically significantly different. Again, it is not clear what use can be made of these individual means.

Subject main effect
The subjects are statistically significantly different. The details of subject results can be found in the accompanying spreadsheets..

8.8.4 Sources of variability

There is definitely a statistically significant and practically significant interaction between codecs and signals. That is, some codecs worked better for some signals than for others. These interactions can best be reviewed by studying the three charts above where, for each codec under test, the quality ratings are shown for each signal.

There is also definitely a statistically significant codec by lab interaction. In other words, some codecs performed relatively better in some testing labs than in others. However, the effect of this interaction compared to, say, the listener differences, the signal differences or the codec-signal interaction is relatively small. If this interaction had not been included in the statistical model, the residual standard error would have been about 8% larger.

8.8.5 Post-screening of data

Of the 720 sets of 9 judgments (one for each codec, reference codec, and anchor) in this experiment, 22 were eliminated by the post-screening procedure. The results of the screening procedure are coded by the Weight variable, where passing judgments received a 1 and eliminated judgments received a 0. In the pivot table, this variable can be manipulated to show the Pivot Table results with all the data. The means do not change much in a practical sense. However, in the analysis of variance, the standard error of the residuals, and thus all confidence interval widths, increases by about 1%.

9 Application of Selection Rules

The Selection Rules as defined in S4-(03)0837 [6] have been applied using the data collected in the experiments being analyzed here. The following are the results.

9.1 PSS/MMS LBRAC Selection Rule 1

These rules are design criteria, and we assume for the purposes of this document that all three candidate codecs pass these rules.

9.2 PSS/MMS LBRAC Selection Rule 2

This rule ensures that each candidate codec outperforms the better of the two reference codecs in each test case. It is easiest to inspect the 8 charts above showing "all data" with confidence intervals to see which candidate codecs performed better than the reference codecs, however the confidence intervals from the ANOVA are tighter and give more statistical power. Therefore two charts are presented, one based on the Pivot Table analysis and the other on the ANOVA. Careful inspection reveals that, as expected, the differences are very minor.

The average results for each test case have been assembled in the following charts. The green cells indicate where the candidate codec is "better than" the reference codecs (in a statistical sense at the 95% level). The red cells indicate where the candidate codec is "worse than" at least one of the reference codecs (in a statistical sense at the 95% level). The light-yellow boxes indicate where the candidate codec is not statistically significantly different from the max of the two reference codecs (i.e. it is neither "better than" nor "worse than").

Pivot Table:

	Codec: Operating condition	AAC+	AMR-WB+	CT	AAC	AMR-WB	Max of AAC, AMR-WB
A1	14 kbps, mono, use case A (PSS)	50.8	62.6	51.5	32.9	44.9	44.9
A2	18 kbps, stereo, use case A (PSS)	37.5	55.6	53.3	20.9	48.2	48.2
A3	24 kbps, mono, use case A (PSS)	74.9	67.4	75.8	50.9	47.4	50.9
A4	24 kbps, stereo, use case A (PSS)	55.3	61.3	67.1	34.8	44.8	44.8
B1	14 kbps, mono, use case B (MMS), 16 kHz inp. and outp. sampling rate	45.4	50.7	44.4	30.7	46.2	46.2
B2	18 kbps, stereo, use case B (MMS)	43.3	50.7	55.7	22.8	46.8	46.8
B3	14 kbps, mono, use case A (PSS), 3% FER	43.1	52.5	44.3	32.1	24.7	32.1
B4	24 kbps, stereo, use case A (PSS), 3% FER	48.9	53.3	58.0	33.1	22.0	33.1

ANOVA:

	Codec: Operating condition	AAC+	AMR-WB+	CT	AAC	AMR-WB	Max of AAC, AMR-WB
A1	14 kbps, mono, use case A (PSS)	50.8	62.7	51.6	32.9	45.0	45.0
A2	18 kbps, stereo, use case A (PSS)	37.5	55.6	53.3	20.9	48.2	48.2
A3	24 kbps, mono, use case A (PSS)	75.0	67.4	75.8	50.9	47.4	50.9
A4	24 kbps, stereo, use case A (PSS)	55.3	61.3	67.1	34.8	44.8	44.8
B1	14 kbps, mono, use case B (MMS), 16 kHz inp. and outp. sampling rate	45.5	50.7	44.4	30.7	46.2	46.2
B2	18 kbps, stereo, use case B (MMS)	43.3	50.7	55.7	22.8	46.8	46.8
B3	14 kbps, mono, use case A (PSS), 3% FER	43.1	52.5	44.4	32.1	24.7	32.1
B4	24 kbps, stereo, use case A (PSS), 3% FER	48.9	53.3	58.0	33.1	22.0	33.1

9.3 PSS/MMS LBRAC Selection Rule 3

As described in the Selection Rules document, and clarified in document [8] the Preferred Figure of Merit calculations were performed and are presented in the following table:

AAC+

Preferred FoM

	m	s	sbm	som	average	min	max
a1	18.71	-9.75	-8.02	6.62	1.89	-37.94	33.26
a2	8.10	-27.17	-20.54	-4.79	-11.10	-43.93	23.81
a3	27.13	11.42	21.11	24.41	21.02	-14.47	42.50
a4	14.06	-4.50	-3.68	19.03	6.23	-31.70	35.14
b1	8.33	-15.19	-10.26	1.40	-3.93	-33.34	16.73
b2	13.61	-16.89	-27.20	11.49	-4.75	-36.82	19.66
b3	1.69	4.97	7.60	18.72	8.25	-28.83	28.97
b4	15.33	5.46	7.42	23.96	13.04	-12.57	39.53
average	13.37	-6.46	-4.20	12.61	3.83	-29.95	29.95
min	-28.83	-43.93	-35.07	-28.45	-34.07	-43.93	
max	42.50	30.24	42.40	39.53	38.67		42.50

FoM L1 44

FoM L2 31

AMR-WB+

Preferred FoM

	m	s	sbm	som	average	min	max
a1	18.38	15.07	16.65	5.27	13.84	-1.40	26.67
a2	12.69	2.72	9.88	1.97	6.82	-18.90	26.10
a3	8.75	21.53	11.42	11.35	13.26	-4.41	27.07
a4	8.60	12.81	16.50	11.73	12.41	-4.60	26.57
b1	3.61	-1.51	5.23	-1.66	1.42	-10.20	13.53
b2	11.61	-0.71	-3.14	2.54	2.58	-19.57	30.83
b3	6.99	19.60	23.77	20.13	17.63	-0.76	32.80
b4	11.15	20.37	19.18	19.30	17.50	3.70	30.33
average	10.22	11.24	12.44	8.83	10.68	-7.02	26.74
min	-13.37	-11.43	-19.57	-18.90	-15.81	-19.57	
max	30.83	27.69	32.80	30.33	30.41		32.80

FoM L1 57

FoM L2 18

CT

Preferred FoM

	m	s	sbm	som	average	min	max
a1	17.55	-7.91	-6.24	6.91	2.58	-37.10	30.19
a2	28.69	-19.66	-0.45	9.99	4.64	-36.37	42.20
a3	27.51	14.02	21.65	24.32	21.87	-15.40	42.00
a4	33.18	6.26	3.81	28.39	17.91	-13.80	44.24
b1	7.75	-15.84	-11.22	-0.52	-4.96	-34.38	15.67
b2	31.29	-8.61	-13.73	20.94	7.47	-27.83	46.00
b3	2.99	5.26	10.35	19.31	9.48	-23.93	30.70
b4	31.35	10.28	11.74	35.05	22.10	-5.07	48.23
average	22.54	-2.03	1.99	18.05	10.14	-24.23	37.40
min	-23.93	-37.10	-27.83	-25.48	-28.59	-37.10	
max	46.00	33.48	40.97	48.23	42.17		48.23

FoM L1 49

FoM L2 26

10 Reference Documents

1. Tdoc S4-(03)0824, “AMR-WB+ and PSS/MMS Low-Rate Audio Selection Test and Processing Plan Version 2.2.
2. RECOMMENDATION ITU-R BS.1534, Method for the subjective assessment of intermediate quality level of coding systems
3. An Introduction to R, Notes on R: A Programming Environment for Data Analysis and Graphics, Version 1.4.1, by W.N. Venables, D.M. Smith and the R Development Core Team (2001) Network Theory Limited.
4. Modern Applied Statistics with S, by W.N. Venables and B.D. Ripley (2002) Springer. Known colloquially as MASS.
5. MASS, p 140ff describe lm(). p 165ff describe aov(), which is a “wrapper” for lm().
6. Tdoc S4-(03)0837. PSS/MMS Audio Codec and Extended AMR-WB Selection Rules, Version 2.0.
7. Tdoc S4-(03)0433. PSS/MSS Audio Codec Selection, Design Constraints and Performance Requirements – Version 2.0.
8. Tdoc S4-040117 Implementation of the preferred FOM of PSS/MMS low-rate audio codec selection rule 3.

Annex I - Low-Rate Experiment Training and Test Items

Training Items

The same training items were used at all test sites. They were:

```
m_vo_x_1_org.wav
s_no_ft_9_org.wav
sbm_fi_x_9_org.wav
som_ot_x_9_org.wav
```

Test Items

Test	Set	Item	Signal
A1	a	1	m_ot_x_8_org.wav
		2	m_ot_x_a_org.wav
		3	m_po_x_5_org.wav
		4	m_po_x_7_org.wav
		5	s_cl_2t_3_org.wav
		6	s_cl_2t_4_org.wav
		7	s_no_2t_1_org.wav
		8	s_no_ft_1_org.wav
		9	sbm_js_x_1_org.wav
		10	sbm_ms_x_1_org.wav
		11	som_fi_x_4_org.wav
		12	som_ot_x_4_org.wav
	b	1	m_ot_x_9_org.wav
		2	m_ot_x_b_org.wav
		3	m_po_x_6_org.wav
		4	m_si_x_3_org.wav
		5	s_cl_2t_5_org.wav
		6	s_cl_mt_2_org.wav
		7	s_no_2t_2_org.wav
		8	s_no_ft_2_org.wav
		9	sbm_sj_x_1_org.wav
		10	sbm_sm_x_6_org.wav
		11	som_ot_x_5_org.wav
		12	som_ot_x_6_org.wav
Test	Set	Item	Signal
A2	a	1	m_ot_x_4_org.wav
		2	m_ot_x_5_org.wav
		3	m_po_x_2_org.wav
		4	m_po_x_3_org.wav
		5	s_cl_2t_4_org.wav
		6	s_cl_ft_3_org.wav
		7	s_no_2t_3_org.wav
		8	s_no_mt_1_org.wav
		9	sbm_js_x_1_org.wav
		10	sbm_sm_x_4_org.wav
		11	som_fi_x_3_org.wav
		12	som_ot_x_2_org.wav
	b	1	m_ot_x_6_org.wav
		2	m_ot_x_7_org.wav
		3	m_po_x_4_org.wav
		4	m_si_x_2_org.wav
		5	s_cl_2t_5_org.wav
		6	s_cl_mt_2_org.wav
		7	s_no_ft_3_org.wav
		8	s_no_ft_4_org.wav
		9	sbm_js_x_2_org.wav
		10	sbm_sm_x_5_org.wav
		11	som_ad_x_1_org.wav
		12	som_ot_x_3_org.wav

Test	Set	Item	Signal
A3	a	1	m_ot_x_2_org.wav
		2	m_po_x_1_org.wav
		3	m_po_x_2_org.wav
		4	m_si_x_1_org.wav
		5	s_cl_2t_1_org.wav
		6	s_cl_ft_3_org.wav
		7	s_no_2t_1_org.wav
		8	s_no_mt_1_org.wav
		9	sbm_ms_x_1_org.wav
		10	sbm_sm_x_2_org.wav
		11	som_nt_x_1_org.wav
		12	som_ot_x_2_org.wav
	b	1	m_ot_x_3_org.wav
		2	m_po_x_3_org.wav
		3	m_po_x_4_org.wav
		4	m_si_x_2_org.wav
		5	s_cl_2t_2_org.wav
		6	s_cl_mt_2_org.wav
		7	s_no_2t_2_org.wav
		8	s_no_ft_4_org.wav
		9	sbm_js_x_2_org.wav
		10	sbm_sm_x_5_org.wav
		11	som_ot_x_1_org.wav
		12	som_ot_x_3_org.wav
Test	Set	Item	Signal
A4	a	1	m_ch_x_1_org.wav
		2	m_ot_x_2_org.wav
		3	m_po_x_1_org.wav
		4	m_si_x_1_org.wav
		5	s_cl_2t_1_org.wav
		6	s_cl_mt_1_org.wav
		7	s_no_2t_1_org.wav
		8	s_no_ft_2_org.wav
		9	sbm_ms_x_1_org.wav
		10	sbm_sm_x_2_org.wav
		11	som_fi_x_1_org.wav
		12	som_nt_x_1_org.wav
	b	1	m_cl_x_1_org.wav
		2	m_cl_x_2_org.wav
		3	m_ot_x_1_org.wav
		4	m_ot_x_3_org.wav
		5	s_cl_2t_2_org.wav
		6	s_cl_2t_3_org.wav
		7	s_no_2t_2_org.wav
		8	s_no_ft_1_org.wav
		9	sbm_sm_x_1_org.wav
		10	sbm_sm_x_3_org.wav
		11	som_fi_x_2_org.wav
		12	som_ot_x_1_org.wav

Test	Set	Item	Signal
B1	a	1	m_ch_x_1_org.wav
		2	m_cl_x_1_org.wav
		3	m_po_x_2_org.wav
		4	m_po_x_3_org.wav
		5	s_cl_2t_4_org.wav
		6	s_cl_ft_3_org.wav
		7	s_no_2t_2_org.wav
		8	s_no_ft_2_org.wav
		9	sbm_js_x_2_org.wav
		10	sbm_ms_x_1_org.wav
		11	som_ad_x_1_org.wav
		12	som_ot_x_4_org.wav
	b	1	m_po_x_4_org.wav
		2	m_po_x_5_org.wav
		3	m_po_x_6_org.wav
		4	m_si_x_2_org.wav
		5	s_cl_2t_2_org.wav
		6	s_cl_mt_1_org.wav
		7	s_no_2t_3_org.wav
		8	s_no_ft_4_org.wav
		9	sbm_sj_x_1_org.wav
		10	sbm_sm_x_4_org.wav
		11	som_ot_x_2_org.wav
		12	som_ot_x_6_org.wav
Test	Set	Item	Signal
B2	a	1	m_cl_x_2_org.wav
		2	m_ot_x_1_org.wav
		3	m_ot_x_8_org.wav
		4	m_ot_x_a_org.wav
		5	s_cl_2t_4_org.wav
		6	s_cl_2t_5_org.wav
		7	s_no_2t_3_org.wav
		8	s_no_ft_2_org.wav
		9	sbm_js_x_1_org.wav
		10	sbm_sm_x_4_org.wav
		11	som_fi_x_1_org.wav
		12	som_ot_x_5_org.wav
	b	1	m_ch_x_1_org.wav
		2	m_cl_x_1_org.wav
		3	m_ot_x_9_org.wav
		4	m_ot_x_b_org.wav
		5	s_cl_2t_3_org.wav
		6	s_cl_mt_1_org.wav
		7	s_no_ft_1_org.wav
		8	s_no_ft_3_org.wav
		9	sbm_sm_x_1_org.wav
		10	sbm_sm_x_3_org.wav
		11	som_fi_x_2_org.wav
		12	som_ot_x_6_org.wav

Test	Set	Item	Signal
B3	a	1	m_cl_x_1_org.wav
		2	m_ot_x_1_org.wav
		3	m_ot_x_5_org.wav
		4	m_ot_x_7_org.wav
		5	s_cl_2t_1_org.wav
		6	s_cl_2t_3_org.wav
		7	s_no_2t_3_org.wav
		8	s_no_ft_4_org.wav
		9	sbm_js_x_2_org.wav
		10	sbm_ms_x_1_org.wav
		11	som_ad_x_1_org.wav
		12	som_fi_x_2_org.wav
	b	1	m_ch_x_1_org.wav
		2	m_cl_x_2_org.wav
		3	m_ot_x_4_org.wav
		4	m_ot_x_6_org.wav
		5	s_cl_2t_2_org.wav
		6	s_cl_mt_1_org.wav
		7	s_no_ft_3_org.wav
		8	s_no_mt_1_org.wav
		9	sbm_js_x_1_org.wav
		10	sbm_sm_x_1_org.wav
		11	som_fi_x_1_org.wav
		12	som_fi_x_3_org.wav
Test	Set	Item	Signal
B4	a	1	m_ot_x_4_org.wav
		2	m_ot_x_8_org.wav
		3	m_po_x_2_org.wav
		4	m_po_x_7_org.wav
		5	s_cl_2t_1_org.wav
		6	s_cl_2t_5_org.wav
		7	s_no_2t_1_org.wav
		8	s_no_ft_3_org.wav
		9	sbm_js_x_2_org.wav
		10	sbm_sm_x_2_org.wav
		11	som_fi_x_3_org.wav
		12	som_ot_x_5_org.wav
	b	1	m_ot_x_5_org.wav
		2	m_ot_x_9_org.wav
		3	m_po_x_3_org.wav
		4	m_si_x_3_org.wav
		5	s_cl_2t_3_org.wav
		6	s_cl_mt_2_org.wav
		7	s_no_ft_1_org.wav
		8	s_no_mt_1_org.wav
		9	sbm_sm_x_1_org.wav
		10	sbm_sm_x_6_org.wav
		11	som_fi_x_4_org.wav
		12	som_ot_x_3_org.wav