# Supplementary Figures associated with:

Maas, E., Mailend, M.-L., & Guenther, F. H.

Feedforward and feedback control in Apraxia of Speech (AOS): Effects of noise masking on vowel production.

# Preliminaries

- Groups:
  - Younger controls (YCON) (N=11)
  - Older controls (OCON) (N=12)
  - Apraxia of Speech (AOS) (N=6)
  - Aphasia, no AOS (Aph) (N=4)
- 5 vowels:
  - /æ/ ‘ae’
  - /ɛ/ ‘eh’
  - /i/ ‘ee’
  - /u/ ‘oo’
  - /ʌ/ ‘uh’
- Mel-transformed formant values
- Measured at 20%, 50%, and 80% of vowel
- Measures:
  - Vowel Duration
  - Average Vowel Spacing (AVS)
  - Vowel Dispersion

# Participant Descriptions

# Participant AOS 200

Participant AOS 200 was a 58-year-old right-handed man, with lesions in Broca's area, the anterior insula and the prefrontal gyrus (based on MRI scans) following a stroke in the left middle cerebral artery territory four and a half years before the study. His primary communication impairment was mild to moderate AOS.

Except for occasional word finding problems, his language was relatively intact, as confirmed by his performance within normal limits on the WAB-R (Kertesz, 2006: AQ = 94.2).

Performance on the ABA-2 (Dabul, 2000) indicated a mild oral apraxia but no evidence of limb apraxia. His voice quality was mildly breathy but there were no other signs of dysarthria. He had minor paresis in his right arm.

# Participant AOS 201

Participant AOS 201 was a 68-year-old right-handed man who suffered a stroke in the left middle cerebral artery territory more than six years prior. He also reported a concussion six years before his stroke with no lasting consequences. No lesion information was available. He held a Masters degree, completed several years of doctoral studies, and was a computer/IT specialist prior to his stroke. His AOS was judged to be relatively mild.

He demonstrated a mild limb apraxia and a mild oral apraxia, as well as a mild right-sided weakness of the lips which affected his speech. He also exhibited mild weakness in his right arm.

The WAB-R indicated a very mild anomic aphasia (AQ = 93.2), characterized by occasional word-finding difficulties and some difficulties in understanding sequential commands.

# Participant AOS 203

Participant AOS 203 was a 67-year-old right-handed man who suffered a left medial cerebral artery ischemic stroke more than two and half years before the study, which resulted in lesions in the left insular cortex and portions of posterior frontal and left parietal lobes. He was bilingual in Spanish and English, and had completed high school and was previously employed as a train mechanic and welder. His AOS was judged to be moderate to severe.

Performance on the ABA-2 (Dabul, 2000) also indicated a mild oral apraxia and a mild limb apraxia. An oral mechanism and motor speech examination (Duffy, 2005) revealed mild right-sided weakness of the cheek and tongue and an occasional harsh voice quality, suggesting a mild unilateral upper motor neuron dysarthria.

Aphasia testing revealed a moderate to severe Broca's aphasia (AQ = 50.3), characterized by severe word finding difficulties and occasional semantic paraphasias, output restricted largely to single words, and some difficulties with comprehension of sequential commands in the context of relatively intact single word and yes/no question comprehension.

# Participant AOS 204

Participant AOS 204 was a 56-year-old woman who was diagnosed with a glioblastoma in the left anterior temporal lobe. She underwent a craniotomy to remove the tumor and suffered a post-operative fronto-temporal hemorrhage approximately five and a half years prior to the study. She had a high school degree and was a baker prior to her stroke. She was bilingual in Spanish and English. Her AOS was judged to be mild to moderate.

An oral mechanism and motor speech exam (Duffy, 2005) revealed a slightly weak cough and glottal stop, but no other abnormalities and no evidence for dysarthria. She had weakness in the right arm and a resting tremor in her left hand, and was in a wheelchair. A mild limb apraxia and a mild oral apraxia were also noted.

Aphasia testing indicated a moderate Broca's aphasia (AQ = 58.7), characterized by agrammatic output consisting largely of single-word utterances and short phrases, word-finding difficulties, relatively intact single-word and yes/no question comprehension, and some difficulties with comprehension of sequential commands. She would occasionally pluralize singular nouns (e.g., 'keys' instead of 'key', 'walls' instead of 'wall').

# Participant AOS 205

Participant AOS 205 was a 59-year-old woman who suffered a stroke in the left middle cerebral artery territory five years before the study. No lesion information was available. She had a high school diploma and worked as a dental office assistant prior to her stroke. Her AOS was judged to be mild to moderate in severity.

Results from the WAB-R indicated some word-finding problems and difficulties with comprehension of sequential commands (anomic aphasia, AQ = 82.1). She produced mainly short sentences but these were generally grammatically correct.

There was no evidence of limb or oral apraxia. A mild rightsided facial weakness might have contributed to imprecision on some sounds (i.e. mild unilateral upper motor neuron dysarthria). She had a significant hemiparesis in her right arm.

# Participant AOS 206

Participant AOS 206 was a 72-year-old man who had a left hemisphere stroke and a small right hemisphere stroke more than seven years prior to the study. MRI scans showed a relatively large left perisylvian lesion extending to the middle parts of medial temporal gyrus anteriorly and inferiorly and to the inferior parietal lobule and occipital lobe dorsally and posteriorly. He held a Bachelor's degree and was a photo journalist and a private pilot instructor before his stroke. His mild AOS was characterized mainly by occasional syllable segregation, effortful struggle on multisyllabic words and occasional consonant and vowel distortions that were relatively consistent in location. His speech included more fluent stretches of speech than the other AOS participants but his rate was slower than normal. He also displayed intermittent hypernasality, voicing errors, and an automatic-volitional discrepancy in terms of distortions (counting forwards vs. backwards).

The WAB-R classified his aphasia as a moderate Wernicke's aphasia (AQ = 69.3), though his speech was neither paragrammatic nor normally fluent.

He had slight rightsided lip weakness and a breathy voice quality, suggesting a possible mild dysarthria. He reported weakness in his right extremities but did not use a cane.

# Participant Aph 301

Participant Aph 301 was a 68-year-old right-handed man seven years post onset of a stroke in the left middle cerebral artery territory. MRI scans revealed a large lesion extending well into the frontal lobe anteriorly covering Broca's area, beyond the central sulcus into the parietal lobe and anterior and middle part of the temporal lobe.

Results from the WAB-R revealed a moderate aphasia (AQ = 74.9) of the Wernicke type, characterized by frequent word-finding difficulties, semantic and phonological paraphasias, empty words in the context of normally fluent speech with good grammatical organization, and difficulties understanding sequential commands.

Although he produced sound substitutions, additions, and omissions, he did not exhibit sound distortions or speech initiation difficulties. He had a mild oral apraxia but no limb apraxia, and although he had some minor weakness in the right side of the face, there were no perceptible effects on speech production.

# Participant Aph 304

Participant Aph 304 was a 64-year-old right-handed woman who suffered a left hemisphere stroke in the middle cerebral artery territory nearly three years prior. Neurological records revealed lesions in the temporal, occipital, and posterior frontal lobes. She had completed several years of college and worked as a youth counselor before her stroke.

Her speech was fluent but relatively empty, characterized by occasional word-finding problems and semantic and phonologic paraphasias. No sound distortions were noted. Results from the BDAE (Goodglass et al., 2000) indicated moderate conduction aphasia (2-3 out of 5).

There was no evidence for limb or oral apraxia, and no signs of neuromuscular impairments.

# Participant Aph 306

Participant Aph 306 was a 40-year-old right-handed man who had a stroke in the left middle cerebral artery territory three years prior to the study. He had completed some years of college and he was a salesman before his stroke. MRI scans revealed a lesion in temporal, parietal and inferior frontal lobes.

Testing indicated a mild anomic aphasia (AQ = 92.0), with occasional word-finding difficulties and some problems with comprehension of sequential commands. His speech was fluent with good grammatical organization and normal sentence length.

Some phonemic paraphasias but no sound distortions were noted. His oral mechanism exam was unremarkable and there were no signs of dysarthria, oral apraxia, or limb apraxia.

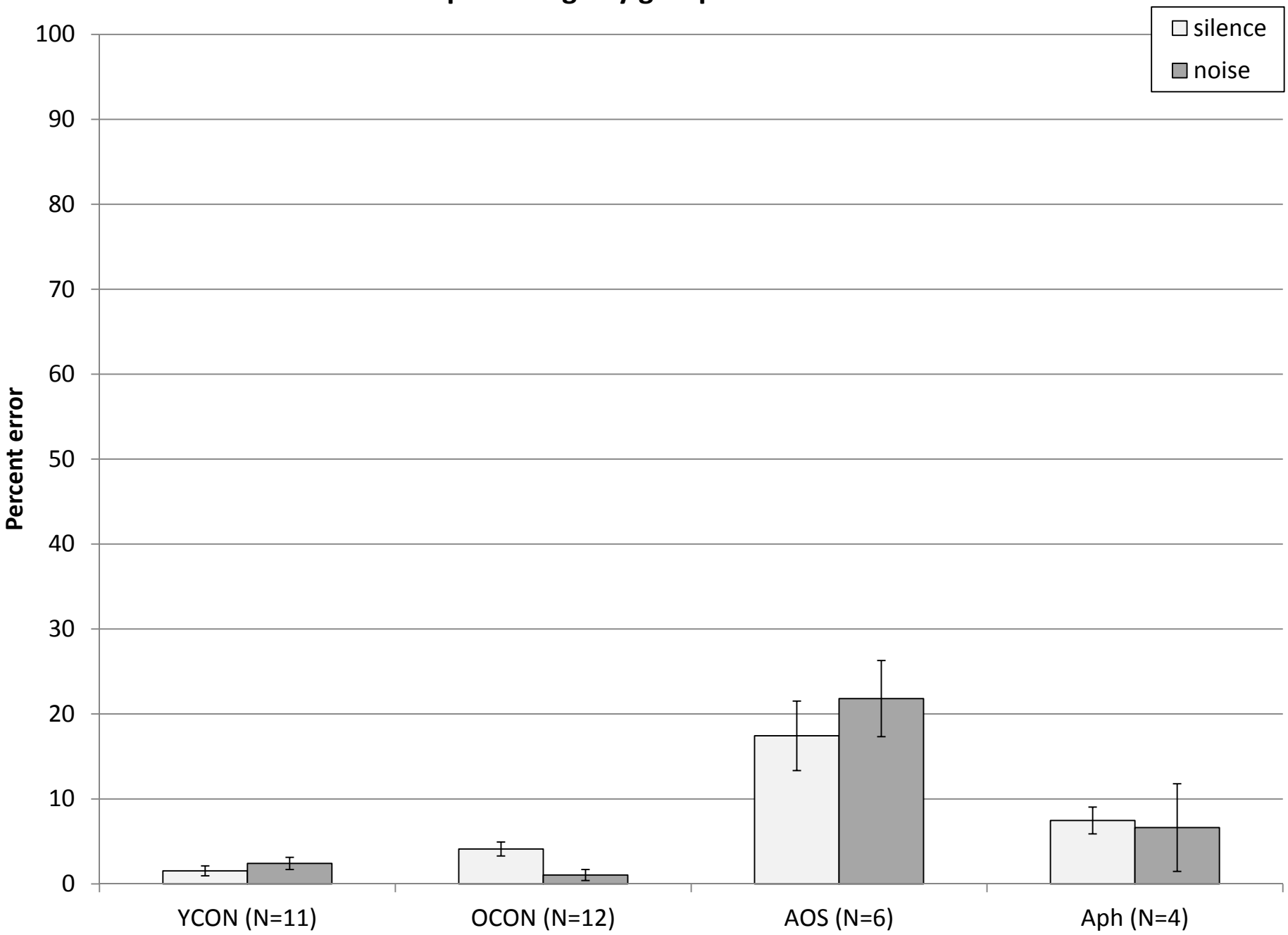
# Participant Aph 307

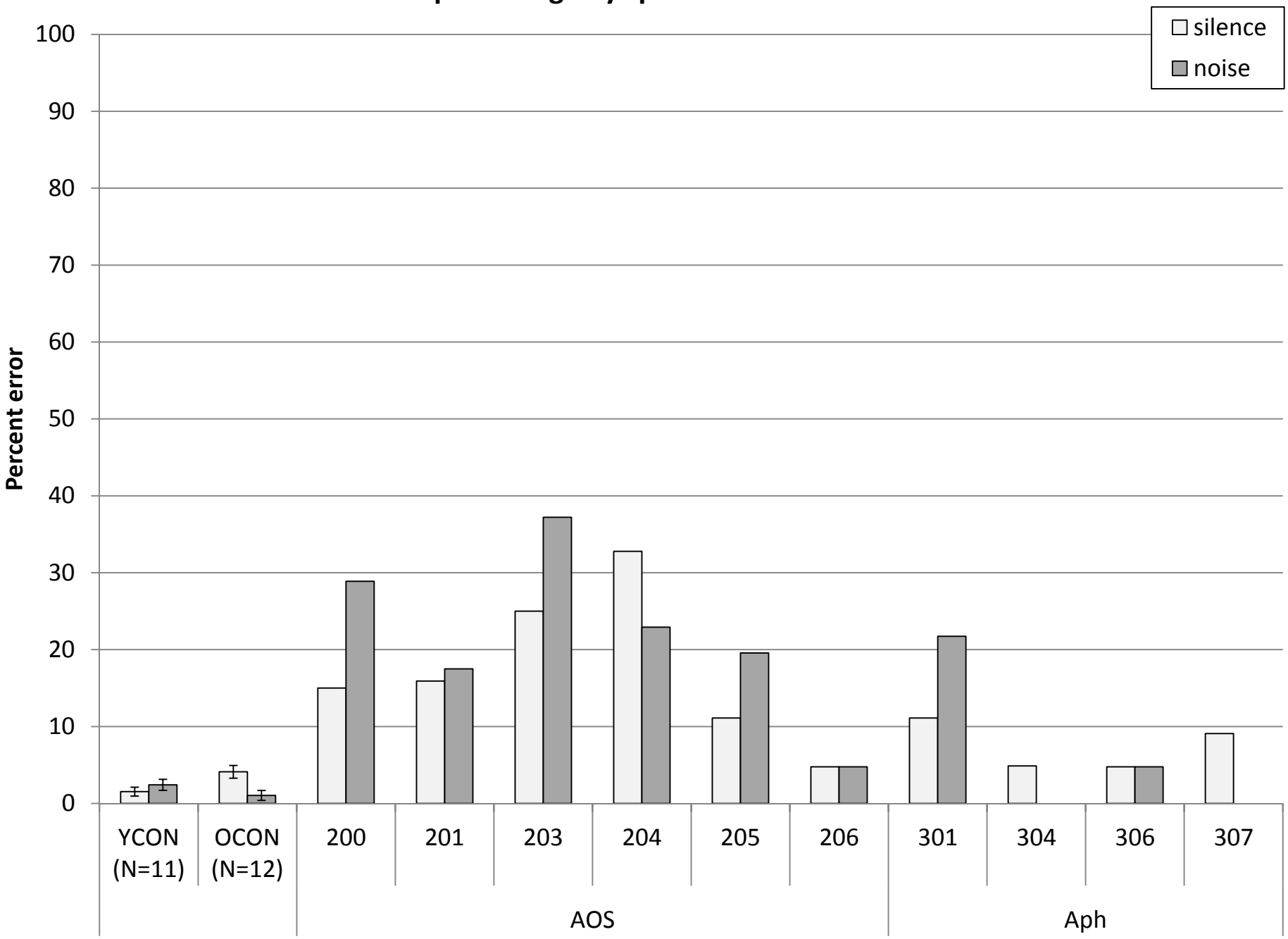
Participant Aph 307 was a 57-year-old woman who was 12 years post a cerebrovascular accident in the left middle cerebral artery territory. MRI scans revealed a large perisylvian lesion extending from the inferior frontal gyrus to the temporo-parieto-occipital junction. She had a high school diploma and worked as a financial litigation agent prior to her stroke.

The WAB-R revealed a mild conduction aphasia (AQ = 86.3). Her main difficulties were in comprehension of sequential commands and repetition of words and phrases. Her speech was fluent with short but generally grammatical sentences, and she exhibited some phonological errors that were inconsistent in time and location.

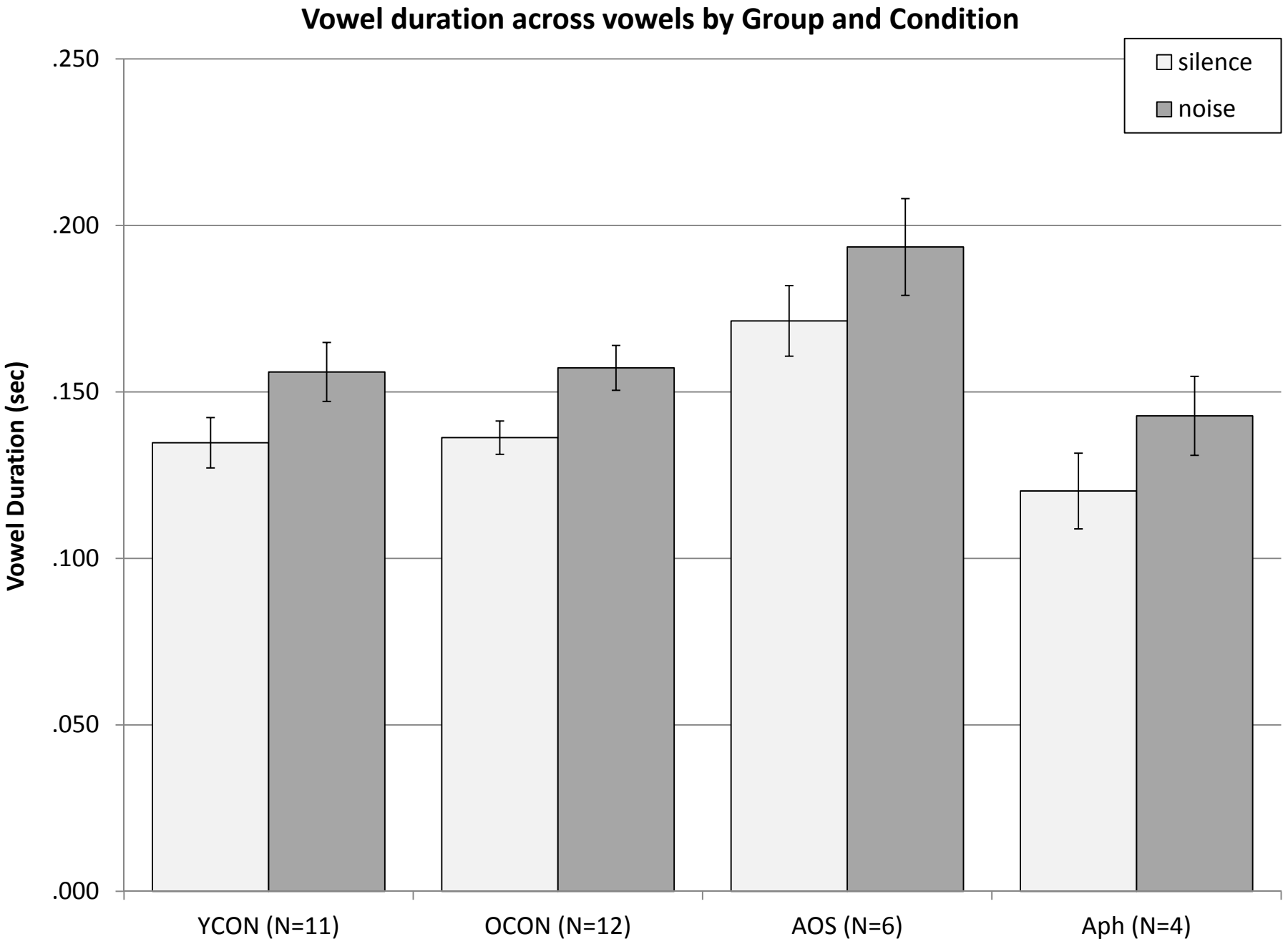
No limb apraxia, oral apraxia, or dysarthria were noted.

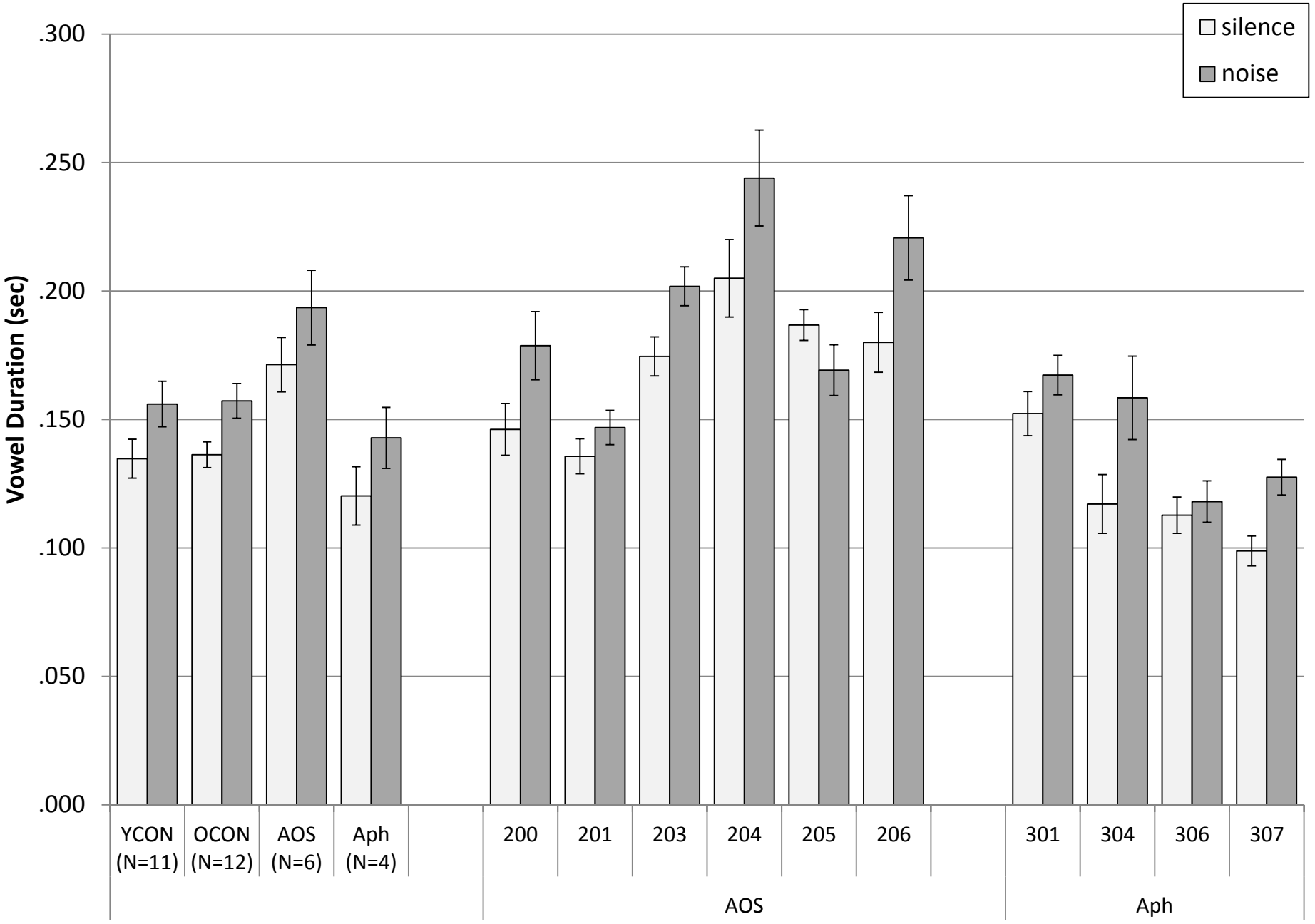
# Error rates

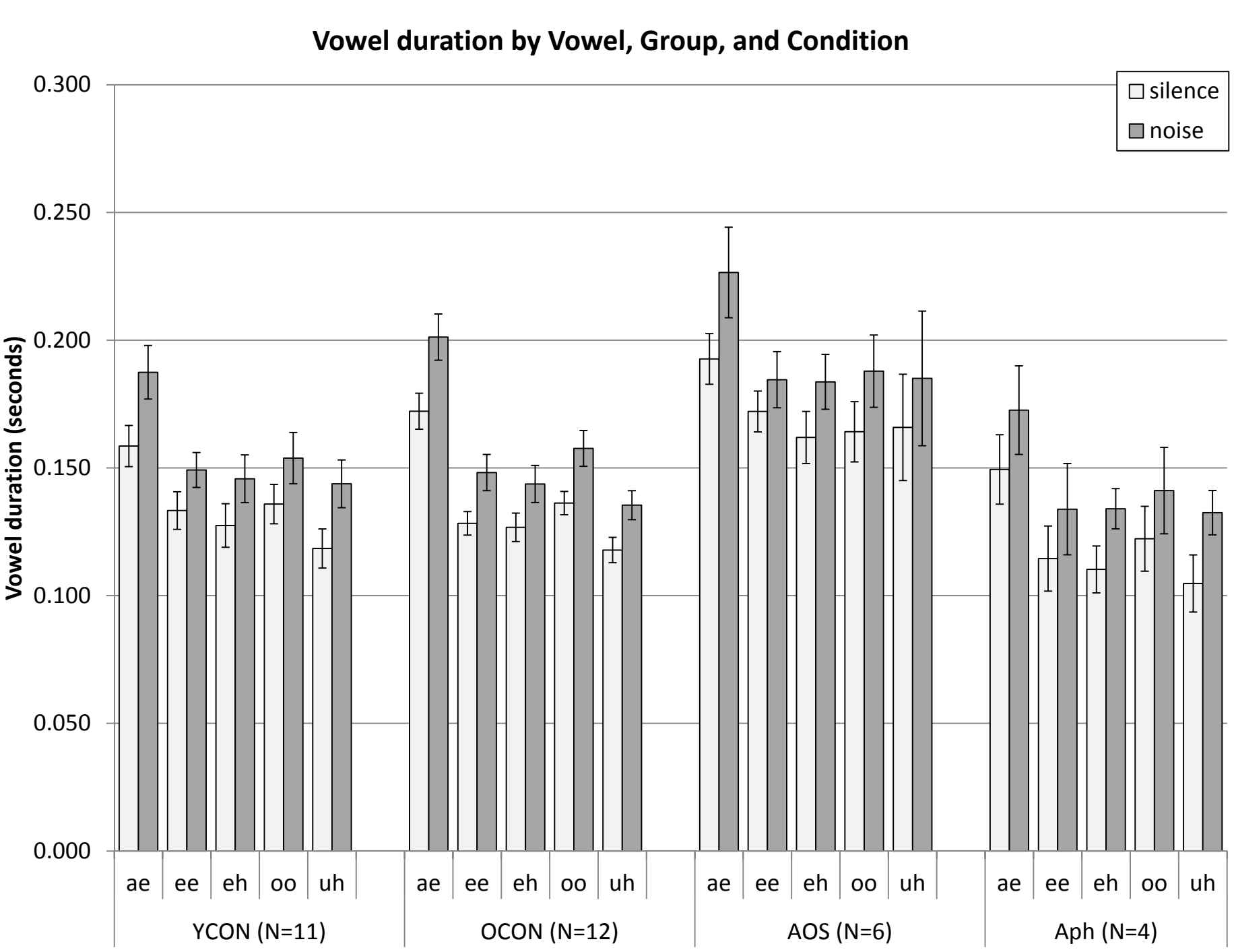

Error percentage by group and condition
silence
noise
Percent error
100
90
80
70
60
50
40
30
20
10
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)


Error percentage by speaker and condition
silence
noise
Percent error
100
90
80
70
60
50
40
30
20
10
0
YCON (N=11)
OCON (N=12)
200
201
203
204
205
206
301
304
306
307
AOS
Aph

# Vowel Duration

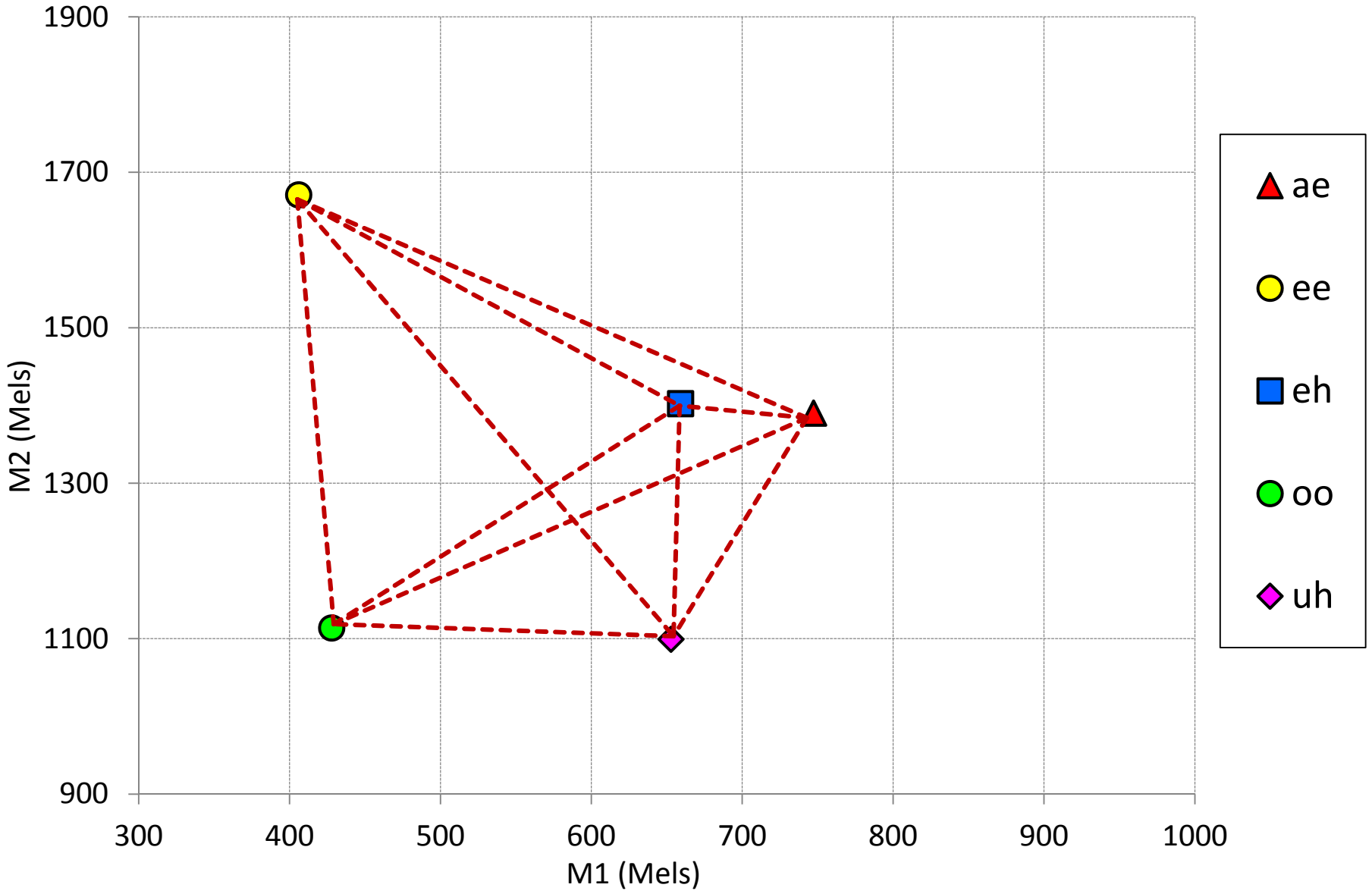

Vowel duration across vowels by Group and Condition
silence
noise
Vowel Duration (sec)
.250
.200
.150
.100
.050
.000
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

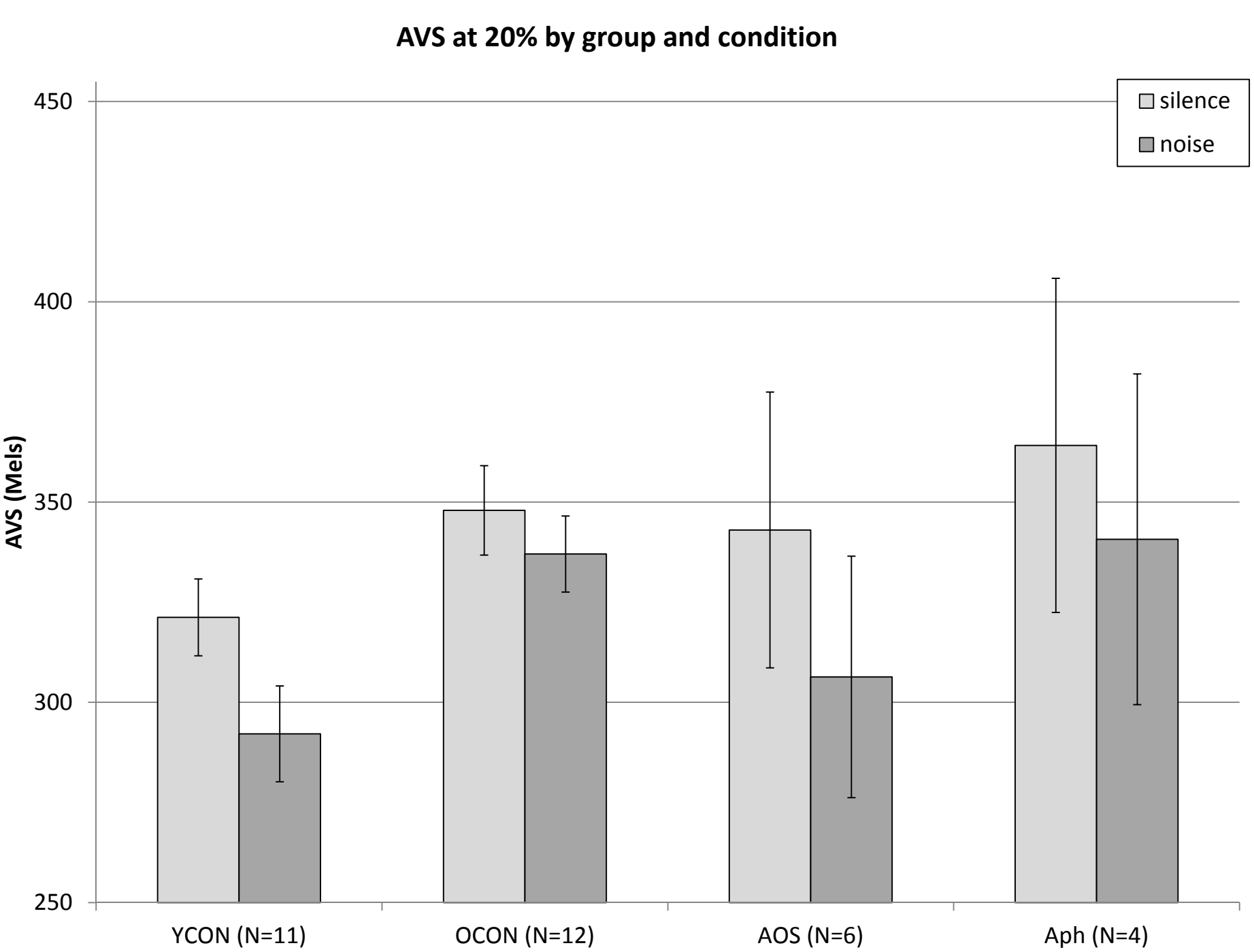

Vowel duration across vowels by participant and condition
silence
noise
Vowel Duration (sec)
.300
.250
.200
.150
.100
.050
.000
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)
200
201
203
204
205
206
301
304
306
307
AOS
Aph

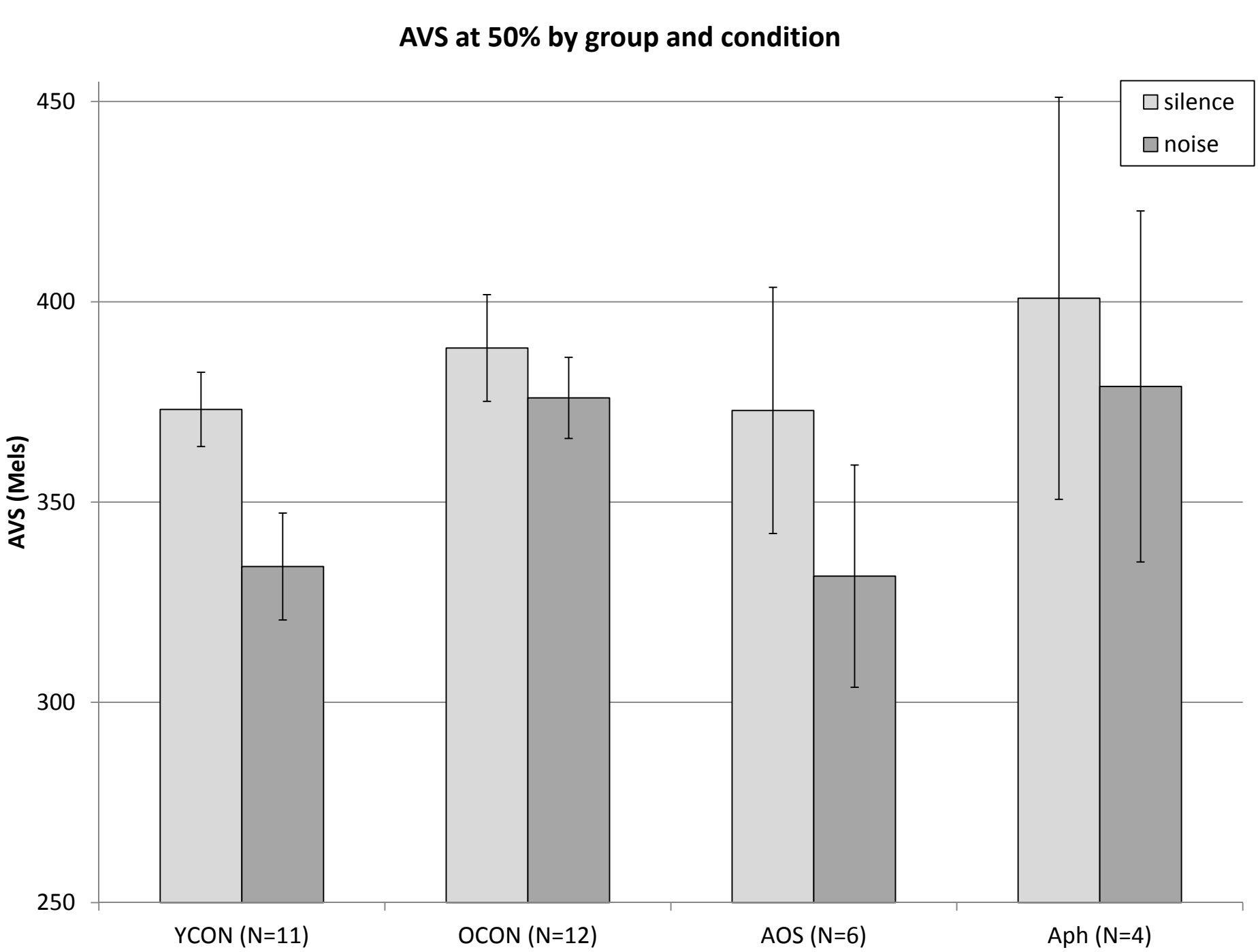

Vowel duration by Vowel, Group, and Condition
Vowel duration (seconds)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
silence
noise
ae
ee
eh
oo
uh
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

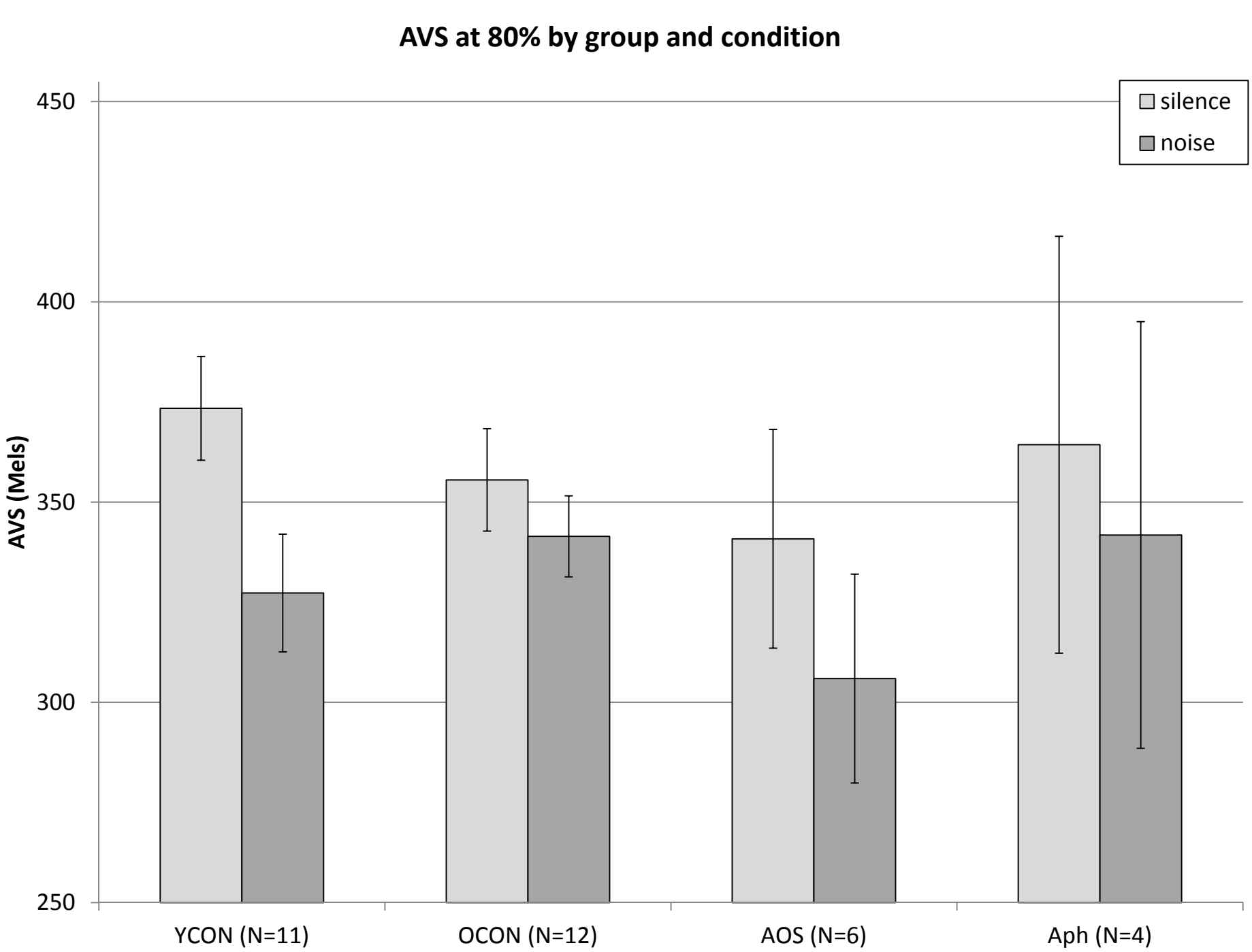
# Average Vowel Spacing (AVS)

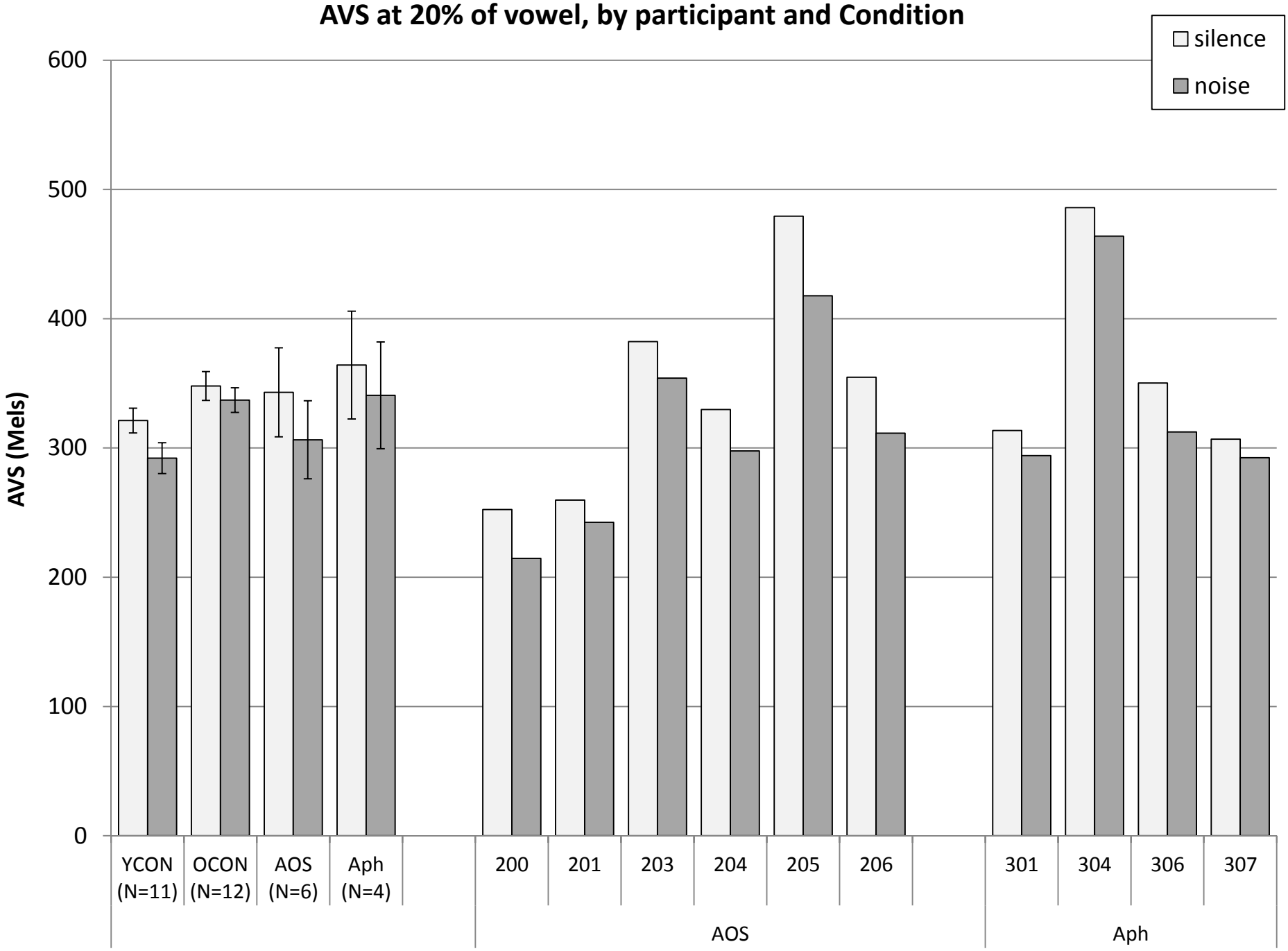
# Vowel contrast: Average Vowel Spacing (AVS) calculation

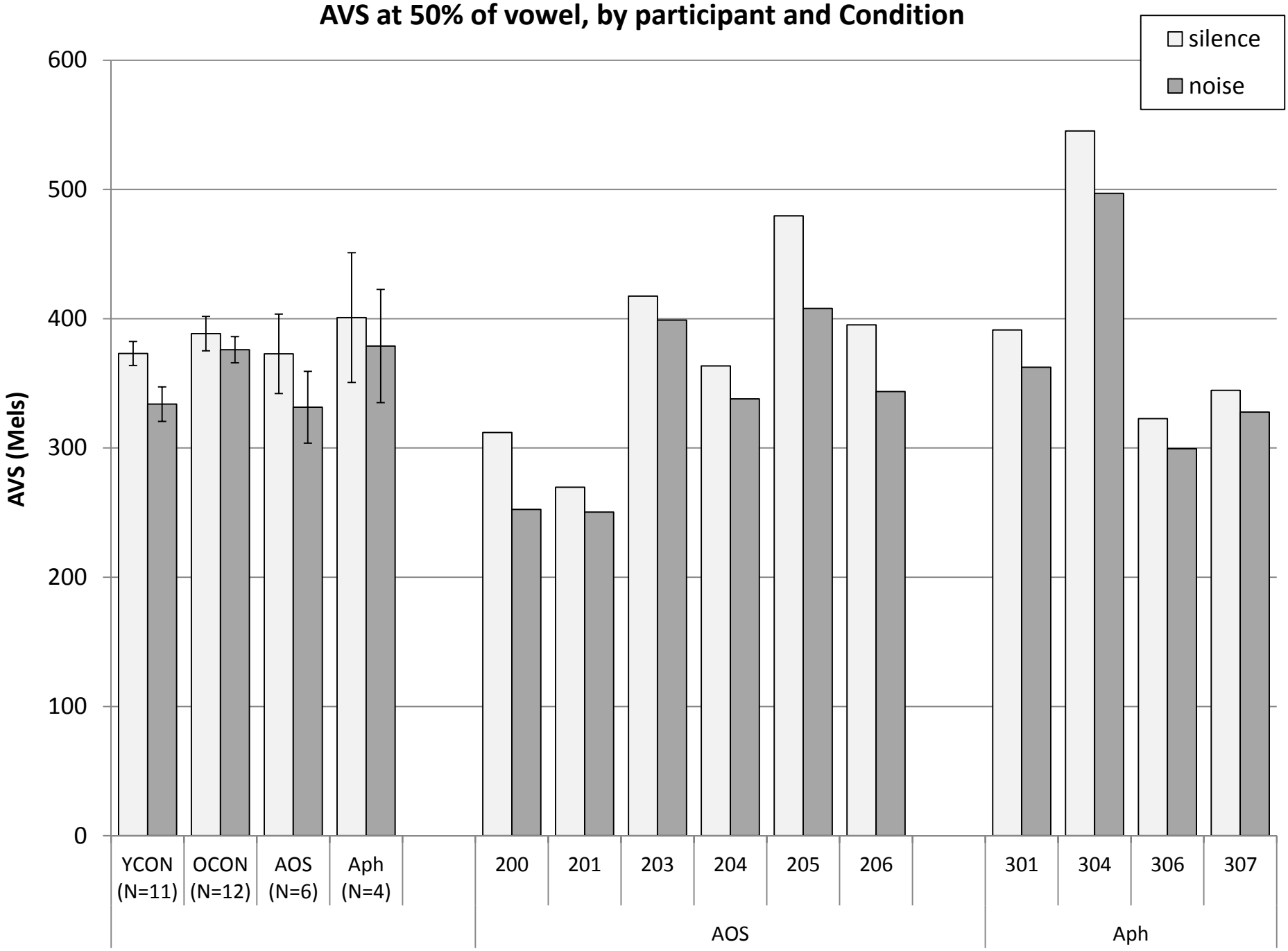


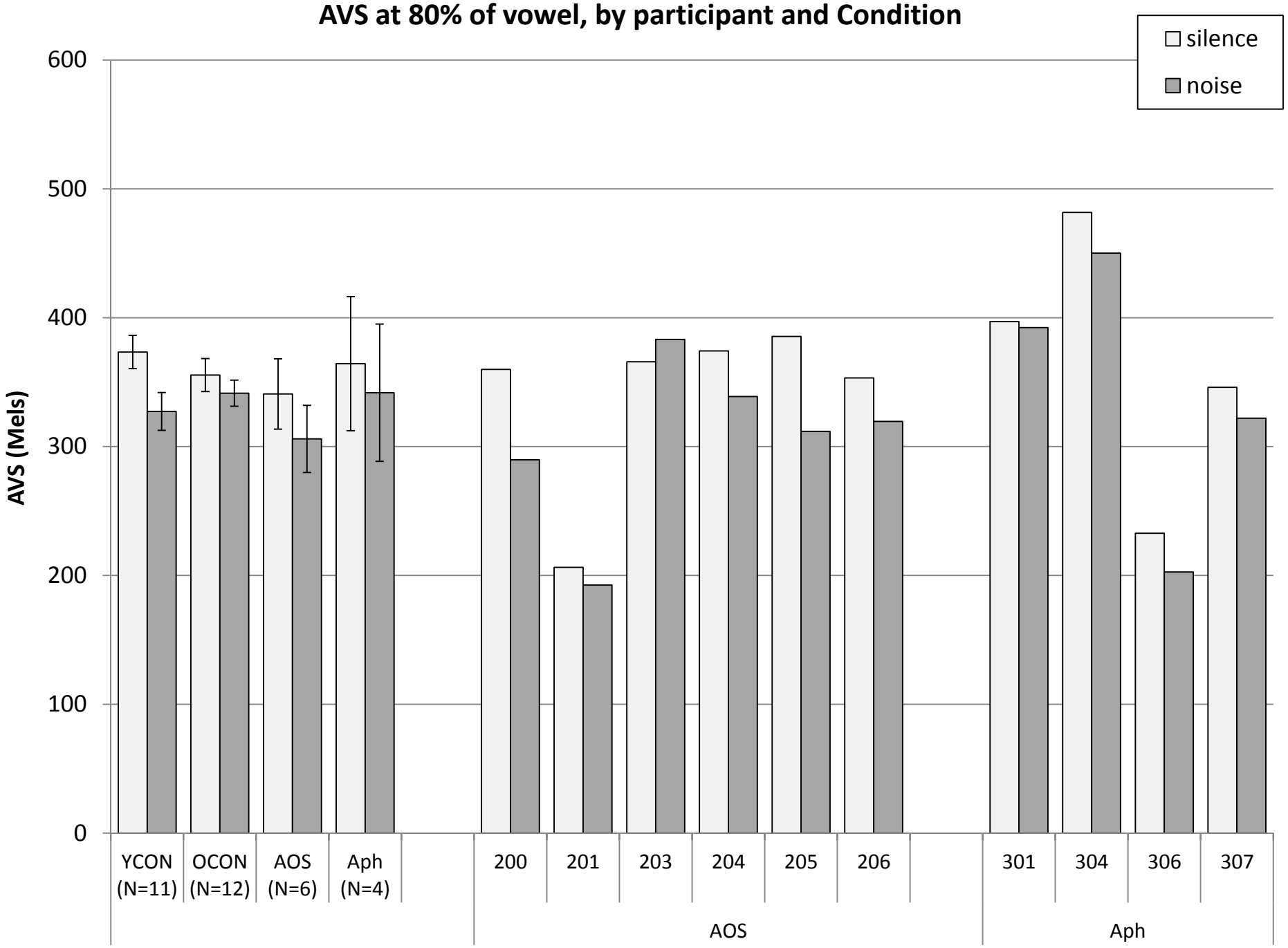

AVS at 20% by group and condition
AVS (Mels)
450
400
350
300
250
silence
noise
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

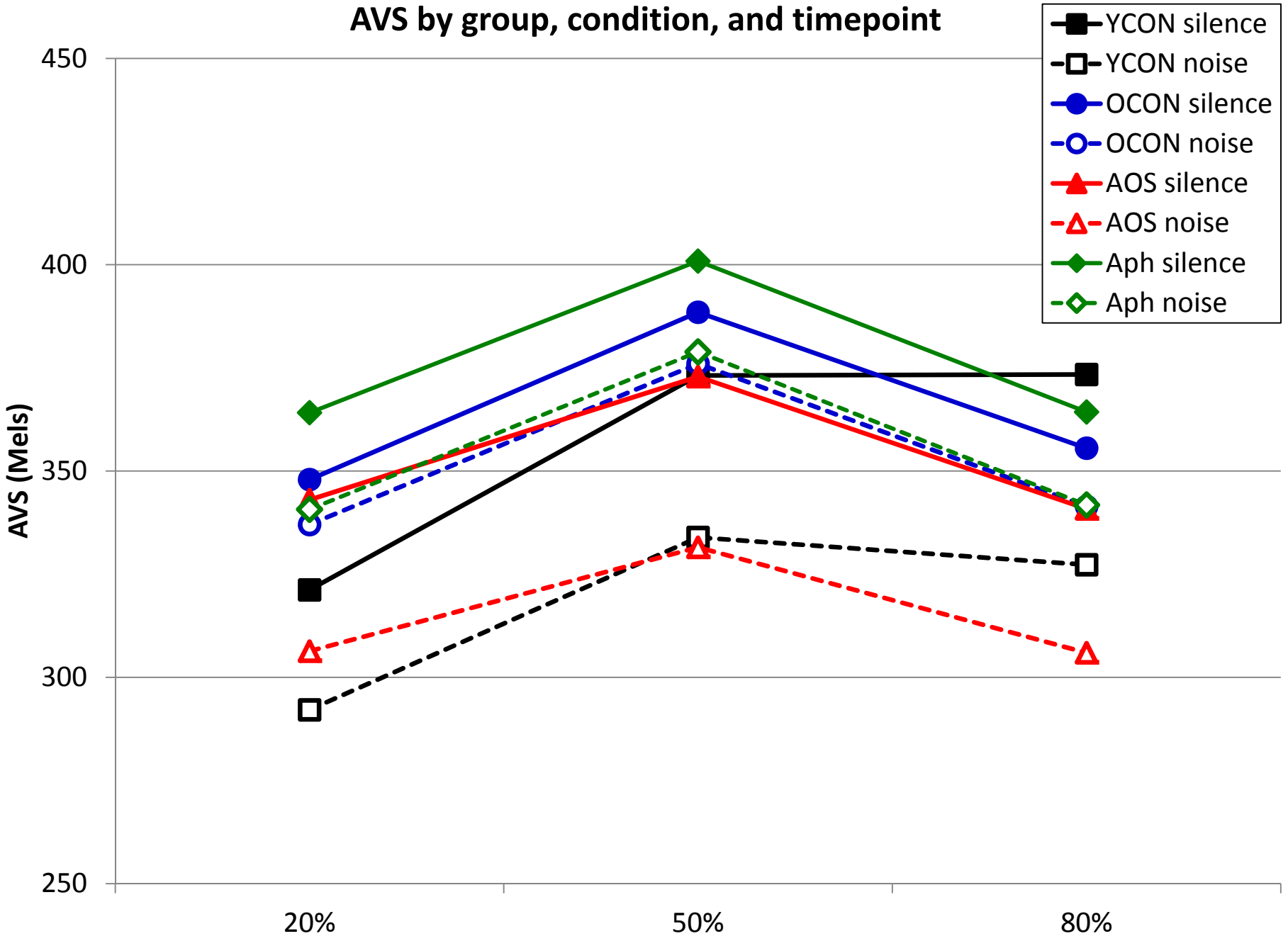

AVS at 50% by group and condition
AVS (Mels)
450
400
350
300
250
silence
noise
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

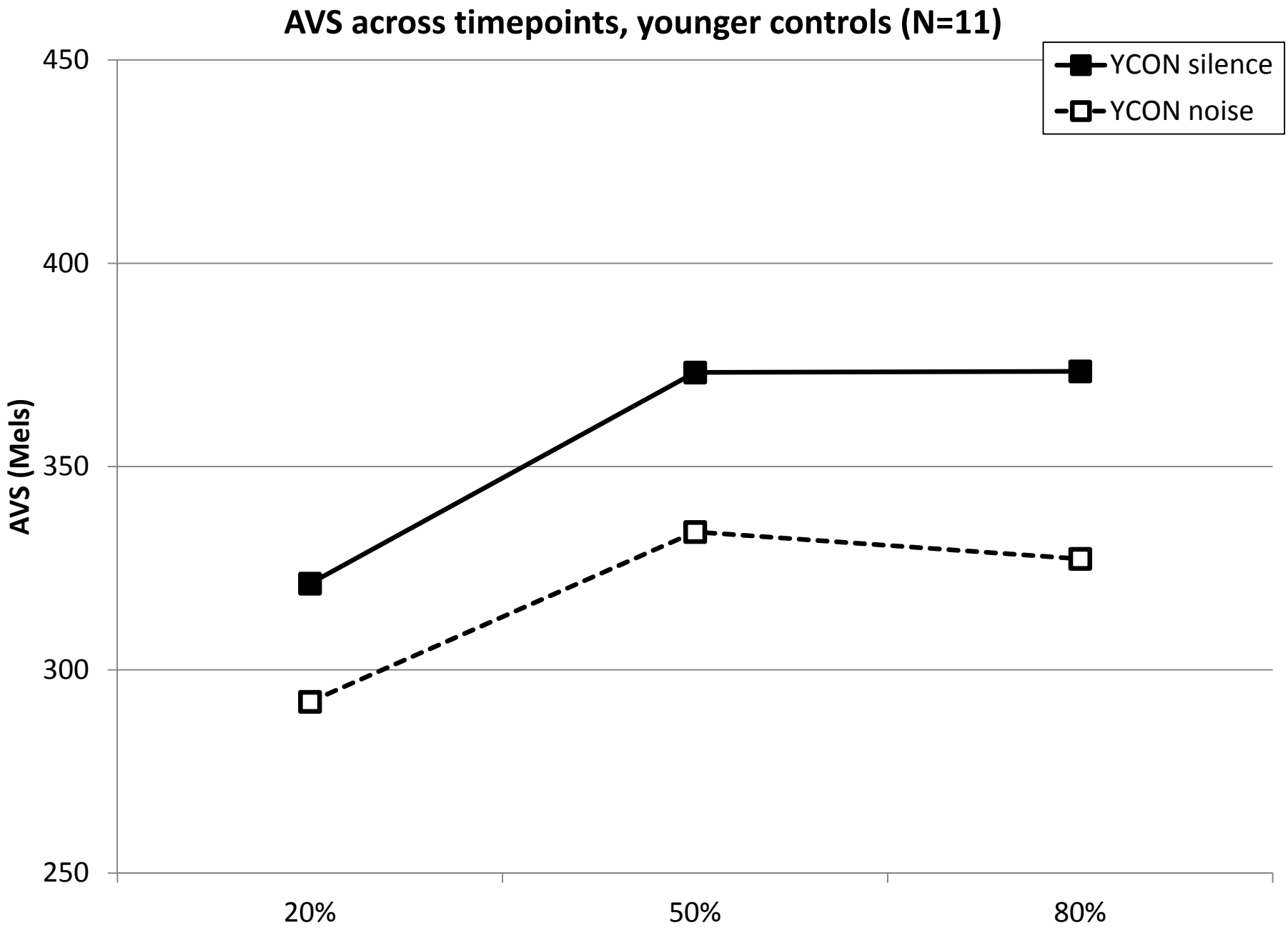

AVS at 80% by group and condition
AVS (Mels)
450
400
350
300
250
silence
noise
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

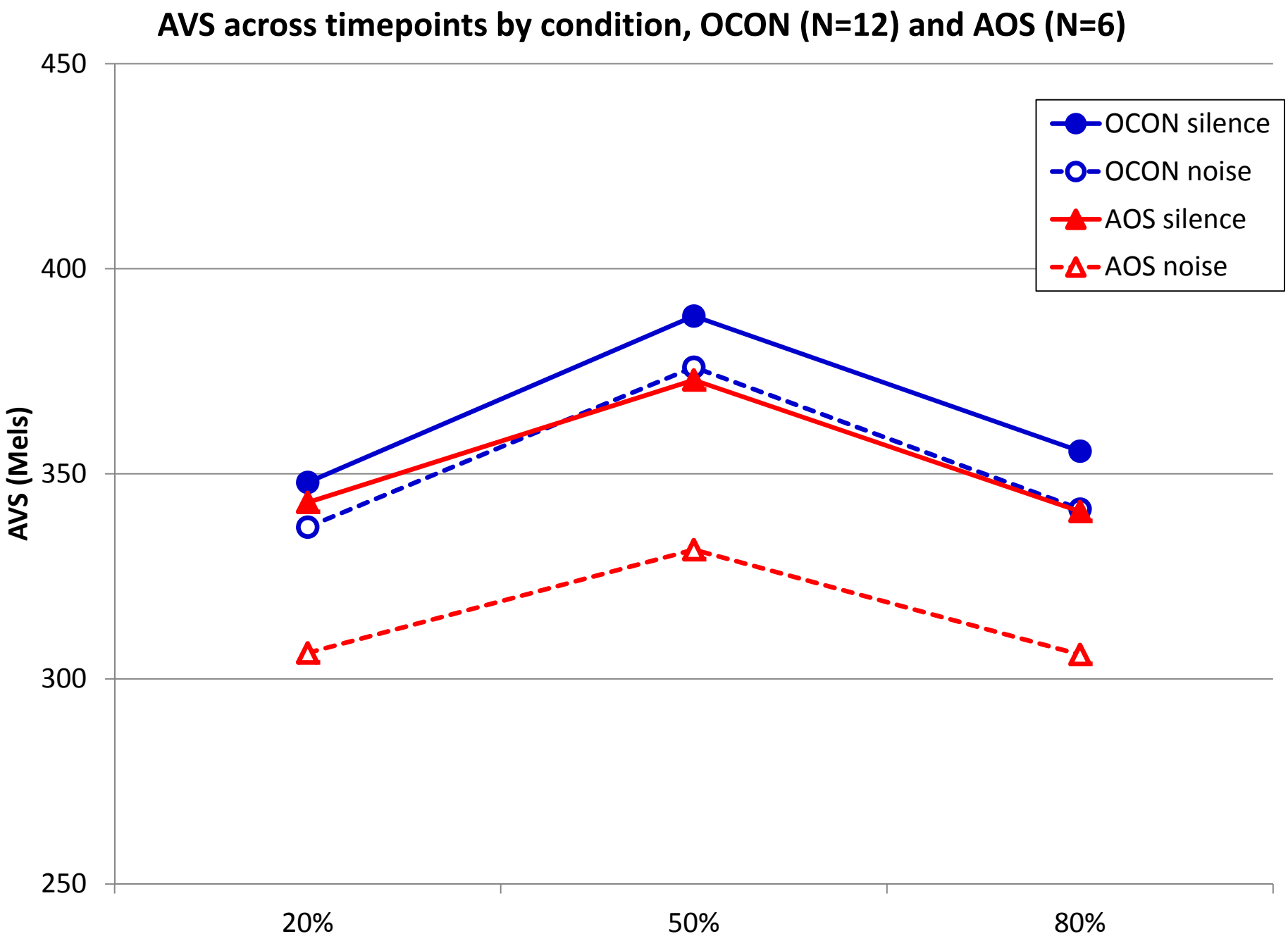

AVS at 20% of vowel, by participant and Condition
silence
noise
AVS (Mels)
600
500
400
300
200
100
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)
200
201
203
204
205
206
301
304
306
307
AOS
Aph

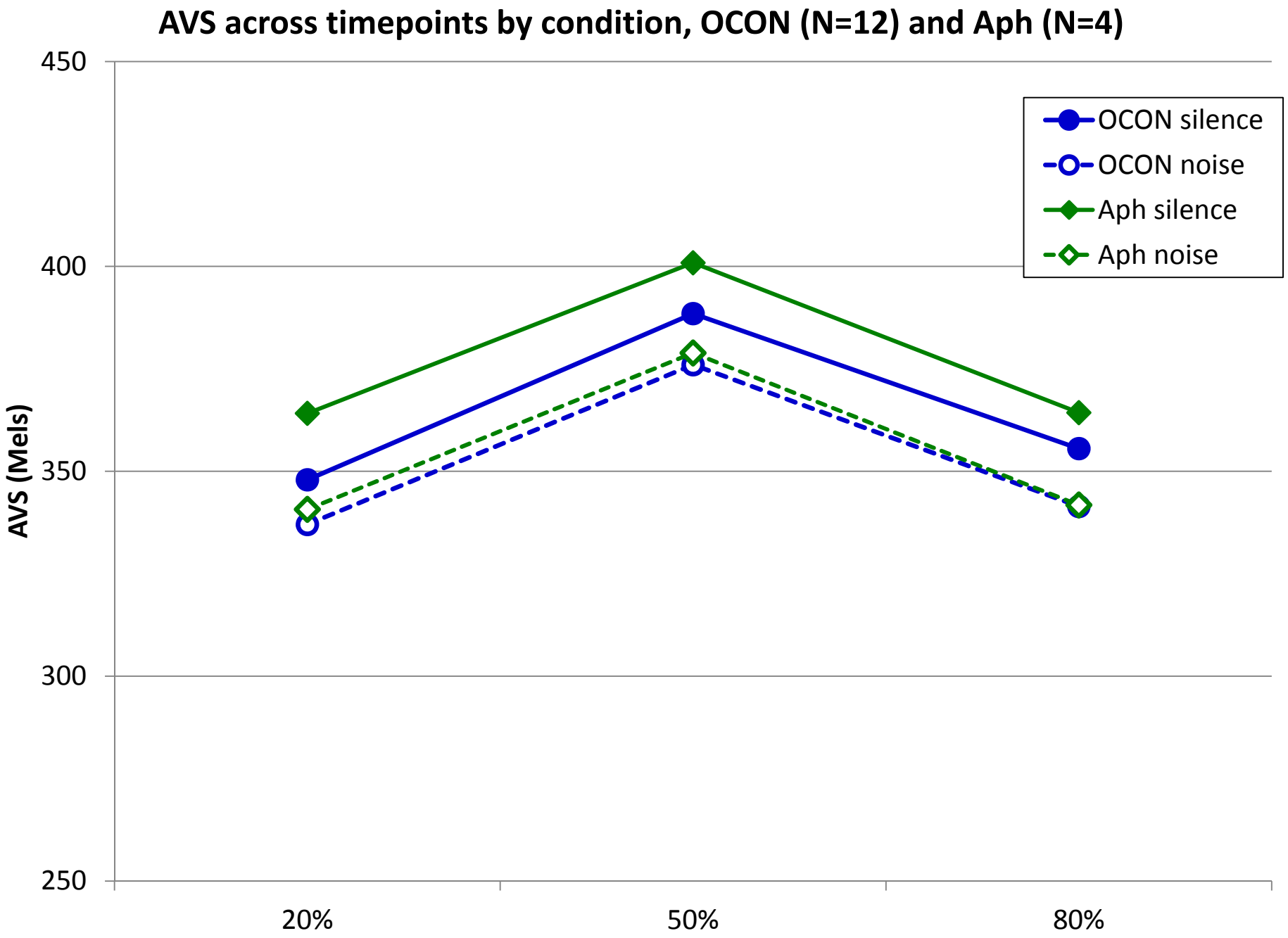

AVS at 50% of vowel, by participant and Condition
silence
noise
AVS (Mels)
600
500
400
300
200
100
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)
200
201
203
204
205
206
301
304
306
307
AOS
Aph

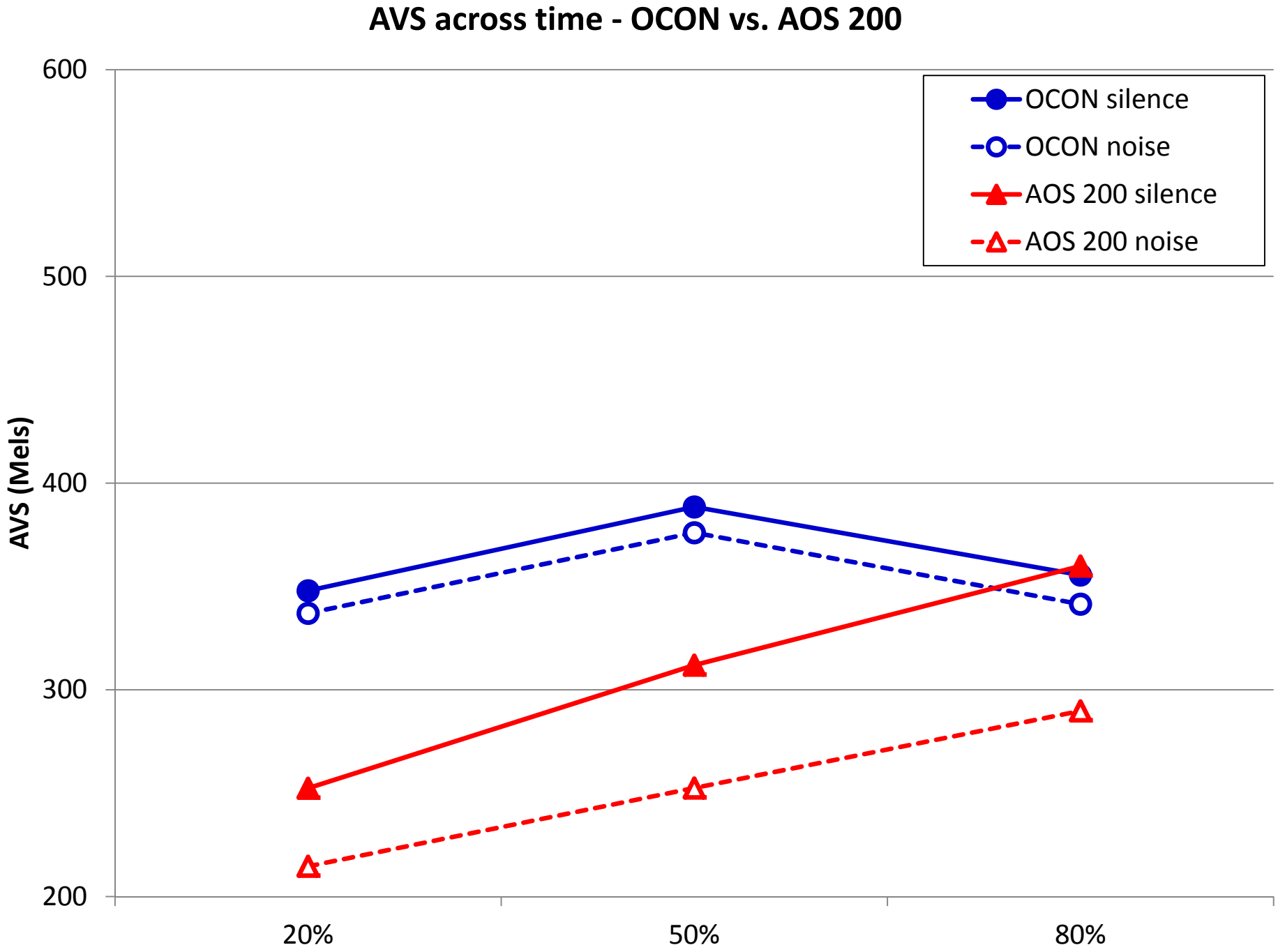

AVS at 80% of vowel, by participant and Condition
silence
noise
AVS (Mels)
600
500
400
300
200
100
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)
200
201
203
204
205
206
301
304
306
307
AOS
Aph

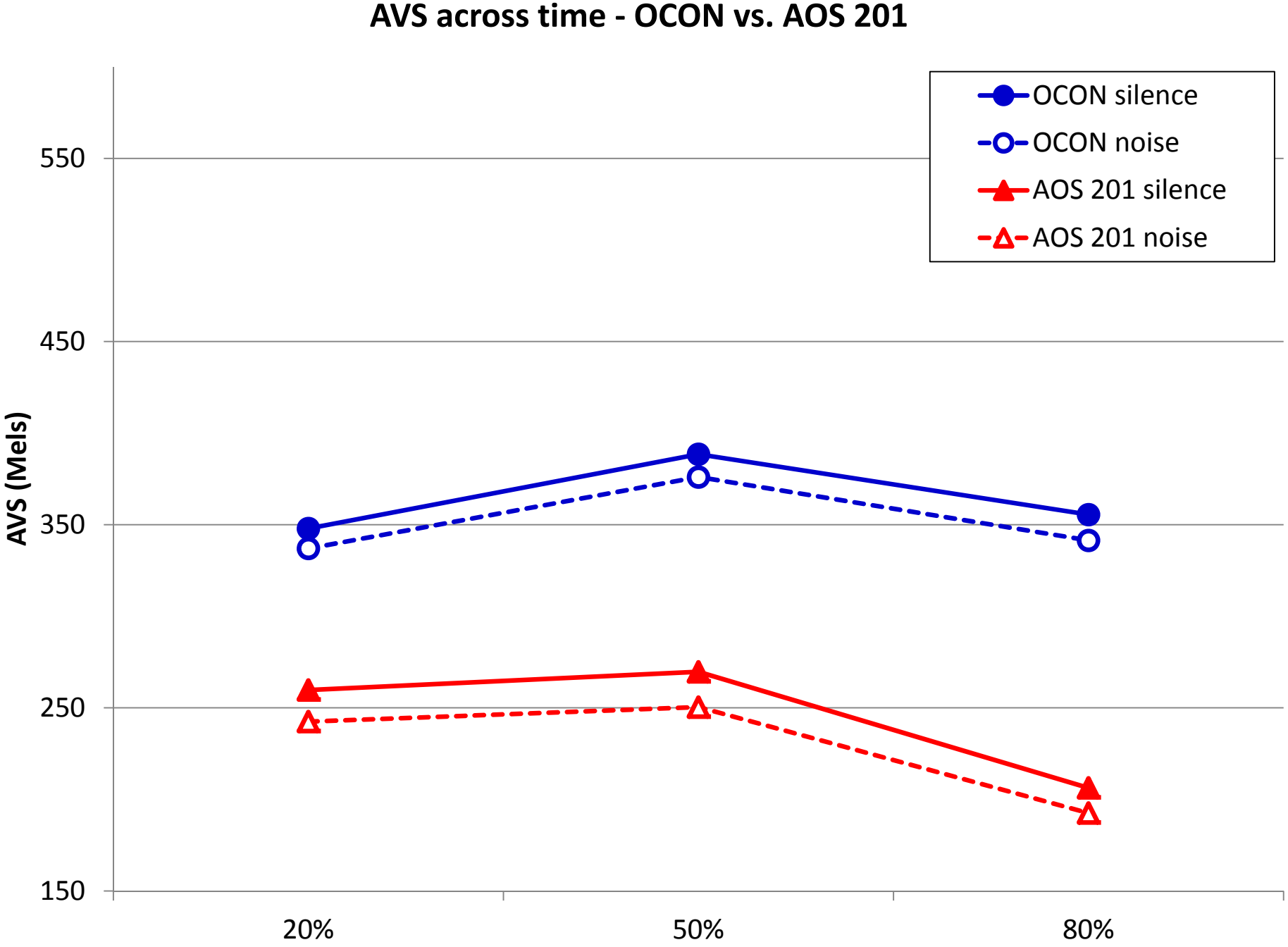

AVS by group, condition, and timepoint
AVS (Mels)
450
400
350
300
250
20%
50%
80%
YCON silence
YCON noise
OCON silence
OCON noise
AOS silence
AOS noise
Aph silence
Aph noise

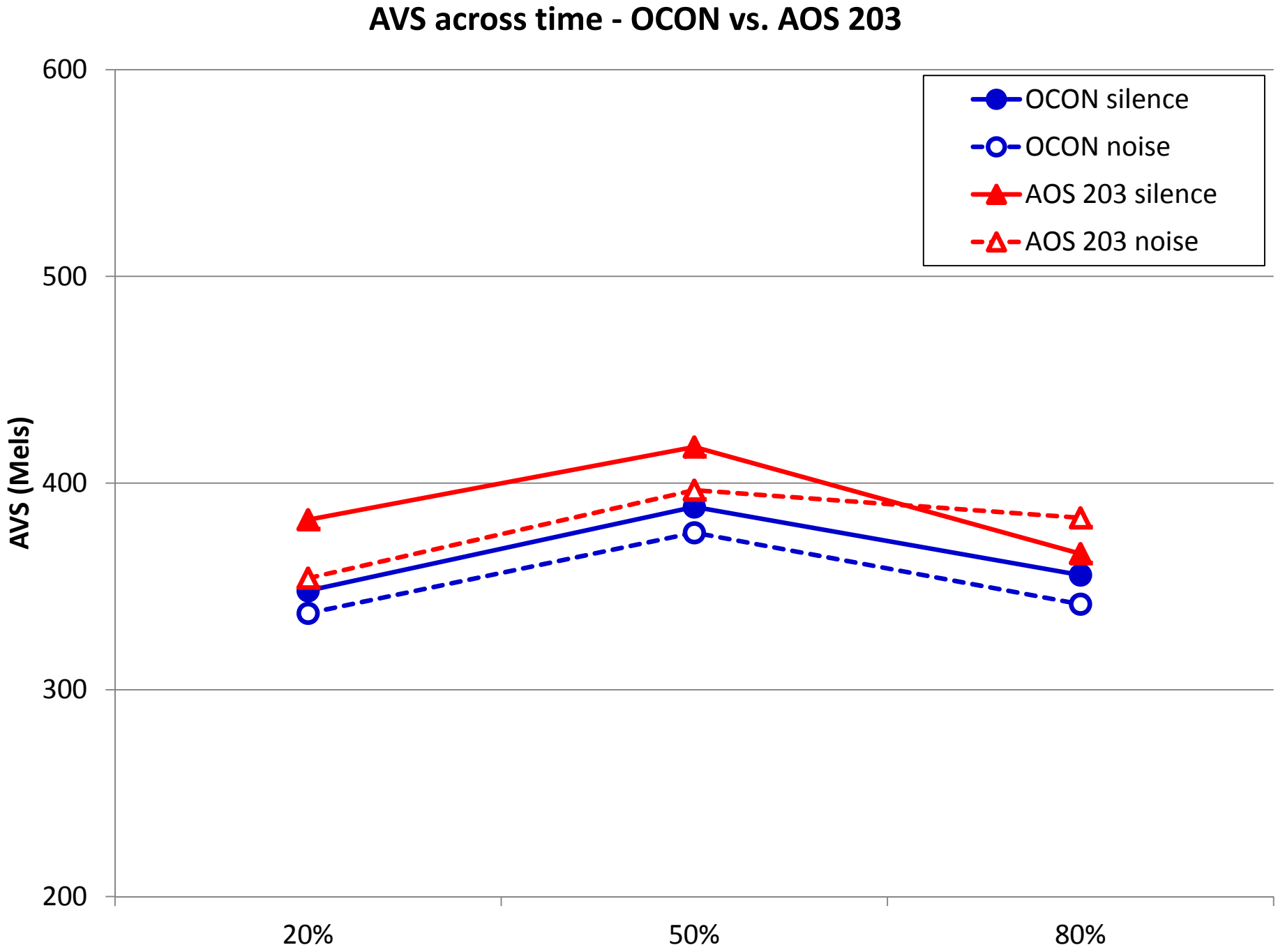

AVS across timepoints, younger controls (N=11)
YCON silence
YCON noise
AVS (Mels)
450
400
350
300
250
20%
50%
80%

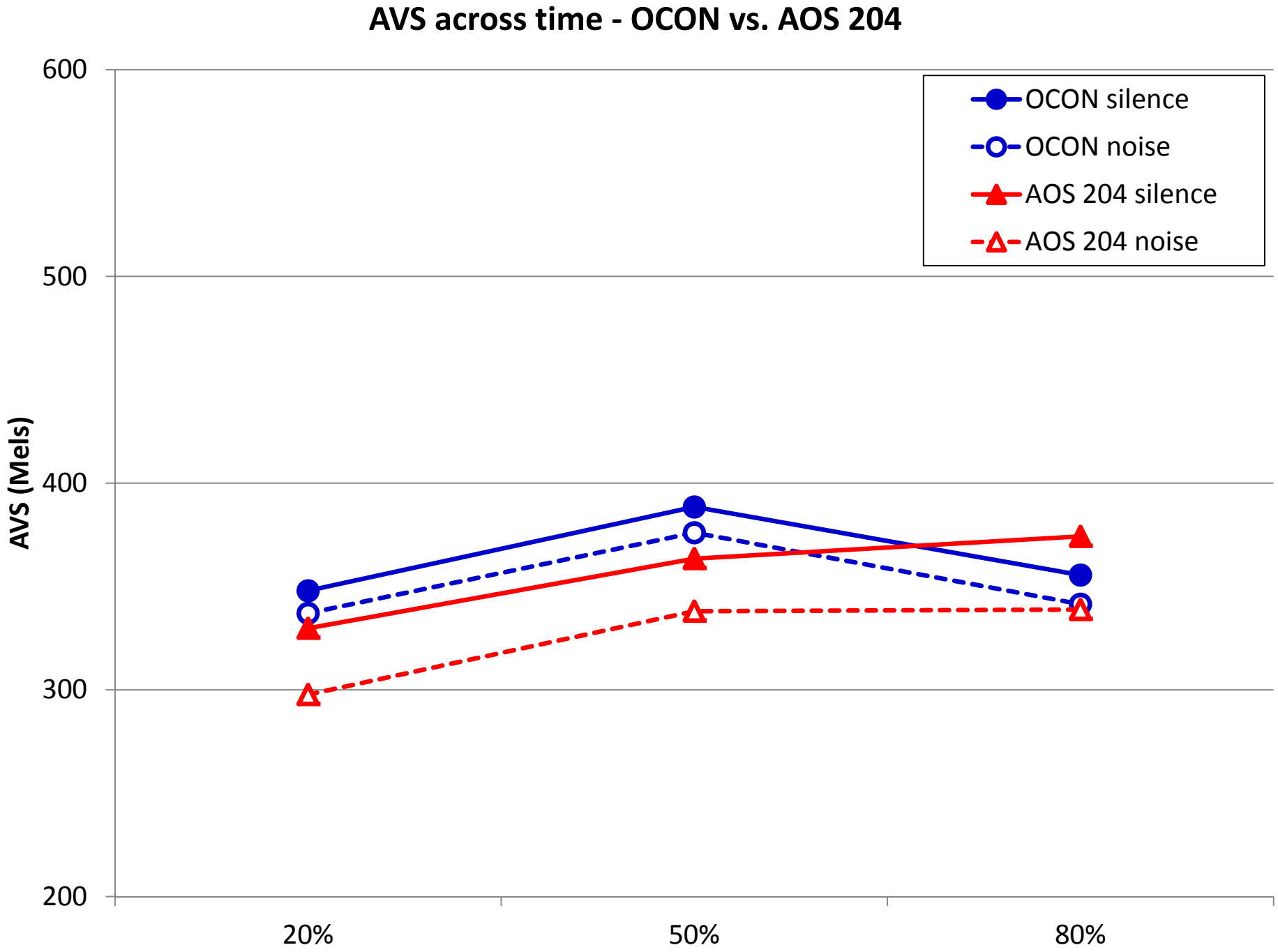

AVS across timepoints by condition, OCON (N=12) and AOS (N=6)
AVS (Mels)
450
400
350
300
250
20%
50%
80%
OCON silence
OCON noise
AOS silence
AOS noise

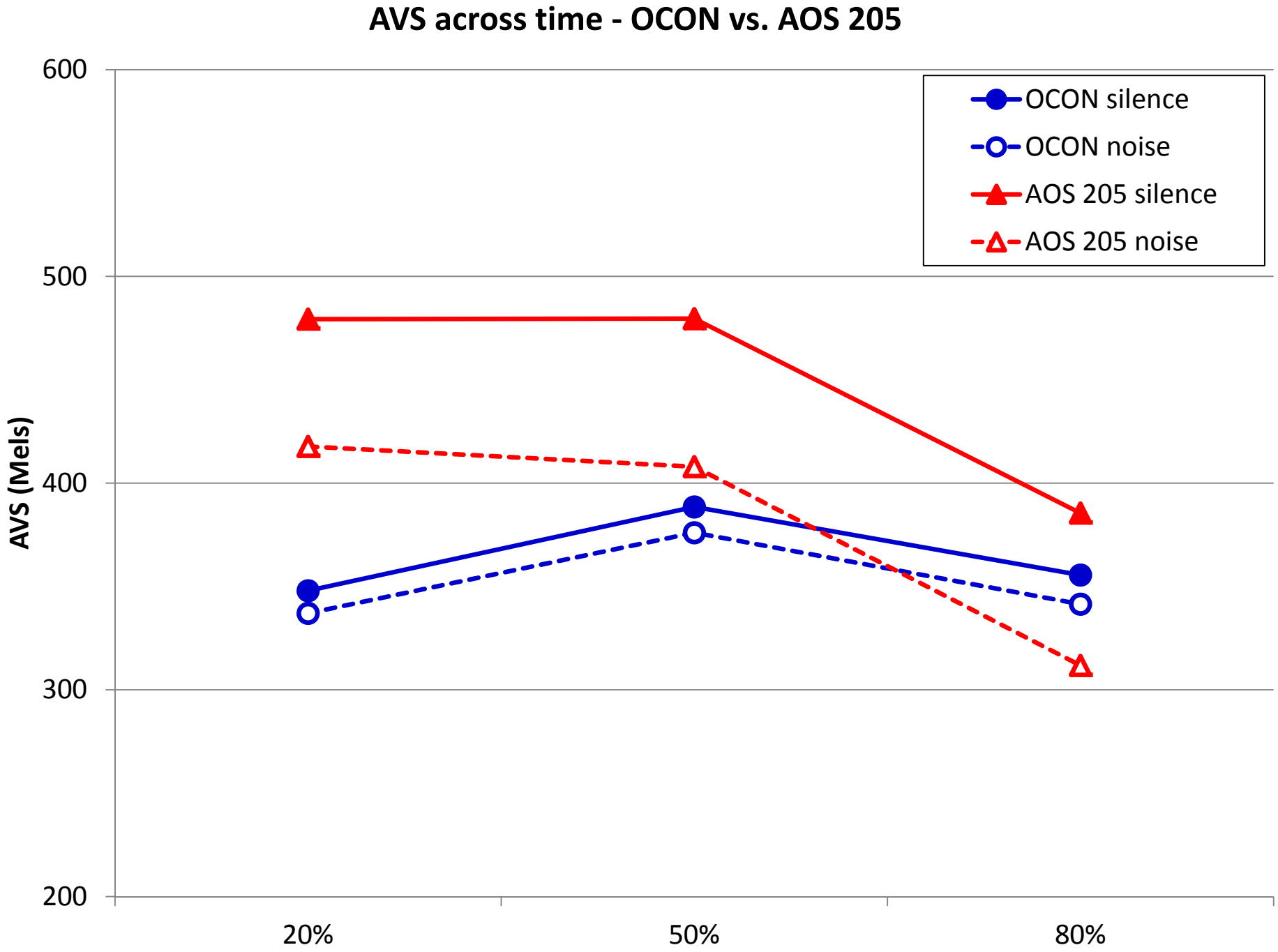

AVS across timepoints by condition, OCON (N=12) and Aph (N=4)
AVS (Mels)
450
400
350
300
250
20%
50%
80%
OCON silence
OCON noise
Aph silence
Aph noise

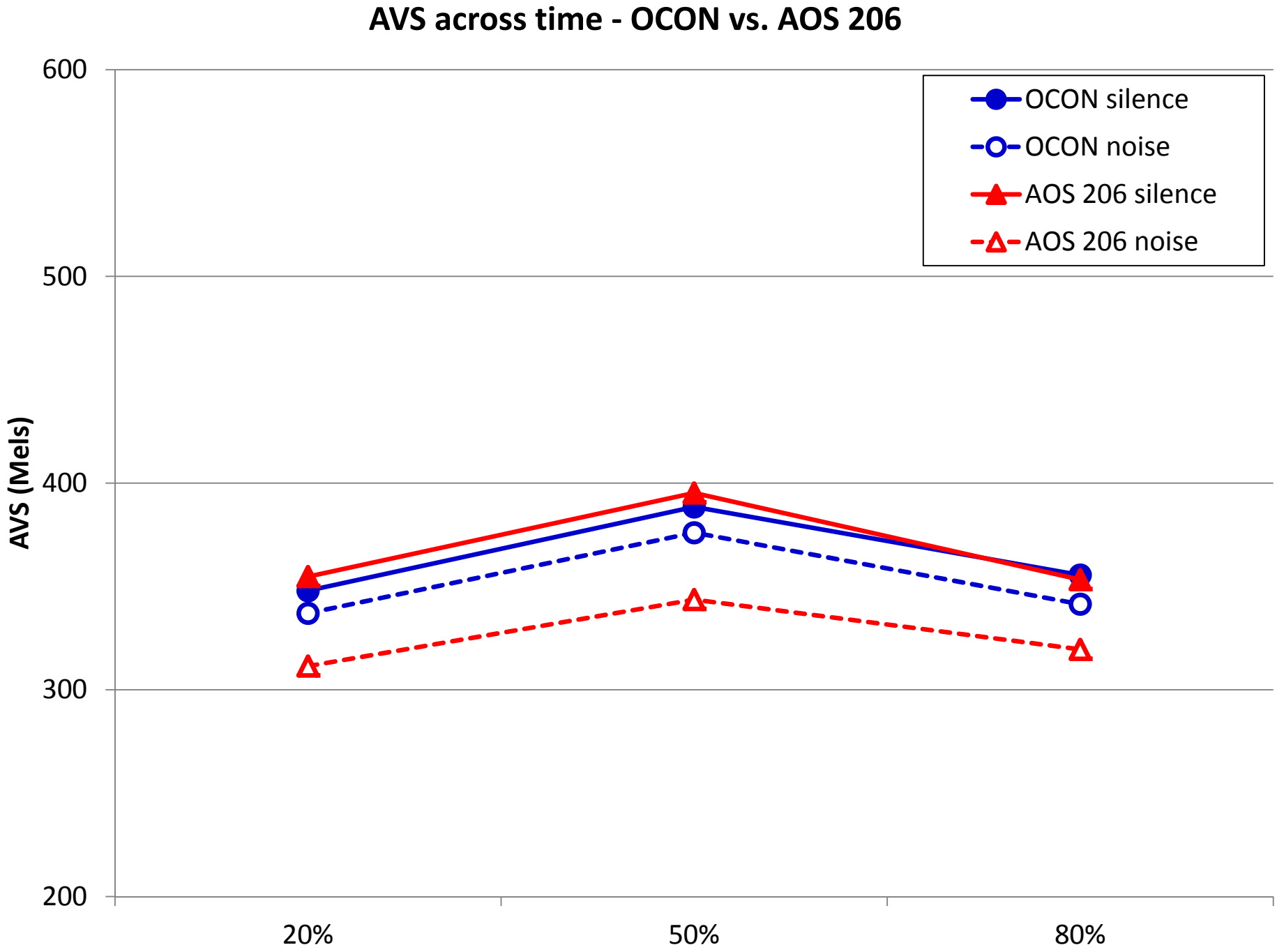

AVS across time - OCON vs. AOS 200
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
AOS 200 silence
AOS 200 noise

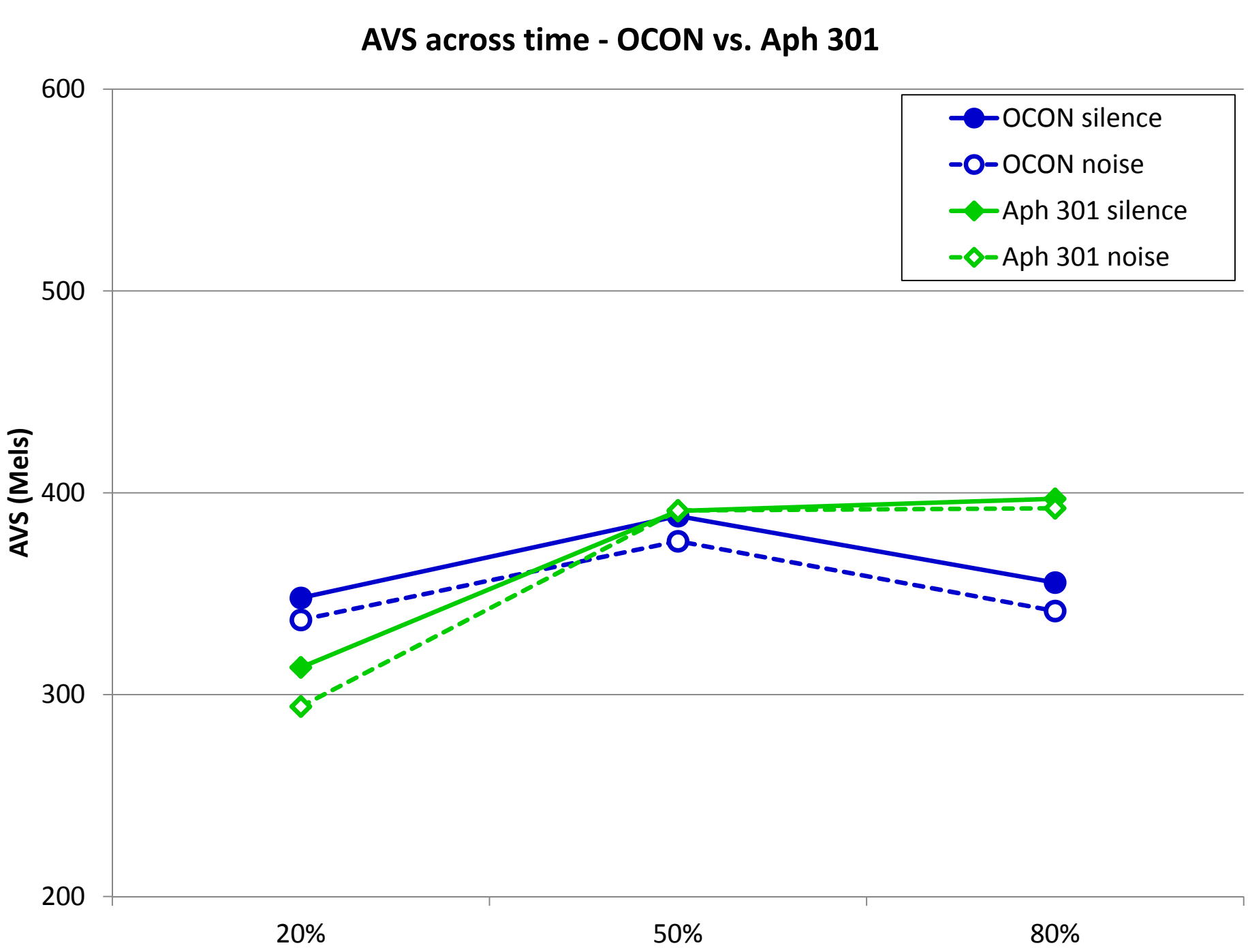

AVS across time - OCON vs. AOS 201
OCON silence
OCON noise
AOS 201 silence
AOS 201 noise
AVS (Mels)
550
450
350
250
150
20%
50%
80%

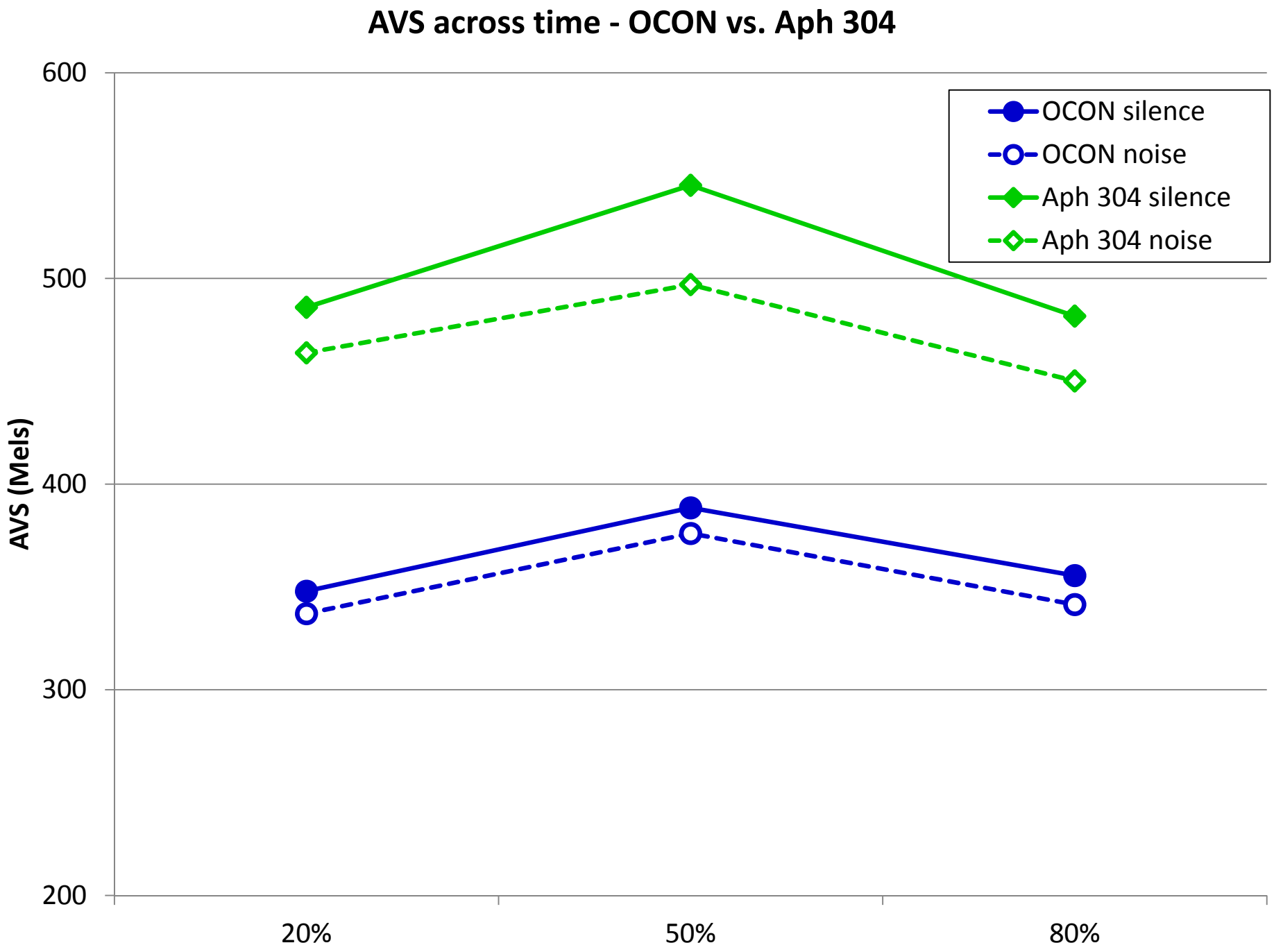

AVS across time - OCON vs. AOS 203
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
AOS 203 silence
AOS 203 noise

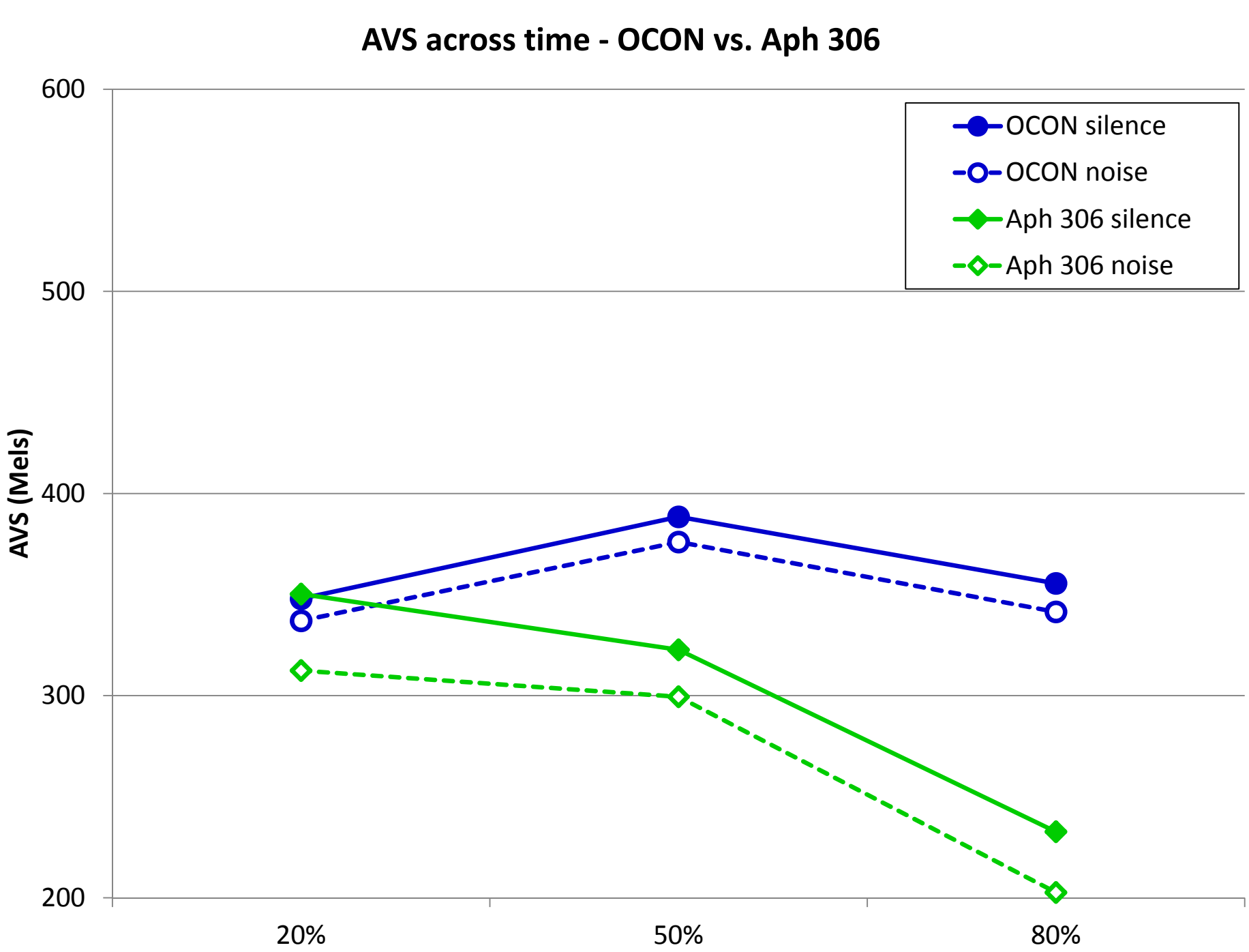

AVS across time - OCON vs. AOS 204
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
AOS 204 silence
AOS 204 noise

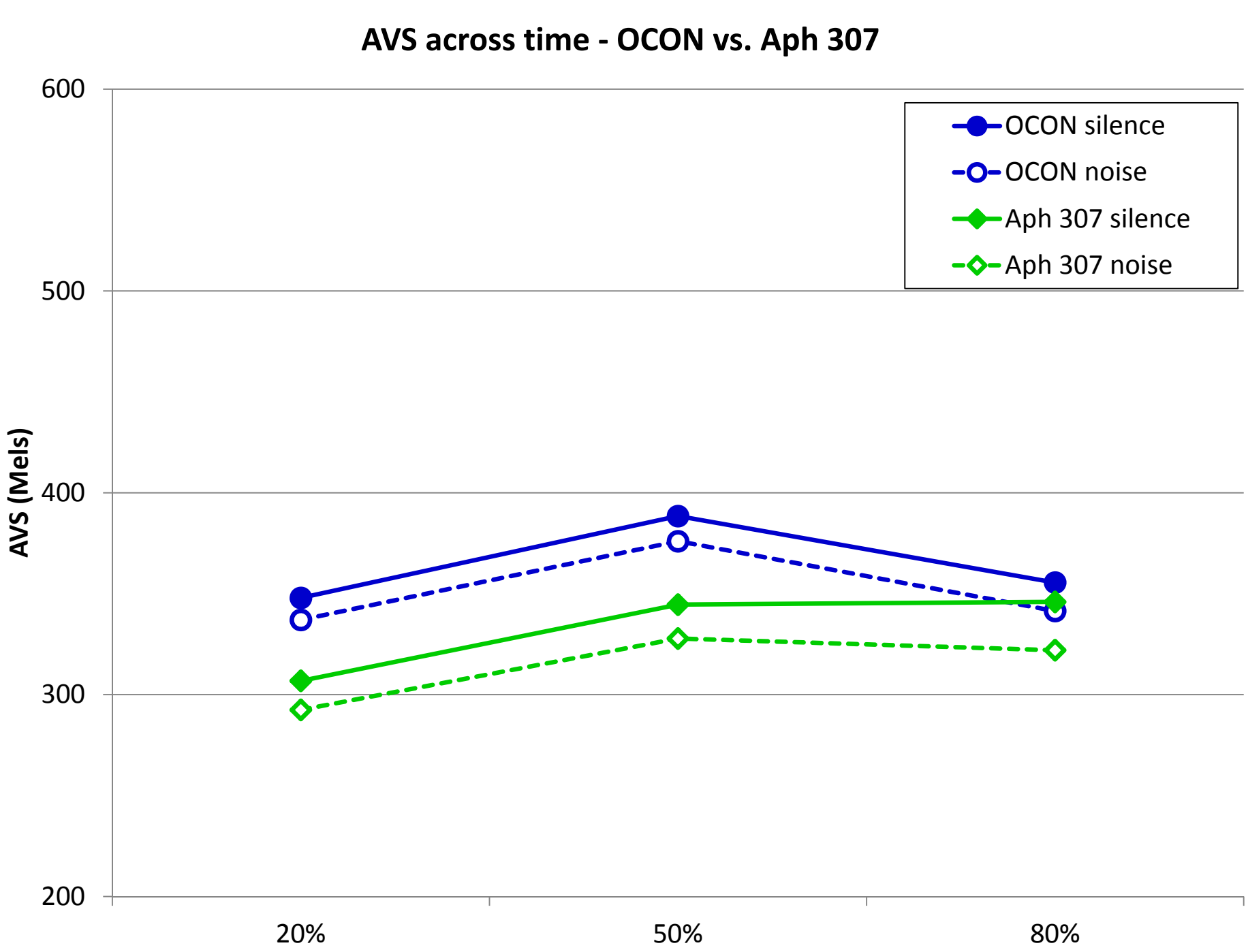

AVS across time - OCON vs. AOS 205
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
AOS 205 silence
AOS 205 noise


AVS across time - OCON vs. AOS 206
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
AOS 206 silence
AOS 206 noise


AVS across time - OCON vs. Aph 301
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
Aph 301 silence
Aph 301 noise

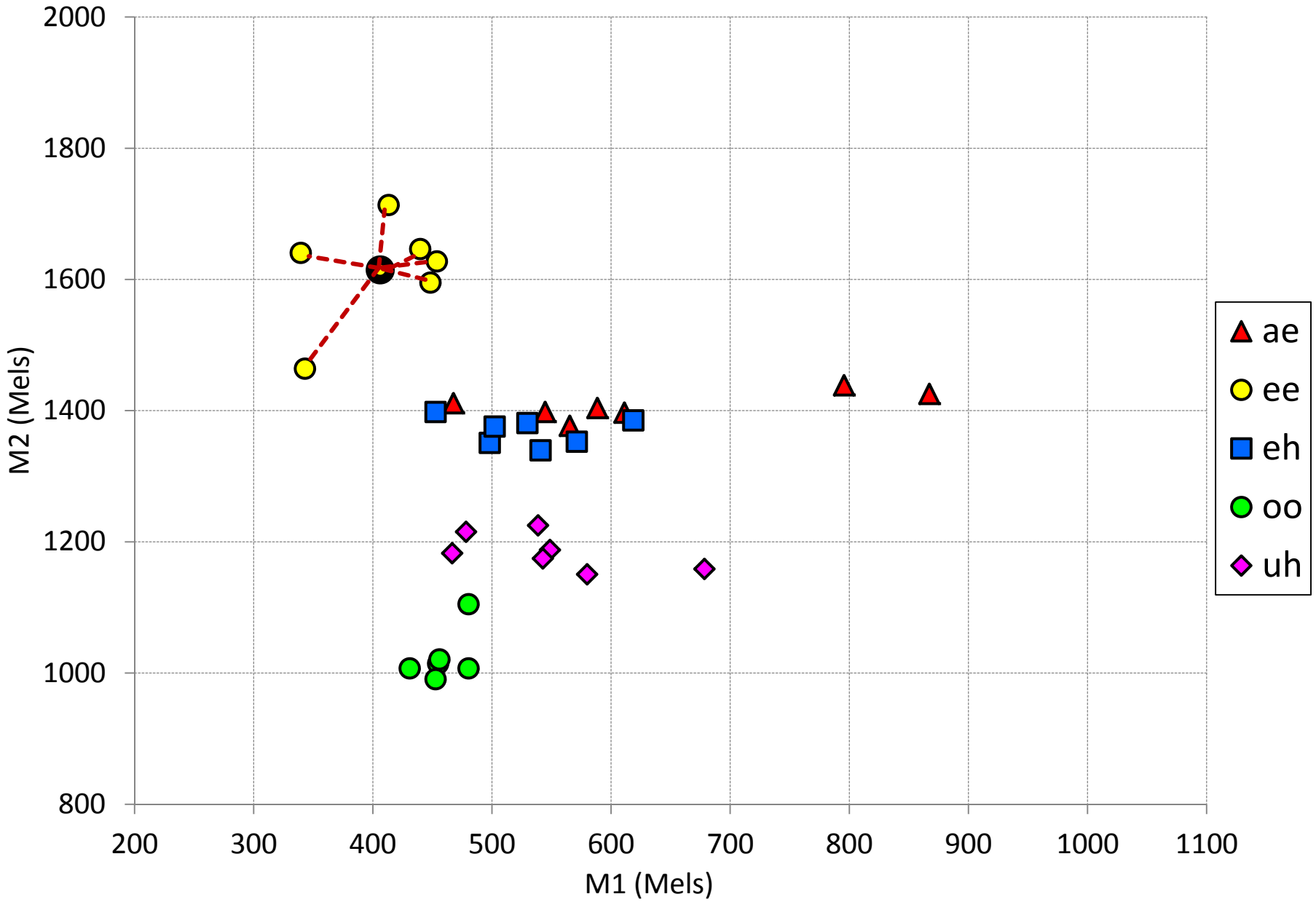

AVS across time - OCON vs. Aph 304
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
Aph 304 silence
Aph 304 noise

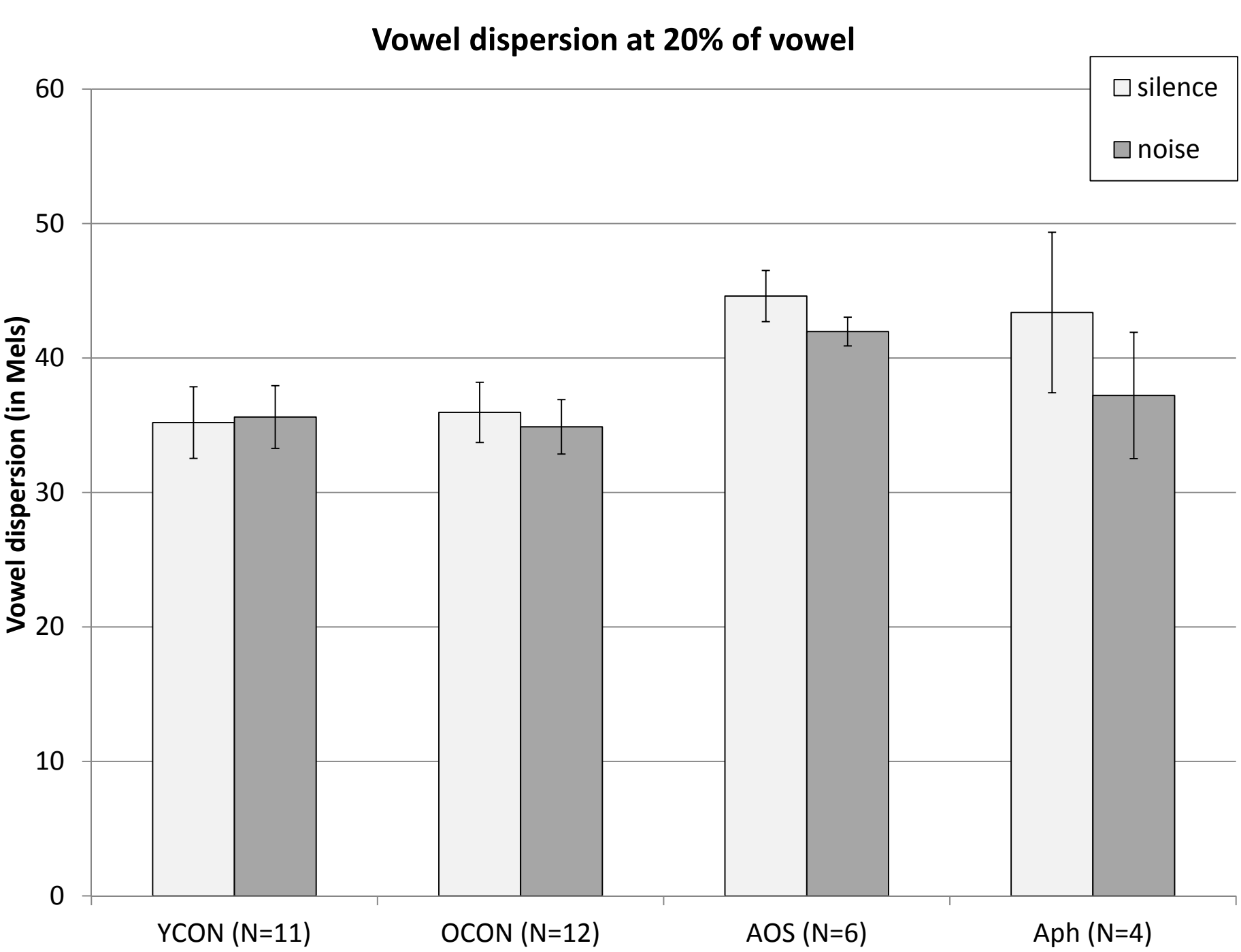

AVS across time - OCON vs. Aph 306
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
Aph 306 silence
Aph 306 noise

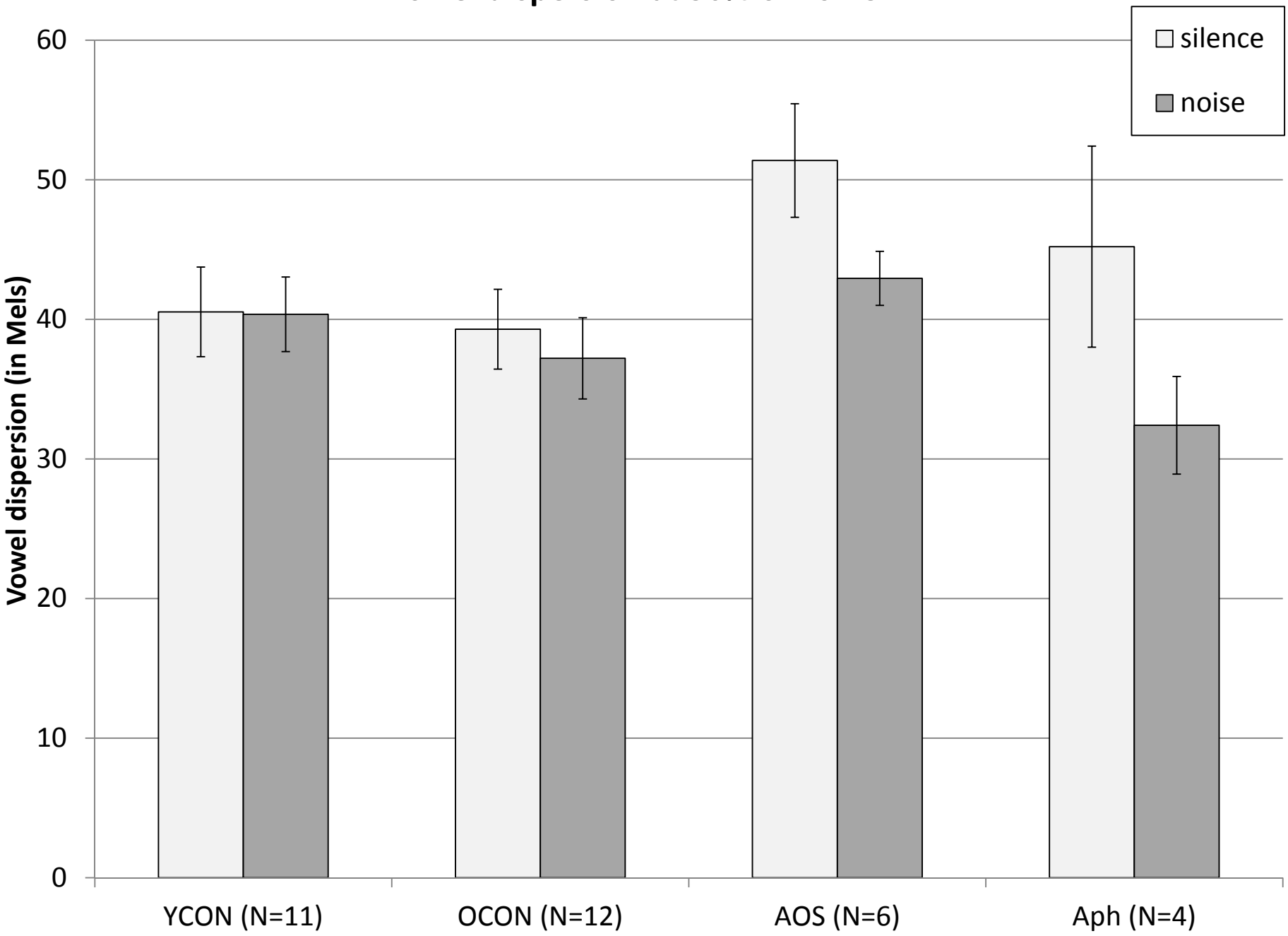

AVS across time - OCON vs. Aph 307
600
500
400
300
200
AVS (Mels)
20%
50%
80%
OCON silence
OCON noise
Aph 307 silence
Aph 307 noise

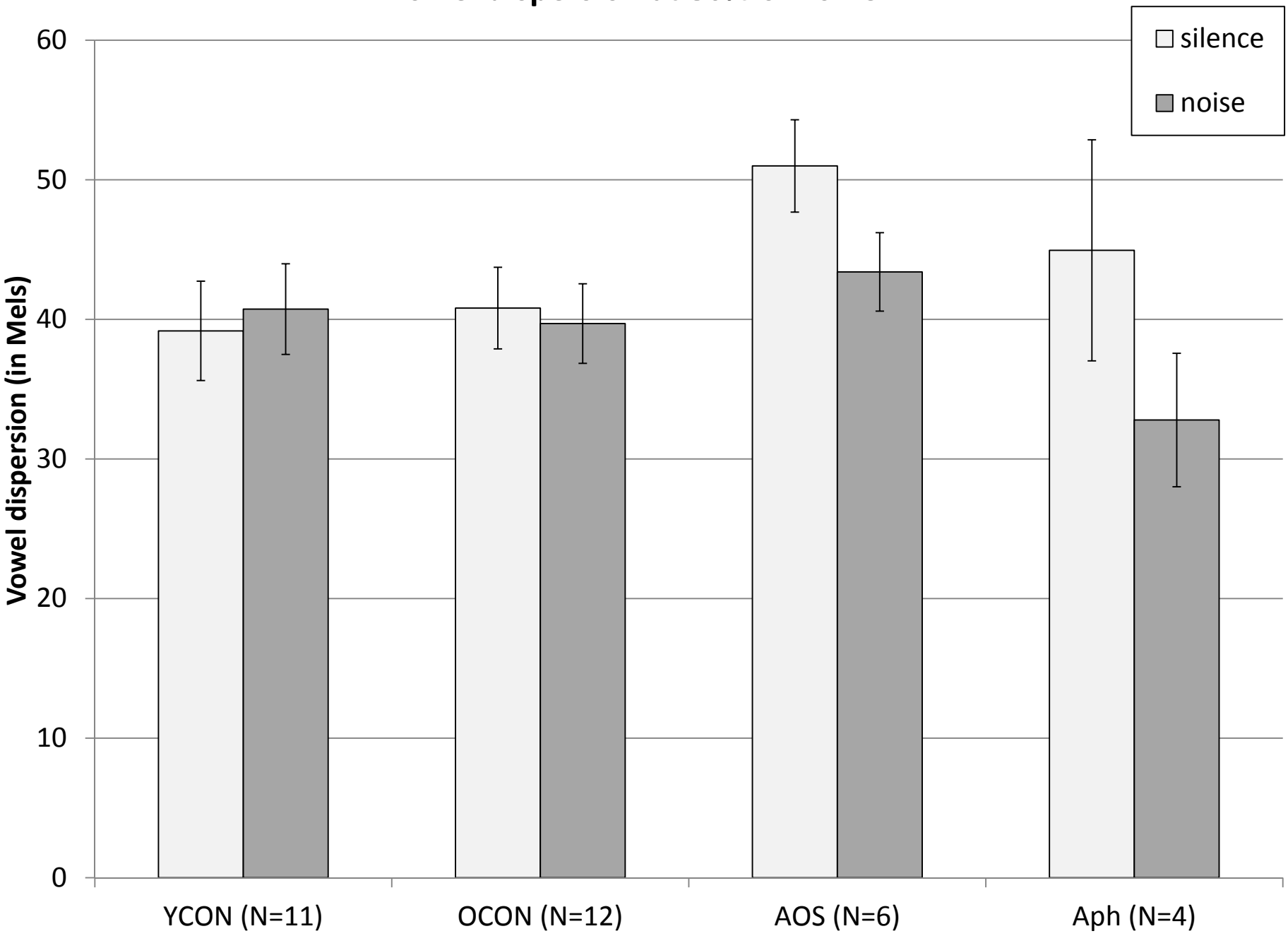
# Vowel Dispersion

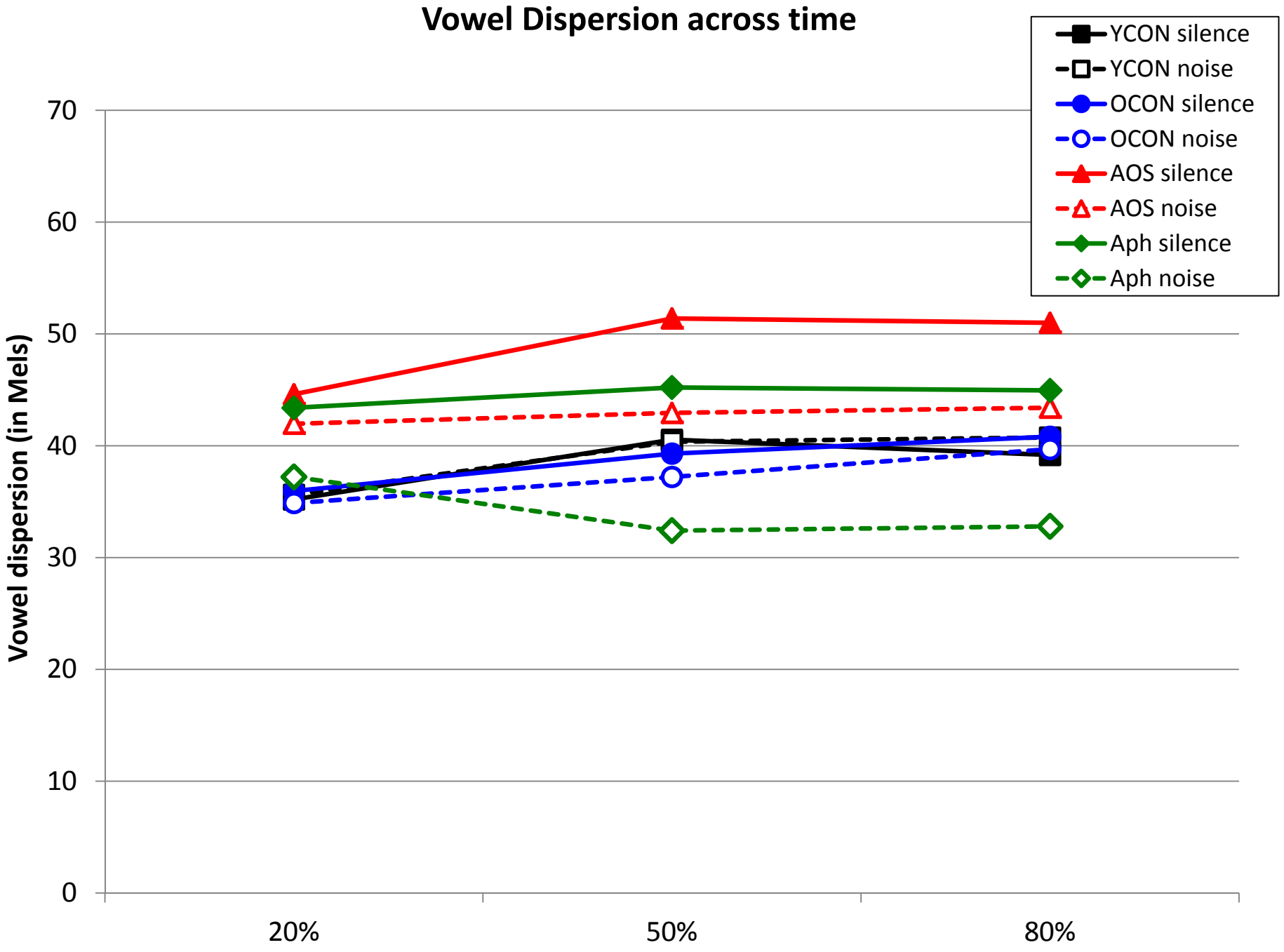
# Token-to-token variability: Vowel Dispersion calculation

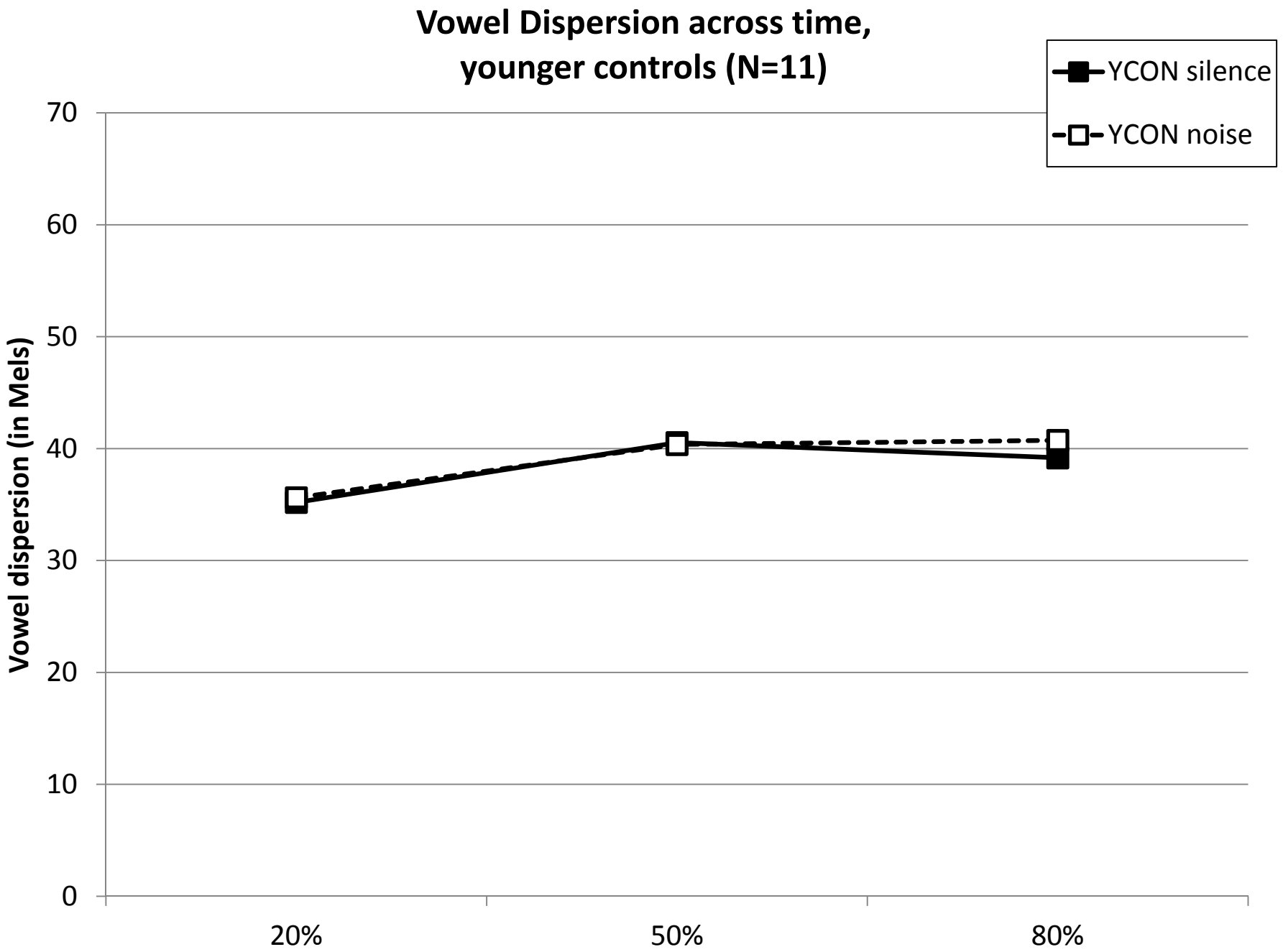


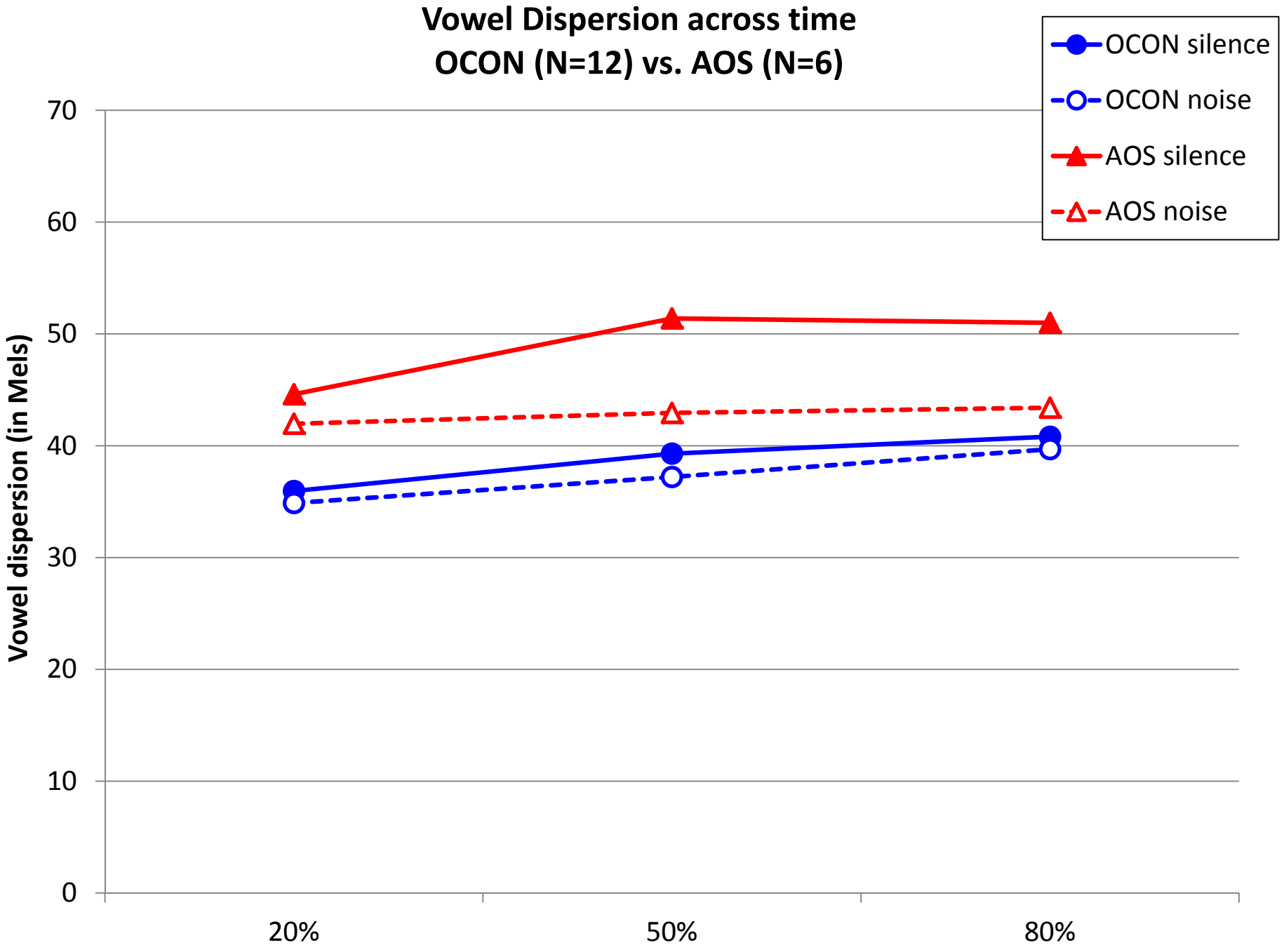

Vowel dispersion at 20% of vowel
silence
noise
Vowel dispersion (in Mels)
60
50
40
30
20
10
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

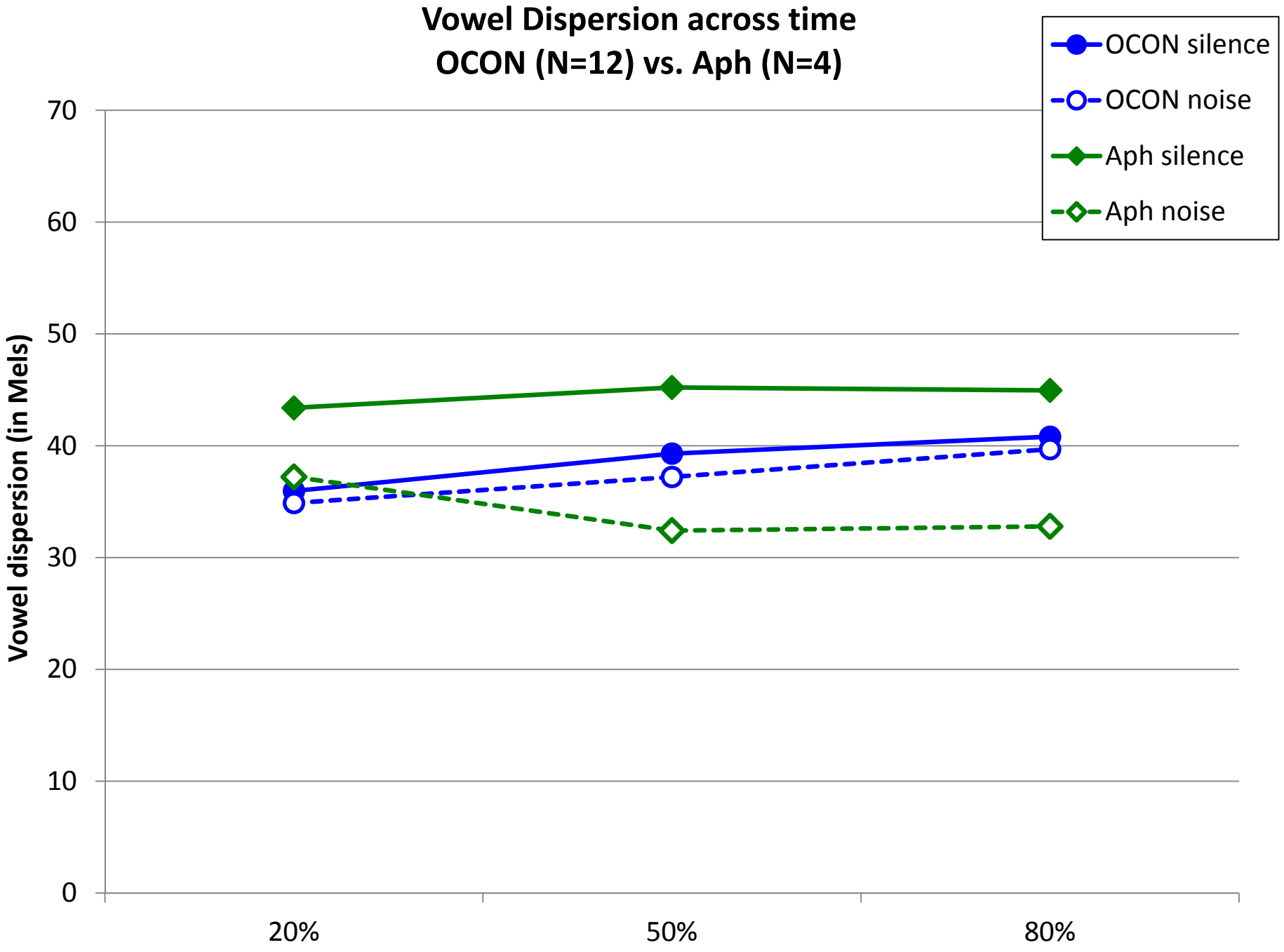

Vowel dispersion at 50% of vowel
silence
noise
Vowel dispersion (in Mels)
60
50
40
30
20
10
0
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

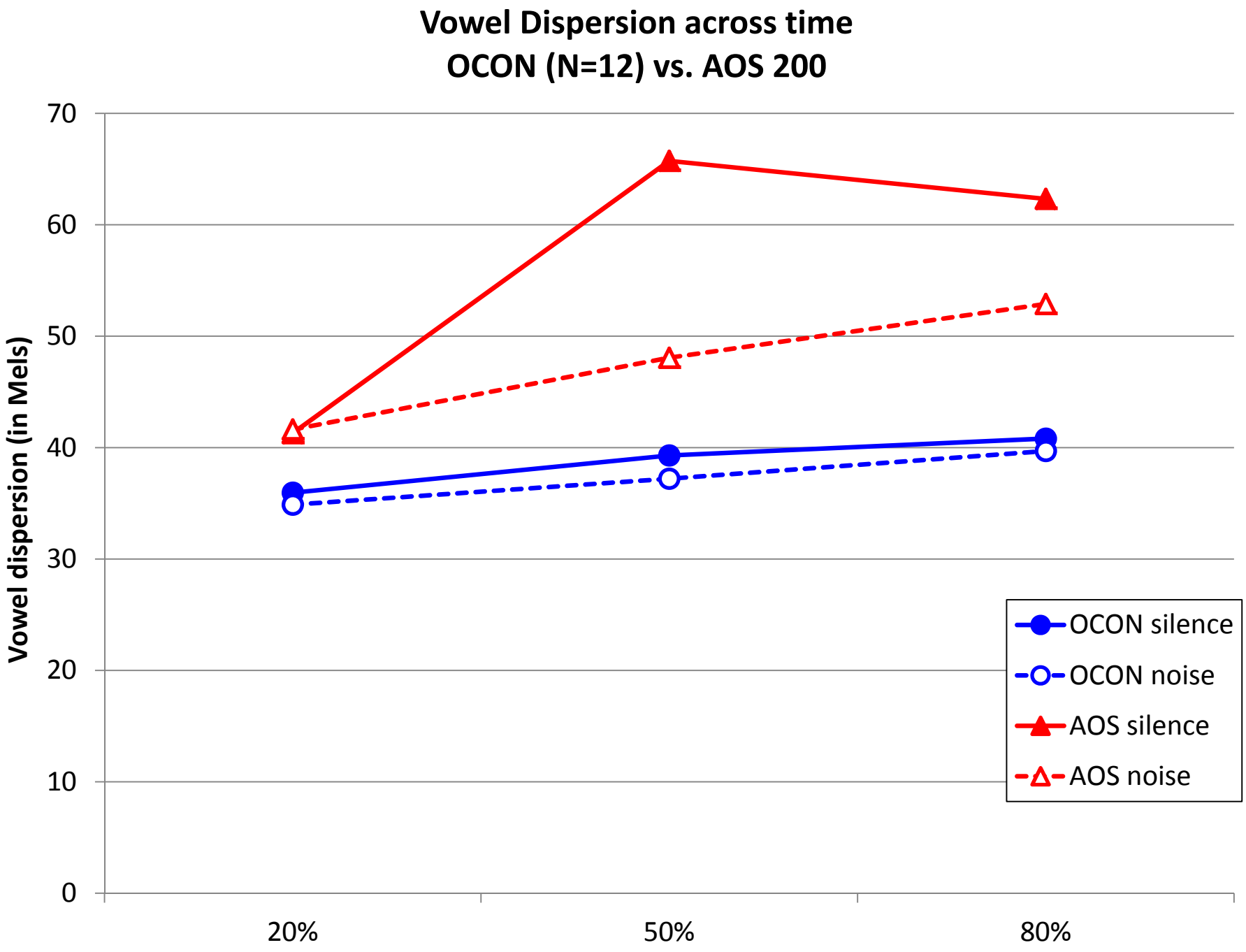

Vowel dispersion at 80% of vowel
Vowel dispersion (in Mels)
60
50
40
30
20
10
0
silence
noise
YCON (N=11)
OCON (N=12)
AOS (N=6)
Aph (N=4)

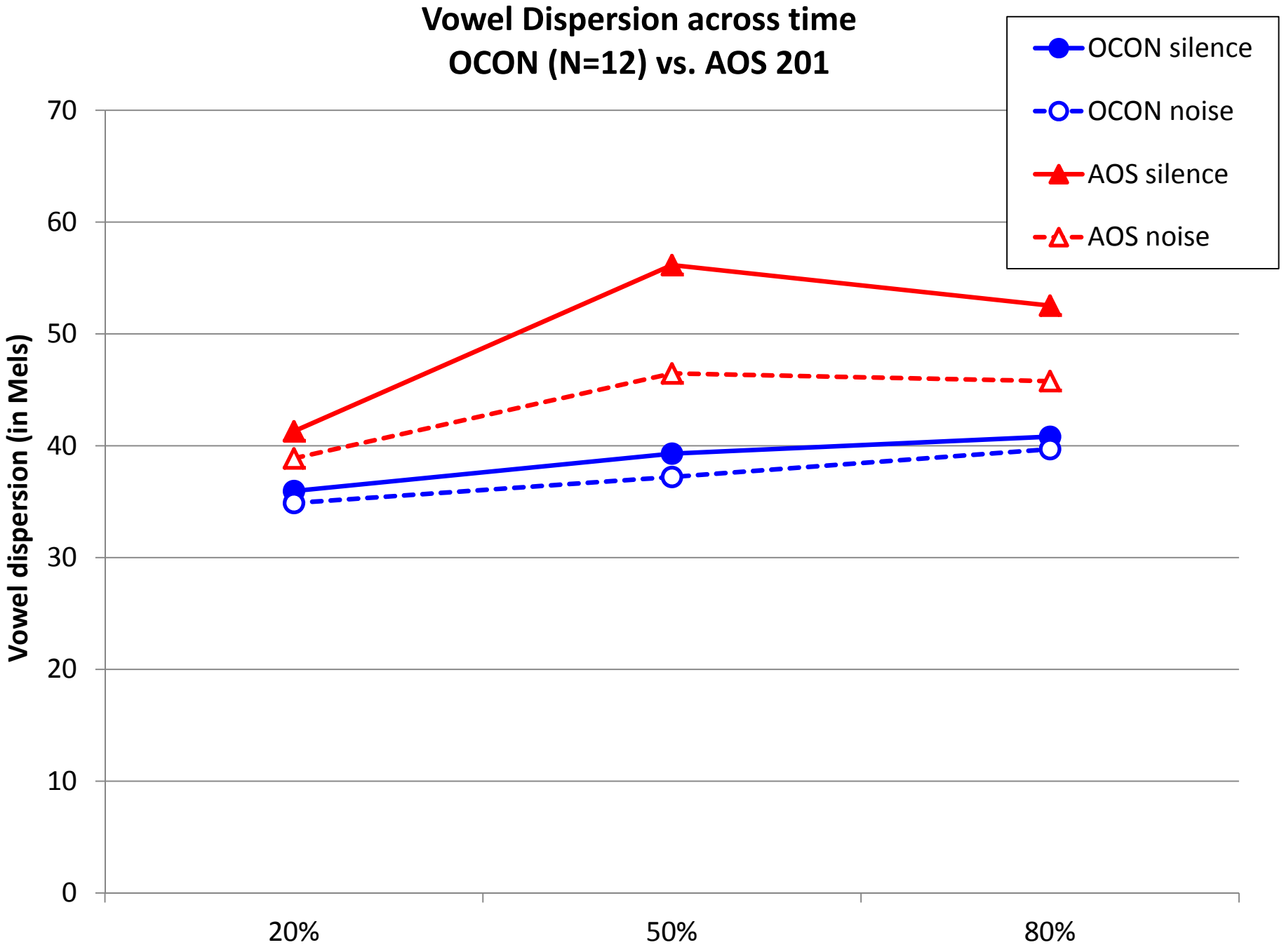

Vowel Dispersion across time
YCON silence
YCON noise
OCON silence
OCON noise
AOS silence
AOS noise
Aph silence
Aph noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

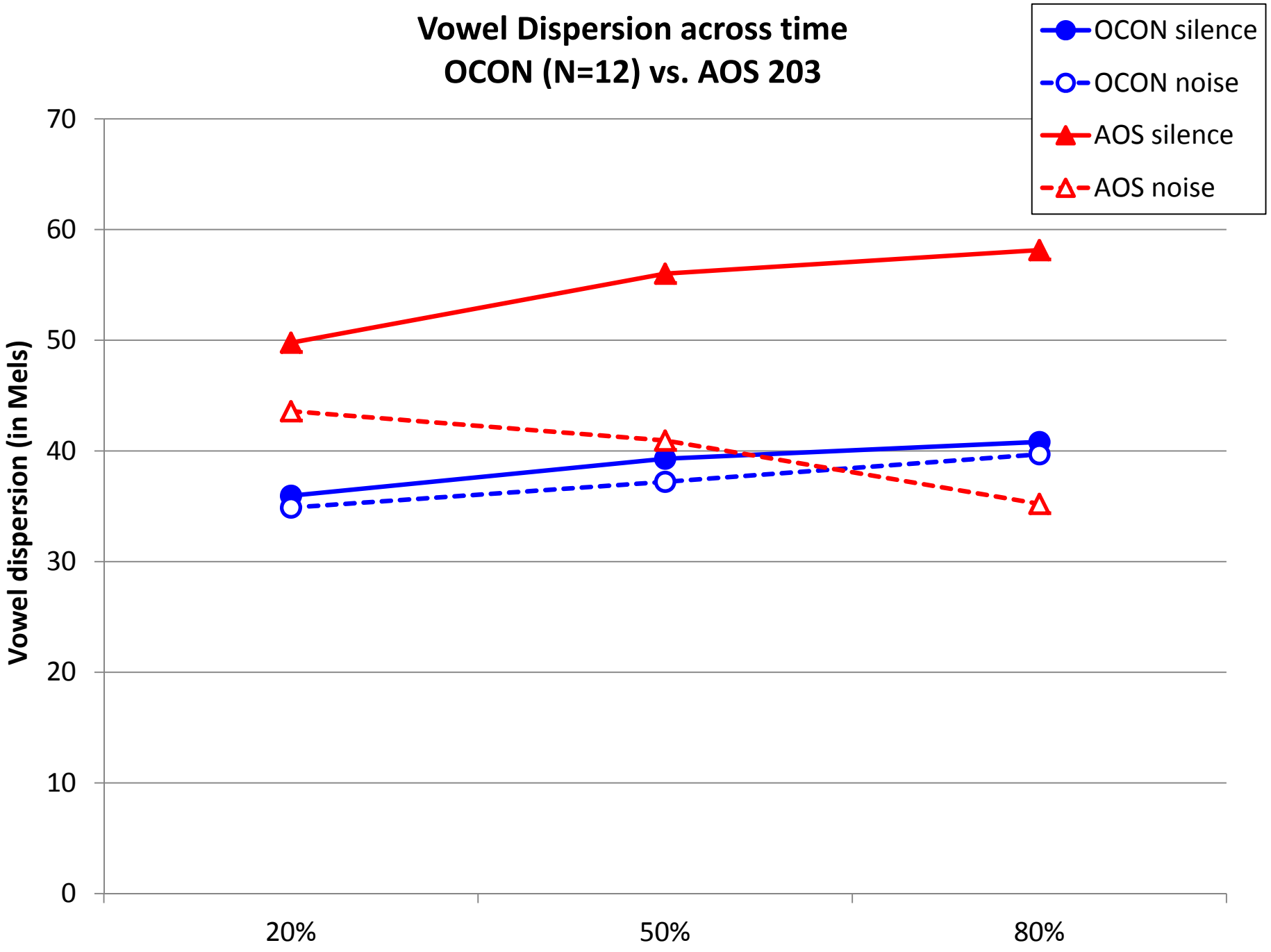

Vowel Dispersion across time,
younger controls (N=11)
YCON silence
YCON noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

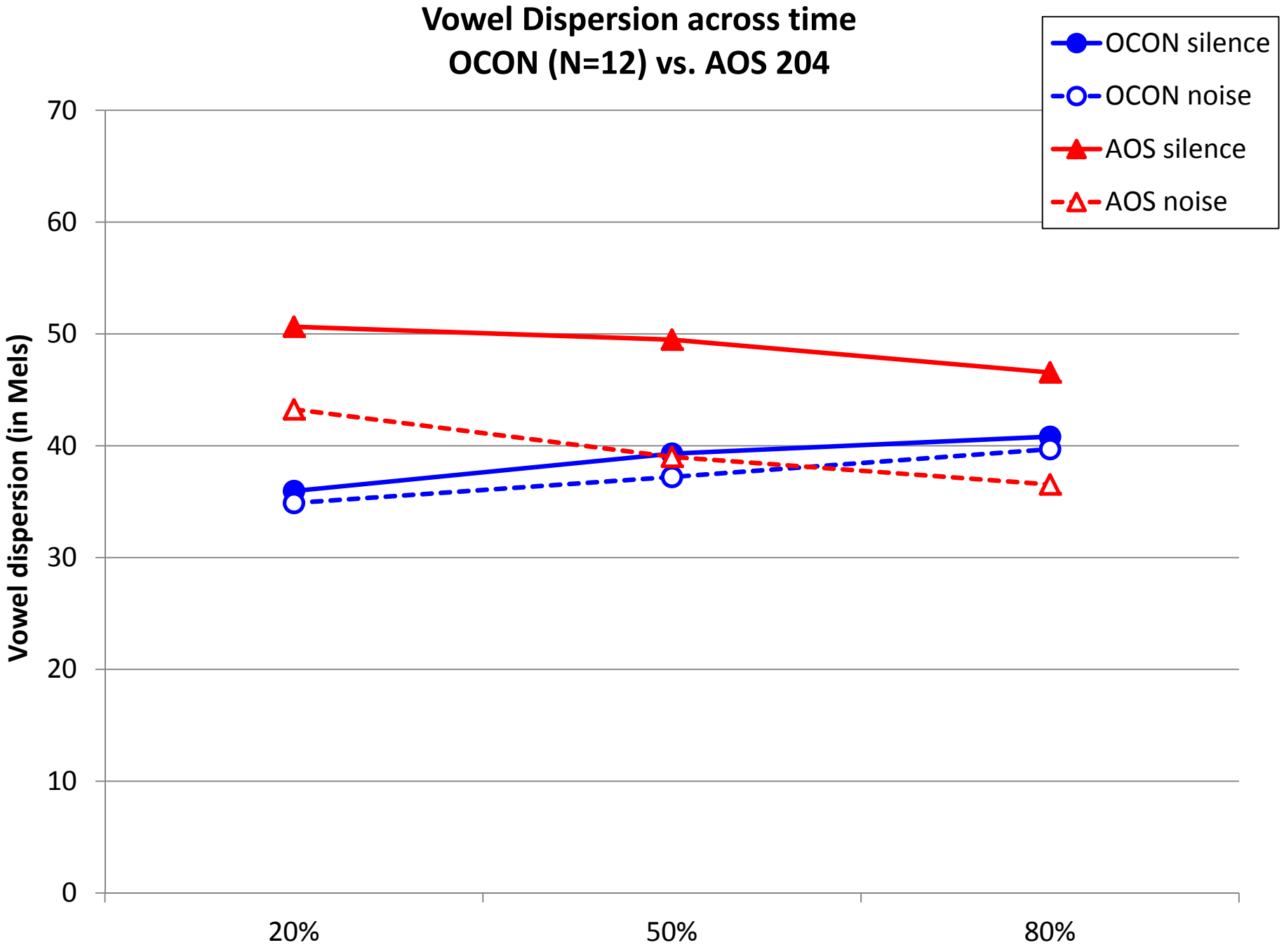

Vowel Dispersion across time
OCON (N=12) vs. AOS (N=6)
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

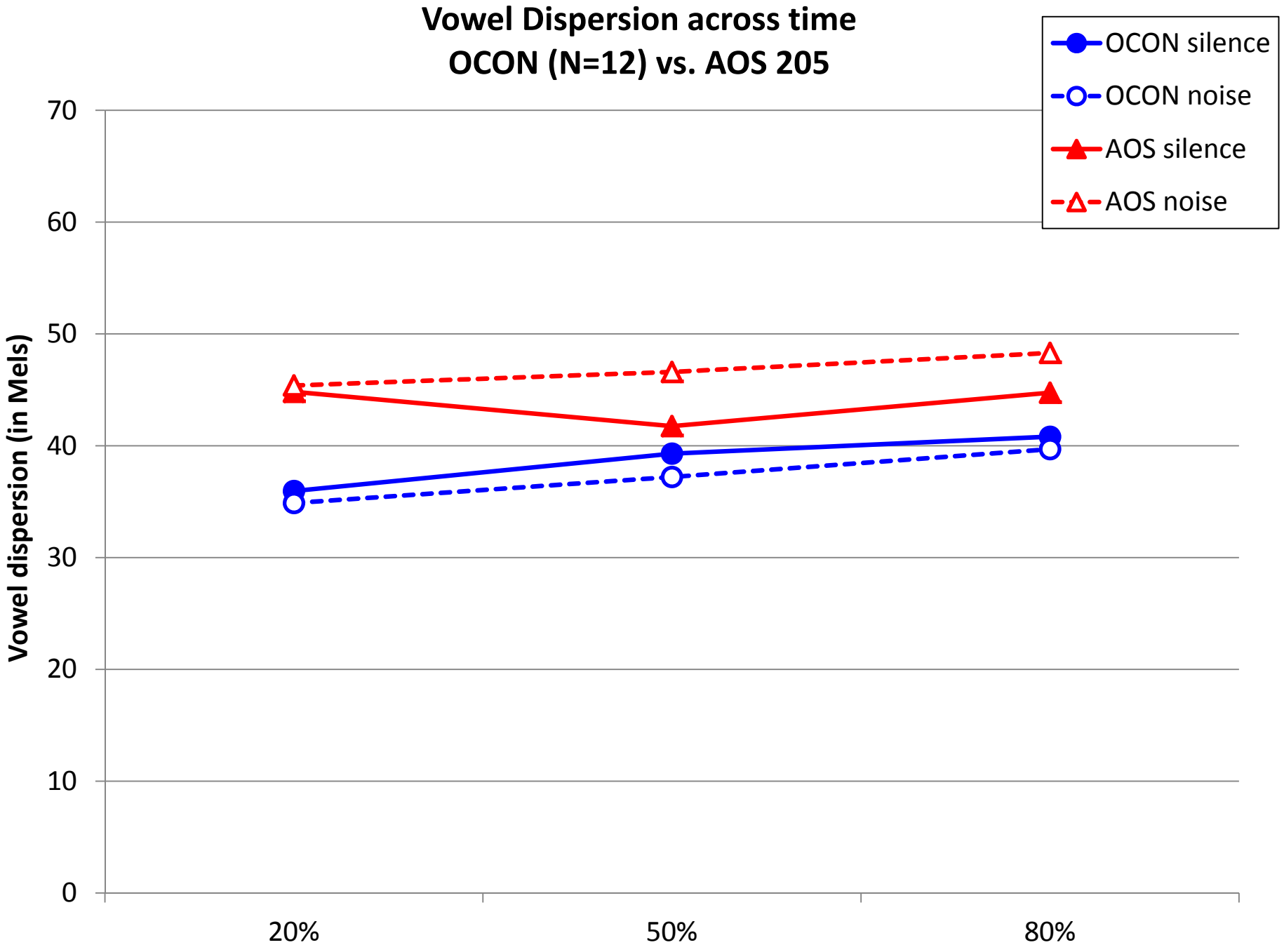

Vowel Dispersion across time
OCON (N=12) vs. Aph (N=4)
OCON silence
OCON noise
Aph silence
Aph noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

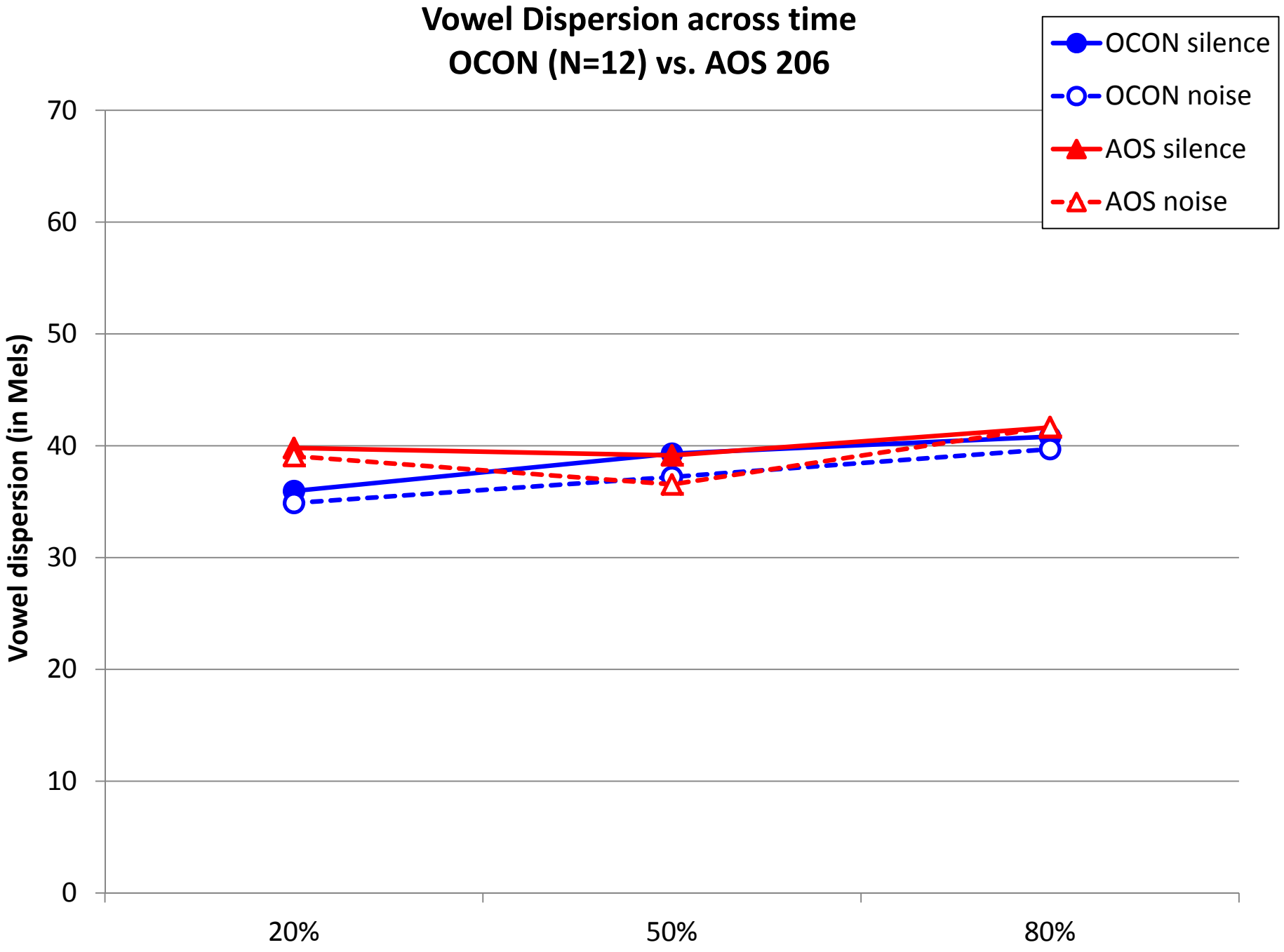

Vowel Dispersion across time
OCON (N=12) vs. AOS 200
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%
OCON silence
OCON noise
AOS silence
AOS noise

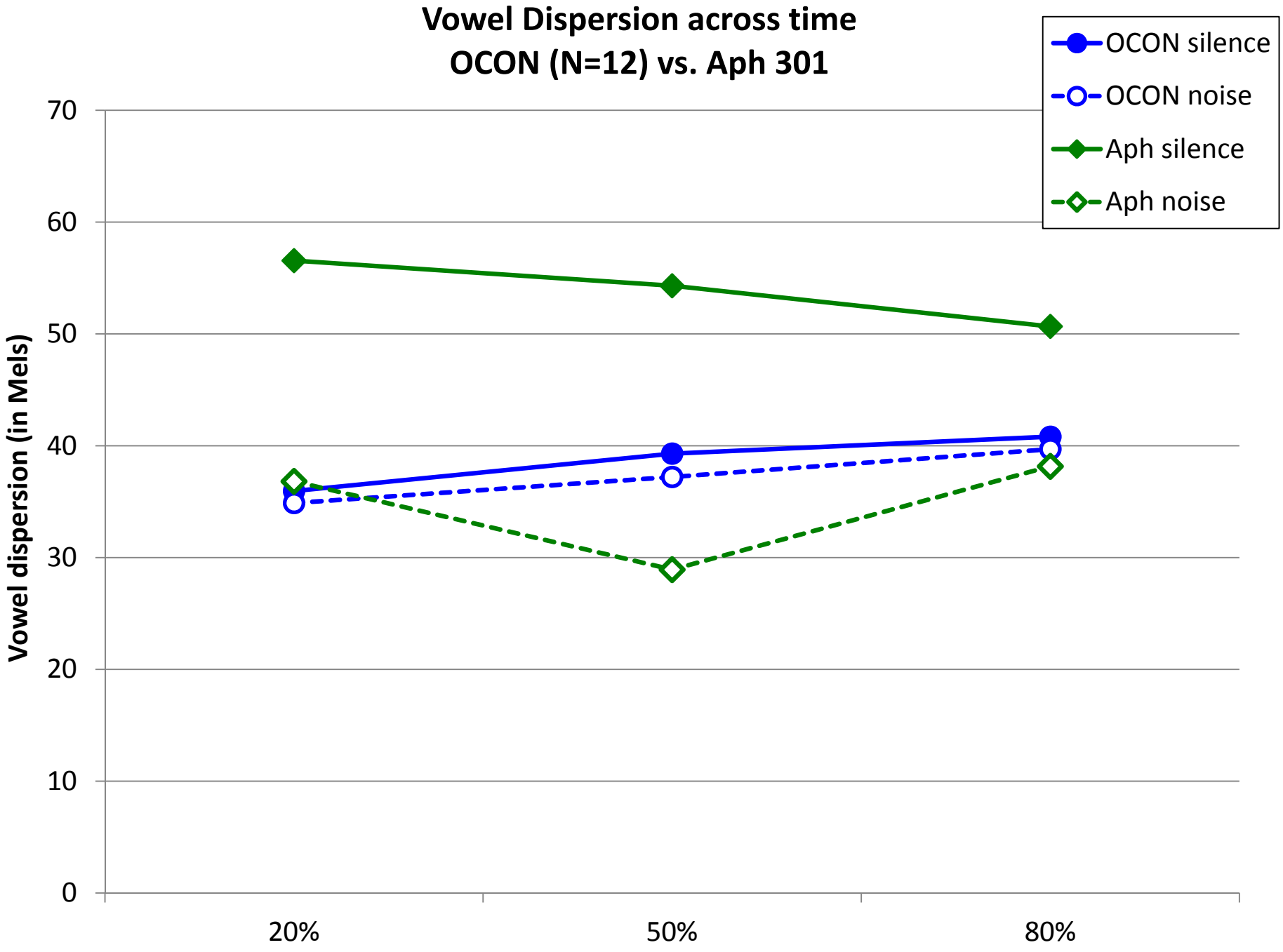

Vowel Dispersion across time
OCON (N=12) vs. AOS 201
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

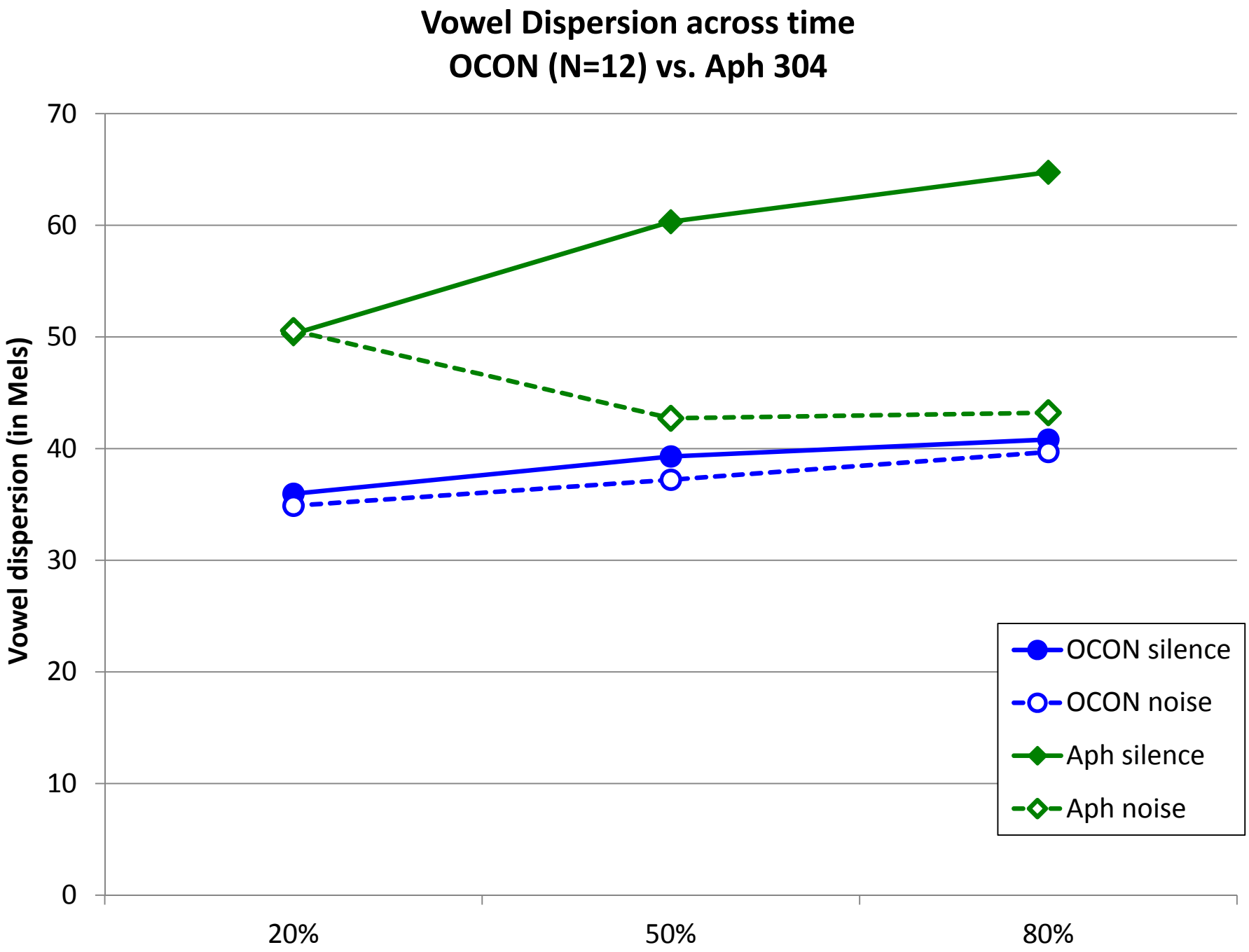

Vowel Dispersion across time
OCON (N=12) vs. AOS 203
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

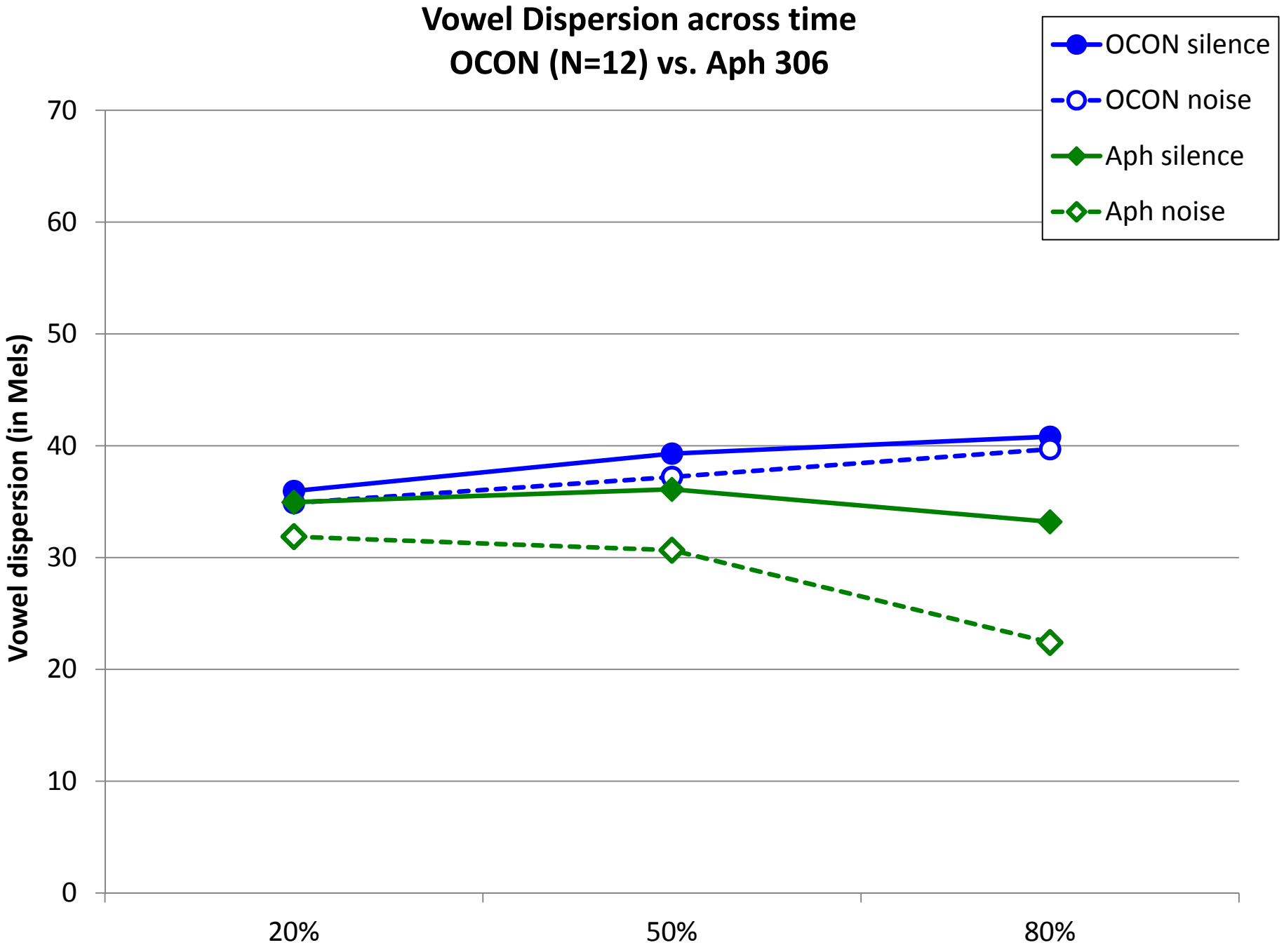

Vowel Dispersion across time
OCON (N=12) vs. AOS 204
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%

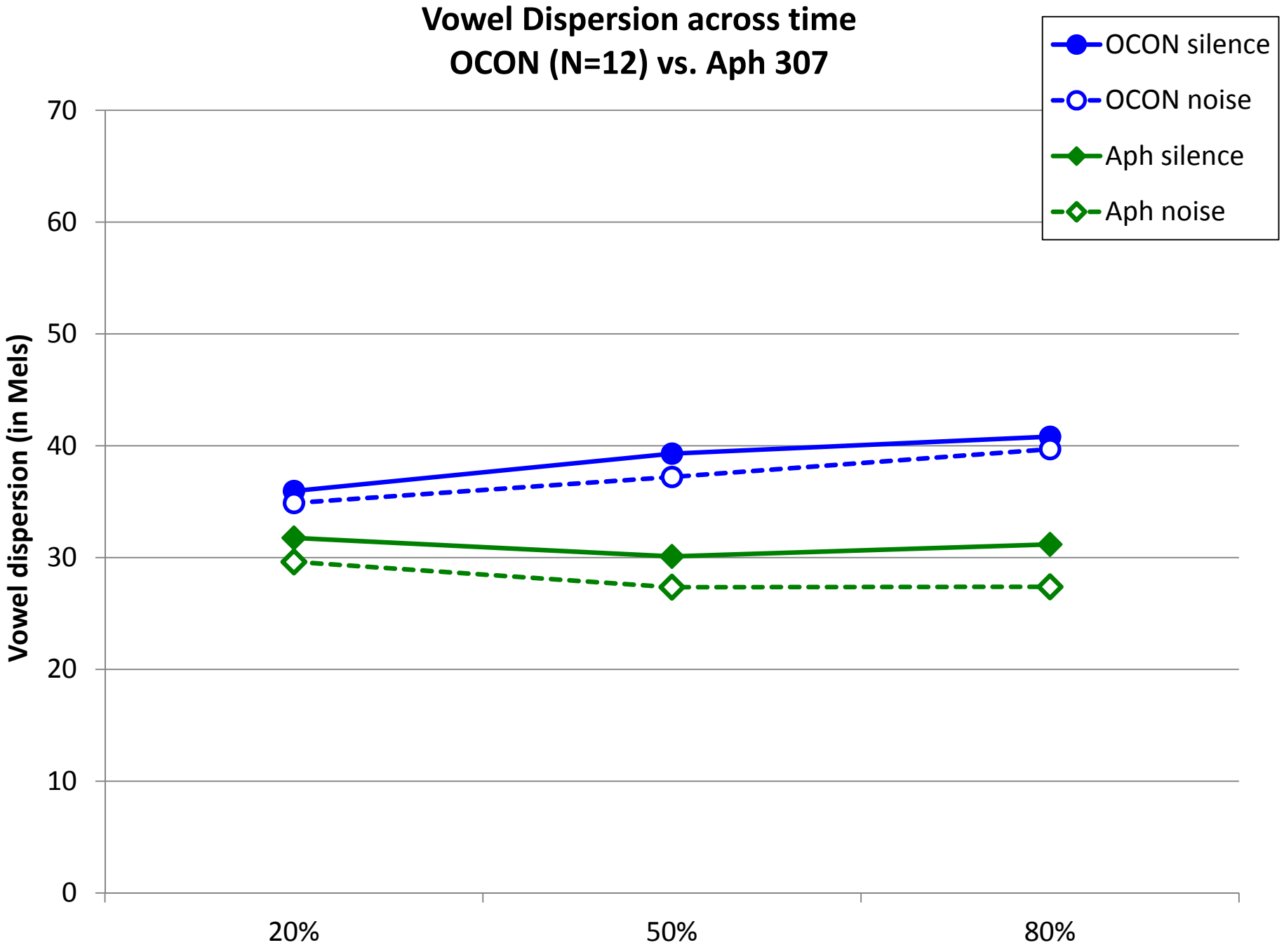

Vowel Dispersion across time
OCON (N=12) vs. AOS 205
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%


Vowel Dispersion across time
OCON (N=12) vs. AOS 206
OCON silence
OCON noise
AOS silence
AOS noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%


Vowel Dispersion across time
OCON (N=12) vs. Aph 301
OCON silence
OCON noise
Aph silence
Aph noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%


Vowel Dispersion across time
OCON (N=12) vs. Aph 304
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%
OCON silence
OCON noise
Aph silence
Aph noise


Vowel Dispersion across time
OCON (N=12) vs. Aph 306
OCON silence
OCON noise
Aph silence
Aph noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%


Vowel Dispersion across time
OCON (N=12) vs. Aph 307
OCON silence
OCON noise
Aph silence
Aph noise
Vowel dispersion (in Mels)
70
60
50
40
30
20
10
0
20%
50%
80%