# Cue weighting in the perception of Dutch sibilants

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**Abstract**

*The sound inventories of languages generally tend to be optimally auditory dispersed (Liljencrants and Lindblom, 1972; Boersma and Hamann, 2008). That is, the auditory contrast tends to be as large as possible in perception, while the articulatory effort tends to be as low as possible in production. The auditory dimension which is most important for the place distinction in sibilants is the spectral mean, i.e. the average concentration of noise energy. In Dutch, the contrast in spectral mean between [s̠] and [ɕ] is smaller than expected for a language with two sibilants (Boersma and Hamann, 2008). In the case of such a small contrast, Boersma and Hamann would predict that already within one generation the contrast becomes larger. If so, there may also be a difference in perception of this contrast between two generations. The present paper investigates the perception of Dutch sibilants by native speakers of Dutch in two age groups. The relative importance of the following auditory cues is studied: frequency of the peak, width of the peak, skewness of the peak, normalized duration, normalized amplitude, and vowel context. Results showed a difference between the two age groups: whereas all the older listeners mainly relied on spectral peak frequency, only half of the younger listeners used this listening strategy. For the other younger listeners, the vowel context (formants or formant transitions in the surrounding vowels) is more important than the peak frequency.*

**Keywords:** Dutch, sibilants, cue weighting, perception, sound change

## 1. Introduction

Sibilants are a type of fricative consonants. Fricatives are produced by air that is pushed through a narrow constriction in the vocal tract which results in a turbulent airstream (noise). The turbulent airstream in sibilants is produced when the jet of air created by the narrow (dental or alveolar) constriction strikes the obstacle of the teeth (e.g. Ladefoged and Maddieson, 1996:137-181). The obstacle is sharper for sibilants and sibilants have more acoustic energy than other fricatives (Ladefoged, 2005:166-7). Sibilants are characterized by a distinct peak in the spectrum, whereas other fricatives have a flat spectrum with energy spread over a larger range of frequencies (Behrens and Blumstein, 1988). Fricatives and sibilants have most energy in the higher frequency regions. For example, in the auditory continuum of the spectral mean for sibilants (see Figure 1, which is an adaptation from Figure 4 from Boersma and Hamann, 2008:229), spectral mean frequencies range from 2000 to 9000 Hz:

**Figure 1:** Auditory continuum of the spectral mean (adapted from Boersma and Hamann, 2008:229)

[ ʂ ʂ̣ ʃ ɕ s̠ sʲ s s̟ s̪ ]

2000 -------------------------------------> 9000 Hz

The auditory dimension which is most important for the place distinction in sibilants is the spectral mean or Centre of Gravity (COG), i.e. the average concentration of noise energy (Jongman, Wayland, and Wong, 2000). Sibilants with a place of articulation in front of the oral cavity have a higher spectral mean than sibilants that are articulated at the back of the oral cavity (e.g. Gordon, Barthmaier, and Sands, 2002). Boersma and Hamann (2008) used the ERB (Equivalent Rectangular Bandwidth) rate scale to express the spectral mean values of sibilants (instead of expressing spectral mean values in Hz). The ERB scale reflects the way sound is perceived by the ear (Hayward, 2000:140-3): perception is more detailed in lower frequencies than in higher frequencies.

The sound inventories of languages generally tend to be optimally auditory dispersed (Liljencrants and Lindblom, 1972; Boersma and Hamann, 2008). That is, the auditory contrast tends to be as large as possible in perception, while the articulatory effort tends to be as low as possible in production. When dispersion is not optimal, this may result in a sound change (e.g. Padgett and Zygis, 2003; Boersma and Hamann, 2008; Zygis and Padgett, 2010). In Dutch, the spectral means of the sibilants, [s̠] and the less frequent [ɕ] (see Table 1), are closer together than the spectral means in other languages having two sibilants (e.g. English, French), namely [s] and [ʃ]. The difference in spectral mean between Dutch sibilants is 2.13 ERB and the difference in spectral mean between French sibilants is 5.25 ERB (Ooijevaar and Seinhorst, 2011). For a language with two sibilants, the difference in spectral mean of 2.13 ERB between [s̠] and [ɕ] is relatively small. In a language with two sibilants, as modeled by Boersma and Hamann (2008), the difference in spectral mean is around 5.2 ERB, if this difference is smaller, within a few generations the distance becomes 5.2 ERB.

**Table 1:** Spectral mean (in Hz and ERB), spectral peak (in Hz) and duration (in ms) of the Dutch sibilants [s̠] and [ɕ], preceded by /ɑ/ and followed by /ə/, values taken from Ooijevaar and Seinhorst (2011)

| **Sibilant** | **Spectral mean (Hz)** | **Spectral mean (ERB)** | **Spectral peak (Hz)** | **Duration (ms)** |
|---|---|---|---|---|
| /s̠/ | 5720 | 29.39 | ± 5000 | 126.7 |
| /ɕ/ | 4335 | 27.26 | ± 3000 - 3500 | 145.0 |
| **Difference** | 1385 | 2.13 | ± 1500 - 2000 | 18.3 |

It is possible that the auditory distance between the spectral means of Dutch sibilants becomes larger in the next generation(s). However, it is also possible that other cues than the spectral mean play a role in the distinction between the sibilants of a language. For example, it seems that there is a small difference in duration (18.3 ms) between the Dutch sibilants [s̠] and [ɕ] (see Table 1), but it is not clear whether this is perceptually salient (Ooijevaar and Seinhorst, 2011).

Another prediction made by Boersma and Hamann (2008:254, footnote 14) is that the small perceptual contrast between the two sibilants will result in the emergence of a ‘bimodal distribution’ of these two sounds: most spectral mean values of [s̠] will be higher than of [ɕ], but there will also be spectral mean values of [s̠] that are lower than of [ɕ]. That is, most speakers will pronounce [s̠] with a higher spectral mean than [ɕ], but for some speakers the spectral mean of [s̠] will be lower than of [ɕ].

In the present paper, I will study the relative importance of the following perceptual cues in the perception of Dutch sibilants (cue weighting): frequency of the spectral peak, width of the peak, skewness of the peak, normalized amplitude, normalized sibilant duration and vowel context. First, I will describe the different perceptual cues for the place distinction in sibilants that have been previously studied. Then, I will show an overview of studies about Dutch production and perception of sibilants and fricatives. In section 2, I will describe the method of the present paper. Section 3 compares the results for listeners of different age, gender and region. Section 4 is the discussion and section 5 concludes.

### *1.1 Previous studies*

In previous studies, several possible cues have been proposed for the place distinction in production and perception between fricatives and between sibilants: spectral, amplitudinal and temporal cues have been studied (see Jongman et al. (2000) for an overview of possible cues, as well as a comparative analysis of all these cues in production for the four English fricatives /f, θ, s, ʃ/ and their voiced counterparts, see Table 2 for a summary of these cues).

**Table 2:** Cues studied by Jongman et al. (2000), pluses indicate that a cue is relevant in the production of a certain contrast, minuses that a cue is not relevant.

| **Cues** | | | **Sibilant vs. non-sibilant** | **/s/-/ʃ/** | **All four places of articulation** |
|---|---|---|---|---|---|
| Static | Spectral peak location | | + | + | + |
| | Spectral moments | M1: mean | + | + | + |
| | | M2: variance | + | + | + |
| | | M3: skewness | + | + | + |
| | | M4: kurtosis | + | + | + |
| | Normalized duration | | + | + | – |
| | Normalized amplitude | | + | + | + |
| | F2 onset frequency | | + | + | – |
| Dynamic | Relative amplitude | | + | + | + |
| | Locus equations | | – | – | – |

Recent studies of fricatives and sibilants focus on spectral moments analysis (Forrest, Weismer, Milenkovic, and Dougall, 1988), in which the frequency distribution of a power spectrum is treated as a random probability distribution (Jongman et al., 2000) of which statistical measures are computed (mean, variance, skewness and kurtosis). Most studies concentrate on the first moment (spectral mean) (see Jongman et al., 2000 for a short overview), but also the third moment (skewness) appears to be a relevant cue for the place distinction in sibilants (Forrest et al., 1988).

An example of some of the cues measured by Jongman et al. (2000) is given in Table 3: the spectral mean, spectral peak, skewness and kurtosis values of American English sibilants. The spectral mean values of English sibilants are somewhat more distinct from each other than the Dutch values: 27.07 ERB (4229 Hz) for /ʃ/ and 29.91 ERB (6133 Hz) for /s/. This is a difference in spectral mean of less than 3 ERB, i.e. 2.84 ERB. Skewness is higher for /ʃ/ than for /s/, which means that /ʃ/ has more spectral energy in the lower frequencies. Kurtosis is higher for /s/ than for /ʃ/, which means that this latter sound has a flat spectrum, whereas the spectrum of the former shows clear distinct peaks.

**Table 3:** Spectral mean (in Hz), spectral peak (in Hz), skewness and kurtosis of the American English sibilants [s] and [ʃ], word-initial sibilants in words of the structure CVC, values taken from Jongman et al. (2000)

| **Sibilant** | **Spectral mean (Hz)** | **Spectral peak (Hz)** | **Skewness** | **Kurtosis** |
|---|---|---|---|---|
| /s/ | 6133 | 6839 | -0.229 | 2.36 |
| /ʃ/ | 4229 | 3820 | 0.693 | 0.42 |
| difference | 1904 | 3019 | 0.922 | 1.94 |

### *1.1.1 Spectral cues*

Earlier studies about sibilants mainly reported spectral differences in the frication noise as being sufficient to distinguish between English /s/ and /ʃ/ (Hughes and Halle, 1956; Harris, 1958; Heinz and Stevens, 1961; LaRiviere, Winitz, and Herriman, 1975; Behrens and Blumstein, 1988a), and considered formant transitions as less important. According to Harris (1958), formant transitions for fricatives are only relevant for the /f/-/θ/ contrast. However, although English /s/ and /ʃ/ are contrasted by a large spectral difference in frication noise, other studies have found that differences in formant transitions (of the second formant, the F2) are relevant as well for the /s/-/ʃ/ contrast (e.g. Mann and Repp, 1980; Whalen, 1981, 1991; Datscheweit, 1990). The F2 of the following vowel (/i/ or /u/, but not /ɑ/) may even already be present in the last 30-60 ms of the fricative (Soli, 1981). In other languages, with two or more sibilants, formant transitions have also been found to be important cues in perception and production of sibilants: Shona (Bladon, Clark, and Mickey, 1987), Toda (Gordon et al., 2002), Polish (Nowak, 2006; McGuire, 2007, 2008; Zygis and Padgett, 2010), Japanese (Toda, 2007; Li, Edwards, and Beckman, 2009; Li, Munson, Edwards, Yoneyama, and Hall, 2011; Holliday, Beckman, and Mays, 2010). However, in an earlier study, Li, Edwards, and Beckman (2007) explored better measures to distinguish sibilants that could be calculated from the frication interval alone.

Children that acquire English as their native language initially rely more on vowel transitions in their perception of sibilants than adults do, but as their age increases, they rely more on frication noise (Nittrouer and Studdert-Kennedy, 1986), which is reflected in their production of sibilants: as the difference between the spectral mean values of /s/ and /ʃ/ they produce increases, the extent of co-articulation with the following vowel decreases (Nittrouer, Studdert-Kennedy and McGowan, 1989).

Like in Dutch, the Japanese sibilants (/s/ and /ɕ/ or /sʲ/) have spectral mean values that are close together (although the exact values are different from those found for Dutch), and /s/ occurs more often than /ɕ/ (e.g. Toda 2007). In addition, in Japanese, /ɕ/ is restricted to a certain vowel environment: the two sibilants are contrasted only before back vowels (Li et al., 2011). Toda (2007) hypothesizes that speakers of languages with a small vowel inventory, such as Japanese (5 vowels), can make more use of vowel transitions than do speakers of a language with larger vowel inventories, such as French (16 vowels) or English (see Holliday et al. 2010). Therefore, Toda (2007) argues that the information in the frication noise should be sufficient to distinguish between place of the sibilants /s/ and /ʃ/ in a language with many vowels whereas in a language having only five vowels, such as Japanese, formant transitions could be (more) useful for the place distinction in sibilants. Dutch is a language with 15 vowels (e.g. see Adank, van Hout and Smits, 2004), so with respect to the number of vowels, Dutch resembles French. However, with respect to the closeness of the spectral mean values of the sibilants, Dutch resembles Japanese. Therefore this prediction made by Toda could be tested.

Gordon et al. (2002) argued that formant transitions may be an important cue when the spectral mean values of sibilants are not significantly differentiated in production, as was the case for three out of four sibilants in Toda. Spectral mean values of sibilants may also overlap within a speaker. In a phoneme identification task, Clouse, Burnham, and Newman (1999:2273) studied the perception of the sibilant contrast /s/-/ʃ/ produced by speakers showing overlap in either spectral peak or spectral mean. Listeners labeled the sounds correctly, but they were slower in recognizing the sounds when there was overlap. Similarly, Newman, Clouse, and Burnham (2001) have found that overlap in spectral mean or skewness was more important than the amount of distance (without overlap) between categories: “overlap between categories is substantially more difficult for listeners than are categories that are simply close together.” (p.1193). If the production of a speaker is variable (i.e. there is category overlap in spectral mean values), listeners have longer reaction times, because they have to switch to alternative cues. If such cues are not available, their accuracy in identifying the tokens also becomes worse. “Listener’s performance will be poorer whenever there is greater variability on an acoustic cue to which listeners are sensitive” (p.1194).

Haley, Seelinger, Mandulak, and Zajac (2010), however, criticize Newman et al. (2001), because the overlap in spectral mean values may be due to the length of the time window (110 ms): only measuring the spectral mean of a large part of the fricative may hide that there are dynamic variations during the production of the fricative, so there could actually be no overlap between the two sibilants in the production of the speaker in Newman et al. (2001). There are dynamic variations during the production of the fricative (which can be shown by time history plots) which most likely reflect the co-articulation with the following vowel. Haley et al. (2010) analyzed a 20 ms time window of the fricative (50 ms after fricative onset). Spectral mean and skewness served to distinguish the two sibilants, but there was overlap across speakers, that is, the spectral mean value of the /s/ of one speaker is similar to the spectral mean value of the /ʃ/ of another speaker. However, for each individual speaker, there was only overlap in skewness, but no overlap in the spectral mean values.

For the sibilant contrast in Dutch (see section 1.2 for an overview of studies about Dutch sibilants and fricatives), formant transitions may also be an important cue, as the spectral mean values are relatively close together and some speakers show overlap in the production of these sounds (Ooijevaar and Seinhorst, 2011). However, previous studies about Dutch fricatives (Klaassen-Don, 1983; Klaassen-Don and Pols, 1983, 1986; Wagner, Ernestus, and Cutler, 2006) reported no influence of vowel formant transitions for the distinction between /s/ and other fricatives (/ʃ/ or /ɕ/ not included). According to Evers, Reetz, and Lahiri (1998), the frication noise is sufficient for the distinction between the phoneme /s/ and its allophone [ʃ] (as well as in English where these sounds are contrastive phonemes, and in Bengali where [s] is an allophone of /ʃ/).

### *1.1.2 Amplitudinal cues*

Behrens and Blumstein did not find a difference in amplitude between American English /s/ and /ʃ/ in production (1988a) nor in perception (1988b). Both /s/ and /ʃ/ are somewhat smaller in absolute amplitude than the vowel, mean value: -6 to -2 dB (1988b). Behrens and Blumstein (1988b) note, however, that there may be differences in relative amplitude in a certain frequency region, as studied by Stevens (1985). According to Hedrick and Ohde (1993), there is a difference in relative amplitude between American English /s/ and /ʃ/ in the F3 region of the vowel which influences perception: when the amplitude of the noise was lower than that of the vowel in the F3 region, more /s/ responses emerged, and when the amplitude of the noise was higher than that of the vowel in the F3 region, more /ʃ/ responses emerged. (However, Hedrick and Ohde see relative amplitude as a secondary cue, in addition to the primary cue of the spectral peak.) Similarly, in production (Jongman et al., 2000), the difference in relative amplitude between the noise and the vowel in the F3 region is larger for /s/ (more energy in higher frequencies), and smaller for /ʃ/ (most energy in this region).

*1.1.3 Temporal cues*

According to Jongman (1985), duration of the frication noise is not a perceptual cue for the distinction in place or manner of fricatives, instead spectral cues are the primary cues. However, 30-50 ms is the minimum duration of frication noise required for the identification of the place of a voiceless sibilant fricative (Jongman, 1989). Behrens and Blumstein (1988a) also did not find differences in duration of the noise between the productions of the sibilants /s/ and /ʃ/. Neither did Gordon et al. (2002) find any significant durational differences between fricatives in the languages they studied. However, Jongman et al. (2000) have found that, although there are no differences in absolute duration (both /s/ and /ʃ/ are 178 ms), there is a small difference in normalized duration (i.e. fricative duration divided by word duration): normalized duration for /ʃ/ (178 / 397 = 0.448) was longer than for /s/ (178 / 406 = 0.438).

In the present study, the following cues are studied for Dutch sibilants: spectral peak frequency (3000-8000 Hz, in 7 steps of 1000 Hz), width of the spectral peak (1000, 2000, or 3000 Hz), skewness of the spectral peak (falling, flat, or rising), duration of the noise (which varies exponentially in three steps (113, 136, or 163 ms), while the duration of the surrounding vowels remains constant), absolute amplitude (0, -10, or -20 dB, i.e. equal or smaller than that of the vowel), and vowel context (taken from a minimal pair differing 'only' in the sibilant: <ta(ss)en>-<ta(sj)e>). In addition, spectral mean values of the created sibilants were computed.

*1.1.4 Dutch sibilants*

According to Boersma and Hamann (2008), Dutch is an example of a language with only one sibilant, namely [s], which has a central spectral mean value (28 ERB). However, they note that there is also another sibilant in Dutch, namely [ɕ] (most often called [ʃ] in other studies), which occurs less frequently than /s/. This sound appears in diminutives, where the underlying sequence |s+j| is realized as [ɕ] (Mees and Collins 1982:6; Booij 1999:7), in words such as *tasje* /tɑɕə/ 'small bag'. This sound also occurs in loanwords (Mees and Collins 1982:6; Booij 1999:7), such as *pistaches* /pistɑɕəs/ 'pistachios' and *chic* /ɕik/ 'chic, stylish'. The combination of /s/ and /j/ is also found in compound words, e.g. in *bedrijfsjubileum* 'company's anniversary', and at word boundaries, e.g. in *zes januari* 'January the sixth' (Rechziegel, 2001). The combination of /s/ and /j/ is assimilated to [ʃ], because of ease of articulation (Rechziegel, 2001). According to Rechziegel, in Czech this process does not happen (but she did not analyze acoustic data), because in this language /ʃ/ has a clear phonemic status. However, it does seem to happen in American English, another language in which /ʃ/ has a phonemic status (Collins and Mees, 1999). When /s/ is followed by /j/ (e.g. in 'miss you'), the sounds are assimilated into one single sibilant sound which is produced by some speakers with acoustic properties in between /s/ and /ʃ/ (Zue and Shattuck-Hufnagel, 1980). In Dutch, the two sibilants /s̠/ and /ɕ/ have spectral mean values that are close together (Ooijevaar and Seinhorst, 2011). Another possibility is that palatalized sibilants show a lowering in spectral mean frequency at the end of the sibilant, e.g. in English (Zsiga, 2000) or in Polish (Zygis and Hamann, 2003). In English, this process occurs across word and morpheme boundaries (Oshika, Zue, Weeks, Neu, and Aurbach, 1975), and more often before pronouns than before content words (Zsiga, 2000).

Most studies about Dutch fricatives or consonants (seem to) assume that there is only one sibilant phoneme in Dutch, namely /s/ (Wagner et al., 2006; Rechziegel, 2001; Evers et al., 1998; Klaassen-Don, 1983; Klaassen-Don and Pols, 1983, 1986). In their perception studies of Dutch consonants, Klaassen-Don (1983) and Klaassen-Don and Pols (1983, 1986) only mention the sibilant fricative /s/. Wagner et al. (2006) mention /ʃ/ between brackets in the Dutch phoneme inventory, but nonetheless they say that Dutch does not contain spectrally similar fricatives. Booij (1999:7) and Evers et al. (1998) explicitly consider the palatal /ʃ/ to be an allophone of /s/. However, Mees and Collins (1982:7) argue that /ɕ/ may be an additional phoneme in Dutch. Similarly, Nooteboom and Cohen (1984) list /ʃ/ as an independent phoneme, because there are minimal pairs in which /s/ and /ʃ/ contrast in Dutch words. According to Kwakkel (2008), such minimal pairs are not frequent, and therefore, the status of Dutch /ʃ/ is different from English /ʃ/. Smits, Warner, McQueen, and Cutler (2003) did not discuss the status of /ʃ/, but they have found that Dutch listeners more often labeled [ʃ] as "s" (14.5%) than they labeled [s] as "sj" (3.3%). This finding is interpreted by Johnson and Babel (2010) as a preference for /s/ in perception, which reflects the allophonic status of /ʃ/. Even though the phonemic status of /ɕ/ (or /ʃ/) is not clear, one can argue that there are two sibilants in Dutch, namely /s̠/ and /ɕ/ (Ooijevaar and Seinhorst, 2011), which can either be considered as two separate phonemes, or as one phoneme with [ɕ] being an allophone of /s̠/.

Evers et al. (1998) compared the production of sibilants in three languages in which the sibilants /s/ and /ʃ/ have a different phonological status: in English, both sibilants contrast phonemically, whereas in Dutch, [ʃ] is an allophone of /s/, and in Bengali [s] is an allophone of /ʃ/. Evers et al. (1998) expected that the difference between /s/ and /ʃ/ would be larger in a language where these sounds contrast phonemically. However, they concluded that in all these three languages, /s/ and /ʃ/ could be distinguished from each other on the basis of one single cue provided by the noise of the sibilant: the overall spectral shape. In all three languages, the 'steepness difference' (the difference in the rate of increase of spectral energy of frequencies below and above 2500 Hz) was larger for /ʃ/ than for /s/, i.e. posterior /ʃ/ always has more noise in the lower frequencies and a lower spectral peak than anterior /s/. This relationship holds for all languages, but the distance (optimal boundary) between /s/ and /ʃ/ differs. Although the exact boundary values of the difference between /s/ and /ʃ/ differed, Evers et al. (1998) argued that this was rather due to individual differences between speakers than to differences between languages. However, there was more variation between Dutch speakers than between English speakers, i.e. there was more overlap between speakers (not within speakers). In addition, due to the difference in optimal boundary between /s/ and /ʃ/ in e.g. English and Bengali, what could sound as an /s/ for English listeners, could sound either as an /s/ or a /ʃ/ to Bengali listeners. Therefore, it seems that there *are* differences in production of sibilants with a different phonological status: phonemes are produced with a larger contrast than allophones of one phoneme.

Johnson and Babel (2010) tested the perception of the fricatives /f, θ, s, ʃ, x, h/ (in VCV sequences spoken by a native speaker of English) by native listeners of Dutch and of English. Of these six fricatives, the English phoneme inventory does not contain /x/, while the Dutch phoneme inventory does not contain /θ/. In addition, as mentioned above, the status of /ʃ/ in Dutch is less clear than in English: it is considered either an allophone of /s/ or a separate phoneme. A perceptual similarity rating task revealed that Dutch listeners rated the pairs /s-ʃ/, /s-θ/, and /ʃ-θ/ as more similar than did English listeners, especially in the [i_i] vowel environment. In the [a_a] vowel environment, only /s-ʃ/ was rated more similar by the Dutch listeners, and in the [u_u] vowel environment, only /s-θ/ was rated more similar by the Dutch listeners. In a speeded discrimination task, there were no differences in reaction time patterns between the two groups of listeners. However, the reaction time patterns were correlated with the results from the similarity rating task. Therefore, Johnson and Babel argue that differences between the groups in the first experiment are probably not due to language experience.

Kwakkel (2008) also did not find differences in perception of the /s/-/ʃ/ contrast due to language experience. Dutch and English listeners were tested on the perception of Dutch sibilants in an experiment where (only) the values of the spectral mean were varied. Participants heard three stimuli following each other and were asked whether the first (X) sound they heard was similar to the second (A) or to the third (B) sound (XAB task). In this way, Kwakkel defined the perceptual boundary between /s/ and /ʃ/ for Dutch native speakers as well as for English native speakers. This turned out to be about the same value for both groups of listeners (4988 Hz, approximately 28 ERB).

Klaassen-Don and Pols (1983:512, 1986) studied vowel transitions in Dutch CV and VC utterances (spoken in isolation or in running speech) from which the consonant was deleted, and in which the fricatives were /f, s, χ, v, z/ (Klaassen-Don and Pols, 1986). In a perception experiment, Dutch listeners had to indicate which consonant they heard on the basis of the vowel transitions. Depending on the consonant, the formant transitions at the beginning (CV) or end (VC) of the vowel contained sufficient information for the identification of certain consonants (namely voiced plosives, liquids and semi-vowels), but fricatives cannot be identified on the basis of the vowel transitions only. (Note however that /s/ is the only sibilant fricative in Dutch studied.) In running speech, listeners can rely less on vowel transitions than when words are spoken in isolation, so it remains unclear to what extent listeners use transitional cues in natural speech (Klaassen-Don and Pols, 1986). In several perception experiments (Klaassen-Don, 1983), Dutch listeners had to identify which fricative they heard (/f, s, χ, v, z/) in /CVt/, /tVC/, and /VCV/ utterances. In these utterances, the noise of the fricative was present or deleted. The listeners could not identify fricatives correctly (below 20 %) when the frication noise was absent. Therefore, Klaassen-Don (1983:79) concludes that “vowel transitions do not contain perceptually relevant information about adjacent fricatives in Dutch for this speaker and under these listening conditions!” However, if /ɕ/ was included, then Klaassen-Don probably could have seen an influence of vowel context: before alveolo-palatal sequences, e.g. /sj/, the back vowels /ɑ/ and /ɔ/ are raised and centralized, e.g. in tasje ‘small bag’ [‘tɑ̈ɕə] (Mees and Collins, 1983). This means that before a /ɕ/, the /ɑ/ is more fronted and has a higher F2 than before an /s̠/.

### *1.2 Research questions*

This paper tries to answer the following research questions: on which auditory cues do Dutch listeners rely to distinguish between the Dutch sibilants /s̠/ and /ɕ/, and is there a difference in perception of this contrast between younger and older listeners? One might expect a difference between younger and older listeners in the perceptual boundary between /s̠/ and /ɕ/: if they both rely on spectral mean, the boundary may be higher for the younger listeners than for the older listeners, i.e. the older listeners may have a larger bias towards /s̠/ than the younger listeners (Smits et al., 2003; Johnson and Babel, 2010). This is expected, because the relatively new sound /ɕ/ pushes the boundary higher to create a more salient perceptual contrast (Kwakkel, 2008). Another hypothesis concerns the importance of vowel context: just as in another language where the sibilants /s̠/ and /ɕ/ have close spectral mean values, i.e. Japanese (Toda, 2007; Li et al. 2009, 2011; Holliday et al., 2010), Dutch listeners may use the formants or formant transitions in the surrounding vowels to perceive the difference between /s̠/ and /ɕ/, because /ɑ/ is more fronted before /ɕ/ than before /s̠/ (Mees and Collins, 1983).

## 2. Method

### *2.1 Stimuli*

The stimuli to which the participants listened during the experiment were the two Dutch words *tassen* ‘bags’ and *tasje* ‘small bag’. The sibilants in these words were created by means of a PRAAT script (see 2.1.1) and inserted in two ‘word contexts’ or ‘vowel contexts’, i.e. the two words <ta(ss)en> and <ta(sj)e> without their sibilants, spoken by a young female native speaker of Dutch (see 2.1.2).

### *2.1.1 Sibilants*

The sibilants differed in the five following cues: (normalized) duration, spectral peak frequency, width of the spectral peak, skewness of the peak, and (normalized) amplitude (see Table 4, note that the values for duration or amplitude in this table are not the normalized values, see the description for each cue below). The values of all these cues are combined with each other yielding a total number of 486 (3*6*3*3*3) sibilants. In addition, each sibilant had a different spectral mean, a value which is dependent on the frequency, the width, and the skewness of the peak, but which is close to the spectral peak frequency.

**Table 4:** Duration (ms), spectral peak and its width (Hz), skewness and amplitude (dB)

| Duration (ms) | Spectral peak (Hz) | Width of the peak (Hz) | Skewness | Amplitude (dB) |
|---|---|---|---|---|
| 162.7 | 3000 | 3000 | Falling(1) | 50 |
| 135.5 | 4000 | 2000 | Flat(2) | 60 |
| 113.0 | 5000 | 1000 | Rising(3) | 70 |
| | 6000 | | | |
| | 7000 | | | |
| | 8000 | | | |

In a PRAAT script (see Annex 1, the formulas (1) to (5) are copied from this script), a mono sound with a sampling frequency of 44100 Hz and a certain duration (either 113.0, 135.5 or 162.7 ms) was created by inserting a formula for creating random noise:

(1) Create Sound from formula... s_'freq' Mono 0 dur'idur' 44100 randomGauss(0,0.1)

where “freq” is the frequency of the spectral peak (included in the name of the stimulus), and “dur” is one of the three durations

In order to create a spectral peak, this sound was converted to a spectrum. Frequencies in the region of the spectral peak kept their own amplitude, whereas other frequencies were set to zero amplitude:

(2) Formula... if *x* > onder and *x* < boven then self else 0 fi

where “onder” is the peak frequency minus half of the width, “boven” is the peak frequency plus half of the width, and *x* is the frequency in Hz

The pattern of skewness was manipulated by applying a formula for linear interpolation if the skewness was falling (negative formula):

(3) Formula... if *x* > onder and *x* < boven then self*(4-3*(*x*-onder) / (boven-onder)) else self fi

or if the skewness was rising (positive formula):

(4) Formula... if *x* > onder and *x* < boven then self*(1+3*(*x*-onder) / (boven-onder)) else self fi

If the spectrum was flat, no formula was applied. The spectrum was reconverted into a sound, of which the last part had to be deleted, because PRAAT added a sine-wave after the sound (i.e. after a duration of 113.0, 135.5, or 162.7 ms) at the frequencies of *x* which are manipulated in the formula, and this influenced the value of the spectral mean. After reconverting the sound into a spectrum, the spectral mean (which depends on other spectral values) could be computed. PRAAT gives this value in Hz. In order to compare the results of the present study with those of Boersma and Hamann (2008), the ERB values of the spectral mean values were also computed:

(5) cog_ERB = 11.17*ln((cog+312)/(cog+14680))+43

where "cog" is the COG (center of gravity, or spectral mean) frequency in Hz

When this spectrum was reconverted to a sound, amplitude could be manipulated. Since this also influenced the duration of the sound, the last part (i.e. after 113.0, 135.5, or 162.7 ms) was again deleted. Each sibilant was placed into both two word contexts <ta(ss)en> and <ta(sj)e> (i.e. concatenated between the first and the last part of each of the two words) and then saved as a .wav file. Values of the manipulated cues as well as of the spectral mean for each sibilants are asked for in PRAAT and copied to a table (see Annex 2) which contains the names of the 972 stimuli and the values of the sibilants therein.

*Duration.* Three values of duration were used: 113.0 ms, 135.5 ms, and 162.7 ms. The second duration value was based on the geometric mean of the mean duration values of the Dutch sibilants as measured by Ooijevaar and Seinhorst (2011): 126.7 ms for /s̠/ and 145.0 ms for /ɕ/ (√(126.7*145.0) = 135.5). Duration values differed with a factor of 1.2: the first value is the second value divided by 1.2 and the third value is 1.2 times the second value. Duration values should not be too short, because they may sound like a stop, /t/ or /d/, instead of a sibilant. Normalized duration was then computed by dividing the duration of the sibilant by the word duration. The word duration is the sum of the duration of the first syllable, /tɑ/, the sibilant duration, and the duration of the /ə/ in the last syllable (see Table 5). Duration values of the first and the last syllable for each word context are shown in Table 7 (section 2.1.2) where a detailed description of the word contexts is given.

**Table 5:** Sibilant duration, word duration and normalized duration

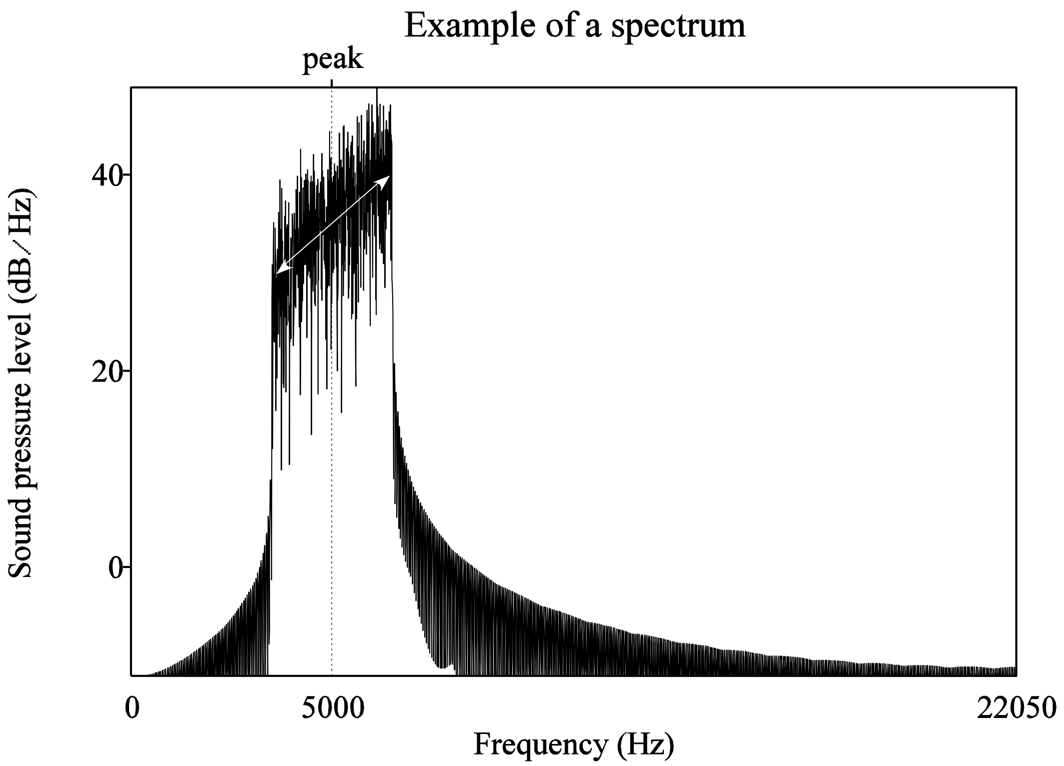
| Word context | Sibilant duration (ms) | Word duration (ms) | Normalized duration |
|---|---|---|---|
| <ta(ss)en> | 113.0 | 338.6 | 0.334 |
| | 135.5 | 361.1 | 0.375 |
| | 162.7 | 388.3 | 0.419 |
| <ta(sj)e> | 113.0 | 338.3 | 0.334 |
| | 135.5 | 360.8 | 0.375 |
| | 162.7 | 388.0 | 0.419 |

Normalized duration values are smaller than those for /s/ (0.438) and /ʃ/ (0.448) measured by Jongman et al. (2000), and the difference between two normalized duration values in the present study is larger, i.e. about 0.04 (instead of 0.01). However, the words in the present study are disyllabic and sibilants are intervocalic, while the words in Jongman et al. (2000) are monosyllabic and sibilants are word-initial.

*Spectral peak frequency.* Spectral peaks with frequencies ranging from 3000 to 8000 Hz in steps of 1000 Hz were used (see Figure 2, where peak frequency is indicated by a vertical dotted line). These six values are within the range of spectral peak frequencies found for a language having two sibilants: e.g. Jongman et al. (2000) found that the spectral peaks of /s/ and /ʃ/ for American English were between 3000 and 8000 Hz. For /s/, the spectral peak is normally found in the region between 3500 and 5000 Hz, whereas /ʃ/ has a lower spectral peak, between 2500 and 3500 Hz (Behrens and Blumstein, 1988a). Spectral peaks of 2000 Hz were not used, because the resulting stimuli did not sound as natural sibilants, especially when the width of the peak was larger than 1000 Hz.

*Width of the peak.* The width of the peak was varied in three steps: 1000, 2000, and 3000 Hz. Sibilants are characterized by a distinct peak in the spectrum, whereas other fricatives have a flat spectrum with energy spread over a larger range of frequencies, somewhere between 1800 and 8500 Hz (Behrens and Blumstein, 1988). According to Strevens (1960), in (Scottish) English, the fricatives /s, ʃ, ç/ have a shorter spectrum (i.e. the frequency bandwidth is 3000-4000 Hz) than other fricatives, /x, χ, h/ (with a bandwidth of 4000-5500 Hz) or /ɸ, f, θ/ (with a bandwidth of 5000-6000 Hz) Therefore, the maximum width of the peak was set at 3000 Hz. The spectral peak frequency was in the middle of the peak, i.e. half of the width was added to the spectral peak frequency and half of the width was subtracted from the spectral peak value (see Figure 2). For example, with a spectral peak frequency of 5000 Hz and a width of 3000 Hz, the band of noise starts at 3500 Hz and ends at 6500 Hz (as can be seen in Figure 2).

**Figure 2:** Example of a spectrum with a peak frequency of 5000 Hz, a width of 3000 Hz and rising skewness




*Skewness of the peak.* Positive (or falling) skewness means that lower frequencies are stronger in amplitude: low minus high frequencies results in a positive number of skewness. Negative (or rising skewness) means that higher frequencies are stronger in amplitude: low minus high frequencies results in a negative number of skewness. In American English, /ʃ/ is characterized by more energy in the lower frequencies (positive skewness), whereas /s/ is characterized by more energy in the higher frequencies (negative skewness, or skewness around 0), e.g. see Jongman et al. (2000), or Haley et al. (2010). In the present paper, three types of skewness were used: falling or positive (the lower the frequencies of the peak are, the stronger their amplitude is), flat (all frequencies of the peak are comparably strong in amplitude) and rising or negative (the higher the frequencies of the peak are, the stronger their amplitude is). Figure 2 shows an example of rising skewness, indicated by the white two-way arrow.

*Normalized amplitude.* Normalized amplitude is the difference between the noise amplitude and the vowel amplitude (Jongman et al., 2000). Fricatives are smaller in amplitude than vowels (at least those measured by Jongman et al., 2000). Therefore, amplitude values of the created sibilants were set to be smaller than those of the surrounding vowels. The word from which these vowels were extracted was normalized to 70 dB. Then, the vowels were extracted from the words and their exact amplitude was measured. The sibilants were created with an amplitude of either 50, 60, or 70 dB[1], which means that normalized amplitude was -20, -10 or 0 dB. Table 6 shows the exact normalized amplitude values of the sibilant with respect to each separate vowel (see Table 7 in section 2.1.2 for the amplitude values of the separate vowels).

**Table 6:** Absolute amplitude, normalized amplitude and amplitude of the sibilant with respect to each separate vowel (in dB)

| **Amplitude** | | **<ta(ss)en>** | | **<ta(sj)e>** | |
|---|---|---|---|---|---|
| 'Absolute' | Normalized | After /ɑ/ | Before /ə/ | After /ɑ/ | Before /ə/ |
| 50 | -20 | -24.3 | -17.0 | -26.0 | -20.5 |
| 60 | -10 | -14.3 | -7.0 | -16.0 | -10.5 |
| 70 | 0 | -4.3 | 3.0 | -6.0 | -0.5 |

*2.1.2 Word context*

The 486 created sibilants were embedded in a word context: each sibilant stimulus was inserted in both of the words of the minimal pair /tɑs̠ə/-/tɑɕəs/ spoken by one female native speaker of Dutch at the age of 25. Participants heard 500 of the (486*2=) 972 possible word stimuli, but in the hypothetical case that one single participant would hear all 972 word stimuli, s/he would hear each created sibilant two times, but as a part of two different words. The words were taken from speaker NL02 (see Ooijevaar and Seinhorst, 2011), because the spectral mean values of her sibilants were closest together of all 10 Dutch native speakers, with an average distance of only 0.65 ERB.

The words were cut in two parts, the part that preceded the sibilant and the part that followed the sibilant. A part of similar duration of /tɑ/ in both words was selected (the cursor was placed at a zero-crossing, before the start of aperiodic noise in the waveform) and then extracted from the word. A part of equal duration of /ə/ in both words was selected (the cursor was placed at a zero-crossing, at the end of the noise when periodicity in the waveform appears and before the following /s/ in the word /tɑɕəs/) and then extracted from the word. The first part of the word, i.e. the first syllable /tɑ/, was concatenated before the sibilant and the next part of the word, i.e. the schwa /ə/ of the second syllable, was concatenated after the sibilant. The sibilant was only inserted between the first and last part of the same word, i.e. the first syllable /tɑ/ of one word was not concatenated (with the sibilant) to the schwa /ə/ of the other word.

[1] Sibilants with higher amplitude values were not used, because they were clipped when the sound was saved to a .wav file, i.e. at certain frequencies some amplitude values were too loud and their amplitude was changed to a maximum value.

The sibilants in the two word tokens which were chosen to serve as word context had a spectral mean value close to 28 ERB and the duration of the sibilants was quite similar: 27.96 ERB and 100.05 ms for /s̱/ (in instance nr. 2 of the word <tassen>), and 27.53 ERB and 101.90 ms for /ɕ/ (in instance nr. 3 of the word <tasjes>). Pitch and intensity contours were similar for the non-sibilant parts of the words. The duration of the first syllable of <tassen> was comparable to the duration of the first syllable of <tasjes>, and the /ə/ in the last syllables of these two words also had an equal duration: i.e. a part of equal duration was extracted from the words. In the following table, values of duration, amplitude and formants of the word contexts are given. Duration and amplitude are kept similar for the two different word contexts. In order to control normalized amplitude, the amplitude of the words from which the vowels were extracted was normalized to 70 dB. Then, the vowels were extracted from the words and their exact amplitude was measured.

The amplitude values of the created sibilants were either 50, 60, or 70 dB, which means that their normalized amplitude was -20, -10 or 0 dB. However, the exact amplitudes of the separate vowels were different: the vowel in the first syllable had a higher amplitude than the vowel in the second syllable (see Table 7, recall that the normalized amplitude values of the sibilants were given in Table 6 in section 2.1.1). The formants given in Table 7 are a mean value of the vowel as a whole. Formants were measured by selecting the whole extracted vowel /ə/, or by starting the selection at the start of periodicity in the waveform of the syllable /tɑ/, where the formants become visible. Then, PRAAT was asked for the values by using the commands "Get pitch…" (for the F0) and "Formant listing…" (for the F1, F2, F3, and the F4).

**Table 7:** Details of the word contexts: mean values of the whole vowel

| Word context | Syllable | Duration (ms) | Amplitude (dB) | F0 (Hz) | F1 (Hz) | F2 (Hz) | F3 (Hz) |
|---|---|---|---|---|---|---|---|
| <ta(ss)en> | /tɑ/ | 120.6 | 74.3 | 224.5 | 648.6 | 1312.5 | 3070.7 |
| <ta(ss)en> | /ə/ | 105.0 | 67.0 | 186.6 | 566.4 | 1511.3 | 2890.6 |
| <ta(sj)e> | /tɑ/ | 121.1 | 76.0 | 215.8 | 631.9 | 1469.8 | 2836.8 |
| <ta(sj)e> | /ə/ | 104.2 | 70.5 | 182.0 | 524.5 | 1719.5 | 2958.4 |

Formant values differed according to the vowel context: before or after an /s̱/ the formant values of the vowels are different than before or after a /ɕ/; they indicate the place of articulation of the sibilants. The vowel /ɑ/ is raised and centralized (more fronted) when it precedes a /sj/ sequence, i.e. /ɕ/ (Mees and Collins, 1983). This means that the F1 is lower and the F2 is higher when /ɑ/ precedes /ɕ/, which is indeed visible in the F1 and F2 values for /ɑ/ in the different word contexts in Table 7 (note that for the /ə/ following /ɕ/, F1 values are also lower and F2 values are also higher than for the /ə/ following /s̱/). The transitions of the second formant (F2) have been found to be most relevant for the place distinction in sibilants (e.g. see Mann and Repp, 1980; Whalen, 1981, 1991; Datscheweit, 1990;

Bladon et al., 1987; Gordon et al., 2002; Nowak, 2006; McGuire, 2007, 2008; Zygis and Padgett, 2010; Toda, 2007; Li et al. 2009, 2011; Holliday et al., 2010). Therefore, the F2 transitions in the vowels were measured as well. Table 8 gives the F2 values in the mid of the vowel, as well as at the vowel offset (for the vowel preceding the sibilant) and the vowel onset (for the vowel following the sibilant).

The F2 was measured at the midpoint of the vowel, and at the endpoint of the vowel for /ɑ/ (preceding the sibilant), and at the beginpoint of the vowel, for /ə/ (following the sibilant). The formants at the endpoint (or beginpoint) are measured by placing the cursor at the latest (or first) red formant point visible in the spectrogram and ask PRAAT for the F2 value. The formants at the midpoint are measured by placing the cursor exactly at the midpoint of the vowel (which is the standard value when you view and edit a sound) and ask PRAAT for the F2 value.

**Table 8:** Details of the word contexts: F2 transitions (in Hz)

| | **First syllable** | | **Second syllable** | |
|---|---|---|---|---|
| **Word context** | F2 mid /ɑ/ | F2 offset /ɑ/ | F2 onset /ə/ | F2 mid /ə/ |
| <ta(ss)en> | 1292.4 | 1332.6 | 1662.1 | 1631.7 |
| <ta(sj)e> | 1484.2 | 1248.2 | 1763.5 | 1677.1 |

Although the mean F2 value for the /ɑ/ preceding /ɕ/ is higher than for the /ɑ/ preceding /s̲/, the /ɑ/ preceding /ɕ/ has a lower F2 offset than the /ɑ/ preceding /s̲/. This may be because the noise for /ɕ/ is lower than the noise of /s̲/. If formant values and/or transitions in the preceding and the following vowel are of importance to the perception of the place of the sibilant, then an effect of word context will be visible in the perception task: the sibilant inserted in the word context <ta(ss)en> will most likely be heard as an /s/ and the sibilant in the word context <ta(sj)e> will most likely be heard as a /ɕ/.

### *2.2 Procedure*

The perception of Dutch sibilants was tested in an identification task (Experiment MFC, in PRAAT), in which participants heard a word, and were asked to identify this word. Participants had to decide whether the word they heard was <tassen> ‘bags’, <tasje> ‘small bag’, or <tatje> as in *patatje* ‘portion of French fries’. If they did not perceive the stimulus as one of these words, they could also click on the option <anders> ‘different’. Stimuli were played in a random order. First, participants were shown a short practice trial with 4 stimuli words, to familiarize with the task and to adjust their volume, if necessary. The sibilant stimuli in this task had spectral peaks of 3000 and 8000 Hz and were embedded in both word contexts. Other values were kept constant at mid values: width of the peak was 2000 Hz, skewness was flat, duration was 135.5 ms, and normalized amplitude was -10 dB. Then, they started the experiment. After every 100 stimuli, participants could take a short break. Each participant heard 500 word stimuli of the total number of different stimuli (N=972), because this is the maximum number of stimuli which is feasible to test during one experiment (Paul Boersma, p.c.). Therefore, the experiment was stopped after five blocks of stimuli had been played (incomplete experiment)[2]. The experiment lasted approximately 20-30 minutes.

### *2.3 Instrumentation*

Participants were tested in a quiet room. Stimuli were played on a computer over headphones. The experiment was started by reading the experiment file in PRAAT (version 5.2.19, which accepts incomplete experiments). Participants chose answers by means of mouse clicks. They clicked on the word, <tassen> in a box at the upper left side of the screen, <tasje> in a box at the upper right side of the screen or <tatje> in a box at the lower left side of the screen. They could also chose the option <anders> in a box at the lower right side of the screen when they thought it did not sound like one of these words at all.

### *2.4 Participants*

In total, 52 native speakers of Dutch participated in the experiment, but the data of two participants could not be analyzed. Participants were selected according to their age (see Table 9): the younger listeners were between 18 and 25 years old (a part of these listeners was contacted via the database *Spreken en Verstaan* of the Linguistics Department of the University of Amsterdam), and the older listeners were between 50 and 71 years old. See Annex 3 for a detailed list of the participants. If there is a change in progress in the pronunciation of Dutch sibilants, then this may be reflected in perception: younger speakers of Dutch may use other cues than older speakers of Dutch.

**Table 9:** Number of participants, their gender, and the mean age (s.d.) for each age group

| **Age group** | **N** | **Men** | **Women** | **Mean age (s.d.)** |
|---|---|---|---|---|
| Old (50-71 years) | 25 | 7 | 18 | 57.4 (5.5) |
| Young (18-25 years) | 25 | 9 | 16 | 21.5 (1.9) |

[2] However, some of the participants did not take breaks in between and did not signal to the experimenter when they had finished a block of 100 stimuli (although explicitly asked for). Because of this reason, they listened to more than 500 stimuli words, but only the responses to the first 500 stimuli are analyzed.

It is also possible that there are differences in perception between participants from different regions. A Dutch /s/ may sound as a /ʃ/ to English ears, especially when it is produced by speakers with an urban Randstad accent, and in some Dutch dialects (e.g. Amsterdam), the contrast /s/-/sj/ may be lost (Collins and Mees, 1999). The participants in the present study were not selected according to their region, but a possible criterion for the distinction of two region groups may therefore be whether someone is born in the Randstad (here defined as the southern part of Noord-Holland (Zaandam, Haarlem and below), Utrecht, Zuid-Holland) or not (see Annex 3). Care was taken so that not most of the older participants fell into one group and the younger participants in the other group. Table 10 shows the number of participants in each region group and their mean age.

**Table 10:** Number of participants, age group, and the mean age (s.d.) for each region group

| **Region group** | **N** | **Young** | **Old** | **Mean age (s.d.)** |
|---|---|---|---|---|
| Randstad | 28 | 16 | 12 | 36.6 (18.6) |
| Non-Randstad | 22 | 9 | 13 | 43.0 (18.9) |

### *2.5 Analysis*

Results of the perception experiment were collected in a Table (one for each participant) in PRAAT. In this table, details about the sibilant stimuli that were played during the experiment (values of all cues) are given and the word in which they were embedded. Reaction times were measured from the start of the stimulus sound (see PRAAT manual, ExperimentMFC 2.9, 17-03-2011). The main aim of the present study is to compare the results for different age groups, but differences in results between men and women and differences in results caused by the region where participants are born are also taken into account.

The number of responses for <tassen> compared to the number of responses for <tasje> for each listener within each age group were analyzed with a two-tailed dependent-samples *t*-test. A difference column for the "/s/-bias" (i.e. the number of responses for <tassen> minus the number of responses for <tasje>) was appended to the table (see Annex 4). The /s/-bias was compared between the two age groups with a two-tailed independent-samples *t*-test. A logistic regression analysis was computed for each listener for the factors context, duration (in ms), peak (in Hz), width (in Hz), skewness, amplitude (in dB), and peak$^2$ (in Hz). The dependent variables were <s> (dependent 1) and <sj> (dependent 2). The log odds ratios of the factors peak and context were used to compute the angle for each participant, differences in angle were analyzed with a two-tailed independent-samples *t*-test. Another regression analysis with only the factors peak and context was computed for each listener to determine the place of the perceptual boundary between /s̠/ and /ɕ/. The coefficients for the factor peak and context were used to compute the perceptual boundary for each participant. Differences in perceptual boundary were analyzed with a two-tailed independent-samples *t*-test.

## 3. Results

Data of two participants (one in each age group) were not taken into account for further analysis: the data of AVOF were lost, and the data of JSYM contained too much negative reaction times (104 out of 500 stimuli) to be reliable (it is not certain to which stimulus each response refers; in addition, log odds ratios were low for all cues). Table 9 (see section 2.4) shows the mean age of the 50 remaining participants in each age group. Of these 50 participants, the number of responses for <tassen> and <tasje> (see Table 11) were compared (see Annex 4 for the number of times each participant clicked on <tasje> and on <tassen>).

In general, most participants, i.e. 39 out of 50 participants, clicked more often on <tassen> (197.9 times) than on <tasje> (137.6 times), that is, they are biased towards hearing /s̲/. A two-tailed dependent-samples *t*-test revealed that this difference was significant: $t = 5.16$, $df = 49$, $p < 0.00001$. To test whether there is a difference in the bias towards /s̲/ between older and younger listeners, the difference between the responses for <tassen> and the responses for <tasje>, the "/s/-bias", was computed for each participant. The values for the /s/-bias ranged from -181 to +242 (see Annex 4). A positive value for the /s/-bias indicates that a listener is biased towards /s̲/. Some of the listeners answered more often <tasje> than <tassen> and therefore had a negative value for the /s/-bias. Therefore, the value of the standard deviation can be larger than the value of the mean /s/-bias (see Table 11). The bias towards /s̲/ is larger for the older participants than for the younger participants ($t$ = 2.24, $df = 48$, $p = 0.0296$).

**Table 11:** Mean number of responses for the words <tassen> and <tasje> and the /s/-bias (s.d. are given within brackets)

| **Age** | **N** | **<tassen>** | **<tasje>** | **/s/-bias** |
|---|---|---|---|---|
| Old (N = 25) | 500 | 205.9 (65.8) | 120.4 (68.6) | 85.5 (79.7) |
| Young (N = 25) | 500 | 189.9 (38.2) | 154.8 (68.5) | 35.1 (78.9) |
| **Mean** | 500 | 197.9 (53.8) | 137.6 (70.0) | 60.3 (82.5) |

There was only a difference in /s/-bias between age groups. The /s/-bias is not significantly smaller for the female listeners than for the male listeners ($t = -0.14$, $df = 48$, $p = 0.9331$).

**Table 12:** Mean number of responses for the words <tassen> and <tasje> and the /s/-bias (s.d. are given within brackets)

| **Gender** | **N** | **<tassen>** | **<tasje>** | **/s/-bias** |
|---|---|---|---|---|
| Women (N = 34) | 500 | 190.5 (58.5) | 130.9 (72.2) | 59.6 (80.4) |
| Men (N = 16) | 500 | 213.7 (39.4) | 151.9 (65.1) | 61.8 (89.5) |

The /s/-bias is slightly smaller for the listeners that were born in the Randstad than for the listeners that were not born in the Randstad, but this difference was not significant ($t$ = -0.15, $df$ = 48, $p$ = 0.8853).

**Table 13:** Mean number of responses for the words <tassen> and <tasje> and the /s/-bias (s.d. are given within brackets)

| **Region** | **N** | **<tassen>** | **<tasje>** | **/s/-bias** |
|---|---|---|---|---|
| Randstad (N = 28) | 500 | 193.3 (54.4) | 134.5 (74.3) | 58.8 (87.8) |
| Non-Randstad (N=22) | 500 | 203.7 (53.8) | 143.0 (67.8) | 62.2 (77.2) |

Therefore, both generations have a bias towards /s̲/ (as was also found or expected in earlier studies about Dutch sibilants, see Smits et al., 2003; Johnson and Babel, 2010), i.e. they both answer more often <tassen> than <tasje>, although the bias is larger in the older listeners than in the younger listeners. There were no differences between male and female listeners nor between listeners that were born in the Randstad versus those who were born in a different region. However, the main question of the present study is whether the two generations use the same or different cues in identifying the /s̲/ and the /ɕ/, and whether they have their perceptual boundary at the same place.

A logistic regression analysis (see Annex 5 for the PRAAT script to run the analysis) was calculated of the stimuli for which the participants responded either <tassen> or <tasje> (recall that they also could choose between the options <tatje> and <anders>). The factors were context, duration (in ms), peak (in Hz), width (in Hz), skewness, amplitude (in dB), and peak$^2$ (in Hz). In order to obtain peak$^2$, the following formula was entered into a PRAAT script (Annex 5):

(6) Formula… peak$^2$ (self [“peak(Hz)”] – 5500)^2

Subtracting the middle value ((3000+8000)/2=5500) from the peak value and then squaring results in a parabola. If the log odds ratio of the peak$^2$ is high, this could show evidence for a bimodal distribution (see Boersma and Hamann, 2008:254, note 14).

The dependent variables were <s> (dependent 1) and <sj> (dependent 2). Only the responses of participants who clicked at least 50 times on <tassen> as well as 50 times on <tasje> were taken into account for further analysis. In total, the responses of 44 out of 50 participants met this criterion. This resulted in a minimum of 100 stimuli on which the logistic regression analysis was based. A minimum value was chosen, because if participants did not click often on a response category, the log odds ratios of that participant became much larger compared to those of the other participants. Therefore, further analysis of the data will only concern the responses given by those 44 participants (see Table 14).

**Table 14:** Number of participants who clicked at least 50 times on <tassen> as well as at least 50 times on <tasje>, their gender, and the mean age (s.d.) for each age group

| | Participants who clicked at least 50 times on both <tassen> and <tasje> | | | |
|---|---|---|---|---|
| **Age group** | N | Men | Women | Mean age (s.d.) |
| Old (50-71 years) | 21 | 8 | 13 | 57.4 (5.5) |
| Young (18-25 years) | 23 | 7 | 16 | 21.4 (1.9) |

Table 15 shows the same number of participants, grouped according to region, and the mean age for each region group:

**Table 15:** Number of participants who clicked at least 50 times on <tassen> as well as at least 50 times on <tasje>, their age group, and the mean age (s.d.) for each region group

| | Participants who clicked at least 50 times on both <tassen> and <tasje> | | | |
|---|---|---|---|---|
| **Region group** | N | Young | Old | Mean age (s.d.) |
| Randstad | 23 | 14 | 9 | 35.6 (18.5) |
| Non-Randstad | 21 | 9 | 12 | 41.9 (18.6) |

In a logistic regression analysis, the odds express how many times more likely it is that a certain event occurs than another event. The log odds is the logarithm of the odds (or the logarithm of the probability of hearing a <sj> minus the logarithm of the probability of hearing an <s>). In the present study, the odds express the probability of hearing a <sj> divided by the probability of hearing an <s>. The odds ratio for the factor peak is the odds of hearing a <sj> rather than <s> at 8000 Hz divided by the odds of hearing a <sj> rather than <s> at 3000 Hz. The log odds ratio is the logarithm of the odds ratio (or the log odds of hearing a <sj> rather than <s> at 8000 Hz minus the log odds of hearing a <sj> rather than <s> at 3000 Hz). If the odds ratio is larger than one, the log odds ratio is positive. If the odds ratio is smaller than one, the log odds ratio is negative. In the present analysis, the log odds ratios of both the factors peak and context are negative: i.e. the log odds of hearing a <sj> rather than an <s> at 8000 Hz is smaller than the log odds of hearing a <sj> rather than an <s> at 3000 Hz. See Annex 6 for a Table with log odds ratios per factor for each participant. To derive the odds ratio from the log odds ratio, take the exponential of the log odds ratio: $e^x$ (where $x$ is the log odds ratio).

In general, the log odds ratios were highest (i.e. most negative) for the factors peak and context. Therefore, these two factors seem to be the most important in the distinction between <s> and <sj>. For some of the participants, the log odds ratio of peak$^2$ is high, sometimes higher than for context. However, the log odds ratios seem to be dependent on those of the peak: when the factor peak was omitted from the logistic regression analysis, the log odds ratios of peak$^2$ turned down. The log odds ratio of peak$^2$ is correlated with the log odds ratio of the peak (Pearson's $r = 0.54$, $df = 42$, $p < 0.0001$). Therefore, this factor does not seem to be important, which means that there is no evidence for a bimodal distribution. Other factors (duration, amplitude, width of the peak, skewness of the peak) were relatively less important as well, although for some of the participants log odds ratios where somewhat higher for certain factors than for the other participants.

**Figure 3:** Perceptual boundaries for the /s̠/-/ɕ/ contrast for the younger vs. the older listeners

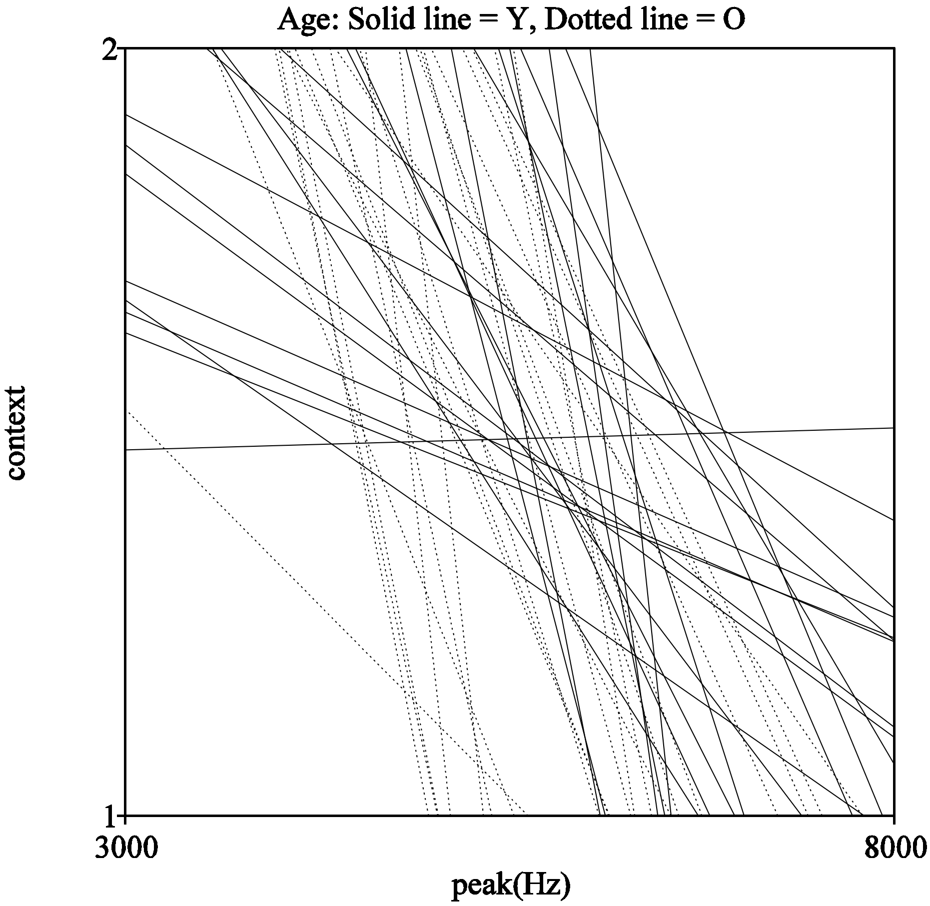


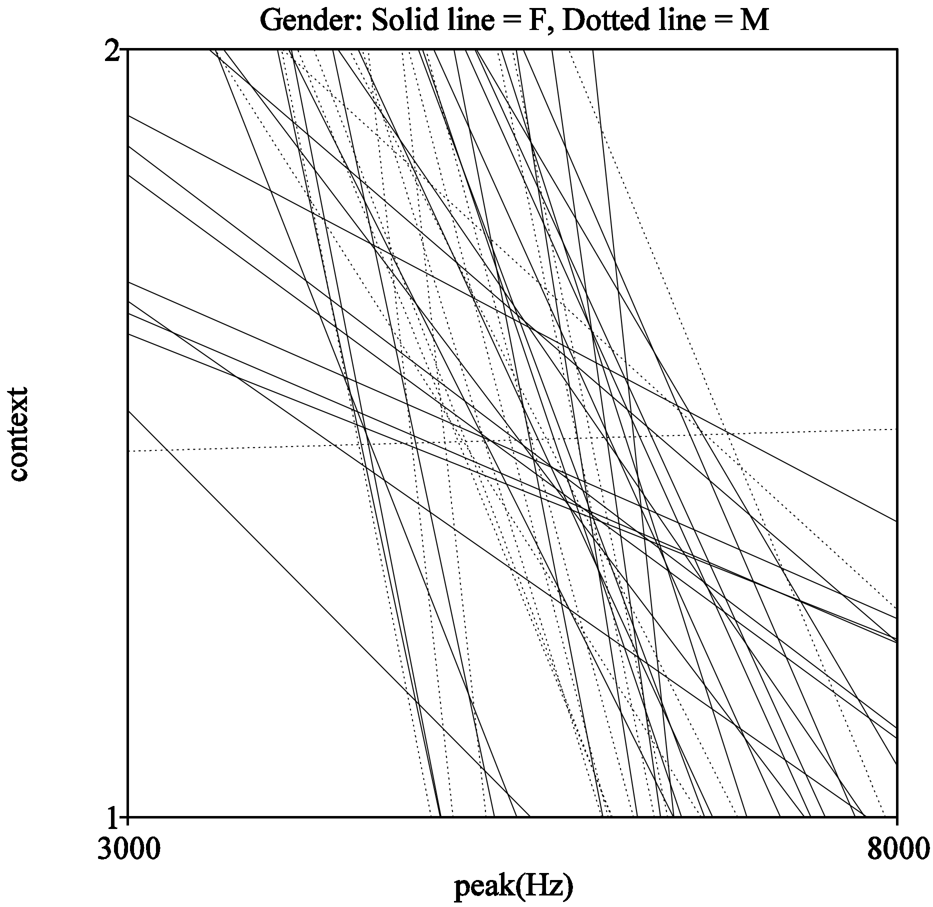

Figure 3 (drawn with the script in Annex 5) shows the perceptual boundaries between /s̠/ and /ɕ/ for each participant: the perceptual boundaries of the younger speakers are drawn in solid lines, while the perceptual boundaries of the older speakers are drawn in dotted lines. Context 1 refers to the word <tasje> and context 2 refers to the word <tassen>. Most of the lines are drawn from the upper left corner to the lower right corner of Figure 3: the lower left corner and the upper right corner remain empty, which means that noise with a low peak frequency in the <tasje> context is always heard as /ɕ/ and noise with a high peak frequency in the <tassen> context is always heard as /s̠/. The dotted lines are mostly vertical, i.e. they start in the upper half and they end in the lower half of the figure. This means that the peak is the most important cue for the older listeners.

This is also reflected in the log odds ratios: for the older listeners, the log odds ratios of the factor peak (mean: -10.98) were always larger than those of the factor context (mean: -3.23). The odds of hearing a <sj> rather than an <s> at 8000 Hz is 58689 times smaller than the odds of hearing a <sj> rather than an <s> at 3000 Hz (the odds ratio is $e^{-10.98}$ = 1/58689). The odds of hearing a <sj> rather than an <s> in context 2 (<tassen>) is only 25 times smaller ($e^{-3.23}$ = 1/25) than the odds of hearing a <sj> rather than an <s> in context 1 (<tasje>). For one female listener from the region of Amsterdam (TVOF), the log odds ratio of the factor peak was only slightly higher than the log odds ratio of the factor context, which means that peak and context are about equally important cues for this listener. This is clearly visible in Figure 3: the boundary of this listener differs from the other older listeners in that it is in the lower left corner, i.e. the probability to hear /s̠/ is larger than the probability to hear /ɕ/.

For about half of the younger listeners (N = 13), the factor peak was also more important than the factor context. For these listeners, the lines of the perceptual boundaries also started at the upper half of Figure 3 and ended at the lower half. The log odds ratios of the factor peak were larger than those of the factor context for these listeners as well. However, the other half of the younger listeners (N = 10) assigned more importance to the factor context than to the factor peak. The lines were more horizontal than for the other listeners, and started at the left part (or at the upper part for two of the participants) of Figure 3 and ended at the right part. For these 10 young listeners, the log odds ratios of the factor context were larger than those of the factor peak. The perceptual boundary of one of the participants (RDYM) was different from all the other participants in that it was an almost perfectly horizontal line, i.e. he listened almost completely to vowel context. The responses given by this participant are excluded for further analysis, because the log odds ratio for the factor peak was positive instead of negative (which resulted in a positive angle and a boundary that was far beyond those of the other listeners, namely more than two times above the maximum peak value of 8000 Hz). The mean log odds ratio for the remaining 22 younger listeners was -7.24 for the factor peak and -3.88 for the factor context. The odds of hearing a <sj> rather than an <s> is 1394 times smaller at 8000 Hz than at 3000 Hz (the odds ratio is $e^{-7.24}$ = 1/1394). The odds of hearing a <sj> rather than an <s> is 48 times smaller ($e^{-3.88}$ = 1/48) in context 2 (<tassen>) than in context 1 (<tasje>).

Figure 4 (drawn with the script in Annex 5) shows the same boundaries, but now the perceptual boundaries of the female listeners (N = 29) are drawn in solid lines, while the perceptual boundaries of the male listeners (N = 14) are drawn in dotted lines. No clear pattern as the one for the different age groups emerges between boundaries of male and of female listeners, but perhaps one can say that female listeners rely more on context than male listeners.

**Figure 4:** Perceptual boundaries for the /s̠/-/ɕ/ contrast for the female vs. the male listeners




The mean log odds ratio for the female listeners was -9.00 for the factor peak and -3.93 for context. The odds of hearing a <sj> rather than an <s> at 8000 Hz is 8103 times smaller than the odds of hearing a <sj> rather than an <s> at 3000 Hz (the odds ratio is $e^{-9.00}$ = 1/8103). The odds of hearing a <sj> rather than an <s> in context 2 (<tassen>) is 51 times smaller ($e^{-3.93}$ = 1/51) than the odds of hearing a <sj> rather than an <s> in context 1 (<tasje>).

The mean log odds ratio for the male listeners was -9.21 for the factor peak and -2.80 for context. The odds of hearing a <sj> rather than an <s> is 9997 times smaller at 8000 Hz than at 3000 Hz (the odds ratio is $e^{-9.21}$ = 1/9997). The odds of hearing a <sj> rather than an <s> is 16 times smaller ($e^{-2.80}$ = 1/16) in context 2 (<tassen>) than in context 1 (<tasje>).

There did not seem to be a clear effect of region, that is, not all participants of one certain region used one listening strategy whereas participants from other regions used the other listening strategy. The mean log odds ratio for the listeners who were born in the Randstad was -10.88 for the factor peak and -3.64 for context. The odds of hearing a <sj> rather than an <s> at 8000 Hz is 53104 times smaller than the odds of hearing a <sj> rather than an <s> at 3000 Hz (the odds ratio is $e^{-10.88}$ =

1/53104). The odds of hearing a <sj> rather than an <s> in context 2 (<tassen>) is 38 times smaller ($e^{-3.64}$ = 1/38) than the odds of hearing a <sj> rather than an <s> in context 1 (<tasje>).

The mean log odds ratio for the listeners who were not born in the Randstad was -7.17 for the factor peak and -3.48 for context. The odds of hearing a <sj> rather than an <s> at 8000 Hz is 1300 times smaller than the odds of hearing a <sj> rather than an <s> at 3000 Hz (the odds ratio is $e^{-7.17}$ = 1/1300). The odds of hearing a <sj> rather than an <s> in context 2 (<tassen>) is 33 times smaller ($e^{-3.48}$ = 1/33) than the odds of hearing a <sj> rather than an <s> in context 1 (<tasje>).

The angle of the boundary for each participant was computed by means of the following formula (see Annex 5, which also shows the angle for each participant):

(7) angle = -arctan (log odds ratio of peak / log odds ratio of context) * 180 / pi

An angle between -90° and -45° means that listeners rely more on the factor peak than on the factor context. An angle between -45° and 0° means that listeners rely more on the factor context than on the factor peak. A smaller negative angle results in a more horizontal line: the more horizontal the line is, the more listeners rely on context. The mean angle was -54.20° for the younger listeners and -71.25° for the older listeners. That is, younger listeners rely more on vowel context than older listeners do. There was a significant difference in the angle between the two age groups ($t$ = -3.42, $df$ = 41, $p$ = 0.0014).

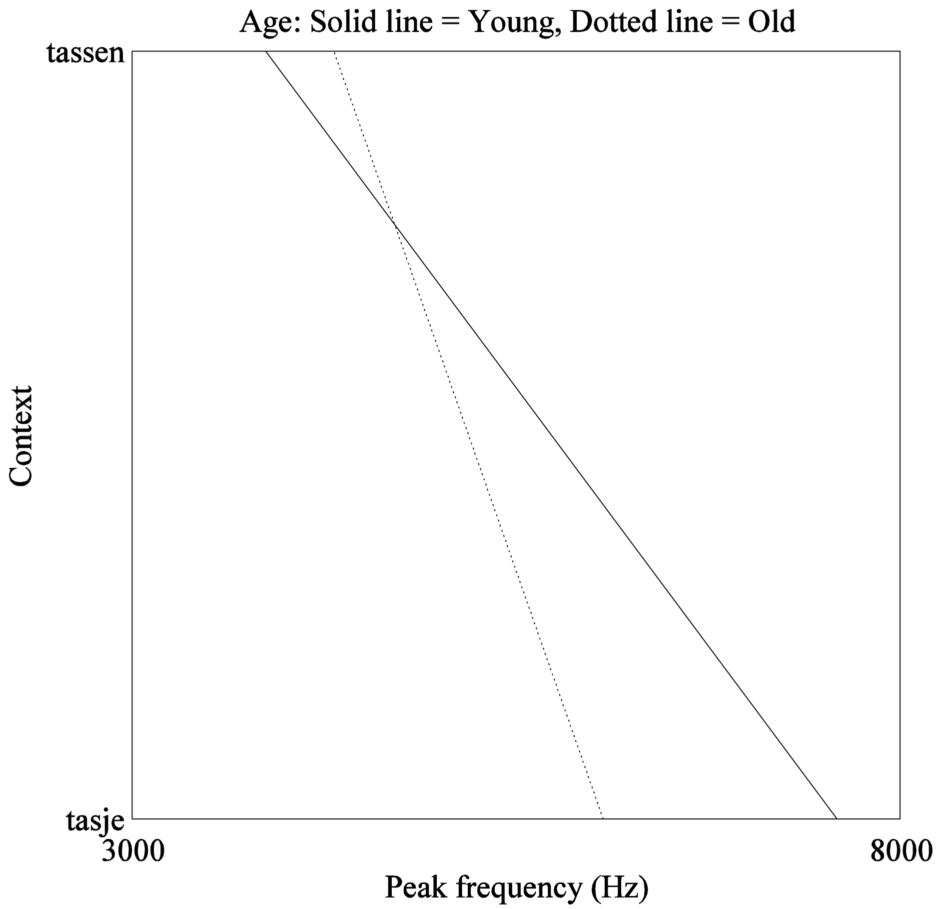
The mean angle was -58.43° for the female listeners and -71.01° for the male listeners. The angle for the female listeners was significantly less negative than for the male listeners ($t$ = -2.21, $df$ = 41, $p$ = 0.0330). That is, the female listeners relied more on context than the male listeners did. The mean angle was -63.49° for listeners born in the Randstad and -61.53° for listeners born in a different region. There was no significant difference in the angle between participants born in different regions ($t$ = 0.35, $df$ = 41, $p$ = 0.7304).

Since the two most important factors were peak and context, another logistic regression analysis (see Annex 7 for the PRAAT script to run this analysis) was calculated with these factors only to determine the place of the perceptual boundary between the dependent variables <s> and <sj>. (With the coefficients and the intercept resulting from a regression analysis containing all factors, boundaries that are within the range of 3000-8000 Hz could not be computed.) At the left of this boundary, the chance to hear /ɕ/ is larger and at the right of this boundary, the chance to hear /s̠/ is larger. The perceptual boundary location for the factor peak was defined by the following formula (copied from Annex 7):

(8) boundary = -(intercept + context coefficient * 1.5) / peak coefficient,

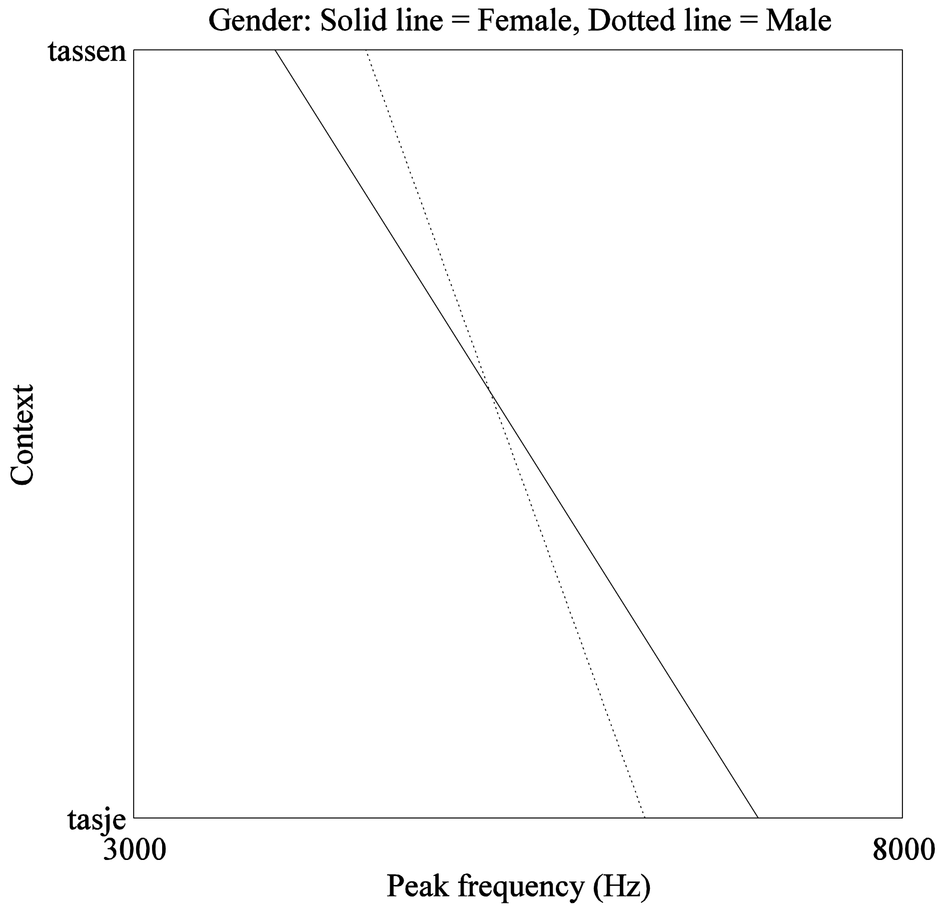
where 1.5 is the “mean context”: i.e. the peak frequency at which the perceptual boundary line intersects an imaginary line at $y = 1.5$, is the boundary location for the peak.

**Figure 5:** The mean perceptual boundaries for the younger vs. the older listeners




Annex 8 shows the log odds ratio for each participant for the factors peak and context, the angle and the boundary, computed with the PRAAT script in Annex 7 (note that for listener TVOF, the log odds ratio for the factor context is now slightly higher than for the factor peak). Only boundary values between 3000 and 8000 Hz are taken into account (RDYM, of whom the responses are excluded, had a boundary value of 19945.4 Hz). The mean boundary for the younger listeners was 5730.8 Hz, whereas the mean boundary for the older listeners was about 540 Hz lower, at 5190.6 Hz (see Figure 5, drawn with the PRAAT script in annex 9). This difference was significant ($t$ = -2.20, $df$ = 41, $p$ = 0.0331). The reason that the perceptual boundary for the younger listeners is higher, is probably because these listeners rely more on context: because the angle of the perceptual boundary line is less negative, it intersects with the mean context line (at 1.5) at a higher frequency than when the angle would be more negative.

**Figure 6:** The mean perceptual boundaries for the female vs. the male listeners




Unlike before, differences between male and female listeners were not significant (*t* = -0.26, *df* = 41, *p* = 0.7942). The mean boundary for peak was 5490.6 Hz for the female listeners and 5418.1 Hz for the male listeners (see Figure 6, drawn with the PRAAT script in Annex 9). As before, differences between listeners from different regions were not significant (*t* = 0.67, *df* = 41, *p* = 0.5050). The mean boundary for peak was 5551.7 Hz for the listeners born in the Randstad and 5378.3 Hz for the listeners born in a different region.

## 4. Discussion

This study sought to answer the question on which auditory cues native speakers of Dutch rely in the perception of the /s̠/-/ɕ/ contrast, and if there is a difference in the perception of this contrast between Dutch listeners of different ages. The frequency of the spectral peak and the vowel context (formant values or transitions in the surrounding vowels) turned out to be the most relevant cues for this contrast. Note that, since the formant values and formant transitions of the vowels in the present study are naturally present in the vowels (i.e. not manipulated), one cannot say with certainty on which cue in the vowel context listeners rely: formant values or formant transitions. Whereas the older listeners mainly relied on the spectral peak frequency, half of the younger listeners relied more on the vowel context. The perceptual boundary for the younger listeners (5731 Hz) was at a higher peak frequency than for the older listeners (5190 Hz). There may also be a gender difference with female listeners relying more on vowel context than male listeners do, but their perceptual boundary for spectral peak is at about the same place (between 5400-5500 Hz). Regional differences do not seem to be important. The perceptual boundary for the younger listeners is relatively high, 11 Hz higher than the spectral mean value of Dutch /s̠/ (5720 Hz) measured by Ooijevaar and Seinhorst (2011), see Table 1, and higher than the perceptual boundary found by Kwakkel (2008). If the /s/-bias (Smits et al., 2003; Johnson and Babel, 2010) was reflected in the perceptual boundary, one would expect the perceptual boundaries to be lower. However, one can see that the older listeners have a larger bias towards /s̠/ than the younger listeners, because the boundary is higher for the younger listeners than for the older listeners.

Results of the present study are not in line with studies that did not find an influence of formant transitions on the perception of the sibilant contrast, or that argued that the noise is a sufficient cue for the place distinction in sibilants. However, these studies only studied English sibilants (Hughes and Halle, 1956; Harris, 1958; Heinz and Stevens, 1961; LaRiviere et al., 1975; Behrens and Blumstein, 1988a). English sibilants are found to be spectrally distinctive, but Jongman et al. (2000) have found relatively close spectral mean values for the American English sibilants /s/ and /ʃ/. Other studies about English sibilants did find that other cues such as formant (F2) transitions are important for English sibilants as well (e.g. Mann and Repp, 1980; Whalen, 1981, 1991; Datscheweit, 1990). Studies about other languages have also found evidence for the importance of transitions in perception of the place distinction in sibilants, e.g. for Shona (Bladon et al., 1987), and Polish (Nowak, 2006; McGuire, 2007, 2008; Zygis and Padgett, 2010).

In a language where sibilants have similar spectra or spectral means, such as Toda (Gordon et al., 2002) or Japanese (Toda, 2007; Li et al. 2009, 2011; Holliday et al., 2010), listeners rely on formant transitions. In that, Dutch is similar to Japanese (Toda, 2007; Li et al. 2009, 2011; Holliday et al., 2010): in both languages the sibilants /s/ and /ɕ/ have spectral mean values that are close together (although the exact values are different), and in both languages one of the sibilants is less frequent than the other. Therefore, listeners also use the formants or formant transitions in the surrounding vowels to distinguish between these sounds. However, only the younger Dutch listeners do so, but it may be that in next generations, native speakers of Dutch will rely more on vowel context for the place contrast in sibilants. The large number of vowels in Dutch does not impede that listeners rely on formants or formant transitions in the surrounding vowels, as was predicted by Toda (2007). Rather, results of the present study suggest that the closeness of the spectral mean values leads to the use of formants or formant transitions as a cue in the perception of the place contrast in sibilants, independent of the number of vowels in a language.

Unlike other studies about Dutch fricatives and sibilants (Klaassen-Don, 1983; Klaassen-Don and Pols, 1983, 1986; Wagner et al., 2006) which found no influence of formant transitions in the vowel for the distinction between /s/ and other fricatives (/ʃ/ or /ɕ/ not included), I did find an influence of vowel context (formants or formant transitions) on the perception of the Dutch sibilant contrast (/ɕ/ included). This is not surprising, because /ɑ/ is more fronted before /ɕ/ (Mees and Collins, 1983). Evers et al. (1998) argued that the noise is a sufficient cue for the place distinction in sibilants, and that the realization of sibilants with a different phonological status in different languages (e.g. /s/ and /ʃ/ in Dutch) do not differ. However, the results of the present study indicate that in perception, Dutch listeners also rely on a cue not present in the noise: namely vowel context. Like Smits et al. (2003), and Johnson and Babel (2010), I have found evidence for a bias towards hearing /s/ in native speakers of Dutch, but this difference is larger for the older listeners than for the younger listeners. The boundary is different from the value found by Kwakkel (2008). I did not find evidence for a bimodal distribution as was speculated by Boersma and Hamann (2008).

The question is whether the differences between the two age groups in the present study are a reflection of a sound change in progress, or whether other factors influence the difference in perception between younger and older listeners (language experience, effects of aging such as hearing loss). Studies about hearing loss show that a decline in hearing starts at higher frequencies (e.g. see Naramura, Nakanishi, Tatara, Ishiyama, Shiraishi, and Yamamoto, 1999; Gordon-Salant, 2005; Mitchell, Gopinath, Jin Wang, McMahon, Schneider, Rochtchina, and Leeder, 2011): listeners need a higher intensity (dB) of the sound to be able to hear sounds of higher frequencies. According to Gordon-Salant (2005), the decline in hearing sensitivity starts above 20-30 years old for men, and above 50 years old for women. For example, the fact that the perceptual boundary for the spectral peak for the older listeners was lower than for the younger listeners, may reflect an influence of hearing decline. If hearing loss influences the results of the present study, one would expect the older listeners (and perhaps mainly the male listeners) to rely more on formants or formant transitions (which take place in lower frequency regions, i.e. between 1200 and 1800 Hz for the second formant of the vowels in this study) than on the frequency of the spectral peak (which is to be found in higher frequency regions, i.e. 3000-8000 Hz for the sibilant noises in this study). However, this was not the case; it was actually the reverse: the older listeners mainly relied on the frequency of the peak while the younger (female) listeners mainly relied on context. Therefore, influence of hearing loss can probably be excluded.

# 5. Conclusion

The results of the present study showed that native speakers of Dutch either rely on the spectral peak frequency or on the formants or formant transitions in the surrounding vowels (vowel context) to identify a sibilant as /s̠/ or /ɕ/. Older listeners mainly rely on the frequency of the spectral peak, whereas younger listeners either use this peak frequency or the vowel context as the primary cue. Therefore, it is possible that a change in perception of these sounds is in progress.

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# 6. References:


Adank, P. van Hout, R., and Smits, R. (2004). An acoustic description of the vowels of Northern and Southern standard Dutch, *Journal of the Acoustical Society of America*, 116 (3), p. 1729-1738.

Behrens, S.J., and Blumstein, S.E. (1988a). Acoustic characteristics of English voiceless fricatives: A descriptive analysis. *Journal of Phonetics, 16*, p. 295-298.

Behrens, S.J., and Blumstein, S.E. (1988b). On the role of the amplitude of the fricative noise in the perception of place of articulation in voiceless fricative consonants. *Journal of the Acoustical Society of America, 84,* p. 861-867.

Bladon, A., Clark, C., and Mickey, K. (1987). Production and perception of sibilant fricatives: Shona data. *Journal of the International Phonetic Association, 17 (1),* p. 39-65.

Boersma, P.P.G., and Hamann, S. (2008). The evolution of auditory dispersion in bidirectional constraint grammars. *Phonology*, *25,* p. 217-270.

Boersma, P.P.G., and Weenink, D.J.M. (1992-2011). *Praat: a system for doing phonetics by computer.* http://www.praat.org. Version 5.2.19.

Booij, G. (1999). *The phonology of Dutch*, Oxford University Press, New York. (First edition: 1995)

Clouse, S.A., Burnham, J.L., and Newman, R.S. (1999). The perceptual consequences of overlap in /s/ and /ʃ/ productions within a talker. *Journal of the Acoustical Society of America, 106,* No. 4, Pt. 2, 138th Meeting: 4pSC18, p. 2273.

Collins, B., and Mees, I. (1999). *The phonetics of English and Dutch*, Brill, Leiden. (First edition: 1981)

Datscheweit, W. (1990). Frication noise and formant-onset frequency as independent cues for the perception of /f/, /s/ and /ʃ/ in vowel-fricative-vowel stimuli. In: *ICSLP-1990*, 18-22 November 1990, Kobe, Japan, p. 561-564.

Evers, V., Reetz, H., and Lahiri, A. (1998). Crosslinguistic acoustic categorization of sibilants independent of phonological status. *Journal of Phonetics, 26,* p. 345-370.

Forrest, K., Weismer, G., Milenkovic, P., and Dougall, R.N. (1988). Statistical analysis of word-initial voiceless obstruents: Preliminary data. *Journal of the Acoustical Society of America, 84 (1),* p. 115-123.

Gordon, M., Barthmaier, P., and Sands, K. (2002). A cross-linguistic acoustic study of voiceless fricatives. *Journal of the International Phonetic Association, 32,* p. 141-174.

Gordon-Salant, S. (2005). Hearing loss and aging: New research findings and clinical implications. *Journal of Rehabilitation Research & Development, 42 (4), Supplement 2*, p. 9-24.

Haley, K.L., Seelinger, E., Mandulak, K.C., and Zajac, D.J. (2010). Letter to the Editor: Evaluating the spectral distinction between sibilant fricatives through a speaker-centered approach. *Journal of Phonetics, 38,* p. 548-554.

Harris, K.S. (1958). Cues for the discrimination of American English fricatives in spoken syllables. *Language and Speech, 1*, p. 1-7.

Hayward, K. (2000). *Experimental phonetics*, Pearson Education, Harlow.

Hedrick, M.S., and Ohde, R.N. (1993). Effect of relative amplitude of frication on perception of place of articulation. *Journal of the Acoustical Society of America, 94 (4),* p. 2005-2026.

Heinz, J.M., and Stevens, K.N. (1961). On the properties of voiceless fricative consonants. *Journal of the Acoustical Society of America, 33,* p. 589-596.

Holliday, J.J., Beckman, M.E., and Mays, C. (2010). Did you say susi or shushi? Measuring the emergence of robust fricative contrasts in English- and Japanese-acquiring children, *InterSpeech 2010,* 4 pages.

Hughes, G.W., and Halle, M. (1956). Spectral properties of fricative consonants. *Journal of the Acoustical Society of America, 28 (2),* p. 303-310.

Johnson, K., and Babel, M. (2010). On the perceptual basis of distinctive features: Evidence from the perception of fricatives by Dutch and English speakers. *Journal of Phonetics, 38,* p. 127-136.

Jongman, A. (1989). Duration of frication noise required for identification of English fricatives. *Journal of the Acoustical Society of America, 85 (4),* p. 1718-1725.

Jongman, A. (1985). Duration of frication noise as a perceptual cue to place and manner of articulation in English fricatives. *Journal of the Acoustical Society of America, Suppl. 1, 77,* S26.

Jongman, A., Wayland, R., and Wong, S. (2000). Acoustic characteristics of English fricatives. *Journal of the Acoustical Society of America, 108,* p. 1252-1263.

Klaassen-Don, L.E.O. (1983). *The influence of vowels on the perception of consonants.* Unpublished Doctoral Dissertation, Reproductiedienst Subfaculteit der Psychologie, Leiden.

Klaassen-Don, L.E.O., and Pols, L.C.W. (1986). *CV-transitions: A perceptual study of coarticulation.* Institute of Phonetic Sciences, University of Amsterdam, Report Nr. 87.

Klaassen-Don, L.E.O., and Pols, L.C.W. (1983). The role of coarticulation for the identification of consonants. In: *Abstracts of the tenth International Congress of Phonetic Sciences.* Cohen, A., and Van de Broecke, M.P.R. (eds.). 1-6 August 1983, Utrecht, the Netherlands. Foris Publications, Dordrecht, p. 512.

Kwakkel, V. (2008). *Sibilants in Dutch and English: Typologies, learning tasks and language change.* Unpublished MA Thesis, University of Utrecht. Retrieved from: http://igitur-archive.library.uu.nl/student-theses/2008-1114-201442/MAthesis_VincentKwakkel.pdf

Ladefoged, P. (2005). *Vowels and consonants*, Blackwell Publishers, Oxford. (First edition: 2001)

Ladefoged, P., and Maddieson, I. (1996). *The sounds of the world's languages,* Blackwell Publishers, Oxford.

LaRiviere, C., Winitz, H., and Herriman, E. (1975). The distribution of perceptual cues in English prevocalic fricatives. *Journal of Speech and Hearing Research, 18,* p. 613-622.

Li, F., Edwards, J., and Beckman, M. (2009). Contrast and covert contrast: The phonetic development of voiceless sibilant fricatives in English and Japanese toddlers. *Journal of Phonetics, 37,* p. 111-124.

Li, F., Edwards, J., and Beckman, M. (2007). Spectral measures for sibilant fricatives of English, Japanese, and Mandarin Chinese. *Proceedings of the 16th International Congress of Phonetic Sciences,* 6-10 August 2007, Saarbrücken, Germany, p. 917-920.

Li, F., Munson, B., Edwards, J., Yoneyama, K., and Hall, K. (2011). Language specificity in the perception of voiceless sibilant fricatives in Japanese and English: Implications for cross-language differences in speech-sound development. *Journal of the Acoustical Society of America, 129 (2),* p. 999-1011.

Liljencrants, J., and Lindblom, B. (1972). Numerical simulation of vowel quality systems: the role of perceptual contrast. *Language, 48 (4),* p. 839-862.

Mann, V.A., and Repp, B.H. (1980). Influence of vocalic context on perception of the [ʃ]-[s] distinction. *Perception and Psychophysics, 28 (3),* p. 213-228.

McGuire, G. (2008). *Selective attention and English listeners' perceptual learning of the Polish post-alveolar sibilant contrast.* Santa Cruz, CA: Ms., UC Santa Cruz.

McGuire, G. (2007). *Phonetic category learning.* PhD Dissertation, UC Berkeley, Berkeley, CA.

Mees, I. and Collins, B. (1983). A phonetic description of the vowel system of Standard Dutch (ABN). *Journal of the International Phonetic Association, 13 (2),* p. 64-75.

Mees, I. and Collins, B. (1982). A phonetic description of the consonant system of Standard Dutch (ABN). *Journal of the International Phonetic Association, 12,* p. 2-12.

Mitchell, P., Gopinath, B., Jin Wang, J., McMahon, C.M., Schneider, J., Rochtchina, E., and Leeder, S.R. (2011). Five-year incidence and progression of hearing impairment in an older population. *Ear and hearing, 32 (2),* p. 251-257.

Naramura, H., Nakanishi, N., Tatara, K., Ishiyama, M., Shiraishi, H., and Yamamoto, A. (1999). Physical and mental correlates of hearing impairment in the elderly in Japan. *Audiology, 38,* p. 24-29.

Newman, R.S., Clouse, S.A., and Burnham, J.L. (2001). The perceptual consequences of within-talker variability in fricative production. *Journal of the Acoustical Society of America, 109 (3),* p. 1181-1196.

Nittrouer, S., and Studdert-Kennedy, M. (1986). The role of coarticulatiory effects in the perception of fricatives by children and adults. Haskins Laboratories: Status Report on Speech Research SR-88, p. 43-93.

Nittrouer, S., Studdert-Kennedy, M., and McGowan, R.S. (1989). The emergence of phonetic segments: Evidence from the spectral structure of fricative-vowel syllables spoken by children and adults. *Journal of Speech and Hearing Research, 32,* p. 120-132.

Nooteboom, S.G., and Cohen, A. (1984). *Spreken en verstaan. Een nieuwe inleiding tot de experimentele fonetiek,* Van Gorcum, Assen. (First edition: 1976)

Nowak, P.M. (2006). The role of vowel transitions and frication noise in the perception of Polish sibilants. *Journal of Phonetics*, *34*, p. 139-152.

Ooijevaar, E.S.M., and Seinhorst, K.T. (2011). *The auditory dispersion of Dutch sibilants*. Unpublished paper for the course "Perspectives on Universals II", RMA Linguistics, University of Amsterdam, p. 1-14.

Oshika, B.T., Zue, V.W., Weeks, R.V., Neu, H., and Aurbach, J. (1975). The role of phonological rules in speech understanding research. *IEEE Transactions on Acoustics, Speech and Signal Processing, 23 (1)*, p. 104-112.

Padgett, J., and Zygis, M. (2003). The evolution of sibilants in Polish and Russian. *ZAS Papers in linguistics*, 22 pages.

Rechziegel, A. (2001). Consonants in contact: On assimilation and cross-language contrast. *Institute of Phonetic Sciences, University of Amsterdam, Proceedings, 24,* p. 103-115.

Smits, R., Warner, N., McQueen, J.M., and Cutler, A. (2003). Unfolding of phonetic information overtime: A database of Dutch diphone perception. *Journal of the Acoustical Society of America, 113(1),* p. 563-574.

Soli, S.D. (1981). Second formants in fricatives: Acoustic consequences of fricative-vowel coarticulation. *Journal of the Acoustical Society of America,70 (4),* p. 976-984.

Stevens, K.N. (1985). Evidence for the role of acoustic boundaries in the perception of speech sounds. In: *Phonetic linguistics: Essays in honor of Peter Ladefoged*, Fromkin V.A. (eds.), Academic, New York, p. 243-255.

Strevens, P. (1960). Spectra of fricative noise in human speech. *Language and Speech, 3 (1)*, p. 32-49.

Toda, M. (2007). Speaker normalization of fricative noise: Considerations on language-specific contrast. *Proceedings of the 16th International Congress of Phonetic Sciences,* 6-10 August 2007, Saarbrücken, Germany, p. 825-828.

Wagner, A., Ernestus, M., and Cutler, A. (2006). Formant transitions in fricative identification: The role of native fricative inventory. *Journal of the Acoustical Society of America, 120 (4),* p. 2267-2277.

Whalen, D.H. (1991). Perception of the English /s/-/ʃ/ distinction relies on fricative noises and transitions, not on brief spectral slices. *Journal of the Acoustical Society of America, 90 (4), Pt. 1,* p. 1776-1785.

Whalen, D.H. (1981). Effects of vocalic formant transitions and vowel quality on the English [s]-[ʃ] boundary. *Journal of the Acoustical Society of America, 69 (1),* p. 275-282.

Zsiga, E.C. (2000). Phonetic alignment constraints: Consonant overlap and palatalization in English and Russian. *Journal of Phonetics, 28,* p. 69-102.

Zue, V.W., and Shattuck-Hufnagel, S. (1980). Palatalization of /s/ in American English: when is a /ʃ/ not a /ʃ/? *Journal of the Acoustical Society of America, 99th Meeting, Suppl. 1, Vol. 67,* S27.

Zygis, M., and Hamann, S. (2003). Perceptual and acoustic cues of Polish coronal fricatives. *Proceedings of the 15th International Congress of Phonetic Sciences,* August 3-9 2003, Barcelona, Spain, p. 395-398.

Zygis, M., and Padgett, J. (2010). A perceptual study of Polish fricatives, and its implications for historical sound change. *Journal of Phonetics, 38,* p. 207-226.

**Annex 1: PRAAT script for the creation of 486 sibilant sounds, concatenated into two word contexts**

```
# Creates 3*6*3*3*3=486 Sounds
# 3 different durations: dur*1.2
# 6 frequencies ranging from 3000 to 8000 Hz (in steps of 1000 Hz)
# 3 widths: 1000, 2000 and 3000 Hz
# 3 degrees of skewness: falling, flat, rising
# 3 amplitudes ranging from 50 to 70 dB (in steps of 10 dB)
# COG is dependent on other values (spectral peak, width and skewness) and differs every time, but is close to spectral peak value
# Values are given in info window
# Concatenates the first syllable, the sibilant and the last syllable into one word: 972 words

Read from file... test/TA-ssen.wav
Read from file... test/TA-sjes.wav

dur2 = sqrt (0.1267 * 0.1450)
dur1 = dur2 / 1.20
dur3 = dur2 * 1.20
echo 'dur1:6' 'dur2:6' 'dur3:6'

echo sibilant	duration(ms)	peak(Hz)	peak(ERB)	width(Hz)	COG(Hz)	COG(ERB)	amplitude(dB)
numberOfDurs = 3
for idur to numberOfDurs
	numberOfSkewnesses = 3
	for iskewness to numberOfSkewnesses
		for ifreq from 3 to 8
			freq = ifreq*1000
			freq_ERB = 11.17*ln((freq+312)/(freq+14680))+43
			for iwidth from 1 to 3
				onder = freq - 500*iwidth
				boven = freq + 500*iwidth
				breedte = boven - onder
				Create Sound from formula... s_'freq' Mono 0 dur'idur' 44100 randomGauss(0,0.1)
				To Spectrum... yes
					if iskewness = 1
						Formula... if x > onder and x < boven then self else 0 fi
						Formula... if x > onder and x < boven then self*(4-3*(x-onder)/(boven-
						…onder)) else self fi
					elsif iskewness = 2
						Formula... if x > onder and x < boven then self else 0 fi
					else
						Formula... if x > onder and x < boven then self else 0 fi
						Formula... if x > onder and x < boven then self*(1+3*(x-onder)/(boven-
						…onder)) else self fi
					endif
				To Sound
				Extract part... 0 dur'idur' rectangular 1 yes
				dur = Get total duration
				dur_ms = dur*1000
				for iamplitude from 5 to 7
					amp = iamplitude*10
					select Sound s_'freq'_part
					Copy... s_'freq'_part_'amp'
					select Sound s_'freq'_part_'amp'
					To Spectrum... yes
					cog = Get centre of gravity... 2
					cog_ERB = 11.17*ln((cog+312)/(cog+14680))+43
					To Sound
					Scale intensity... amp
					Extract part... 0 dur'idur' rectangular 1 yes
					Read from file... test/tass-EN.wav
					select Sound TA-ssen
					plus Sound s_'freq'_part_'amp'_part
					plus Sound tass-EN
					Concatenate
					select Sound chain
					Save as WAV file...
					…test/tassen'dur_ms:0'_'freq:0'_'breedte:0'_skewness'iskewness'_'amp'.wav
					Read from file... test/tasj-ES.wav
					select Sound TA-sjes
					plus Sound s_'freq'_part_'amp'_part
					plus Sound tasj-ES
					Concatenate
					select Sound chain
					Save as WAV file...
					…test/tasjes'dur_ms:0'_'freq:0'_'breedte:0'_skewness'iskewness'_'amp'.wav
```

```
					printline 'dur_ms:0'_'freq:0'_'breedte:0'_skewness'iskewness'_'amp'
					…'dur_ms:2'	'freq'	'freq_ERB:2'	'breedte'	'cog:2'
					…'cog_ERB:2'	'amp'
#					printline	"'tassen'dur_ms:0'_'freq:0'_'breedte:0'_skewness'iskewness'_'amp'" ""
#					printline	"'tasjes'dur_ms:0'_'freq:0'_'breedte:0'_skewness'iskewness'_'amp'" ""
				endfor
			endfor
		endfor
	endfor
endfor


# copy to Word and arrange alphabetically:  part 1 to a .txt file, part 2 back to the info window
```

**Annex 2: Table with the values for each cue for each of the 486 sibilants**

| Sibilant | duration(ms) | peak(Hz) | peak(ERB) | width(Hz) | COG(Hz) | COG(ERB) | amplitude(dB) |
|---|---|---|---|---|---|---|---|
| 113_3000_1000_skewness1_50 | 112.95 | 3000 | 24.29 | 1000 | 2827.02 | 23.80 | 50 |
| 113_3000_1000_skewness1_60 | 112.95 | 3000 | 24.29 | 1000 | 2827.02 | 23.80 | 60 |
| 113_3000_1000_skewness1_70 | 112.95 | 3000 | 24.29 | 1000 | 2827.02 | 23.80 | 70 |
| 113_3000_2000_skewness1_50 | 112.95 | 3000 | 24.29 | 2000 | 2637.50 | 23.23 | 50 |
| 113_3000_2000_skewness1_60 | 112.95 | 3000 | 24.29 | 2000 | 2637.50 | 23.23 | 60 |
| 113_3000_2000_skewness1_70 | 112.95 | 3000 | 24.29 | 2000 | 2637.50 | 23.23 | 70 |
| 113_3000_3000_skewness1_50 | 112.95 | 3000 | 24.29 | 3000 | 2417.64 | 22.51 | 50 |
| 113_3000_3000_skewness1_60 | 112.95 | 3000 | 24.29 | 3000 | 2417.64 | 22.51 | 60 |
| 113_3000_3000_skewness1_70 | 112.95 | 3000 | 24.29 | 3000 | 2417.64 | 22.51 | 70 |
| 113_4000_1000_skewness1_50 | 112.95 | 4000 | 26.62 | 1000 | 3808.00 | 26.23 | 50 |
| 113_4000_1000_skewness1_60 | 112.95 | 4000 | 26.62 | 1000 | 3808.00 | 26.23 | 60 |
| 113_4000_1000_skewness1_70 | 112.95 | 4000 | 26.62 | 1000 | 3808.00 | 26.23 | 70 |
| 113_4000_2000_skewness1_50 | 112.95 | 4000 | 26.62 | 2000 | 3723.73 | 26.05 | 50 |
| 113_4000_2000_skewness1_60 | 112.95 | 4000 | 26.62 | 2000 | 3723.73 | 26.05 | 60 |
| 113_4000_2000_skewness1_70 | 112.95 | 4000 | 26.62 | 2000 | 3723.73 | 26.05 | 70 |
| 113_4000_3000_skewness1_50 | 112.95 | 4000 | 26.62 | 3000 | 3459.08 | 25.46 | 50 |
| 113_4000_3000_skewness1_60 | 112.95 | 4000 | 26.62 | 3000 | 3459.08 | 25.46 | 60 |
| 113_4000_3000_skewness1_70 | 112.95 | 4000 | 26.62 | 3000 | 3459.08 | 25.46 | 70 |
| 113_5000_1000_skewness1_50 | 112.95 | 5000 | 28.37 | 1000 | 4812.60 | 28.08 | 50 |
| 113_5000_1000_skewness1_60 | 112.95 | 5000 | 28.37 | 1000 | 4812.60 | 28.08 | 60 |
| 113_5000_1000_skewness1_70 | 112.95 | 5000 | 28.37 | 1000 | 4812.60 | 28.08 | 70 |
| 113_5000_2000_skewness1_50 | 112.95 | 5000 | 28.37 | 2000 | 4630.49 | 27.78 | 50 |
| 113_5000_2000_skewness1_60 | 112.95 | 5000 | 28.37 | 2000 | 4630.49 | 27.78 | 60 |
| 113_5000_2000_skewness1_70 | 112.95 | 5000 | 28.37 | 2000 | 4630.49 | 27.78 | 70 |
| 113_5000_3000_skewness1_50 | 112.95 | 5000 | 28.37 | 3000 | 4462.68 | 27.49 | 50 |
| 113_5000_3000_skewness1_60 | 112.95 | 5000 | 28.37 | 3000 | 4462.68 | 27.49 | 60 |
| 113_5000_3000_skewness1_70 | 112.95 | 5000 | 28.37 | 3000 | 4462.68 | 27.49 | 70 |
| 113_6000_1000_skewness1_50 | 112.95 | 6000 | 29.74 | 1000 | 5840.55 | 29.55 | 50 |
| 113_6000_1000_skewness1_60 | 112.95 | 6000 | 29.74 | 1000 | 5840.55 | 29.55 | 60 |
| 113_6000_1000_skewness1_70 | 112.95 | 6000 | 29.74 | 1000 | 5840.55 | 29.55 | 70 |
| 113_6000_2000_skewness1_50 | 112.95 | 6000 | 29.74 | 2000 | 5641.79 | 29.29 | 50 |
| 113_6000_2000_skewness1_60 | 112.95 | 6000 | 29.74 | 2000 | 5641.79 | 29.29 | 60 |
| 113_6000_2000_skewness1_70 | 112.95 | 6000 | 29.74 | 2000 | 5641.79 | 29.29 | 70 |
| 113_6000_3000_skewness1_50 | 112.95 | 6000 | 29.74 | 3000 | 5429.27 | 29.00 | 50 |
| 113_6000_3000_skewness1_60 | 112.95 | 6000 | 29.74 | 3000 | 5429.27 | 29.00 | 60 |
| 113_6000_3000_skewness1_70 | 112.95 | 6000 | 29.74 | 3000 | 5429.27 | 29.00 | 70 |
| 113_7000_1000_skewness1_50 | 112.95 | 7000 | 30.86 | 1000 | 6819.72 | 30.67 | 50 |
| 113_7000_1000_skewness1_60 | 112.95 | 7000 | 30.86 | 1000 | 6819.72 | 30.67 | 60 |
| 113_7000_1000_skewness1_70 | 112.95 | 7000 | 30.86 | 1000 | 6819.72 | 30.67 | 70 |
| 113_7000_2000_skewness1_50 | 112.95 | 7000 | 30.86 | 2000 | 6723.79 | 30.57 | 50 |
| 113_7000_2000_skewness1_60 | 112.95 | 7000 | 30.86 | 2000 | 6723.79 | 30.57 | 60 |
| 113_7000_2000_skewness1_70 | 112.95 | 7000 | 30.86 | 2000 | 6723.79 | 30.57 | 70 |
| 113_7000_3000_skewness1_50 | 112.95 | 7000 | 30.86 | 3000 | 6485.01 | 30.31 | 50 |
| 113_7000_3000_skewness1_60 | 112.95 | 7000 | 30.86 | 3000 | 6485.01 | 30.31 | 60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 113_7000_3000_skewness1_70 | 112.95 | 7000 | 30.86 | 3000 | 6485.01 | 30.31 | 70 |
| 113_8000_1000_skewness1_50 | 112.95 | 8000 | 31.79 | 1000 | 7815.19 | 31.63 | 50 |
| 113_8000_1000_skewness1_60 | 112.95 | 8000 | 31.79 | 1000 | 7815.19 | 31.63 | 60 |
| 113_8000_1000_skewness1_70 | 112.95 | 8000 | 31.79 | 1000 | 7815.19 | 31.63 | 70 |
| 113_8000_2000_skewness1_50 | 112.95 | 8000 | 31.79 | 2000 | 7623.41 | 31.46 | 50 |
| 113_8000_2000_skewness1_60 | 112.95 | 8000 | 31.79 | 2000 | 7623.41 | 31.46 | 60 |
| 113_8000_2000_skewness1_70 | 112.95 | 8000 | 31.79 | 2000 | 7623.41 | 31.46 | 70 |
| 113_8000_3000_skewness1_50 | 112.95 | 8000 | 31.79 | 3000 | 7400.56 | 31.25 | 50 |
| 113_8000_3000_skewness1_60 | 112.95 | 8000 | 31.79 | 3000 | 7400.56 | 31.25 | 60 |
| 113_8000_3000_skewness1_70 | 112.95 | 8000 | 31.79 | 3000 | 7400.56 | 31.25 | 70 |
| 113_3000_1000_skewness2_50 | 112.95 | 3000 | 24.29 | 1000 | 2939.81 | 24.12 | 50 |
| 113_3000_1000_skewness2_60 | 112.95 | 3000 | 24.29 | 1000 | 2939.81 | 24.12 | 60 |
| 113_3000_1000_skewness2_70 | 112.95 | 3000 | 24.29 | 1000 | 2939.81 | 24.12 | 70 |
| 113_3000_2000_skewness2_50 | 112.95 | 3000 | 24.29 | 2000 | 3028.87 | 24.37 | 50 |
| 113_3000_2000_skewness2_60 | 112.95 | 3000 | 24.29 | 2000 | 3028.87 | 24.37 | 60 |
| 113_3000_2000_skewness2_70 | 112.95 | 3000 | 24.29 | 2000 | 3028.87 | 24.37 | 70 |
| 113_3000_3000_skewness2_50 | 112.95 | 3000 | 24.29 | 3000 | 3004.07 | 24.30 | 50 |
| 113_3000_3000_skewness2_60 | 112.95 | 3000 | 24.29 | 3000 | 3004.07 | 24.30 | 60 |
| 113_3000_3000_skewness2_70 | 112.95 | 3000 | 24.29 | 3000 | 3004.07 | 24.30 | 70 |
| 113_4000_1000_skewness2_50 | 112.95 | 4000 | 26.62 | 1000 | 4003.86 | 26.63 | 50 |
| 113_4000_1000_skewness2_60 | 112.95 | 4000 | 26.62 | 1000 | 4003.86 | 26.63 | 60 |
| 113_4000_1000_skewness2_70 | 112.95 | 4000 | 26.62 | 1000 | 4003.86 | 26.63 | 70 |
| 113_4000_2000_skewness2_50 | 112.95 | 4000 | 26.62 | 2000 | 4003.41 | 26.63 | 50 |
| 113_4000_2000_skewness2_60 | 112.95 | 4000 | 26.62 | 2000 | 4003.41 | 26.63 | 60 |
| 113_4000_2000_skewness2_70 | 112.95 | 4000 | 26.62 | 2000 | 4003.41 | 26.63 | 70 |
| 113_4000_3000_skewness2_50 | 112.95 | 4000 | 26.62 | 3000 | 4096.87 | 26.81 | 50 |
| 113_4000_3000_skewness2_60 | 112.95 | 4000 | 26.62 | 3000 | 4096.87 | 26.81 | 60 |
| 113_4000_3000_skewness2_70 | 112.95 | 4000 | 26.62 | 3000 | 4096.87 | 26.81 | 70 |
| 113_5000_1000_skewness2_50 | 112.95 | 5000 | 28.37 | 1000 | 5013.07 | 28.39 | 50 |
| 113_5000_1000_skewness2_60 | 112.95 | 5000 | 28.37 | 1000 | 5013.07 | 28.39 | 60 |
| 113_5000_1000_skewness2_70 | 112.95 | 5000 | 28.37 | 1000 | 5013.07 | 28.39 | 70 |
| 113_5000_2000_skewness2_50 | 112.95 | 5000 | 28.37 | 2000 | 5046.43 | 28.44 | 50 |
| 113_5000_2000_skewness2_60 | 112.95 | 5000 | 28.37 | 2000 | 5046.43 | 28.44 | 60 |
| 113_5000_2000_skewness2_70 | 112.95 | 5000 | 28.37 | 2000 | 5046.43 | 28.44 | 70 |
| 113_5000_3000_skewness2_50 | 112.95 | 5000 | 28.37 | 3000 | 5031.28 | 28.42 | 50 |
| 113_5000_3000_skewness2_60 | 112.95 | 5000 | 28.37 | 3000 | 5031.28 | 28.42 | 60 |
| 113_5000_3000_skewness2_70 | 112.95 | 5000 | 28.37 | 3000 | 5031.28 | 28.42 | 70 |
| 113_6000_1000_skewness2_50 | 112.95 | 6000 | 29.74 | 1000 | 5982.29 | 29.72 | 50 |
| 113_6000_1000_skewness2_60 | 112.95 | 6000 | 29.74 | 1000 | 5982.29 | 29.72 | 60 |
| 113_6000_1000_skewness2_70 | 112.95 | 6000 | 29.74 | 1000 | 5982.29 | 29.72 | 70 |
| 113_6000_2000_skewness2_50 | 112.95 | 6000 | 29.74 | 2000 | 5984.05 | 29.72 | 50 |
| 113_6000_2000_skewness2_60 | 112.95 | 6000 | 29.74 | 2000 | 5984.05 | 29.72 | 60 |
| 113_6000_2000_skewness2_70 | 112.95 | 6000 | 29.74 | 2000 | 5984.05 | 29.72 | 70 |
| 113_6000_3000_skewness2_50 | 112.95 | 6000 | 29.74 | 3000 | 5956.20 | 29.69 | 50 |
| 113_6000_3000_skewness2_60 | 112.95 | 6000 | 29.74 | 3000 | 5956.20 | 29.69 | 60 |
| 113_6000_3000_skewness2_70 | 112.95 | 6000 | 29.74 | 3000 | 5956.20 | 29.69 | 70 |

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|---|---|---|---|---|---|---|---|
| 113_7000_1000_skewness2_50 | 112.95 | 7000 | 30.86 | 1000 | 7018.19 | 30.88 | 50 |
| 113_7000_1000_skewness2_60 | 112.95 | 7000 | 30.86 | 1000 | 7018.19 | 30.88 | 60 |
| 113_7000_1000_skewness2_70 | 112.95 | 7000 | 30.86 | 1000 | 7018.19 | 30.88 | 70 |
| 113_7000_2000_skewness2_50 | 112.95 | 7000 | 30.86 | 2000 | 7022.17 | 30.88 | 50 |
| 113_7000_2000_skewness2_60 | 112.95 | 7000 | 30.86 | 2000 | 7022.17 | 30.88 | 60 |
| 113_7000_2000_skewness2_70 | 112.95 | 7000 | 30.86 | 2000 | 7022.17 | 30.88 | 70 |
| 113_7000_3000_skewness2_50 | 112.95 | 7000 | 30.86 | 3000 | 7053.97 | 30.91 | 50 |
| 113_7000_3000_skewness2_60 | 112.95 | 7000 | 30.86 | 3000 | 7053.97 | 30.91 | 60 |
| 113_7000_3000_skewness2_70 | 112.95 | 7000 | 30.86 | 3000 | 7053.97 | 30.91 | 70 |
| 113_8000_1000_skewness2_50 | 112.95 | 8000 | 31.79 | 1000 | 8028.14 | 31.81 | 50 |
| 113_8000_1000_skewness2_60 | 112.95 | 8000 | 31.79 | 1000 | 8028.14 | 31.81 | 60 |
| 113_8000_1000_skewness2_70 | 112.95 | 8000 | 31.79 | 1000 | 8028.14 | 31.81 | 70 |
| 113_8000_2000_skewness2_50 | 112.95 | 8000 | 31.79 | 2000 | 7932.57 | 31.73 | 50 |
| 113_8000_2000_skewness2_60 | 112.95 | 8000 | 31.79 | 2000 | 7932.57 | 31.73 | 60 |
| 113_8000_2000_skewness2_70 | 112.95 | 8000 | 31.79 | 2000 | 7932.57 | 31.73 | 70 |
| 113_8000_3000_skewness2_50 | 112.95 | 8000 | 31.79 | 3000 | 7885.44 | 31.69 | 50 |
| 113_8000_3000_skewness2_60 | 112.95 | 8000 | 31.79 | 3000 | 7885.44 | 31.69 | 60 |
| 113_8000_3000_skewness2_70 | 112.95 | 8000 | 31.79 | 3000 | 7885.44 | 31.69 | 70 |
| 113_3000_1000_skewness3_50 | 112.95 | 3000 | 24.29 | 1000 | 3188.21 | 24.79 | 50 |
| 113_3000_1000_skewness3_60 | 112.95 | 3000 | 24.29 | 1000 | 3188.21 | 24.79 | 60 |
| 113_3000_1000_skewness3_70 | 112.95 | 3000 | 24.29 | 1000 | 3188.21 | 24.79 | 70 |
| 113_3000_2000_skewness3_50 | 112.95 | 3000 | 24.29 | 2000 | 3359.29 | 25.22 | 50 |
| 113_3000_2000_skewness3_60 | 112.95 | 3000 | 24.29 | 2000 | 3359.29 | 25.22 | 60 |
| 113_3000_2000_skewness3_70 | 112.95 | 3000 | 24.29 | 2000 | 3359.29 | 25.22 | 70 |
| 113_3000_3000_skewness3_50 | 112.95 | 3000 | 24.29 | 3000 | 3515.94 | 25.59 | 50 |
| 113_3000_3000_skewness3_60 | 112.95 | 3000 | 24.29 | 3000 | 3515.94 | 25.59 | 60 |
| 113_3000_3000_skewness3_70 | 112.95 | 3000 | 24.29 | 3000 | 3515.94 | 25.59 | 70 |
| 113_4000_1000_skewness3_50 | 112.95 | 4000 | 26.62 | 1000 | 4181.94 | 26.98 | 50 |
| 113_4000_1000_skewness3_60 | 112.95 | 4000 | 26.62 | 1000 | 4181.94 | 26.98 | 60 |
| 113_4000_1000_skewness3_70 | 112.95 | 4000 | 26.62 | 1000 | 4181.94 | 26.98 | 70 |
| 113_4000_2000_skewness3_50 | 112.95 | 4000 | 26.62 | 2000 | 4312.66 | 27.22 | 50 |
| 113_4000_2000_skewness3_60 | 112.95 | 4000 | 26.62 | 2000 | 4312.66 | 27.22 | 60 |
| 113_4000_2000_skewness3_70 | 112.95 | 4000 | 26.62 | 2000 | 4312.66 | 27.22 | 70 |
| 113_4000_3000_skewness3_50 | 112.95 | 4000 | 26.62 | 3000 | 4544.18 | 27.63 | 50 |
| 113_4000_3000_skewness3_60 | 112.95 | 4000 | 26.62 | 3000 | 4544.18 | 27.63 | 60 |
| 113_4000_3000_skewness3_70 | 112.95 | 4000 | 26.62 | 3000 | 4544.18 | 27.63 | 70 |
| 113_5000_1000_skewness3_50 | 112.95 | 5000 | 28.37 | 1000 | 5160.91 | 28.61 | 50 |
| 113_5000_1000_skewness3_60 | 112.95 | 5000 | 28.37 | 1000 | 5160.91 | 28.61 | 60 |
| 113_5000_1000_skewness3_70 | 112.95 | 5000 | 28.37 | 1000 | 5160.91 | 28.61 | 70 |
| 113_5000_2000_skewness3_50 | 112.95 | 5000 | 28.37 | 2000 | 5344.53 | 28.88 | 50 |
| 113_5000_2000_skewness3_60 | 112.95 | 5000 | 28.37 | 2000 | 5344.53 | 28.88 | 60 |
| 113_5000_2000_skewness3_70 | 112.95 | 5000 | 28.37 | 2000 | 5344.53 | 28.88 | 70 |
| 113_5000_3000_skewness3_50 | 112.95 | 5000 | 28.37 | 3000 | 5507.37 | 29.11 | 50 |
| 113_5000_3000_skewness3_60 | 112.95 | 5000 | 28.37 | 3000 | 5507.37 | 29.11 | 60 |
| 113_5000_3000_skewness3_70 | 112.95 | 5000 | 28.37 | 3000 | 5507.37 | 29.11 | 70 |
| 113_6000_1000_skewness3_50 | 112.95 | 6000 | 29.74 | 1000 | 6195.30 | 29.98 | 50 |

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|---|---|---|---|---|---|---|---|
| 113_6000_1000_skewness3_60 | 112.95 | 6000 | 29.74 | 1000 | 6195.30 | 29.98 | 60 |
| 113_6000_1000_skewness3_70 | 112.95 | 6000 | 29.74 | 1000 | 6195.30 | 29.98 | 70 |
| 113_6000_2000_skewness3_50 | 112.95 | 6000 | 29.74 | 2000 | 6367.48 | 30.18 | 50 |
| 113_6000_2000_skewness3_60 | 112.95 | 6000 | 29.74 | 2000 | 6367.48 | 30.18 | 60 |
| 113_6000_2000_skewness3_70 | 112.95 | 6000 | 29.74 | 2000 | 6367.48 | 30.18 | 70 |
| 113_6000_3000_skewness3_50 | 112.95 | 6000 | 29.74 | 3000 | 6556.31 | 30.39 | 50 |
| 113_6000_3000_skewness3_60 | 112.95 | 6000 | 29.74 | 3000 | 6556.31 | 30.39 | 60 |
| 113_6000_3000_skewness3_70 | 112.95 | 6000 | 29.74 | 3000 | 6556.31 | 30.39 | 70 |
| 113_7000_1000_skewness3_50 | 112.95 | 7000 | 30.86 | 1000 | 7128.09 | 30.99 | 50 |
| 113_7000_1000_skewness3_60 | 112.95 | 7000 | 30.86 | 1000 | 7128.09 | 30.99 | 60 |
| 113_7000_1000_skewness3_70 | 112.95 | 7000 | 30.86 | 1000 | 7128.09 | 30.99 | 70 |
| 113_7000_2000_skewness3_50 | 112.95 | 7000 | 30.86 | 2000 | 7311.23 | 31.17 | 50 |
| 113_7000_2000_skewness3_60 | 112.95 | 7000 | 30.86 | 2000 | 7311.23 | 31.17 | 60 |
| 113_7000_2000_skewness3_70 | 112.95 | 7000 | 30.86 | 2000 | 7311.23 | 31.17 | 70 |
| 113_7000_3000_skewness3_50 | 112.95 | 7000 | 30.86 | 3000 | 7493.55 | 31.34 | 50 |
| 113_7000_3000_skewness3_60 | 112.95 | 7000 | 30.86 | 3000 | 7493.55 | 31.34 | 60 |
| 113_7000_3000_skewness3_70 | 112.95 | 7000 | 30.86 | 3000 | 7493.55 | 31.34 | 70 |
| 113_8000_1000_skewness3_50 | 112.95 | 8000 | 31.79 | 1000 | 8189.72 | 31.95 | 50 |
| 113_8000_1000_skewness3_60 | 112.95 | 8000 | 31.79 | 1000 | 8189.72 | 31.95 | 60 |
| 113_8000_1000_skewness3_70 | 112.95 | 8000 | 31.79 | 1000 | 8189.72 | 31.95 | 70 |
| 113_8000_2000_skewness3_50 | 112.95 | 8000 | 31.79 | 2000 | 8390.02 | 32.11 | 50 |
| 113_8000_2000_skewness3_60 | 112.95 | 8000 | 31.79 | 2000 | 8390.02 | 32.11 | 60 |
| 113_8000_2000_skewness3_70 | 112.95 | 8000 | 31.79 | 2000 | 8390.02 | 32.11 | 70 |
| 113_8000_3000_skewness3_50 | 112.95 | 8000 | 31.79 | 3000 | 8501.75 | 32.20 | 50 |
| 113_8000_3000_skewness3_60 | 112.95 | 8000 | 31.79 | 3000 | 8501.75 | 32.20 | 60 |
| 113_8000_3000_skewness3_70 | 112.95 | 8000 | 31.79 | 3000 | 8501.75 | 32.20 | 70 |
| 136_3000_1000_skewness1_50 | 135.54 | 3000 | 24.29 | 1000 | 2853.90 | 23.88 | 50 |
| 136_3000_1000_skewness1_60 | 135.54 | 3000 | 24.29 | 1000 | 2853.90 | 23.88 | 60 |
| 136_3000_1000_skewness1_70 | 135.54 | 3000 | 24.29 | 1000 | 2853.90 | 23.88 | 70 |
| 136_3000_2000_skewness1_50 | 135.54 | 3000 | 24.29 | 2000 | 2650.19 | 23.27 | 50 |
| 136_3000_2000_skewness1_60 | 135.54 | 3000 | 24.29 | 2000 | 2650.19 | 23.27 | 60 |
| 136_3000_2000_skewness1_70 | 135.54 | 3000 | 24.29 | 2000 | 2650.19 | 23.27 | 70 |
| 136_3000_3000_skewness1_50 | 135.54 | 3000 | 24.29 | 3000 | 2433.17 | 22.56 | 50 |
| 136_3000_3000_skewness1_60 | 135.54 | 3000 | 24.29 | 3000 | 2433.17 | 22.56 | 60 |
| 136_3000_3000_skewness1_70 | 135.54 | 3000 | 24.29 | 3000 | 2433.17 | 22.56 | 70 |
| 136_4000_1000_skewness1_50 | 135.54 | 4000 | 26.62 | 1000 | 3844.41 | 26.31 | 50 |
| 136_4000_1000_skewness1_60 | 135.54 | 4000 | 26.62 | 1000 | 3844.41 | 26.31 | 60 |
| 136_4000_1000_skewness1_70 | 135.54 | 4000 | 26.62 | 1000 | 3844.41 | 26.31 | 70 |
| 136_4000_2000_skewness1_50 | 135.54 | 4000 | 26.62 | 2000 | 3601.02 | 25.78 | 50 |
| 136_4000_2000_skewness1_60 | 135.54 | 4000 | 26.62 | 2000 | 3601.02 | 25.78 | 60 |
| 136_4000_2000_skewness1_70 | 135.54 | 4000 | 26.62 | 2000 | 3601.02 | 25.78 | 70 |
| 136_4000_3000_skewness1_50 | 135.54 | 4000 | 26.62 | 3000 | 3397.75 | 25.31 | 50 |
| 136_4000_3000_skewness1_60 | 135.54 | 4000 | 26.62 | 3000 | 3397.75 | 25.31 | 60 |
| 136_4000_3000_skewness1_70 | 135.54 | 4000 | 26.62 | 3000 | 3397.75 | 25.31 | 70 |
| 136_5000_1000_skewness1_50 | 135.54 | 5000 | 28.37 | 1000 | 4841.36 | 28.12 | 50 |
| 136_5000_1000_skewness1_60 | 135.54 | 5000 | 28.37 | 1000 | 4841.36 | 28.12 | 60 |

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| 136_5000_1000_skewness1_70 | 135.54 | 5000 | 28.37 | 1000 | 4841.36 | 28.12 | 70 |
| 136_5000_2000_skewness1_50 | 135.54 | 5000 | 28.37 | 2000 | 4631.59 | 27.78 | 50 |
| 136_5000_2000_skewness1_60 | 135.54 | 5000 | 28.37 | 2000 | 4631.59 | 27.78 | 60 |
| 136_5000_2000_skewness1_70 | 135.54 | 5000 | 28.37 | 2000 | 4631.59 | 27.78 | 70 |
| 136_5000_3000_skewness1_50 | 135.54 | 5000 | 28.37 | 3000 | 4500.44 | 27.56 | 50 |
| 136_5000_3000_skewness1_60 | 135.54 | 5000 | 28.37 | 3000 | 4500.44 | 27.56 | 60 |
| 136_5000_3000_skewness1_70 | 135.54 | 5000 | 28.37 | 3000 | 4500.44 | 27.56 | 70 |
| 136_6000_1000_skewness1_50 | 135.54 | 6000 | 29.74 | 1000 | 5819.35 | 29.52 | 50 |
| 136_6000_1000_skewness1_60 | 135.54 | 6000 | 29.74 | 1000 | 5819.35 | 29.52 | 60 |
| 136_6000_1000_skewness1_70 | 135.54 | 6000 | 29.74 | 1000 | 5819.35 | 29.52 | 70 |
| 136_6000_2000_skewness1_50 | 135.54 | 6000 | 29.74 | 2000 | 5599.65 | 29.23 | 50 |
| 136_6000_2000_skewness1_60 | 135.54 | 6000 | 29.74 | 2000 | 5599.65 | 29.23 | 60 |
| 136_6000_2000_skewness1_70 | 135.54 | 6000 | 29.74 | 2000 | 5599.65 | 29.23 | 70 |
| 136_6000_3000_skewness1_50 | 135.54 | 6000 | 29.74 | 3000 | 5467.70 | 29.05 | 50 |
| 136_6000_3000_skewness1_60 | 135.54 | 6000 | 29.74 | 3000 | 5467.70 | 29.05 | 60 |
| 136_6000_3000_skewness1_70 | 135.54 | 6000 | 29.74 | 3000 | 5467.70 | 29.05 | 70 |
| 136_7000_1000_skewness1_50 | 135.54 | 7000 | 30.86 | 1000 | 6810.05 | 30.66 | 50 |
| 136_7000_1000_skewness1_60 | 135.54 | 7000 | 30.86 | 1000 | 6810.05 | 30.66 | 60 |
| 136_7000_1000_skewness1_70 | 135.54 | 7000 | 30.86 | 1000 | 6810.05 | 30.66 | 70 |
| 136_7000_2000_skewness1_50 | 135.54 | 7000 | 30.86 | 2000 | 6603.91 | 30.44 | 50 |
| 136_7000_2000_skewness1_60 | 135.54 | 7000 | 30.86 | 2000 | 6603.91 | 30.44 | 60 |
| 136_7000_2000_skewness1_70 | 135.54 | 7000 | 30.86 | 2000 | 6603.91 | 30.44 | 70 |
| 136_7000_3000_skewness1_50 | 135.54 | 7000 | 30.86 | 3000 | 6426.11 | 30.25 | 50 |
| 136_7000_3000_skewness1_60 | 135.54 | 7000 | 30.86 | 3000 | 6426.11 | 30.25 | 60 |
| 136_7000_3000_skewness1_70 | 135.54 | 7000 | 30.86 | 3000 | 6426.11 | 30.25 | 70 |
| 136_8000_1000_skewness1_50 | 135.54 | 8000 | 31.79 | 1000 | 7825.01 | 31.64 | 50 |
| 136_8000_1000_skewness1_60 | 135.54 | 8000 | 31.79 | 1000 | 7825.01 | 31.64 | 60 |
| 136_8000_1000_skewness1_70 | 135.54 | 8000 | 31.79 | 1000 | 7825.01 | 31.64 | 70 |
| 136_8000_2000_skewness1_50 | 135.54 | 8000 | 31.79 | 2000 | 7636.58 | 31.47 | 50 |
| 136_8000_2000_skewness1_60 | 135.54 | 8000 | 31.79 | 2000 | 7636.58 | 31.47 | 60 |
| 136_8000_2000_skewness1_70 | 135.54 | 8000 | 31.79 | 2000 | 7636.58 | 31.47 | 70 |
| 136_8000_3000_skewness1_50 | 135.54 | 8000 | 31.79 | 3000 | 7483.77 | 31.33 | 50 |
| 136_8000_3000_skewness1_60 | 135.54 | 8000 | 31.79 | 3000 | 7483.77 | 31.33 | 60 |
| 136_8000_3000_skewness1_70 | 135.54 | 8000 | 31.79 | 3000 | 7483.77 | 31.33 | 70 |
| 136_3000_1000_skewness2_50 | 135.54 | 3000 | 24.29 | 1000 | 2994.78 | 24.28 | 50 |
| 136_3000_1000_skewness2_60 | 135.54 | 3000 | 24.29 | 1000 | 2994.78 | 24.28 | 60 |
| 136_3000_1000_skewness2_70 | 135.54 | 3000 | 24.29 | 1000 | 2994.78 | 24.28 | 70 |
| 136_3000_2000_skewness2_50 | 135.54 | 3000 | 24.29 | 2000 | 3004.07 | 24.30 | 50 |
| 136_3000_2000_skewness2_60 | 135.54 | 3000 | 24.29 | 2000 | 3004.07 | 24.30 | 60 |
| 136_3000_2000_skewness2_70 | 135.54 | 3000 | 24.29 | 2000 | 3004.07 | 24.30 | 70 |
| 136_3000_3000_skewness2_50 | 135.54 | 3000 | 24.29 | 3000 | 2972.84 | 24.22 | 50 |
| 136_3000_3000_skewness2_60 | 135.54 | 3000 | 24.29 | 3000 | 2972.84 | 24.22 | 60 |
| 136_3000_3000_skewness2_70 | 135.54 | 3000 | 24.29 | 3000 | 2972.84 | 24.22 | 70 |
| 136_4000_1000_skewness2_50 | 135.54 | 4000 | 26.62 | 1000 | 4009.10 | 26.64 | 50 |
| 136_4000_1000_skewness2_60 | 135.54 | 4000 | 26.62 | 1000 | 4009.10 | 26.64 | 60 |
| 136_4000_1000_skewness2_70 | 135.54 | 4000 | 26.62 | 1000 | 4009.10 | 26.64 | 70 |

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| 136_4000_2000_skewness2_50 | 135.54 | 4000 | 26.62 | 2000 | 4001.10 | 26.63 | 50 |
| 136_4000_2000_skewness2_60 | 135.54 | 4000 | 26.62 | 2000 | 4001.10 | 26.63 | 60 |
| 136_4000_2000_skewness2_70 | 135.54 | 4000 | 26.62 | 2000 | 4001.10 | 26.63 | 70 |
| 136_4000_3000_skewness2_50 | 135.54 | 4000 | 26.62 | 3000 | 4055.98 | 26.73 | 50 |
| 136_4000_3000_skewness2_60 | 135.54 | 4000 | 26.62 | 3000 | 4055.98 | 26.73 | 60 |
| 136_4000_3000_skewness2_70 | 135.54 | 4000 | 26.62 | 3000 | 4055.98 | 26.73 | 70 |
| 136_5000_1000_skewness2_50 | 135.54 | 5000 | 28.37 | 1000 | 5019.81 | 28.40 | 50 |
| 136_5000_1000_skewness2_60 | 135.54 | 5000 | 28.37 | 1000 | 5019.81 | 28.40 | 60 |
| 136_5000_1000_skewness2_70 | 135.54 | 5000 | 28.37 | 1000 | 5019.81 | 28.40 | 70 |
| 136_5000_2000_skewness2_50 | 135.54 | 5000 | 28.37 | 2000 | 5023.44 | 28.41 | 50 |
| 136_5000_2000_skewness2_60 | 135.54 | 5000 | 28.37 | 2000 | 5023.44 | 28.41 | 60 |
| 136_5000_2000_skewness2_70 | 135.54 | 5000 | 28.37 | 2000 | 5023.44 | 28.41 | 70 |
| 136_5000_3000_skewness2_50 | 135.54 | 5000 | 28.37 | 3000 | 4962.16 | 28.31 | 50 |
| 136_5000_3000_skewness2_60 | 135.54 | 5000 | 28.37 | 3000 | 4962.16 | 28.31 | 60 |
| 136_5000_3000_skewness2_70 | 135.54 | 5000 | 28.37 | 3000 | 4962.16 | 28.31 | 70 |
| 136_6000_1000_skewness2_50 | 135.54 | 6000 | 29.74 | 1000 | 5960.94 | 29.70 | 50 |
| 136_6000_1000_skewness2_60 | 135.54 | 6000 | 29.74 | 1000 | 5960.94 | 29.70 | 60 |
| 136_6000_1000_skewness2_70 | 135.54 | 6000 | 29.74 | 1000 | 5960.94 | 29.70 | 70 |
| 136_6000_2000_skewness2_50 | 135.54 | 6000 | 29.74 | 2000 | 5930.83 | 29.66 | 50 |
| 136_6000_2000_skewness2_60 | 135.54 | 6000 | 29.74 | 2000 | 5930.83 | 29.66 | 60 |
| 136_6000_2000_skewness2_70 | 135.54 | 6000 | 29.74 | 2000 | 5930.83 | 29.66 | 70 |
| 136_6000_3000_skewness2_50 | 135.54 | 6000 | 29.74 | 3000 | 6006.79 | 29.75 | 50 |
| 136_6000_3000_skewness2_60 | 135.54 | 6000 | 29.74 | 3000 | 6006.79 | 29.75 | 60 |
| 136_6000_3000_skewness2_70 | 135.54 | 6000 | 29.74 | 3000 | 6006.79 | 29.75 | 70 |
| 136_7000_1000_skewness2_50 | 135.54 | 7000 | 30.86 | 1000 | 6978.33 | 30.84 | 50 |
| 136_7000_1000_skewness2_60 | 135.54 | 7000 | 30.86 | 1000 | 6978.33 | 30.84 | 60 |
| 136_7000_1000_skewness2_70 | 135.54 | 7000 | 30.86 | 1000 | 6978.33 | 30.84 | 70 |
| 136_7000_2000_skewness2_50 | 135.54 | 7000 | 30.86 | 2000 | 6999.56 | 30.86 | 50 |
| 136_7000_2000_skewness2_60 | 135.54 | 7000 | 30.86 | 2000 | 6999.56 | 30.86 | 60 |
| 136_7000_2000_skewness2_70 | 135.54 | 7000 | 30.86 | 2000 | 6999.56 | 30.86 | 70 |
| 136_7000_3000_skewness2_50 | 135.54 | 7000 | 30.86 | 3000 | 6988.27 | 30.85 | 50 |
| 136_7000_3000_skewness2_60 | 135.54 | 7000 | 30.86 | 3000 | 6988.27 | 30.85 | 60 |
| 136_7000_3000_skewness2_70 | 135.54 | 7000 | 30.86 | 3000 | 6988.27 | 30.85 | 70 |
| 136_8000_1000_skewness2_50 | 135.54 | 8000 | 31.79 | 1000 | 8075.50 | 31.85 | 50 |
| 136_8000_1000_skewness2_60 | 135.54 | 8000 | 31.79 | 1000 | 8075.50 | 31.85 | 60 |
| 136_8000_1000_skewness2_70 | 135.54 | 8000 | 31.79 | 1000 | 8075.50 | 31.85 | 70 |
| 136_8000_2000_skewness2_50 | 135.54 | 8000 | 31.79 | 2000 | 8027.19 | 31.81 | 50 |
| 136_8000_2000_skewness2_60 | 135.54 | 8000 | 31.79 | 2000 | 8027.19 | 31.81 | 60 |
| 136_8000_2000_skewness2_70 | 135.54 | 8000 | 31.79 | 2000 | 8027.19 | 31.81 | 70 |
| 136_8000_3000_skewness2_50 | 135.54 | 8000 | 31.79 | 3000 | 7975.77 | 31.77 | 50 |
| 136_8000_3000_skewness2_60 | 135.54 | 8000 | 31.79 | 3000 | 7975.77 | 31.77 | 60 |
| 136_8000_3000_skewness2_70 | 135.54 | 8000 | 31.79 | 3000 | 7975.77 | 31.77 | 70 |
| 136_3000_1000_skewness3_50 | 135.54 | 3000 | 24.29 | 1000 | 3167.40 | 24.74 | 50 |
| 136_3000_1000_skewness3_60 | 135.54 | 3000 | 24.29 | 1000 | 3167.40 | 24.74 | 60 |
| 136_3000_1000_skewness3_70 | 135.54 | 3000 | 24.29 | 1000 | 3167.40 | 24.74 | 70 |
| 136_3000_2000_skewness3_50 | 135.54 | 3000 | 24.29 | 2000 | 3323.33 | 25.13 | 50 |

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| 136_3000_2000_skewness3_60 | 135.54 | 3000 | 24.29 | 2000 | 3323.33 | 25.13 | 60 |
| 136_3000_2000_skewness3_70 | 135.54 | 3000 | 24.29 | 2000 | 3323.33 | 25.13 | 70 |
| 136_3000_3000_skewness3_50 | 135.54 | 3000 | 24.29 | 3000 | 3505.49 | 25.56 | 50 |
| 136_3000_3000_skewness3_60 | 135.54 | 3000 | 24.29 | 3000 | 3505.49 | 25.56 | 60 |
| 136_3000_3000_skewness3_70 | 135.54 | 3000 | 24.29 | 3000 | 3505.49 | 25.56 | 70 |
| 136_4000_1000_skewness3_50 | 135.54 | 4000 | 26.62 | 1000 | 4145.80 | 26.91 | 50 |
| 136_4000_1000_skewness3_60 | 135.54 | 4000 | 26.62 | 1000 | 4145.80 | 26.91 | 60 |
| 136_4000_1000_skewness3_70 | 135.54 | 4000 | 26.62 | 1000 | 4145.80 | 26.91 | 70 |
| 136_4000_2000_skewness3_50 | 135.54 | 4000 | 26.62 | 2000 | 4340.97 | 27.27 | 50 |
| 136_4000_2000_skewness3_60 | 135.54 | 4000 | 26.62 | 2000 | 4340.97 | 27.27 | 60 |
| 136_4000_2000_skewness3_70 | 135.54 | 4000 | 26.62 | 2000 | 4340.97 | 27.27 | 70 |
| 136_4000_3000_skewness3_50 | 135.54 | 4000 | 26.62 | 3000 | 4526.56 | 27.60 | 50 |
| 136_4000_3000_skewness3_60 | 135.54 | 4000 | 26.62 | 3000 | 4526.56 | 27.60 | 60 |
| 136_4000_3000_skewness3_70 | 135.54 | 4000 | 26.62 | 3000 | 4526.56 | 27.60 | 70 |
| 136_5000_1000_skewness3_50 | 135.54 | 5000 | 28.37 | 1000 | 5164.54 | 28.62 | 50 |
| 136_5000_1000_skewness3_60 | 135.54 | 5000 | 28.37 | 1000 | 5164.54 | 28.62 | 60 |
| 136_5000_1000_skewness3_70 | 135.54 | 5000 | 28.37 | 1000 | 5164.54 | 28.62 | 70 |
| 136_5000_2000_skewness3_50 | 135.54 | 5000 | 28.37 | 2000 | 5333.11 | 28.86 | 50 |
| 136_5000_2000_skewness3_60 | 135.54 | 5000 | 28.37 | 2000 | 5333.11 | 28.86 | 60 |
| 136_5000_2000_skewness3_70 | 135.54 | 5000 | 28.37 | 2000 | 5333.11 | 28.86 | 70 |
| 136_5000_3000_skewness3_50 | 135.54 | 5000 | 28.37 | 3000 | 5577.83 | 29.20 | 50 |
| 136_5000_3000_skewness3_60 | 135.54 | 5000 | 28.37 | 3000 | 5577.83 | 29.20 | 60 |
| 136_5000_3000_skewness3_70 | 135.54 | 5000 | 28.37 | 3000 | 5577.83 | 29.20 | 70 |
| 136_6000_1000_skewness3_50 | 135.54 | 6000 | 29.74 | 1000 | 6179.42 | 29.96 | 50 |
| 136_6000_1000_skewness3_60 | 135.54 | 6000 | 29.74 | 1000 | 6179.42 | 29.96 | 60 |
| 136_6000_1000_skewness3_70 | 135.54 | 6000 | 29.74 | 1000 | 6179.42 | 29.96 | 70 |
| 136_6000_2000_skewness3_50 | 135.54 | 6000 | 29.74 | 2000 | 6337.87 | 30.15 | 50 |
| 136_6000_2000_skewness3_60 | 135.54 | 6000 | 29.74 | 2000 | 6337.87 | 30.15 | 60 |
| 136_6000_2000_skewness3_70 | 135.54 | 6000 | 29.74 | 2000 | 6337.87 | 30.15 | 70 |
| 136_6000_3000_skewness3_50 | 135.54 | 6000 | 29.74 | 3000 | 6554.29 | 30.39 | 50 |
| 136_6000_3000_skewness3_60 | 135.54 | 6000 | 29.74 | 3000 | 6554.29 | 30.39 | 60 |
| 136_6000_3000_skewness3_70 | 135.54 | 6000 | 29.74 | 3000 | 6554.29 | 30.39 | 70 |
| 136_7000_1000_skewness3_50 | 135.54 | 7000 | 30.86 | 1000 | 7168.11 | 31.03 | 50 |
| 136_7000_1000_skewness3_60 | 135.54 | 7000 | 30.86 | 1000 | 7168.11 | 31.03 | 60 |
| 136_7000_1000_skewness3_70 | 135.54 | 7000 | 30.86 | 1000 | 7168.11 | 31.03 | 70 |
| 136_7000_2000_skewness3_50 | 135.54 | 7000 | 30.86 | 2000 | 7305.56 | 31.16 | 50 |
| 136_7000_2000_skewness3_60 | 135.54 | 7000 | 30.86 | 2000 | 7305.56 | 31.16 | 60 |
| 136_7000_2000_skewness3_70 | 135.54 | 7000 | 30.86 | 2000 | 7305.56 | 31.16 | 70 |
| 136_7000_3000_skewness3_50 | 135.54 | 7000 | 30.86 | 3000 | 7590.38 | 31.43 | 50 |
| 136_7000_3000_skewness3_60 | 135.54 | 7000 | 30.86 | 3000 | 7590.38 | 31.43 | 60 |
| 136_7000_3000_skewness3_70 | 135.54 | 7000 | 30.86 | 3000 | 7590.38 | 31.43 | 70 |
| 136_8000_1000_skewness3_50 | 135.54 | 8000 | 31.79 | 1000 | 8192.05 | 31.95 | 50 |
| 136_8000_1000_skewness3_60 | 135.54 | 8000 | 31.79 | 1000 | 8192.05 | 31.95 | 60 |
| 136_8000_1000_skewness3_70 | 135.54 | 8000 | 31.79 | 1000 | 8192.05 | 31.95 | 70 |
| 136_8000_2000_skewness3_50 | 135.54 | 8000 | 31.79 | 2000 | 8313.04 | 32.05 | 50 |
| 136_8000_2000_skewness3_60 | 135.54 | 8000 | 31.79 | 2000 | 8313.04 | 32.05 | 60 |

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| 136_8000_2000_skewness3_70 | 135.54 | 8000 | 31.79 | 2000 | 8313.04 | 32.05 | 70 |
| 136_8000_3000_skewness3_50 | 135.54 | 8000 | 31.79 | 3000 | 8479.94 | 32.18 | 50 |
| 136_8000_3000_skewness3_60 | 135.54 | 8000 | 31.79 | 3000 | 8479.94 | 32.18 | 60 |
| 136_8000_3000_skewness3_70 | 135.54 | 8000 | 31.79 | 3000 | 8479.94 | 32.18 | 70 |
| 163_3000_1000_skewness1_50 | 162.65 | 3000 | 24.29 | 1000 | 2832.97 | 23.82 | 50 |
| 163_3000_1000_skewness1_60 | 162.65 | 3000 | 24.29 | 1000 | 2832.97 | 23.82 | 60 |
| 163_3000_1000_skewness1_70 | 162.65 | 3000 | 24.29 | 1000 | 2832.97 | 23.82 | 70 |
| 163_3000_2000_skewness1_50 | 162.65 | 3000 | 24.29 | 2000 | 2631.39 | 23.21 | 50 |
| 163_3000_2000_skewness1_60 | 162.65 | 3000 | 24.29 | 2000 | 2631.39 | 23.21 | 60 |
| 163_3000_2000_skewness1_70 | 162.65 | 3000 | 24.29 | 2000 | 2631.39 | 23.21 | 70 |
| 163_3000_3000_skewness1_50 | 162.65 | 3000 | 24.29 | 3000 | 2519.54 | 22.85 | 50 |
| 163_3000_3000_skewness1_60 | 162.65 | 3000 | 24.29 | 3000 | 2519.54 | 22.85 | 60 |
| 163_3000_3000_skewness1_70 | 162.65 | 3000 | 24.29 | 3000 | 2519.54 | 22.85 | 70 |
| 163_4000_1000_skewness1_50 | 162.65 | 4000 | 26.62 | 1000 | 3818.34 | 26.25 | 50 |
| 163_4000_1000_skewness1_60 | 162.65 | 4000 | 26.62 | 1000 | 3818.34 | 26.25 | 60 |
| 163_4000_1000_skewness1_70 | 162.65 | 4000 | 26.62 | 1000 | 3818.34 | 26.25 | 70 |
| 163_4000_2000_skewness1_50 | 162.65 | 4000 | 26.62 | 2000 | 3643.46 | 25.88 | 50 |
| 163_4000_2000_skewness1_60 | 162.65 | 4000 | 26.62 | 2000 | 3643.46 | 25.88 | 60 |
| 163_4000_2000_skewness1_70 | 162.65 | 4000 | 26.62 | 2000 | 3643.46 | 25.88 | 70 |
| 163_4000_3000_skewness1_50 | 162.65 | 4000 | 26.62 | 3000 | 3452.39 | 25.44 | 50 |
| 163_4000_3000_skewness1_60 | 162.65 | 4000 | 26.62 | 3000 | 3452.39 | 25.44 | 60 |
| 163_4000_3000_skewness1_70 | 162.65 | 4000 | 26.62 | 3000 | 3452.39 | 25.44 | 70 |
| 163_5000_1000_skewness1_50 | 162.65 | 5000 | 28.37 | 1000 | 4841.86 | 28.12 | 50 |
| 163_5000_1000_skewness1_60 | 162.65 | 5000 | 28.37 | 1000 | 4841.86 | 28.12 | 60 |
| 163_5000_1000_skewness1_70 | 162.65 | 5000 | 28.37 | 1000 | 4841.86 | 28.12 | 70 |
| 163_5000_2000_skewness1_50 | 162.65 | 5000 | 28.37 | 2000 | 4634.07 | 27.78 | 50 |
| 163_5000_2000_skewness1_60 | 162.65 | 5000 | 28.37 | 2000 | 4634.07 | 27.78 | 60 |
| 163_5000_2000_skewness1_70 | 162.65 | 5000 | 28.37 | 2000 | 4634.07 | 27.78 | 70 |
| 163_5000_3000_skewness1_50 | 162.65 | 5000 | 28.37 | 3000 | 4466.48 | 27.50 | 50 |
| 163_5000_3000_skewness1_60 | 162.65 | 5000 | 28.37 | 3000 | 4466.48 | 27.50 | 60 |
| 163_5000_3000_skewness1_70 | 162.65 | 5000 | 28.37 | 3000 | 4466.48 | 27.50 | 70 |
| 163_6000_1000_skewness1_50 | 162.65 | 6000 | 29.74 | 1000 | 5819.33 | 29.52 | 50 |
| 163_6000_1000_skewness1_60 | 162.65 | 6000 | 29.74 | 1000 | 5819.33 | 29.52 | 60 |
| 163_6000_1000_skewness1_70 | 162.65 | 6000 | 29.74 | 1000 | 5819.33 | 29.52 | 70 |
| 163_6000_2000_skewness1_50 | 162.65 | 6000 | 29.74 | 2000 | 5685.59 | 29.34 | 50 |
| 163_6000_2000_skewness1_60 | 162.65 | 6000 | 29.74 | 2000 | 5685.59 | 29.34 | 60 |
| 163_6000_2000_skewness1_70 | 162.65 | 6000 | 29.74 | 2000 | 5685.59 | 29.34 | 70 |
| 163_6000_3000_skewness1_50 | 162.65 | 6000 | 29.74 | 3000 | 5534.56 | 29.14 | 50 |
| 163_6000_3000_skewness1_60 | 162.65 | 6000 | 29.74 | 3000 | 5534.56 | 29.14 | 60 |
| 163_6000_3000_skewness1_70 | 162.65 | 6000 | 29.74 | 3000 | 5534.56 | 29.14 | 70 |
| 163_7000_1000_skewness1_50 | 162.65 | 7000 | 30.86 | 1000 | 6826.64 | 30.68 | 50 |
| 163_7000_1000_skewness1_60 | 162.65 | 7000 | 30.86 | 1000 | 6826.64 | 30.68 | 60 |
| 163_7000_1000_skewness1_70 | 162.65 | 7000 | 30.86 | 1000 | 6826.64 | 30.68 | 70 |
| 163_7000_2000_skewness1_50 | 162.65 | 7000 | 30.86 | 2000 | 6647.46 | 30.49 | 50 |
| 163_7000_2000_skewness1_60 | 162.65 | 7000 | 30.86 | 2000 | 6647.46 | 30.49 | 60 |
| 163_7000_2000_skewness1_70 | 162.65 | 7000 | 30.86 | 2000 | 6647.46 | 30.49 | 70 |

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|---|---|---|---|---|---|---|---|
| 163_7000_3000_skewness1_50 | 162.65 | 7000 | 30.86 | 3000 | 6456.60 | 30.28 | 50 |
| 163_7000_3000_skewness1_60 | 162.65 | 7000 | 30.86 | 3000 | 6456.60 | 30.28 | 60 |
| 163_7000_3000_skewness1_70 | 162.65 | 7000 | 30.86 | 3000 | 6456.60 | 30.28 | 70 |
| 163_8000_1000_skewness1_50 | 162.65 | 8000 | 31.79 | 1000 | 7837.80 | 31.65 | 50 |
| 163_8000_1000_skewness1_60 | 162.65 | 8000 | 31.79 | 1000 | 7837.80 | 31.65 | 60 |
| 163_8000_1000_skewness1_70 | 162.65 | 8000 | 31.79 | 1000 | 7837.80 | 31.65 | 70 |
| 163_8000_2000_skewness1_50 | 162.65 | 8000 | 31.79 | 2000 | 7628.83 | 31.46 | 50 |
| 163_8000_2000_skewness1_60 | 162.65 | 8000 | 31.79 | 2000 | 7628.83 | 31.46 | 60 |
| 163_8000_2000_skewness1_70 | 162.65 | 8000 | 31.79 | 2000 | 7628.83 | 31.46 | 70 |
| 163_8000_3000_skewness1_50 | 162.65 | 8000 | 31.79 | 3000 | 7476.22 | 31.32 | 50 |
| 163_8000_3000_skewness1_60 | 162.65 | 8000 | 31.79 | 3000 | 7476.22 | 31.32 | 60 |
| 163_8000_3000_skewness1_70 | 162.65 | 8000 | 31.79 | 3000 | 7476.22 | 31.32 | 70 |
| 163_3000_1000_skewness2_50 | 162.65 | 3000 | 24.29 | 1000 | 3018.51 | 24.34 | 50 |
| 163_3000_1000_skewness2_60 | 162.65 | 3000 | 24.29 | 1000 | 3018.51 | 24.34 | 60 |
| 163_3000_1000_skewness2_70 | 162.65 | 3000 | 24.29 | 1000 | 3018.51 | 24.34 | 70 |
| 163_3000_2000_skewness2_50 | 162.65 | 3000 | 24.29 | 2000 | 3004.65 | 24.30 | 50 |
| 163_3000_2000_skewness2_60 | 162.65 | 3000 | 24.29 | 2000 | 3004.65 | 24.30 | 60 |
| 163_3000_2000_skewness2_70 | 162.65 | 3000 | 24.29 | 2000 | 3004.65 | 24.30 | 70 |
| 163_3000_3000_skewness2_50 | 162.65 | 3000 | 24.29 | 3000 | 3074.89 | 24.49 | 50 |
| 163_3000_3000_skewness2_60 | 162.65 | 3000 | 24.29 | 3000 | 3074.89 | 24.49 | 60 |
| 163_3000_3000_skewness2_70 | 162.65 | 3000 | 24.29 | 3000 | 3074.89 | 24.49 | 70 |
| 163_4000_1000_skewness2_50 | 162.65 | 4000 | 26.62 | 1000 | 4010.88 | 26.65 | 50 |
| 163_4000_1000_skewness2_60 | 162.65 | 4000 | 26.62 | 1000 | 4010.88 | 26.65 | 60 |
| 163_4000_1000_skewness2_70 | 162.65 | 4000 | 26.62 | 1000 | 4010.88 | 26.65 | 70 |
| 163_4000_2000_skewness2_50 | 162.65 | 4000 | 26.62 | 2000 | 4015.52 | 26.66 | 50 |
| 163_4000_2000_skewness2_60 | 162.65 | 4000 | 26.62 | 2000 | 4015.52 | 26.66 | 60 |
| 163_4000_2000_skewness2_70 | 162.65 | 4000 | 26.62 | 2000 | 4015.52 | 26.66 | 70 |
| 163_4000_3000_skewness2_50 | 162.65 | 4000 | 26.62 | 3000 | 4020.67 | 26.67 | 50 |
| 163_4000_3000_skewness2_60 | 162.65 | 4000 | 26.62 | 3000 | 4020.67 | 26.67 | 60 |
| 163_4000_3000_skewness2_70 | 162.65 | 4000 | 26.62 | 3000 | 4020.67 | 26.67 | 70 |
| 163_5000_1000_skewness2_50 | 162.65 | 5000 | 28.37 | 1000 | 5028.70 | 28.42 | 50 |
| 163_5000_1000_skewness2_60 | 162.65 | 5000 | 28.37 | 1000 | 5028.70 | 28.42 | 60 |
| 163_5000_1000_skewness2_70 | 162.65 | 5000 | 28.37 | 1000 | 5028.70 | 28.42 | 70 |
| 163_5000_2000_skewness2_50 | 162.65 | 5000 | 28.37 | 2000 | 4977.70 | 28.34 | 50 |
| 163_5000_2000_skewness2_60 | 162.65 | 5000 | 28.37 | 2000 | 4977.70 | 28.34 | 60 |
| 163_5000_2000_skewness2_70 | 162.65 | 5000 | 28.37 | 2000 | 4977.70 | 28.34 | 70 |
| 163_5000_3000_skewness2_50 | 162.65 | 5000 | 28.37 | 3000 | 4964.76 | 28.32 | 50 |
| 163_5000_3000_skewness2_60 | 162.65 | 5000 | 28.37 | 3000 | 4964.76 | 28.32 | 60 |
| 163_5000_3000_skewness2_70 | 162.65 | 5000 | 28.37 | 3000 | 4964.76 | 28.32 | 70 |
| 163_6000_1000_skewness2_50 | 162.65 | 6000 | 29.74 | 1000 | 5995.69 | 29.74 | 50 |
| 163_6000_1000_skewness2_60 | 162.65 | 6000 | 29.74 | 1000 | 5995.69 | 29.74 | 60 |
| 163_6000_1000_skewness2_70 | 162.65 | 6000 | 29.74 | 1000 | 5995.69 | 29.74 | 70 |
| 163_6000_2000_skewness2_50 | 162.65 | 6000 | 29.74 | 2000 | 5987.32 | 29.73 | 50 |
| 163_6000_2000_skewness2_60 | 162.65 | 6000 | 29.74 | 2000 | 5987.32 | 29.73 | 60 |
| 163_6000_2000_skewness2_70 | 162.65 | 6000 | 29.74 | 2000 | 5987.32 | 29.73 | 70 |
| 163_6000_3000_skewness2_50 | 162.65 | 6000 | 29.74 | 3000 | 5952.63 | 29.69 | 50 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 163_6000_3000_skewness2_60 | 162.65 | 6000 | 29.74 | 3000 | 5952.63 | 29.69 | 60 |
| 163_6000_3000_skewness2_70 | 162.65 | 6000 | 29.74 | 3000 | 5952.63 | 29.69 | 70 |
| 163_7000_1000_skewness2_50 | 162.65 | 7000 | 30.86 | 1000 | 7013.54 | 30.87 | 50 |
| 163_7000_1000_skewness2_60 | 162.65 | 7000 | 30.86 | 1000 | 7013.54 | 30.87 | 60 |
| 163_7000_1000_skewness2_70 | 162.65 | 7000 | 30.86 | 1000 | 7013.54 | 30.87 | 70 |
| 163_7000_2000_skewness2_50 | 162.65 | 7000 | 30.86 | 2000 | 6952.08 | 30.81 | 50 |
| 163_7000_2000_skewness2_60 | 162.65 | 7000 | 30.86 | 2000 | 6952.08 | 30.81 | 60 |
| 163_7000_2000_skewness2_70 | 162.65 | 7000 | 30.86 | 2000 | 6952.08 | 30.81 | 70 |
| 163_7000_3000_skewness2_50 | 162.65 | 7000 | 30.86 | 3000 | 7040.00 | 30.90 | 50 |
| 163_7000_3000_skewness2_60 | 162.65 | 7000 | 30.86 | 3000 | 7040.00 | 30.90 | 60 |
| 163_7000_3000_skewness2_70 | 162.65 | 7000 | 30.86 | 3000 | 7040.00 | 30.90 | 70 |
| 163_8000_1000_skewness2_50 | 162.65 | 8000 | 31.79 | 1000 | 7985.26 | 31.78 | 50 |
| 163_8000_1000_skewness2_60 | 162.65 | 8000 | 31.79 | 1000 | 7985.26 | 31.78 | 60 |
| 163_8000_1000_skewness2_70 | 162.65 | 8000 | 31.79 | 1000 | 7985.26 | 31.78 | 70 |
| 163_8000_2000_skewness2_50 | 162.65 | 8000 | 31.79 | 2000 | 8019.97 | 31.80 | 50 |
| 163_8000_2000_skewness2_60 | 162.65 | 8000 | 31.79 | 2000 | 8019.97 | 31.80 | 60 |
| 163_8000_2000_skewness2_70 | 162.65 | 8000 | 31.79 | 2000 | 8019.97 | 31.80 | 70 |
| 163_8000_3000_skewness2_50 | 162.65 | 8000 | 31.79 | 3000 | 7981.40 | 31.77 | 50 |
| 163_8000_3000_skewness2_60 | 162.65 | 8000 | 31.79 | 3000 | 7981.40 | 31.77 | 60 |
| 163_8000_3000_skewness2_70 | 162.65 | 8000 | 31.79 | 3000 | 7981.40 | 31.77 | 70 |
| 163_3000_1000_skewness3_50 | 162.65 | 3000 | 24.29 | 1000 | 3208.88 | 24.84 | 50 |
| 163_3000_1000_skewness3_60 | 162.65 | 3000 | 24.29 | 1000 | 3208.88 | 24.84 | 60 |
| 163_3000_1000_skewness3_70 | 162.65 | 3000 | 24.29 | 1000 | 3208.88 | 24.84 | 70 |
| 163_3000_2000_skewness3_50 | 162.65 | 3000 | 24.29 | 2000 | 3354.88 | 25.21 | 50 |
| 163_3000_2000_skewness3_60 | 162.65 | 3000 | 24.29 | 2000 | 3354.88 | 25.21 | 60 |
| 163_3000_2000_skewness3_70 | 162.65 | 3000 | 24.29 | 2000 | 3354.88 | 25.21 | 70 |
| 163_3000_3000_skewness3_50 | 162.65 | 3000 | 24.29 | 3000 | 3530.24 | 25.62 | 50 |
| 163_3000_3000_skewness3_60 | 162.65 | 3000 | 24.29 | 3000 | 3530.24 | 25.62 | 60 |
| 163_3000_3000_skewness3_70 | 162.65 | 3000 | 24.29 | 3000 | 3530.24 | 25.62 | 70 |
| 163_4000_1000_skewness3_50 | 162.65 | 4000 | 26.62 | 1000 | 4160.38 | 26.94 | 50 |
| 163_4000_1000_skewness3_60 | 162.65 | 4000 | 26.62 | 1000 | 4160.38 | 26.94 | 60 |
| 163_4000_1000_skewness3_70 | 162.65 | 4000 | 26.62 | 1000 | 4160.38 | 26.94 | 70 |
| 163_4000_2000_skewness3_50 | 162.65 | 4000 | 26.62 | 2000 | 4323.28 | 27.24 | 50 |
| 163_4000_2000_skewness3_60 | 162.65 | 4000 | 26.62 | 2000 | 4323.28 | 27.24 | 60 |
| 163_4000_2000_skewness3_70 | 162.65 | 4000 | 26.62 | 2000 | 4323.28 | 27.24 | 70 |
| 163_4000_3000_skewness3_50 | 162.65 | 4000 | 26.62 | 3000 | 4513.49 | 27.58 | 50 |
| 163_4000_3000_skewness3_60 | 162.65 | 4000 | 26.62 | 3000 | 4513.49 | 27.58 | 60 |
| 163_4000_3000_skewness3_70 | 162.65 | 4000 | 26.62 | 3000 | 4513.49 | 27.58 | 70 |
| 163_5000_1000_skewness3_50 | 162.65 | 5000 | 28.37 | 1000 | 5207.20 | 28.68 | 50 |
| 163_5000_1000_skewness3_60 | 162.65 | 5000 | 28.37 | 1000 | 5207.20 | 28.68 | 60 |
| 163_5000_1000_skewness3_70 | 162.65 | 5000 | 28.37 | 1000 | 5207.20 | 28.68 | 70 |
| 163_5000_2000_skewness3_50 | 162.65 | 5000 | 28.37 | 2000 | 5359.05 | 28.90 | 50 |
| 163_5000_2000_skewness3_60 | 162.65 | 5000 | 28.37 | 2000 | 5359.05 | 28.90 | 60 |
| 163_5000_2000_skewness3_70 | 162.65 | 5000 | 28.37 | 2000 | 5359.05 | 28.90 | 70 |
| 163_5000_3000_skewness3_50 | 162.65 | 5000 | 28.37 | 3000 | 5543.83 | 29.16 | 50 |
| 163_5000_3000_skewness3_60 | 162.65 | 5000 | 28.37 | 3000 | 5543.83 | 29.16 | 60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 163_5000_3000_skewness3_70 | 162.65 | 5000 | 28.37 | 3000 | 5543.83 | 29.16 | 70 |
| 163_6000_1000_skewness3_50 | 162.65 | 6000 | 29.74 | 1000 | 6156.65 | 29.93 | 50 |
| 163_6000_1000_skewness3_60 | 162.65 | 6000 | 29.74 | 1000 | 6156.65 | 29.93 | 60 |
| 163_6000_1000_skewness3_70 | 162.65 | 6000 | 29.74 | 1000 | 6156.65 | 29.93 | 70 |
| 163_6000_2000_skewness3_50 | 162.65 | 6000 | 29.74 | 2000 | 6350.85 | 30.16 | 50 |
| 163_6000_2000_skewness3_60 | 162.65 | 6000 | 29.74 | 2000 | 6350.85 | 30.16 | 60 |
| 163_6000_2000_skewness3_70 | 162.65 | 6000 | 29.74 | 2000 | 6350.85 | 30.16 | 70 |
| 163_6000_3000_skewness3_50 | 162.65 | 6000 | 29.74 | 3000 | 6595.12 | 30.43 | 50 |
| 163_6000_3000_skewness3_60 | 162.65 | 6000 | 29.74 | 3000 | 6595.12 | 30.43 | 60 |
| 163_6000_3000_skewness3_70 | 162.65 | 6000 | 29.74 | 3000 | 6595.12 | 30.43 | 70 |
| 163_7000_1000_skewness3_50 | 162.65 | 7000 | 30.86 | 1000 | 7155.27 | 31.01 | 50 |
| 163_7000_1000_skewness3_60 | 162.65 | 7000 | 30.86 | 1000 | 7155.27 | 31.01 | 60 |
| 163_7000_1000_skewness3_70 | 162.65 | 7000 | 30.86 | 1000 | 7155.27 | 31.01 | 70 |
| 163_7000_2000_skewness3_50 | 162.65 | 7000 | 30.86 | 2000 | 7386.88 | 31.24 | 50 |
| 163_7000_2000_skewness3_60 | 162.65 | 7000 | 30.86 | 2000 | 7386.88 | 31.24 | 60 |
| 163_7000_2000_skewness3_70 | 162.65 | 7000 | 30.86 | 2000 | 7386.88 | 31.24 | 70 |
| 163_7000_3000_skewness3_50 | 162.65 | 7000 | 30.86 | 3000 | 7576.75 | 31.41 | 50 |
| 163_7000_3000_skewness3_60 | 162.65 | 7000 | 30.86 | 3000 | 7576.75 | 31.41 | 60 |
| 163_7000_3000_skewness3_70 | 162.65 | 7000 | 30.86 | 3000 | 7576.75 | 31.41 | 70 |
| 163_8000_1000_skewness3_50 | 162.65 | 8000 | 31.79 | 1000 | 8185.12 | 31.94 | 50 |
| 163_8000_1000_skewness3_60 | 162.65 | 8000 | 31.79 | 1000 | 8185.12 | 31.94 | 60 |
| 163_8000_1000_skewness3_70 | 162.65 | 8000 | 31.79 | 1000 | 8185.12 | 31.94 | 70 |
| 163_8000_2000_skewness3_50 | 162.65 | 8000 | 31.79 | 2000 | 8282.69 | 32.02 | 50 |
| 163_8000_2000_skewness3_60 | 162.65 | 8000 | 31.79 | 2000 | 8282.69 | 32.02 | 60 |
| 163_8000_2000_skewness3_70 | 162.65 | 8000 | 31.79 | 2000 | 8282.69 | 32.02 | 70 |
| 163_8000_3000_skewness3_50 | 162.65 | 8000 | 31.79 | 3000 | 8574.12 | 32.25 | 50 |
| 163_8000_3000_skewness3_60 | 162.65 | 8000 | 31.79 | 3000 | 8574.12 | 32.25 | 60 |
| 163_8000_3000_skewness3_70 | 162.65 | 8000 | 31.79 | 3000 | 8574.12 | 32.25 | 70 |

**Annex 3: List of participants**

| Listener | Age | Gender | Testingdate | Place of birth | Place of residence | Born in Randstad | Age |
|---|---|---|---|---|---|---|---|
| ASOF | O | F | 23-5-2011 | Bovenkarspel | Bovenkarspel | 0 | 50 |
| DYOF | O | F | 26-5-2011 | Laren | Amsterdam | 1 | 58 |
| EROF | O | F | 18-6-2011 | Amsterdam | Grootebroek | 1 | 52 |
| GWOF | O | F | 6-6-2011 | Amsterdam | Amsterdam | 1 | 66 |
| LEOF | O | F | 25-5-2011 | Venhuizen | Grootebroek | 0 | 66 |
| LSOF | O | F | 15-6-2011 | Bussum | Hoogkarspel | 0 | 54 |
| MDOF | O | F | 26-5-2011 | Amsterdam | Amsterdam | 1 | 54 |
| MJOF | O | F | 26-5-2011 | Roermond | Landsmeer | 0 | 61 |
| MLOF | O | F | 20-5-2011 | Bergen | Beets | 0 | 51 |
| MROF | O | F | 23-6-2011 | Amsterdam | Amsterdam | 1 | 66 |
| PSOF | O | F | 24-5-2011 | Haarlem | Amsterdam | 1 | 53 |
| SDOF | O | F | 26-5-2011 | Hoogeveen | Amsterdam | 0 | 58 |
| TBOF | O | F | 25-5-2011 | Amsterdam | Amsterdam | 1 | 64 |
| TKOF | O | F | 18-5-2011 | Zwaag | Lutjebroek | 0 | 71 |
| TVOF | O | F | 26-5-2011 | Amsterdam | Amstelveen | 1 | 53 |
| WGOF | O | F | 26-5-2011 | Den Bosch | Almere | 0 | 55 |
| ASOM | O | M | 23-5-2011 | Venhuizen | Bovenkarspel | 0 | 56 |
| DOOM | O | M | 10-5-2011 | Hoorn | Hoogkarspel | 0 | 59 |
| FAOM | O | M | 10-6-2011 | Amsterdam | Amsterdam | 1 | 53 |
| FBOM | O | M | 9-6-2011 | Harderwijk | Amsterdam | 0 | 57 |
| GMOM | O | M | 26-5-2011 | Ede | Amsterdam | 0 | 58 |
| JZOM | O | M | 25-5-2011 | Zandvoort | Hoogkarspel | 1 | 56 |
| PHOM | O | M | 29-6-2011 | Haarlem | Amsterdam | 1 | 51 |
| RLOM | O | M | 20-5-2011 | Purmerend | Beets | 0 | 56 |
| RROM | O | M | 18-6-2011 | Amsterdam | Grootebroek | 1 | 56 |
| ATYF | Y | F | 18-5-2011 | Utrecht | Amsterdam | 1 | 24 |
| CCYF | Y | F | 19-5-2011 | Heemstede | Amsterdam | 1 | 23 |
| CMYF | Y | F | 26-5-2011 | Alkmaar | Amsterdam | 0 | 23 |
| EV2YF | Y | F | 1-6-2011 | Purmerend | Volendam | 0 | 22 |
| EVYF | Y | F | 17-5-2011 | Amsterdam | Amsterdam | 1 | 22 |
| JMYF | Y | F | 26-5-2011 | Goes | Amstelveen | 0 | 20 |
| JTYF | Y | F | 20-5-2011 | Zaandam | Amsterdam | 1 | 20 |
| JWYF | Y | F | 11-5-2011 | Rotterdam | Amsterdam | 1 | 21 |
| KBYF | Y | F | 19-5-2011 | Amsterdam | Amsterdam | 1 | 19 |
| LSYF | Y | F | 1-6-2011 | Deventer | Amsterdam | 0 | 21 |
| MBYF | Y | F | 25-5-2011 | Leidschendam | Haarlem | 1 | 25 |
| MFYF | Y | F | 19-5-2011 | Zeeland | Amsterdam | 0 | 19 |
| MK2YF | Y | F | 6-6-2011 | Amsterdam | Amsterdam | 1 | 24 |
| MKYF | Y | F | 31-5-2011 | Veghel | Amsterdam | 0 | 25 |
| MMYF | Y | F | 10-6-2011 | Groningen | Amsterdam | 0 | 19 |
| MSYF | Y | F | 13-5-2011 | Leiden | Delft | 1 | 21 |
| NGYF | Y | F | 9-6-2011 | Gorinchem | Amsterdam | 1 | 21 |
| SCYF | Y | F | 12-5-2011 | Amsterdam | Amsterdam | 1 | 21 |
| ABYM | Y | M | 20-5-2011 | Amsterdam | Amsterdam | 1 | 21 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| JS2YM | Y | M | 8-6-2011 | Alkmaar | Egmond aan Zee | 0 | 23 |
| KTYM | Y | M | 31-5-2011 | Amsterdam | Amsterdam | 1 | 18 |
| LHYM | Y | M | 12-5-2011 | Den Haag | Den Haag | 1 | 22 |
| MOYM | Y | M | 24-5-2011 | Hoorn | Amsterdam | 0 | 21 |
| RDYM | Y | M | 18-5-2011 | Leiden | Amsterdam | 1 | 21 |
| THYM | Y | M | 6-6-2011 | Aalsmeer | Amsterdam | 1 | 21 |

In the column ‘Born in Randstad’, 0 = not born in Randstad, and 1 = born in Randstad

**Annex 4: Number of times that participants clicked on <tassen> or <tasje>**

| Listener | N | <s> | <s> first 500 stimuli | <sj> | <sj> first 500 stimuli | >50 on <tassen> as well as on <tasje> | /s/-bias |
|---|---|---|---|---|---|---|---|
| ASOF | 500 | 164 | 164 | 50 | 50 | 1 | 114 |
| DYOF | 526 | 68 | 68 | 5 | 5 | 0 | 63 |
| EROF | 600 | 282 | 239 | 136 | 107 | 1 | 132 |
| GWOF | 500 | 147 | 147 | 193 | 193 | 1 | -46 |
| LEOF | 500 | 88 | 88 | 5 | 5 | 0 | 83 |
| LSOF | 500 | 151 | 151 | 94 | 94 | 1 | 57 |
| MDOF | 500 | 230 | 230 | 2 | 2 | 0 | 228 |
| MJOF | 500 | 250 | 250 | 217 | 217 | 1 | 33 |
| MLOF | 500 | 208 | 208 | 184 | 184 | 1 | 24 |
| MROF | 500 | 136 | 136 | 163 | 163 | 1 | -27 |
| PSOF | 600 | 200 | 170 | 128 | 104 | 1 | 66 |
| SDOF | 561 | 246 | 214 | 131 | 127 | 1 | 87 |
| TBOF | 500 | 184 | 184 | 271 | 271 | 1 | -87 |
| TKOF | 500 | 145 | 145 | 119 | 119 | 1 | 26 |
| TVOF | 500 | 343 | 343 | 117 | 117 | 1 | 226 |
| WGOF | 500 | 330 | 330 | 164 | 164 | 1 | 166 |
| ASOM | 760 | 258 | 182 | 137 | 112 | 1 | 70 |
| DOOM | 500 | 217 | 217 | 143 | 143 | 1 | 74 |
| FAOM | 500 | 212 | 212 | 85 | 85 | 1 | 127 |
| FBOM | 500 | 236 | 236 | 143 | 143 | 1 | 93 |
| GMOM | 800 | 383 | 275 | 239 | 158 | 1 | 117 |
| JZOM | 500 | 192 | 192 | 147 | 147 | 1 | 45 |
| PHOM | 500 | 242 | 242 | 0 | 0 | 0 | 242 |
| RLOM | 500 | 273 | 273 | 140 | 140 | 1 | 133 |
| RROM | 510 | 256 | 251 | 165 | 161 | 1 | 90 |
| ATYF | 500 | 114 | 114 | 119 | 119 | 1 | -5 |
| CCYF | 500 | 172 | 172 | 28 | 28 | 0 | 144 |
| CMYF | 500 | 226 | 226 | 80 | 80 | 1 | 146 |
| EV2YF | 500 | 197 | 197 | 112 | 112 | 1 | 85 |
| EVYF | 500 | 226 | 226 | 201 | 201 | 1 | 25 |
| JMYF | 500 | 175 | 175 | 169 | 169 | 1 | 6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| JTYF | 500 | 188 | 188 | 143 | 143 | 1 | 45 |
| JWYF | 500 | 198 | 198 | 108 | 108 | 1 | 90 |
| KBYF | 500 | 235 | 235 | 138 | 138 | 1 | 97 |
| LSYF | 500 | 226 | 226 | 109 | 109 | 1 | 117 |
| MBYF | 500 | 226 | 226 | 155 | 155 | 1 | 71 |
| MFYF | 500 | 170 | 170 | 184 | 184 | 1 | -14 |
| MK2YF | 500 | 130 | 130 | 232 | 232 | 1 | -102 |
| MKYF | 500 | 162 | 162 | 222 | 222 | 1 | -60 |
| MMYF | 500 | 214 | 214 | 88 | 88 | 1 | 126 |
| MSYF | 500 | 117 | 117 | 0 | 0 | 0 | 117 |
| NGYF | 500 | 238 | 238 | 206 | 206 | 1 | 32 |
| SCYF | 600 | 225 | 195 | 281 | 233 | 1 | -38 |
| ABYM | 500 | 226 | 226 | 145 | 145 | 1 | 81 |
| JS2YM | 500 | 142 | 142 | 323 | 323 | 1 | -181 |
| KTYM | 500 | 146 | 146 | 165 | 165 | 1 | -19 |
| LHYM | 500 | 211 | 211 | 193 | 193 | 1 | 18 |
| MOYM | 503 | 238 | 237 | 172 | 170 | 1 | 67 |
| RDYM | 500 | 181 | 181 | 145 | 145 | 1 | 36 |
| THYM | 500 | 196 | 196 | 201 | 201 | 1 | -5 |

In the column ‘>50 on <tassen> as well as on <tasje>’, 0 = a participant clicked less than 50 times on one or both of the words <tassen> and <tasje>, 1 = a participant clicked at least 50 times on <tassen> as well as at least 50 times on <tasje>

**Annex 5: PRAAT script for the first logistic regression analysis (all factors)**

```
list = Create Strings as file list... list Results500/NLtest*allResults+values.Table
numberOfFiles = Get number of strings
echo
participant'tab$'age'tab$'gender'tab$'s'tab$'sj'tab$'context'tab$'duration'tab$'peak'tab$'width'tab$'skewness'tab$'amplitude'tab$'peak2'tab$'ang
le
for file to numberOfFiles
	select list
	file$ = Get string... file
	table = Read from file... Results500/'file$'
	numberOfResponses = Get number of rows
	numberOfS = Get mean... s
	numberOfS = round (numberOfS * numberOfResponses)
	numberOfSj = Get mean... sj
	numberOfSj = round (numberOfSj * numberOfResponses)
	Append column... peak2
	Formula... peak2   (self ["peak(Hz)"] - 5500) ^ 2
	participant$ = mid$ (file$ - "allResults+values.Table", 7, 1000)
	gender$ = right$ (participant$)
	assert gender$ = "F" or gender$ = "M"
	age$ = left$ (right$ (participant$, 2))
	assert age$ = "Y" or age$ = "O"
	participant$ = participant$ - right$ (participant$, 2)
	if numberOfS >= 50 and numberOfSj >= 50
		regression = To logistic regression... "context duration(ms) peak(Hz) width(Hz) skewness amplitude(dB) peak2" s sj
		info$ = Info
		logoddsContext = extractNumber (info$, "Log odds ratio of factor context: ")
		logoddsDuration = extractNumber (info$, "Log odds ratio of factor duration(ms): ")
		logoddsPeak = extractNumber (info$, "Log odds ratio of factor peak(Hz): ")
		logoddsWidth = extractNumber (info$, "Log odds ratio of factor width(Hz): ")
		logoddsSkewness = extractNumber (info$, "Log odds ratio of factor skewness: ")
		logoddsAmplitude = extractNumber (info$, "Log odds ratio of factor amplitude(dB): ")
		logoddsPeak2 = extractNumber (info$, "Log odds ratio of factor peak2: ")
		angle = -arctan(logoddsPeak/logoddsContext)*180/pi
		printline 'participant$''tab$''age$''tab$''gender$''tab$''numberOfS''tab$''numberOfSj''tab$'
		...'logoddsContext:3''tab$''logoddsDuration:3''tab$''logoddsPeak:3''tab$''logoddsWidth:3''tab$''logoddsSkewness:3''tab$'
		...'logoddsAmplitude:3''tab$''logoddsPeak2:3''tab$''angle:1'
Select outer viewport... 0 6 0 6
Select inner viewport... 1 5 1 5
Text top... no Age: Solid line = Y, Dotted line = O
		if age$ = "Y"
			Solid line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
		if age$ = "O"
			Dotted line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
Select outer viewport... 0 6 6 12
Select inner viewport... 1 5 7 11
Text top... no Gender: Solid line = F, Dotted line = M
		if gender$ = "F"
			Solid line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
		if gender$ = "M"
			Dotted line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
	endif
endfor
```

**Annex 6: Table with log odds ratios and angle for each participant (First logistic regression analysis)**

| Listener | <tassen> | <tasje> | Context | Duration | Peak | Width | Skewness | Amplitude | Peak2 | Angle |
|---|---|---|---|---|---|---|---|---|---|---|
| ASOF | 164 | 50 | -4.058 | 2.014 | -10.351 | 0.507 | -0.168 | 2.084 | 0.294 | -68.6 |
| EROF | 239 | 107 | -2.015 | 0.168 | -9.570 | -1.015 | -0.372 | -1.158 | -2.941 | -78.1 |
| GWOF | 147 | 193 | -1.855 | 0.038 | -4.073 | 0.338 | -0.010 | -0.339 | -0.627 | -65.5 |
| LSOF | 151 | 94 | -4.139 | 0.572 | -6.036 | -1.454 | -0.072 | -0.419 | -0.594 | -55.6 |
| MJOF | 250 | 217 | -2.555 | -0.323 | -16.218 | 0.925 | -1.934 | 1.478 | 4.439 | -81.0 |
| MLOF | 208 | 184 | -2.562 | 0.417 | -6.879 | 0.002 | -0.461 | -0.211 | 0.378 | -69.6 |
| MROF | 136 | 163 | -3.321 | 0.789 | -7.363 | 0.999 | -0.643 | -0.152 | 2.635 | -65.7 |
| PSOF | 170 | 104 | -10.162 | 0.884 | -52.356 | 0.847 | -0.739 | -0.897 | -18.332 | -79.0 |
| SDOF | 214 | 127 | -4.219 | 0.522 | -8.433 | 1.889 | -0.694 | 1.555 | 1.115 | -63.4 |
| TBOF | 184 | 271 | -4.135 | 0.630 | -9.194 | 0.200 | -1.733 | -0.172 | 3.089 | -65.8 |
| TKOF | 145 | 119 | -2.099 | 1.023 | -6.236 | 1.472 | -0.312 | 0.350 | 3.421 | -71.4 |
| TVOF | 343 | 117 | -6.022 | 0.937 | -6.094 | 0.035 | -0.391 | 1.028 | -0.852 | -45.3 |
| WGOF | 330 | 164 | -1.732 | 0.345 | -8.185 | 1.150 | -1.639 | 0.807 | 0.033 | -78.1 |
| ASOM | 182 | 112 | -0.571 | 0.576 | -5.213 | -0.058 | -0.575 | 0.055 | 1.125 | -83.8 |
| DOOM | 217 | 143 | -2.866 | -0.521 | -14.042 | 0.432 | 0.047 | -0.260 | 2.847 | -78.5 |
| FAOM | 212 | 85 | -1.906 | 1.191 | -7.057 | 1.022 | -0.152 | 0.160 | 0.731 | -74.9 |
| FBOM | 236 | 143 | -2.897 | 0.275 | -7.493 | 0.538 | -0.148 | 0.345 | -0.196 | -68.9 |
| GMOM | 275 | 158 | -0.848 | 0.261 | -7.702 | 1.800 | -0.232 | 0.773 | 1.679 | -83.7 |
| JZOM | 192 | 147 | -4.355 | 0.471 | -22.35 | 3.690 | -1.914 | 3.081 | -0.643 | -79.0 |
| RLOM | 273 | 140 | -2.936 | -0.236 | -7.172 | 0.506 | -0.862 | -0.136 | 2.284 | -67.7 |
| RROM | 251 | 161 | -2.645 | 0.225 | -8.488 | 1.444 | -1.615 | 0.157 | 2.969 | -72.7 |
| ATYF | 114 | 119 | -4.899 | 0.275 | -2.596 | 1.242 | 0.529 | 1.223 | -1.311 | -27.9 |
| CMYF | 226 | 80 | -5.822 | 0.321 | -2.502 | 0.210 | 0.789 | 0.491 | -1.725 | -23.3 |
| EVYF | 226 | 201 | -4.843 | 0.636 | -3.555 | 1.742 | -0.353 | 1.420 | -1.365 | -36.3 |
| EV2YF | 197 | 112 | -3.623 | 0.387 | -2.751 | -0.081 | -0.547 | 0.395 | -0.620 | -37.2 |
| JMYF | 175 | 169 | -5.795 | 0.469 | -4.998 | 0.853 | -0.173 | 0.974 | -0.281 | -40.8 |
| JTYF | 188 | 143 | -4.160 | 0.184 | -5.509 | 1.040 | -1.105 | 0.574 | -0.148 | -52.9 |
| JWYF | 198 | 108 | -4.245 | 1.062 | -1.690 | -0.620 | -0.069 | 0.294 | 0.447 | -21.7 |
| KBYF | 235 | 138 | -2.405 | -0.112 | -12.427 | 1.747 | -2.607 | 0.916 | 4.157 | -79.0 |
| LSYF | 226 | 109 | -5.597 | -0.297 | -2.455 | 0.447 | -0.727 | 0.267 | 0.706 | -23.7 |
| MBYF | 226 | 155 | -2.736 | 0.209 | -19.406 | 0.981 | -0.471 | -0.579 | 3.544 | -82.0 |
| MFYF | 170 | 184 | -1.436 | -0.123 | -4.488 | -0.121 | -0.238 | 0.203 | 1.207 | -72.3 |
| MKYF | 162 | 222 | -3.481 | 0.506 | -8.059 | 1.374 | -0.523 | 0.484 | 0.920 | -66.6 |
| MK2YF | 130 | 232 | -5.187 | 0.381 | -8.848 | 1.442 | -1.128 | 1.409 | 0.232 | -59.6 |
| MMYF | 214 | 88 | -5.778 | 0.881 | -4.042 | 0.135 | -1.066 | -1.624 | 0.637 | -35.0 |
| NGYF | 238 | 206 | -2.936 | -0.163 | -6.369 | 0.164 | -1.198 | -0.618 | 1.906 | -65.2 |
| SCYF | 195 | 233 | -2.133 | -0.725 | -20.198 | 2.161 | -0.905 | 0.509 | 4.917 | -84.0 |
| ABYM | 226 | 145 | -5.040 | 0.559 | -7.971 | 1.119 | -0.587 | 1.177 | 1.179 | -57.7 |
| JS2YM | 142 | 323 | -3.401 | -0.298 | -8.255 | 0.073 | -1.126 | 0.040 | 2.215 | -67.6 |
| KTYM | 146 | 165 | -2.799 | 0.030 | -2.555 | 0.368 | -0.464 | -0.104 | 0.113 | -42.4 |
| LHYM | 211 | 193 | -2.815 | 0.031 | -13.966 | 2.214 | -0.488 | -0.399 | 3.278 | -78.6 |
| MOYM | 237 | 170 | -3.735 | 0.337 | -7.397 | 0.338 | -0.248 | -0.463 | 0.815 | -63.2 |
| RDYM | 181 | 145 | -4.565 | 0.115 | 0.132 | 0.086 | 0.140 | -0.996 | 0.916 | 1.7 |
| THYM | 196 | 201 | -2.411 | 0.616 | -9.294 | 1.496 | -0.791 | 1.463 | -2.205 | -75.5 |

**Annex 7: PRAAT script for the second logistic regression analysis (factors: peak and context)**

```
list = Create Strings as file list... list Results500/NLtest*allResults+values.Table
numberOfFiles = Get number of strings
echo participant'tab$'age'tab$'gender'tab$'s'tab$'sj'tab$'context'tab$'peak'tab$'angle'tab$'boundary
for file to numberOfFiles
	select list
	file$ = Get string... file
	table = Read from file... Results500/'file$'
	numberOfResponses = Get number of rows
	numberOfS = Get mean... s
	numberOfS = round (numberOfS * numberOfResponses)
	numberOfSj = Get mean... sj
	numberOfSj = round (numberOfSj * numberOfResponses)
	participant$ = mid$ (file$ - "allResults+values.Table", 7, 1000)
	gender$ = right$ (participant$)
	assert gender$ = "F" or gender$ = "M"
	age$ = left$ (right$ (participant$, 2))
	assert age$ = "Y" or age$ = "O"
	participant$ = participant$ - right$ (participant$, 2)
	if numberOfS >= 50 and numberOfSj >= 50
		regression = To logistic regression... "context peak(Hz)" s sj
		info$ = Info
		logoddsratioContext = extractNumber (info$, "Log odds ratio of factor context: ")
		logoddsratioPeak = extractNumber (info$, "Log odds ratio of factor peak(Hz): ")
		intercept = extractNumber (info$, "Intercept: ")
		coefficientContext = extractNumber (info$, "Coefficient of factor context: ")
		coefficientPeak = extractNumber (info$, "Coefficient of factor peak(Hz): ")
		angle = -arctan(logoddsratioPeak/logoddsratioContext)*180/pi
		boundary = -(intercept + coefficientContext * 1.5) / coefficientPeak
		printline 'participant$''tab$''age$''tab$''gender$''tab$''numberOfS''tab$''numberOfSj''tab$'
		...'logoddsratioContext:3''tab$''logoddsratioPeak:3''tab$''angle:1''tab$''boundary:2'
Select outer viewport... 0 6 0 6
Select inner viewport... 1 5 1 5
Text top... no Age: Solid line = Y, Dotted line = O
		if age$ = "Y"
			Solid line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
		if age$ = "O"
			Dotted line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
Select outer viewport... 0 6 6 12
Select inner viewport... 1 5 7 11
Text top... no Gender: Solid line = F, Dotted line = M
		if gender$ = "F"
			Solid line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
		if gender$ = "M"
			Dotted line
			Draw boundary... peak(Hz) 0 0 context 0 0 yes
		endif
	endif
endfor
```

**Annex 8: Table with log odds ratios, angle, and boundary for each participant (Second logistic regression analysis)**

| Listener | <tassen> | <tasje> | Context | Peak | Angle | Boundary |
|---|---|---|---|---|---|---|
| ASOF | 164 | 50 | -3.442 | -8.397 | -67.7 | 4521.85 |
| EROF | 239 | 107 | -1.619 | -7.849 | -78.3 | 5300.22 |
| GWOF | 147 | 193 | -1.804 | -4.179 | -66.6 | 6509.84 |
| LSOF | 151 | 94 | -3.694 | -6.038 | -58.5 | 6063.61 |
| MJOF | 250 | 217 | -1.892 | -11.815 | -80.9 | 5337.21 |
| MLOF | 208 | 184 | -2.498 | -6.551 | -69.1 | 5730.49 |
| MROF | 136 | 163 | -3.235 | -6.726 | -64.3 | 5747.00 |
| PSOF | 170 | 104 | -2.849 | -13.076 | -77.7 | 5245.90 |
| SDOF | 214 | 127 | -4.098 | -7.724 | -62.1 | 5335.12 |
| TBOF | 184 | 271 | -3.727 | -6.500 | -60.2 | 6108.61 |
| TKOF | 145 | 119 | -1.999 | -6.159 | -72.0 | 5247.49 |
| TVOF | 343 | 117 | -6.193 | -5.909 | -43.7 | 3208.51 |
| WGOF | 330 | 164 | -1.584 | -7.471 | -78.0 | 4513.39 |
| ASOM | 182 | 112 | -0.554 | -5.34 | -84.1 | 4970.50 |
| DOOM | 217 | 143 | -2.592 | -11.825 | -77.6 | 5479.55 |
| FAOM | 212 | 85 | -1.744 | -6.235 | -74.4 | 5437.99 |
| FBOM | 236 | 143 | -2.918 | -7.455 | -68.6 | 5228.58 |
| GMOM | 275 | 158 | -0.934 | -8.034 | -83.4 | 4665.93 |
| JZOM | 192 | 147 | -3.977 | -14.892 | -75.0 | 4652.36 |
| RLOM | 273 | 140 | -2.687 | -6.623 | -67.9 | 4834.14 |
| RROM | 251 | 161 | -2.273 | -8.107 | -74.3 | 4864.24 |
| ATYF | 114 | 119 | -4.603 | -2.523 | -28.7 | 7556.72 |
| CMYF | 226 | 80 | -5.322 | -2.165 | -22.1 | 4883.24 |
| EVYF | 226 | 201 | -4.204 | -3.067 | -36.1 | 5430.63 |
| EV2YF | 197 | 112 | -3.583 | -2.934 | -39.3 | 5711.34 |
| JMYF | 175 | 169 | -5.478 | -4.896 | -41.8 | 6477.23 |
| JTYF | 188 | 143 | -3.972 | -5.481 | -54.1 | 5593.73 |
| JWYF | 198 | 108 | -4.023 | -1.552 | -21.1 | 4418.67 |
| KBYF | 235 | 138 | -1.729 | -8.994 | -79.1 | 5078.17 |
| LSYF | 226 | 109 | -5.565 | -2.504 | -24.2 | 5410.51 |
| MBYF | 226 | 155 | -2.432 | -15.905 | -81.3 | 5697.99 |
| MFYF | 170 | 184 | -1.439 | -4.016 | -70.3 | 6013.45 |
| MKYF | 162 | 222 | -3.443 | -6.820 | -63.2 | 6602.19 |
| MK2YF | 130 | 232 | -4.984 | -7.847 | -57.6 | 6863.43 |
| MMYF | 214 | 88 | -5.126 | -3.189 | -31.9 | 3552.69 |
| NGYF | 238 | 206 | -2.644 | -5.723 | -65.2 | 5295.41 |
| SCYF | 195 | 233 | -1.760 | -13.255 | -82.4 | 5773.07 |
| ABYM | 226 | 145 | -4.746 | -7.559 | -57.9 | 5192.59 |
| JS2YM | 142 | 323 | -3.469 | -6.141 | -60.5 | 6845.46 |
| KTYM | 146 | 165 | -2.766 | -2.494 | -42.0 | 6709.65 |
| LHYM | 211 | 193 | -2.361 | -10.844 | -77.7 | 5528.7.0 |
| MOYM | 237 | 170 | -3.644 | -6.651 | -61.3 | 5539.65 |
| RDYM | 181 | 145 | -4.284 | 0.043 | 0.6 | 19945.43 |
| THYM | 196 | 201 | -2.109 | -8.383 | -75.9 | 5903.79 |

**Annex 9: PRAAT script to draw mean boundaries**

```
# Older vs. younger listeners:

Erase all
Select outer viewport... 0 6 0 6
Select inner viewport... 1 5 1 5
Text top... no Age: Solid line = Young, Dotted line = Old
Axes... 3000 8000 1 2
One mark left... 1 no no no tasje
One mark left... 2 no no no tassen
Text left... yes Context
Marks bottom... 2 yes no no
Text bottom... yes Peak frequency (Hz)
Dotted line
tangens = tan(-70.6857142857142*pi/180)
tangens2 = tangens/5000
Draw line... (5190.59666666666-0.5/tangens2) 1 (5190.59666666666+0.5/tangens2) 2
Solid line
tangens = tan(-53.3499999999999*pi/180)
tangens2 = tangens/5000
Draw line... (5730.83227272727-0.5/tangens2) 1 (5730.83227272727+0.5/tangens2) 2
Draw rectangle... 3000 8000 2 1

# Female vs. male listeners:

Select outer viewport... 0 6 6 12
Select inner viewport... 1 5 7 11
Text top... no Gender: Solid line = Female, Dotted line = Male
Axes... 3000 8000 1 2
One mark left... 1 no no no tasje
One mark left... 2 no no no tassen
Text left... yes Context
Marks bottom... 2 yes no no
Text bottom... yes Peak frequency (Hz)
Dotted line
tangens = tan(-70.0428571428571*pi/180)
tangens2 = tangens/5000
Draw line... (5418.08071428571-0.5/tangens2) 1 (5418.08071428571+0.5/tangens2) 2
Solid line
tangens = tan(-57.8448275862068*pi/180)
tangens2 = tangens/5000
Draw line... (5490.61068965517-0.5/tangens2) 1 (5490.61068965517+0.5/tangens2) 2
Draw rectangle... 3000 8000 2 1
```