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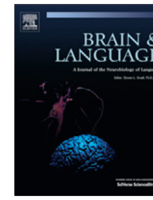

Short Communication

Hemispheric differences in the effects of context on vowel perception

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Listeners perceive speech sounds relative to context. Contextual influences might differ over hemispheres if different types of auditory processing are lateralized. Hemispheric differences in contextual influences on vowel perception were investigated by presenting speech targets and both speech and non-speech contexts to listeners' right or left ears (contexts and targets either to the same or to opposite ears). Listeners performed a discrimination task. Vowel perception was influenced by acoustic properties of the context signals. The strength of this influence depended on laterality of target presentation, and on the speech/non-speech status of the context signal. We conclude that contrastive contextual influences on vowel perception are stronger when targets are processed predominately by the right hemisphere. In the left hemisphere, contrastive effects are smaller and largely restricted to speech contexts.

1. Introduction

One of the most well-established findings in cognitive neuroscience is that strokes to the left perisylvian region lead to stronger language impairments than strokes to the right perisylvian region (Ingram, 2007). The imaging literature on speech perception, however, consistently implicates both hemispheres (Poeppel, 2003). This apparent contradiction is addressed by the Asymmetric Sampling in Time (AST) hypothesis (Hickok & Poeppel, 2007; Poeppel, 2003), which suggests that there is bilateral processing of spoken language, but with a functional asymmetry: It is proposed that the left hemisphere integrates information over shorter time windows (i.e., ~20–50 ms) than the right hemisphere (i.e., ~150–300 ms). This would make the left hemisphere well equipped to deal with the fast temporal changes that are necessary for identifying speech sounds, while the right hemisphere would be better equipped for the fine-grained spectral analysis needed for the perception of music and intonation contours. Scott and Wise (2004), however, have argued that there is no convincing evidence that left auditory cortex has a preference for fast transitions. They also conclude that "It is simply not meaningful to consider 'temporal' and 'spectral' in the auditory system as delineating the ends of a dimension which affords rapid temporal resolution at one end and pitch processing at the other" (p. 38).

It is thus not clear whether the hemispheric difference in integration window – if it even exists – is there to support a division of labor between 'temporal' and 'spectral' processes. But there may be a different reason why the proposed short window of integration in the left hemisphere may be useful for speech processing. Short windows are necessary to account for contrastive context effects, such as those first reported by Ladefoged and Broadbent (1957). For instance, when participants categorized targets on a continuum ranging from "itch" to "etch", they categorized more stimuli as "itch" when a context sentence was processed by a filter that suppressed the frequencies that are more dominant in /ɪ/ than in /ɛ/ (Watkins, 1991). Similar effects have been observed with non-speech contexts and over relatively long silent intervals between contexts and targets (Holt, 2005; Sjerps, Mitterer, & McQueen, 2011a; Sjerps, Mitterer, & McQueen, 2011b). The common denominator in all these studies is "contrast": A given stimulus is perceived relative to context, so that a "high" context makes "low" percepts more likely, and vice versa (Kluender, Coady, & Kiefte, 2003). In the case of vowel perception, for example, more vowels on a 1st formant (F_1) continuum are identified as the low-F_1 endpoint vowel in a context with a high F_1 than in a context with a low F_1.

Contrast effects can obviously only arise if target and context are perceived as separate entities. If information that is processed in the left hemisphere is integrated over shorter time windows, such that context and target are processed in separate windows, contrastive effects should arise ("high" contexts should make "low" percepts more likely). If the right hemisphere, however, uses larger windows of integration, context and target information are more likely to be integrated because they are more likely to fall in the same analysis window ("high" contexts should make "high" percepts more likely). The need to be able to perceive separate acoustic events as separate, a feature that might be especially

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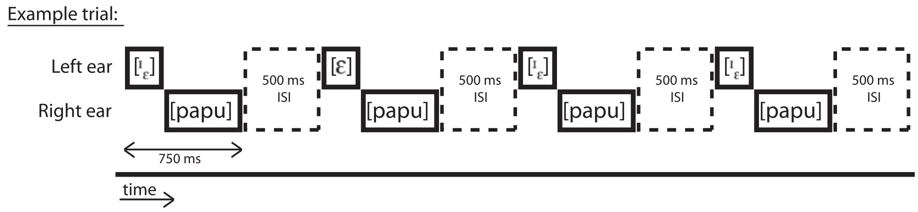

Fig. 1. Time-line for an example trial in which context and target are presented to different ears.

useful in speech perception, thus constitutes a new raison d'être for the AST hypothesis. This explanation is independent of the motivation based on the distinction between spectral and temporal properties in auditory processing. If this reasoning is correct, we should find contrastive effects for stimuli that are processed primarily by the left hemisphere, but integrative effects for stimuli that are processed primarily by the right hemisphere.

The outcome of different contrastive and integrative effects over the hemispheres could also shed light on some puzzling contradictory findings. As it turns out, the size and direction of context effects have differed across materials. For instance, Watkins (1991) found no effect of contralaterally presented noise contexts on the perception of speech targets, but speech analogs of these stimuli did elicit contrastive effects. Moreover, integrative effects have been reported in the spectral domain (Aravamudhan, Lotto, & Hawks, 2008; Mitterer, 2006) and with respect to durational distinctions (Fowler, 1992; van Dommelen, 1999). These inconsistencies between contrastive and integrative effects could reflect differences in the relative involvement of the two hemispheres with speech and non-speech stimuli. The present study was thus set up to test whether hemispheric differences influence extrinsic normalization of vowels. To test this, we made use of two manipulations. First, we used both speech and non-speech stimuli. Second, we presented these stimuli either to participants' right ears or to their left ears.

Monaural input is more strongly transferred to the hemisphere contralaterally to the ear of presentation, for primary and non-primary auditory cortex (Jäncke, Wüstenberg, Schulze, & Heinze, 2002; Loveless, Vasama, Makela, & Hari, 1994; Stefanatos, Joe, Aguirre, Detre, & Wetmore, 2008; Suzuki et al., 2002). Activation levels are two to three times as large in the contralateral as in the ipsilateral hemisphere (Jäncke, Wüstenberg, Schulze, et al., 2002; Suzuki et al., 2002), although with speech stimuli the contralateral dominance effect has been reported to be larger for the right than for the left ear (Stefanatos et al., 2008). We manipulated dominance of hemispheric processing by presenting stimuli monaurally to the left or the right ear.

There is, however, a caveat to consider. Signals that are close together in time influence each other at peripheral stages in auditory pathways when presented to the same ear. These influences are contrastive (Summerfield, Haggard, Foster, & Gray, 1984). Such influences would obscure our investigation because we are interested in central (cortical) levels of processing. Preceding context was therefore separated from targets by a 500 ms silent interval. Moreover, across conditions, contexts and targets were presented either to the same ears or to opposite ears. These precautions allow us to reduce and control the influence of peripheral adaptation (Summerfield et al., 1984).

We investigated context effects in a 4I-oddity discrimination design. In this task, listeners are asked to detect whether a deviant (D), presented among a set of standards (S), occurred in either second or third position (e.g. SDSS or SSDS). The use of this task reduces influences from response strategies (such as balancing the number of responses between each of the two labels). This is mainly so because the 4I-oddity task does not require the use of category labels, and as such encourages listeners to focus on auditory aspects of target stimuli (Gerrits & Schouten, 2004).

A continuum of target stimuli was created between the Dutch vowels /ɛ/ and /ɪ/ (which is mainly an F_1 distinction). Vowels were presented in a non-word context (/papu/) that was manipulated to have a high- or a low-F_1 contour. A context effect should result in a difference in discriminability between an ambiguous sound with the [ɛ] and [ɪ] endpoints. To exemplify, consider a categorization experiment: in a low-F_1 context, listeners categorize ambiguous vowels more as /ɛ/ (Watkins, 1991). The perceptual distance between the ambiguous sound [$^{\text{ɪ}}_{\text{ɛ}}$] and [ɛ] is thus smaller in this condition than the distance between [$^{\text{ɪ}}_{\text{ɛ}}$] and [ɪ]. This pattern reverses for vowels that are presented in a high-F_1 context. In our 4I-oddity discrimination task, context effects should then lead to reduced discriminability between [$^{\text{ɪ}}_{\text{ɛ}}$] and [ɛ] in a low-F_1 context (and between [$^{\text{ɪ}}_{\text{ɛ}}$] and [ɪ] in a high-F_1 context).

Listeners heard sets of three ambiguous standards ([$^{\text{ɪ}}_{\text{ɛ}}$]) and one unambiguous deviant (either [ɪ] or [ɛ]). The bisyllable [papu] was manipulated to have a high or a low average F_1 and thereby provided listeners with information about the speaker's vocal tract properties. The context was spliced onto the target vowels such that listeners heard nonsense words like [$^{\text{ɪ}}_{\text{ɛ}}$papu] (standards) and [ɪpapu] or [ɛpapu] (deviants). In one group of listeners the target vowels and contexts were always presented contralaterally. For another group of listeners the target vowels and contexts were always presented to the same ear. The stimuli were presented in sets of four, with the [papu] part identical in all four non-words in a set. Fig. 1 displays an example trial for participants in the group that were presented with targets and contexts contralaterally, for a trial in which the targets were presented to the left ear, and with the deviant vowel ([ɛ]) in second position.

In a further condition, the contexts were non-speech stimuli. The [papu] parts now consisted of noise that had the same amplitude envelope as the original [papu] parts. Two of the non-speech versions of the noise precursor were made, one with the same Long-Term Average Spectrum (LTAS) as the low-F_1 [papu] part and one with the same LTAS as the high-F_1 [papu] part. This is important as the LTAS of context signals has been argued to be the main cause of contrast effects (Watkins, 1991).

To summarize, we tested whether contextual influences on vowel perception differ in the two hemispheres. Target vowels were presented in two types of context: a speaker with a high F_1 or a speaker with a low F_1. Effects were tested in a discrimination task. Context effects were expected as a difference in the discriminability of the two deviant vowels across F_1 contexts. Targets were presented to the right or to the left ear (and contexts were, across two groups of listeners, presented to the same and to the opposite ears). Furthermore, context stimuli consisted either of speech (the bisyllable: [papu]) or a non-speech version of this sequence that had the same amplitude envelope and LTAS as the speech version. According to the predictions of the AST hypothesis we should find that contrastive context effects are stronger when stimuli are presented primarily to the left hemisphere (i.e., the right ear) than when they were presented primarily to the right hemisphere (i.e., the left ear).

2. Analysis and results

The results were analyzed using linear mixed effects models in R (*version 2.10.0*; The R foundation for statistical computing) as provided in the lme4 package (Bates & Sarkar, 2007). For the dichotomous dependent variable of correct responses (i.e., correct = 1 vs. incorrect = 0), a logit linking function was used. Responses were analyzed by fitting models with participants as random factor. All fixed factors were centered around zero. These were Context (with the levels low-F_1 = −1 vs. high-F_1 = 1), indicating the F_1 range in the [papu] part; Deviant (with the levels [ɪ] = −1 vs. [ε] = 1), indicating vowel identity; Speech (with the levels Non-speech = −1 vs. Speech = 1), indicating the speech-status of the context; Ear of Target presentation (with the levels Left = −1 vs. Right = 1) indicating the ear to which the target was presented; and Ear of Context presentation (with the levels Left = −1 vs. Right = 1) indicating the ear to which the context was presented. Only those responses that were made after the first vowel of the second target stimulus (the first possible point for mismatch detection) were included (98.8% of the responses were kept).

Fig. 2 displays the discrimination scores. Each separate panel displays discrimination scores for the two vowels in the two context conditions. The dotted line represents discrimination scores with a low-F_1 context, the solid line represents the results in the high-F_1 context condition. The values on the left represent the discrimination scores obtained when the deviant was [ɪ], the values on the right represent those when the deviant was [ε]. Context effects are revealed as an interaction between the factors Context and Deviant. The separate panels display the discrimination scores in the different conditions (see the labels in Fig. 2).

Consider the top left panel of Fig. 2. The pattern reflects that, in the context of a high-F_1 speaker, listeners found it harder to detect a shift from the ambiguous standard [$^{\text{I}}{}_{\varepsilon}$] to [ɪ] (left point of the solid line) than to [ε] (right point of the solid line). This is a contrastive influence as the high-F_1 speaker apparently makes the ambiguous stimulus sound more like the low-F_1 vowel (i.e., [ɪ]). This pattern was reversed in the context of a low-F_1 speaker. Analyses were run to test whether this effect was significant and whether it differed over the data for the different panels.

For each analysis, an optimal model was established by a backward-elimination procedure such that non-significant predictors were taken out of the analysis in a stepwise fashion, starting from the highest order interaction, until no predictors could be removed without significant loss of fit. If an interaction was only just significant, the optimal model without this interaction was also found. The best model was then established by means of a likelihood-ratio test. The first analysis included all factors along with their interactions.

The optimal statistical model for the overall analysis revealed an effect for the Intercept ($b_{Intercept}$ = 1.153, z = 8.933, $p < 0.001$) because listeners scored higher than chance. Main effects were found for the following factors: Context ($b_{Context}$ = −0.116, z = −5.344, $p < 0.001$), indicating that deviant detection was better in the low-F_1 context condition (or its non-speech analog); Deviant ($b_{Deviant}$ = 0.156, z = 7.189, $p < 0.001$), indicating that deviant detection was better for [ε]; Speech (b_{Speech} = −0.144, z = −6.646, $p < 0.001$), indicating that deviant detection was better when the

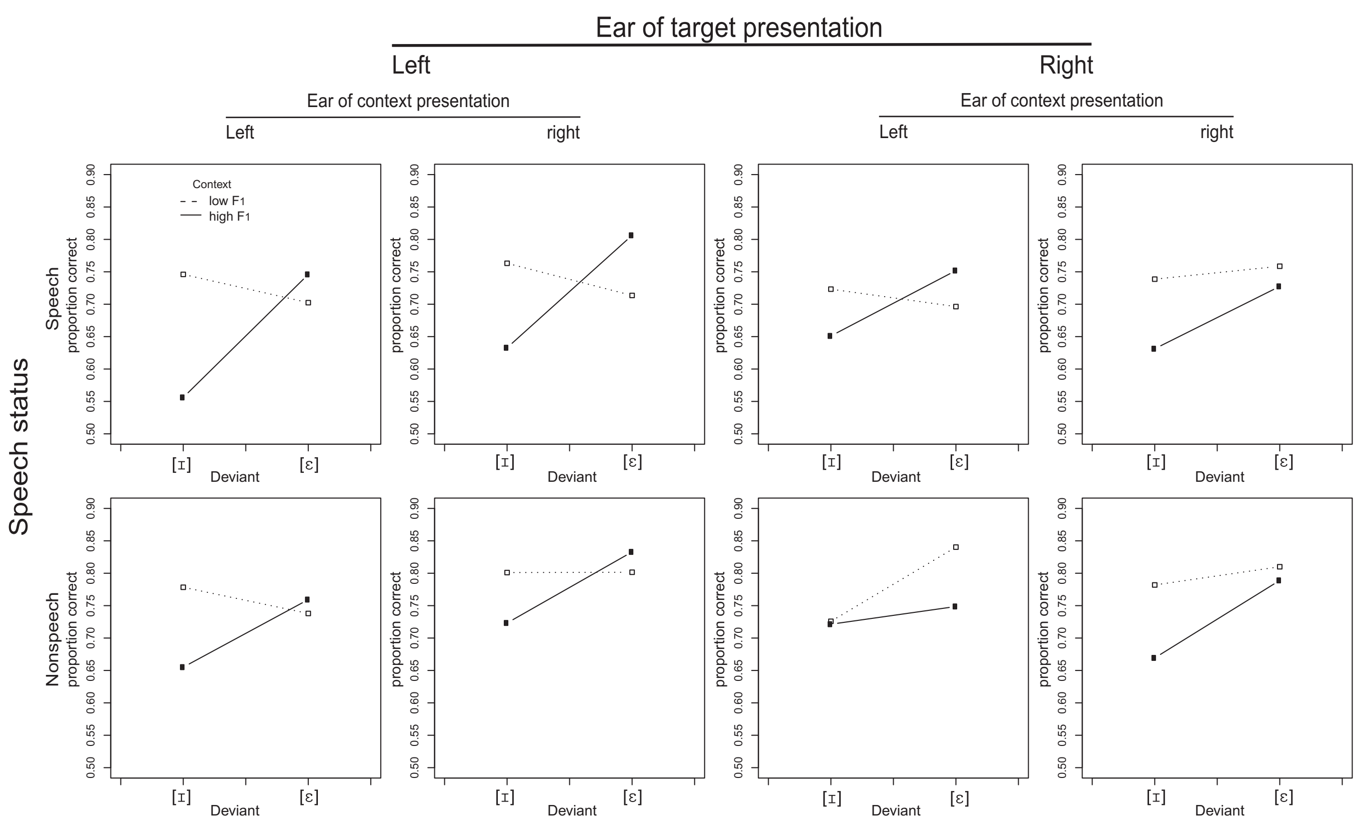

Fig. 2. Discrimination data: Mean probability of a correct discrimination response to pairs of stimuli in the 4I-oddity task. Listeners performed a discrimination task in both a low-F_1 and a high-F_1 speaker condition (defined by the height of the F_1 contour in the [papu] part). Deviant stimuli consisted of either [Ipapu] ([I]-deviant) or [εpapu] ([ε]-deviant). The standard stimuli consisted of an ambiguous stimulus [$^{\text{I}}{}_{\varepsilon}$papu]. The eight panels represent the data split over three additional factors: Laterality of presentation of targets; laterality of presentation of contexts; and speech/non-speech status of the context. Left-hand panels display data for which the target was presented to the left ear, right-hand panels display data for which the target was presented to the right ear. Top panels display data for which the contexts consisted of speech signals. Bottom panels display data for which the contexts consisted of noise that had the same amplitude envelope and the same LTAS as the speech contexts (in both the high-F_1 and the low-F_1 conditions).

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context consisted of non-speech; and Ear of Context Presentation ($b_{ContextEar} = 0.078$, $z = 3.639$, $p < 0.001$), indicating that deviant detection was better when the context was presented to the right ear. A two-way interaction was found between the factors Context and Deviant ($b_{Context*Deviant} = 0.150$, $z = 6.941$, $p < 0.001$), reflecting the critical context effect which was, on average, contrastive. Finally, two three-way interactions were found between the factors Context, Deviant and Speech ($b_{Context*Deviant*Speech} = 0.064$, $z = 2.965$, $p = 0.003$), and Context, Deviant and Ear of Target Presentation ($b_{Context*Deviant*TargetEar} = -0.091$, $z = -4.222$, $p < 0.001$). Note the direction of these interactions. The positive regression weight for the Context * Deviant * Speech interaction indicates that the context effect was more contrastive with speech than with non-speech. The negative regression weight for the Context * Deviant * TargetEar interaction indicates that the context effect was less contrastive when the target was presented to the right ear.

To further explore this interaction, separate analyses were conducted for the data with right and left target presentation. The optimal models revealed an effect for the Intercept (L: $b_{Intercept} = 1.140$, $z = 9.278$, $p < 0.001$; R: $b_{Intercept} = 1.181$, $z = 8.109$, $p < 0.001$) – reflecting above-chance performance – and the same main effects as the overall analysis (Left: $b_{Context} = -0.100$, $z = -3.282$, $p = 0.001$; $b_{Deviant} = 0.144$, $z = 4.715$, $p < 0.001$; $b_{Speech} = -0.149$, $z = -4.886$, $p < 0.001$; Right: $b_{Context} = -0.134$, $z = -4.353$, $p = 0.001$; $b_{Deviant} = 0.171$, $z = 5.575$, $p < 0.001$; $b_{Speech} = -0.148$, $z = -4.829$, $p < 0.001$). The critical two-way interaction between Context and Deviant was found with left target presentation ($b_{Context*Deviant} = 0.244$, $z = 7.949$, $p < 0.001$), and was equivalent for speech and non-speech targets. For targets presented to the right, however, the critical interaction was not significant ($b_{Context*Deviant} = 0.059$, $z = 1.914$, $p = 0.056$) and qualified by an additional interaction ($b_{Context*Deviant*Speech} = 0.073$, $z = 2.386$, $p = 0.017$). Additional testing with stimuli presented to the right ear showed that the critical interaction was present with speech contexts ($b_{Context*Deviant} = 0.134$, $z = 3.183$, $p = 0.001$), but not for non-speech contexts ($b_{Context*Deviant} = -0.013$, $z = -0.307$, $p = 0.759$). In the latter case, we observed an integrative effect for targets preceded by an ipsilateral context ($b_{Context*Deviant} = -0.149$, $z = -2.343$, $p = 0.019$). Ipsilateral presentation rules out the possibility of peripheral context effects, which are always contrastive. The latter condition was thus expected to be most sensitive to potential integrative effects.

3. Discussion

This study was set up to investigate a prediction derived from AST (Poeppel, 2003) with respect to contextual influences on vowel perception. AST proposes that the right hemisphere integrates information over longer time windows than the left hemisphere. This led to the prediction that processes in the right hemisphere would lead to more integrative effects than those in the left hemisphere. Combined with the fact that biological systems are naturally more sensitive to contrast (Kluender & Kiefte, 2006), it was predicted that processing in the left hemisphere would induce stronger contrastive effects on vowel targets than processing in the right hemisphere. This hypothesis offered a possible explanation for earlier demonstrations of variation in the strength and direction of context effects on vowel perception (Aravamudhan et al., 2008; Mitterer, 2006; Sjerps et al., 2011a; Wade & Holt, 2005; Watkins, 1991). We indeed observed an influence of laterality on the strength of context effects, but the influence was in the opposite direction from that predicted by AST.

We probed laterality of processing using the fact that transfer of information is stronger over contralateral than ipsilateral connections between the cochlea and the cortex (Jäncke, Wüstenberg, Schulze, et al., 2002; Loveless et al., 1994; Suzuki et al., 2002). In general, contrastive context effects on vowel perception were observed. In the context of a speaker with a high-F_1 contour, listeners found it more difficult to detect a shift from [ᴵε] to [I] (a low F_1 vowel) than a shift from [ᴵε] to [ε] (a high F_1 vowel). In the context of a speaker with a low-F_1 contour, this effect was reversed. However, when the target signal was presented to the left ear, so that its processing would presumably be primarily in the right hemisphere, the contrastive context effect was larger than when the target signal was presented to the right ear. Furthermore, when the context consisted of a speech signal, the contrastive effect was generally larger than when it was replaced by a noise version, as has previously been reported (Watkins, 1991).

The separate analyses of targets presented to the two ears showed that, for targets presented to the left ear, context effects were rather uniformly distributed, such that the factor of speech status did not significantly modulate the strength of context effects. It has been argued that biological systems are generally sensitive to contrast (Kluender & Kiefte, 2006). The current results confirm this suggestion for speech processing, especially in the right hemisphere. In the left hemisphere, however, the tendency for contrastive effects with speech sounds was strongly reduced. In particular, the contrastive effect due to predominately left-hemisphere processing was found for speech stimuli but not for non-speech stimuli. We suggest that, especially for the left hemisphere, context effects could be more dependent on learnt properties of language. Exposure to language, and the learnt covariations between vocal tract properties within a particular speaker, might have influenced the tendency for listeners to compensate for vocal tract properties in a preceding sentence.

This suggestion, however, still does not completely explain the conflicting results that were the starting point of this study (Aravamudhan et al., 2008; Sjerps et al., 2011a; Wade & Holt, 2005; Watkins, 1991), such as the occurrence of integrative effects. In the experiment reported here, variance in the strength of context effects was also found, and this was mainly predictable on the basis of the speech status of the contexts and the hemisphere in which the target was most dominantly processed. In one condition we observed a small integrative effect. The same combination of the factors ear of target presentation and speech status of the context led to a contrastive effect when target and context where presented to the same ear (compare the two bottom-left panels of Fig. 2). Given the integrative effects reported in the literature and here, however, we think it is still tenable that there is an interplay between contrastive and integrative effects. It has been shown, for instance, that under binaural presentation, voiced-consonant+vowel syllables are more bilaterally processed in auditory areas like the planum temporale than voiceless-consonant + vowel syllables, like the context signals used here (Jäncke, Wüstenberg, Scheich, & Heinze, 2002). These differences in lateralization between different phoneme types could therefore modulate the strength of contextual influences.

The data presented here show that the two hemispheres contribute differently to context effects. This general observation seems to be consistent with the predictions of AST. The detailed results, however, paradoxically turn out to be opposite from those predicted by AST. Furthermore, an additional observation is also not in line with AST. If the right hemisphere were better at resolving spectral differences, target stimuli should have been better discriminated when presented to the left ear than when presented to the right ear. No such effect was found. In fact, ear of target presentation only modulated the context by target interaction. These findings show that, for vowel discrimination per se, neither hemisphere has an advantage over the other. However, the two hemispheres do display different influences of the spectral properties of *contexts*.

To conclude, the present results suggest that variability in the strength of context effects is for a large part dependent on the

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hemisphere in which the target sounds are most dominantly processed. The two hemispheres may not be differentially sensitive to spectral properties of stimuli per se, but they do show different sensitivities to acoustic properties of context sounds. This is important, for instance because stimuli can elicit context effects on subsequent stimuli. These results thus provide restrictions for the design of future experiments that attempt to investigate differences in hemispheric specialization in speech perception. The present findings already make clear, however, that hemispheric differences do impact on the way vowels are perceived in context.

4. Method

4.1. Participants

32 native Dutch participants were tested. Participants were invited if they indicated that their right hand was dominant (in response to the question: "Indicate whether you are right or left-handed"). Seven were employees of the Max Planck Institute for Psycholinguistics (MPI) and 25 were participants selected from the MPI participant database (all were uninformed about the purpose of the study). None of the participants reported hearing impairment. All participants can be considered bilingual in at least Dutch and English as the average amount of formal English education for this population is 7–8 years (Broersma & Cutler, 2008).

4.2. Stimuli

For all manipulations Praat was used (Boersma & Weenink, 2005). An instance of [ɛ] was cut out of a recorded version of the non-word [ɛpapu] spoken by a female native speaker of Dutch. Source and filter properties were estimated with Burg's Linear Predictive Coding (LPC) and formant estimation methods in Praat. The F_1 range of the [ɛ] was decreased in three steps over a range of 140 Hz to create a continuum from [ɛ] to [ɪ]. The filter model was then recombined with the estimated source model. The created steps had an F_1 decrease of: −170 Hz ([ɪ]), −100 Hz (ambiguous: [$^{\text{I}}{}_{\varepsilon}$]) and −30 Hz ([ɛ]), relative to the originally recorded instance of [ɛ] (which had an F_1 of 734 Hz). More details on the manipulation procedure can be found in Sjerps et al. (2011a). The [papu] context was manipulated with the same approach to create a generally high-F_1 contour (+200 Hz) or a generally low-F_1 contour (−200 Hz). For the non-speech stimuli a noise signal was created that had the same duration and amplitude envelope as an unmanipulated version of the [papu] part. This sound was, in two versions, filtered to match the LTAS of the high-F_1 and of the low-F_1 speech contexts in analogy to Watkins (1991). The vowels were then spliced onto the contexts. Stimuli were combined in quadruplets of three ambiguous standards ([$^{\text{I}}{}_{\varepsilon}$papu]) and one deviant. The deviant could be either [ɛpapu] or [ɪpapu] and deviants occurred in second (SDSS) or third (SSDS) position.

4.3. Design and procedure

One group of participants heard only trials in which both context and target were presented to the same ear. A second group always heard targets and precursors in different ears. There were 16 different conditions per participant: ear of target presentation (left, right) by speech status of context (speech, non-speech) by deviant vowel ([ɛ], [ɪ]) by context type (high vs. low F_1). These conditions were presented in separate subparts, which in turn were presented in semi-random order across participants. The order in which the two conditions of a factor were presented was balanced across participants for all factors. Within every subpart three sets of eight trials were presented. Within such a set, the deviant occurred in second or third position four times each, presented in random order. In all conditions the participant's task was to indicate on each trial whether the deviant was in second or third position (by pressing one of two buttons, labeled "2" and "3"). An experiment consisted of 384 trials and lasted 30 min. The experiment was divided in four blocks (each containing the subparts for four conditions). Blocks were separated by self-paced pauses.

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