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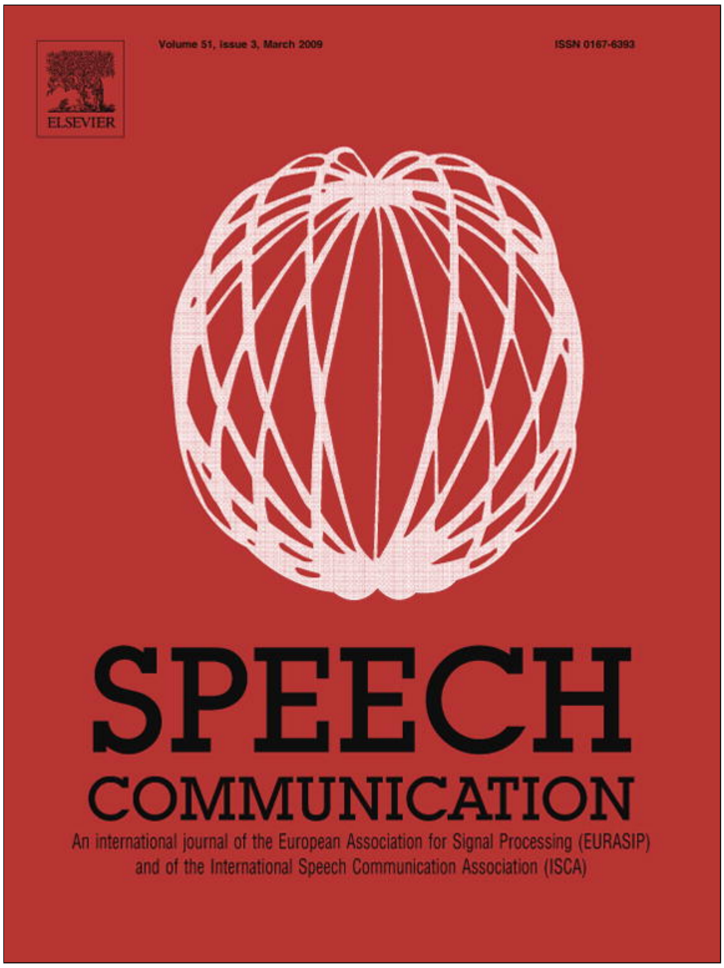

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Dispersion and variability in Catalan five and six peripheral vowel systems

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Abstract

This study compares $F1$ and $F2$ for the vowels of the five and six peripheral vowel systems of four minor dialects of Catalan (Felanitxer, Gironí, Sitgetà, Rossellonès), with those of the seven peripheral vowel systems of the major dialects those minor dialects belong to (Majorcan, Eastern). Results indicate that most mid vowel pairs subjected to neutralization may be characterized as near-mergers. Merging appears to have proceeded through two stages: in the first place, one of the two mid vowel pairs undergoes neutralization yielding a relatively close mid vowel in the resulting six vowel system; then, the members of the second vowel pair approach each other until they cease to be contrastive, and the front and back mid vowels of the resulting five vowel system tend to occupy a fairly equidistant position with respect to the mid high and mid low cognates. Moreover, in six vowel systems with a single mid vowel pair, the contrasting members of this pair approach each other if belonging to the back series but not if belonging to the front series. These findings are in support of two hypotheses: vowel systems tend to be symmetrical; reparation of six vowel systems is most prone to occur if the system is unoptimal. Predictions of the adaptive dispersion theory were not supported by the data. Thus, smaller vowel systems turned out not to be less disperse than larger ones, and mid vowels were not clearly more variable in five or six vowel systems than in seven vowel systems. It appears that for these predictions to come into play, the systems being compared need to differ considerably in number of vowels.
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1. Introduction

A well-known fact about vowel system inventories is that they may or may not have mid vowels in phonological contrast. This is, for example, the scenario in the Romance languages where we find languages and dialects with five vowels (Spanish, Sardinian Logudorese) and languages and dialects with seven peripheral vowels (Catalan, Portuguese, Sardinian Campidanese, Italian). This paper investigates the relationship between the number of mid vowels in vowel system inventories and the location of these vowels within the $F1 \times F2$ space. Another research issue is the validity of several predictions of the adaptive dispersion theory (ADT) regarding vowel space dispersion and individual vowel variability as a function of the number of vowels in the system. It is believed that this analysis results will provide a more detailed knowledge about several sound changes and phonological processes affecting vowels.

This investigation is a follow-up study of Recasens and Espinosa (2006) where the same research topics were analyzed for four major Catalan dialects, namely, Eastern and Western Catalan (spoken in Catalonia, a region located in the northeastern corner of the Iberian peninsula), Valencian (spoken in the Valencian region towards the south of Catalonia) and Majorcan (spoken in the Balearic islands located eastwards of Catalonia and the Valencian region). Eastern and Western Catalan and

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Valencian exhibit the seven vowels /i, e, ɛ, a, ɔ, o, u/, while Majorcan Catalan has /ə/ in addition to the seven vowels just mentioned (/i, e, ɛ, a, ɔ, o, u, ə/).

The present paper deals with the following four less crowded, minor dialects of Catalan where a reduction in the number of vowels has been achieved through neutralization of the mid high and mid low cognates of the front and/or back vowel series (Veny, 1983; Recasens, 1996):

(a) A subdialect of Majorcan, i.e., Felanitxer, which is said to neutralize the /e/–/ɛ/ contrast while keeping the distinction between /o/ and /ɔ/. In comparison to Majorcan, this minor dialect has seven vowels instead of eight, i.e., /i, E, a, ɔ, o, u, ə/, where the symbol /E/ represents the neutralized outcome of the /e/–/ɛ/ pair.
(b) Two subdialects of Eastern Catalan, i.e., Gironí where the /o/–/ɔ/ pair has undergone neutralization and Sitgetà where neutralization has affected the /e/–/ɛ/ and the /o/–/ɔ/ pairs. In comparison to the seven vowel system of Eastern Catalan, Gironí has the six vowels /i, e, ɛ, a, O, u/ and Sitgetà the five vowels /i, E, a, O, u/. (/E/ and /O/ stand for the neutralized outcomes of the /e/–/ɛ/ and /o/–/ɔ/ pairs, respectively).
(c) Rossellonès which is spoken in the southeastern French region of Roussillon and, analogously to Sitgetà, exhibits the five vowel phonemes /i, E, a, O, u/. Though it may be characterized as a dialect of its own, Rossellonès resembles Eastern Catalan in many respects and will be considered part of the Eastern dialect throughout this paper. Rossellonès and Eastern shared the same seven vowel system before the two mid vowel pairs /e/–/ɛ/ and /o/–/ɔ/ underwent neutralization a few centuries ago (Veny, 1983, p. 59).

The present investigation explores several research topics about the acoustic vowel spaces of the four minor dialects of Catalan presented above. A first goal is to establish the relative placement of the vowels generated through mid vowel neutralization with respect to the mid high and mid low vowel cognates in systems where the latter remain contrastive. A related topic is whether the neutralization of one mid vowel pair causes the two mid vowels of the other pair to approach one another. Another research goal is to elicit whether the degree of vowel space dispersion varies directly with the number of vowels in the system, and if a given mid vowel outcome issued through neutralization exhibits greater phonetic variability than the two originary mid vowel cognates.

1.1. Mid vowel merging

Mid vowel neutralization appears to have proceeded through a chain shift in Felanitxer and Rossellonès but not in Gironí and Sitgetà. In Felanitxer, an especially front realization of /a/, which is available in other present-day Majorcan speaking areas, may have pushed /ɛ/ towards the /e/ space (Veny, 1983, p. 100). /ɛ/ raising in Felanitxer could also be explained assuming that this vowel is especially tense and thus, prone to rise along the peripheral vowel system track in chain shifts (Labov, 1994, p. 176). This account is consistent with coarticulation data showing that Majorcan /ɛ/ is especially resistant to consonant-dependent effects (Recasens and Espinosa, 2006). In Rossellonès, a chain shift appears to have caused /ɔ/ to rise towards the /o/ space after /o/ became /u/ (Veny, 1983, p. 59). In Gironí and Sitgetà, on the other hand, mid vowel neutralization must have been arrived at through progressive approximation of the mid low and mid high vowels, i.e., /ɔ/ and /o/ in Gironí, and /ɛ/ and /e/ and /ɔ/ and /o/ in Sitgetà.

A relevant research topic of the present investigation is to determine whether mid vowel merging in the four Catalan dialects of interest is complete or not. Near-mergers occur when two vowels undergoing neutralization are distinguished in production but cannot be discriminated perceptually. Though, in principle, the existence of near-mergers ought to be assessed through both production analysis and perceptual evaluation, it makes sense to claim that, if two phonemes become very close at the production level, listeners should not be able to discriminate them. Near-mergers have been reported to occur in certain varieties of American English, e.g., /u/ and /ʊ/ before /l/ as in fool and full and /ɑ/ and /ɔ/ as in cot and caught (Labov, 1994, pp. 360–364).

An open issue is how small the acoustic distance between two mid vowels needs to be so that they become perceptually undistinguishable. Labov's data indicate that a less than 50 Hz $F1$ difference should render two neighbouring mid vowels non-contrastive. A more perceptually based acoustic difference is a JND ("just noticeable difference") of about 0.2 bark which amounts to about 25 Hz in the case of $F1$ and to about 60 Hz in the case of $F2$ (Boersma, 1998, p. 104). We could therefore safely assume that, in order for two mid vowels differing in height to be considered near-mergers, their $F1$ should not be more than about 25 Hz apart.

1.2. Vowel space location

Another interesting topic is whether mid vowels resulting from neutralization occupy a vowel space location which is intermediate between that of the originary mid high and mid low vowels, or else approach either the originary mid high vowel cognate or the mid low one.

The $F1$ frequency value for mid /E/ and /O/ in five vowel system languages such as Greek, Spanish, Japanese and Hebrew is about 450–500 Hz (see Table 1), and thus is intermediate between the $F1$ frequencies for the cardinal vowels /e, o/ (385 Hz) and /ɛ, ɔ/ (625 Hz, 525 Hz) (Ladefoged, 1967, pp. 88–89). These data imply that, once a given mid vowel pair is neutralized, the output vowel will tend to occupy an intermediate position between the mid high and

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Table 1
(Left) *F*1 frequency values for /E, O/ in languages with five vowels (top) and for /e, ɛ, o, ɔ/ in languages and dialects with seven peripheral vowels (bottom)

	/E/	/O/	/O/-/E/	
Greek	463	475	12	Fourakis et al. (1999)
Greek	475	477	2	Jongman et al. (1989)
Spanish	470	500	30	Quilis (1981)
Spanish	458	460	2	Bradlow (1995)
Japanese	475	481	6	Keating and Huffman (1984)
Hebrew	455	478	23	Most et al. (2000)

	/e/	/ɛ/	/o/	/ɔ/	/o/-/e/	/ɔ/-/ɛ/	
Majorcan Catalan	489	659	547	708	49	58	Recasens and Espinosa (2006)
Valencian Catalan	460	601	493	621	20	33	Recasens and Espinosa (2006)
Western Catalan	448	595	477	586	9	29	Recasens and Espinosa (2006)
Eastern Catalan	450	581	489	608	27	39	Recasens and Espinosa (2006)
Italian	350	490	390	550	60	40	Ferrero et al. (1978)
European Portuguese	403	501	426	531	30	23	Delgado Martins (1964–1973)
Brazilian Portuguese	424	516	424	538	22	0	Nobre and Ingemann (1987)
Yoruba	360	570	409	599	49	29	Disner (1983)

(Right) *F*1 frequency differences between mid back and mid front vowels of the same height.

mid low vowels of languages where the contrast remains distinctive. Moreover, if merging has affected one mid vowel pair in the first place and the other pair later on, the outcome of the second mid vowel pair undergoing neutralization will occupy a similar intermediate position as the outcome of the first vowel pair. This evolution may have operated in Rossellonès (also in Sitgetà), where mid /E/ and /O/ have been characterized as neither too close or too open in the literature.

A related topic is whether, independently of being more close or more open, the mid front and mid back vowel outcomes arising through neutralization (i.e., /E/ and /O/) aim at the same *F*1 frequency height. It has been stated that symmetry plays a relevant role in the distribution of vowels in vowel spaces (Boersma, 1998, pp. 347–350). Symmetry is expected to work out mostly along the *F*1 dimension since this formant is the main spectral correlate of vowel height, and is more intense and more resistant to noise than *F*2 (Lindblom, 1986). As pointed out by de Boer (2000, 2001), if a language has a front unrounded vowel of a given height, it tends to have a back rounded vowel of the same height; accordingly, [ɔ] occurs in 73% of the world's languages that have [ɛ], and [ɛ] occurs in 83% of the world's languages endowed with [ɔ]. Simulation studies (Lindblom, 1986; Schwartz et al., 1997b) also predict that, whenever vowel systems with one mid front vowel and one mid back vowel are generated, those vowels happen to be fairly equidistant with respect to high /i/ or /u/ and low /a/, respectively. Perturbations performed around the target articulatory shapes for vowels in a seven vowel system also yield /e/ and /o/ spaces which are roughly equidistant to /i/ and /u/ along the *F*1 dimension (Goldstein, 1983).

A trend towards vowel symmetry appears to operate in sound change as well. This principle may have applied historically to the mid front and mid back vowels of Rossellonès such that, after /ɔ/ became the only mid back system vowel, /e/ and /ɛ/ ceased to be contrastive perhaps in order to maintain a symmetrical arrangement with the mid back vowel series (Veny, 1983, p. 59). Examples from other languages may also be adduced though, in arguing for a trend towards symmetry, one should also justify why symmetrical vowel systems may change into more asymmetrical ones. Thus, in Old English, the asymmetrical short vowel system /i, e, æ, o, u/ evolved into the symmetrical system /ɪ, ɛ, æ, ɒ, ʌ, ʊ/ in Modern English through /o/ lowering to /ɒ/ and /u/ splitting into /ʌ, ʊ/; on the other hand, the unbalanced long vowel system /iː, eː, ɛː, aː, oː, uː/ of the North Middle English dialects became more symmetrical through the addition of /ɔː/ after short /i, e, o, u/ opened and lengthened into /eː, ɛː, ɔː, oː/ (Lass, 1992, pp. 47–48, 1994, pp. 246-247, 1999, pp. 86–91). Further evidence comes from South Slavonic where the asymmetrical system /i, e, ɛ, a, ɔ, u/ achieved symmetry through merging of the two front vowels or the addition of /o/ depending on the dialectal variety (Chapter, 2004). Another interesting case has been reported for the Francoprovençal dialects of the region of Hauteville (Martinet, 1970, pp. 86–88): in the first place, /i, e, ɛ, a, o, u, y, ø/ shifted to the more balanced system /i, e, æ, ɑ, o, u, y, ø/ through /ɛ/ lowering and /a/ backing; then, the system became asymmetrical after /ɛ/ joined the vowel inventory (/i, e, ɛ, æ, ɑ, o, u, y, ø/)

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and regained balance through the successive changes /ɑ/ > /ɔ/ and /æ/ > /a/ (/i, e, ɛ, a, ɔ, o, u, y, ø/).

The vowel space location of mid vowels agreeing in height but differing in fronting may not be perfectly symmetrical both for language-specific and universal reasons. As for the language-specific side, it has been shown that two languages sharing the same vowel inventory may exhibit different $F1$ distances between adjacent vowels. Thus, for example, Yoruba and Italian have the same seven vowels /i, e, ɛ, a, ɔ, o, u/, but differ with respect to the $F1$ distance between /i/ and /e/ and between /u/ and /o/ because /e, o/ are higher in Yoruba than in Italian (Disner, 1983). The precise phonetic realization of mid vowels may also differ in dialects of the same language; thus, in Catalan, /ɔ/ and, less so, /ɛ/ are closer to /a/ in Majorcan and Valencian than in the Western and Eastern dialects (Recasens and Espinosa, 2006).

More generally, mid back vowels may exhibit a slightly higher $F1$ than mid front vowels of the same degree of height (see also Boersma, 1998, p. 349). This slight asymmetry does not seem to affect necessarily small vowel size systems though. As shown in Table 1, /E/ and /O/ may share highly similar $F1$ frequencies in the five vowel systems of Greek, Spanish and Japanese or else $F1$ is higher for /O/ than for /E/ in Greek, Spanish and Hebrew. In most of the more complex systems with seven peripheral vowels of the table, however, mid back /o/ has a higher $F1$ than mid front /e/ and the same applies to mid low /ɔ/ with respect to mid front /ɛ/. Moreover, the size of this $F1$ difference does not exceed 60 Hz. Other more crowded vowel systems not appearing in the table also show a higher $F1$ for /o/ than for /e/ and for /ɔ/ than for /ɛ/, e.g., those of French (11 vowels; De Graaf and Koopmans-van Beinum, 1984), Dutch (12 vowels; Koopmans-van Beinum, 1973) and North German (10 vowels; Bohn, 2004). This $F1$ difference parallels that between /i/ and /u/ (see, e.g., Peterson and Barney, 1952 for American English), and may be attributed to the presence of a more retracted pharyngeal constriction and a lower tongue front position for mid back rounded vowels than for mid front ones. Indeed, according to the acoustic theory of speech production, an increase in back constriction narrowing and in cross-sectional area in the anterior cavity causes $F1$ to rise (Stevens, 1998, pp. 268–269).

Asymmetry in the number of vowels leads to six vowel systems such as those of the minor Catalan dialects subjected to analysis in this paper. Data and simulation outcomes on vowel inventories (Schwartz et al., 1997a,b) reveal that, in asymmetrical six vowel systems, the number of front vowels is likely to be greater than the number of back vowels. Also in seven vowel systems with /ə/ or /y/, the distinction between mid high and mid low vowels are more likely to be maintained in the front series than in the back series. When applied to Catalan, this means that /e/ and /ɛ/ rather than /o/ and /ɔ/ should be kept distinct, and therefore that the vowel system of Gironí should be optimal while that of Felanitxer should not. Moreover, this scenario predicts that, in six vowel systems, a trend towards neutralization of the contrasting mid vowel series is more prone to take place between /o/ and /ɔ/ (in Felanitxer) than between /e/ and /ɛ/ (in Gironí).

In the light of these observations, the present paper will investigate the position of /E, O/ with respect to /e/ and /ɛ/ and to /o/ and /ɔ/, and the extent to which /E/ or /O/ share the same $F1$ height in six vowel systems (Felanitxer, Gironí) as in five vowel systems (Sitgetà, Rossellonès). We will also attempt to establish whether the two mid vowels in a five vowel system are roughly symmetrical and if the back vowel cognate has a slightly higher $F1$ than the front one. Finally, if six vowel systems lacking a mid front vowel are more unstable than those lacking a mid back vowel, then Felanitxer /o/ and /ɔ/ should approach each other while Gironí /e/ and /ɛ/ should not.

1.3. Vowel space dispersion

Two related predictions regarding space dispersion in vowel systems have been proposed. According to one version dispersion should be maximal, i.e., it should be based exclusively on maximization of perceptual distances, regardless of the number of vowels (Liljencrants and Lindblom, 1972). A more elaborate version is that of sufficient dispersion, i.e., an increase in the number of vowels should cause the overall vowel system to expand. Sufficient expansion could occur either per se (Lindblom, 1986), or in combination with principles such as organizational symmetry (Boersma, 1998, p. 347), minimization of articulatory effort and maximization of number of contrasts (Flemming, 2004), and global dispersion and local focalization (Schwartz et al., 1997b, 2007). The goal of the present paper is to test the sufficient dispersion hypothesis referred to as adaptive dispersion theory (ADT).

Studies from the literature provide contradictory evidence regarding the predictions of ADT. Most studies on vowel dispersion compare large with small vowel inventories. Larger vowel inventories have been reported to exhibit larger tongue height and formant frequency differences between point vowels than smaller ones, i.e., those of English vs. Spanish (Flege, 1989) and of German and English vs. Greek (Jongman et al., 1989). Greater overall space dispersion in larger vs. smaller vowel systems has also been shown to occur when all system vowels are taken into consideration, e.g., in French and Jordanian Arabic vs. Maroccan Arabic (Al Tamimi and Ferragne, 2005). Other studies, however, conclude that vowel space dispersion is not greater for larger than for smaller vowel systems whether the dispersion measure is calculated using the common edge vowels (English, Spanish and Greek; Bradlow, 1995) or all vowels (English, French and Spanish; Meunier et al., 2003). Less studies have tested the ADT hypothesis for systems with a similar number of vowels. According to an analysis of 28 languages, systems of less than about eight vowels do not show differences in point vowel distance while larger systems may (Livjn, 2000). In

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disagreement with this finding, a study of Quichua–Spanish bilinguals found the five vowel system of Spanish to be more dispersed than the three vowel system of Quichua (Guion, 2003). Also, the seven vowel system /i, e, ɛ, a, ɔ, o, u/ of Tuscan Italian turned out to be more dispersed in the Florentine dialect than in the Pisan dialect (Calamai, 2002).

Data for Catalan reported in Recasens and Espinosa (2006) reveal that vowel space dispersion is essentially identical for the seven vowel systems of Valencian, Western Catalan and Eastern Catalan, and slightly greater for Majorcan which has the additional central vowel /ə/. Schwa appears to behave as a transparent vowel whose presence or absence does not affect the structure of the vowel system (Schwartz et al., 1997a,b). There is also a trend for formant frequency ranges between point vowels to be largest in Majorcan, though not clearly so when the maximally and minimally attested formant frequency values are taken into consideration.

These findings appear to be in agreement with the observation that differences in vowel expansion apply mainly when the languages or dialects being compared differ considerably in number of vowels (Livjn, 2000). They do not confirm a strong version of the adaptive dispersion theory and suggest that schwa behaves as a neutral vowel regarding vowel dispersion (though, in Catalan, this vowel could be specified for a mid high position and therefore, may not be completely targetless).

Experimental evidence disconfirms another prediction of the adaptive dispersion theory, namely, that vowel system size should affect the acoustic distance between adjacent vowels such that these vowels ought to become less distinct as vowel system size increases (Flemming, 2002). As pointed out in Section 1.2, data from different languages exhibiting the same number of vowel phonemes show that the frequency intervals between adjacent vowels conform to dialect-dependent patterns rather than to universal ones. For example, Yoruba and Italian differ in degree of height for /e, o/ such that the distance between those vowels and /i, u/ also varies, and Japanese and Spanish differ regarding the acoustic distance between /i/ and /u/ just because the back vowel is more anterior in the former language than in the latter (Disner, 1983; Papçun, 1976; Keating and Huffman, 1984).

Besides vowel system size, vowel space dispersion may be proportional to vowel duration such that vowel spaces become more reduced and, therefore, vowels undergo more undershoot, at faster vs slower rates (Moon and Lindblom, 1994; Fourakis et al., 1999). Other factors such as speaker-dependent speech intelligibility and lexical difficulty may also affect vowel dispersion, i.e., the less intelligible the speech, the more reduced the vowel space (Bradlow et al., 1996), and vowel spaces associated with high-density words are more expanded than those associated with low-density words (Munson and Solomon, 2004).

Within this theoretical framework, this paper will test several predictions of the adaptive dispersion theory presented above through a comparison between the less crowded vowel systems of Felanitxer, Gironí, Sitgetà and Rossellonès, and the more crowded systems of Eastern and Majorcan where those minor dialects belong to. If the adaptive dispersion theory is correct, the former vowel systems should show less overall vowel space dispersion and/or a smaller separation between point vowels than the latter.

1.4. Contextual variability

According to the adaptive dispersion theory, individual vowel variability should be conditioned by vowel system size. Thus, in conjunction with claims about vowel space dispersion, this theory predicts that vowels should be freer to vary in small than in large vowel systems because there should be more acoustic space available in the former case (Lindblom, 1986). In support of this hypothesis, Manuel found that vowels are more variable in Shona than in English (Manuel, 1990). However, other studies report no substantial differences in individual vowel variability between languages endowed with vowel systems differing in size, i.e., Spanish and English (Bradlow et al., 1996; Flege, 1989), Greek and German or English (Jongman et al., 1989; Hawks and Fourakis, 1995), Mandarin and Cantonese Chinese (Mok, 2006), and Shona and English (Beddor et al., 2002).

A problem with the ADT hypothesis is that individual vowels may be subjected to specific dialect-dependent production requirements which may affect their degree of phonetic variability independently of vowel system size. Thus, for example, contextual variability for mid low /ɛ/ and /ɔ/ was found to be less in Majorcan than in Valencian, Western Catalan and Eastern Catalan perhaps in line with the fact that these vowels are somewhat lower and perhaps tenser in the former dialect than in the three latter ones (Recasens and Espinosa, 2006).

Within this framework, the present investigation carries out an analysis of vowel variability in Catalan dialects with special reference to the mid vowel outcomes of neutralization processes. The adaptive dispersion theory predicts that mid /E/ and /O/ in the four minor Catalan dialects of interest ought to be more variable than /e/ and /ɛ/ and /o/ and /ɔ/ in other dialects where the two mid high and mid low pairs are set in contrast.

Variability will be evaluated as a function of consonant context. Contextual variability is associated both with the articulatory requirements on vowel production as well as with the relative compatibility between the articulatory gestures for adjacent vowels and consonants (Recasens, 1985; Stevens and House, 1963; Hillenbrand et al., 2001). Regarding $F2$, front vowels and especially /i/ are more resistant to consonant coarticulation than back vowels. C-to-V effects on front vowels are associated mostly with jaw and tongue predorsum lowering and with tongue postdorsum retraction in sequences with dark /l/, trill /r/ and /w/, while C-to-V effects on low and back rounded

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vowels are mostly related to tongue dorsum raising and fronting and to delabialization triggered by dentoalveolar and palatal consonants. $F1$ variability is greater for low than for high vowels and for mid front than for mid back vowels, and is associated with variations in jaw and tongue dorsum height for consonants (Keating et al., 1994). Whether stressed or unstressed, /ə/ exhibits much context-dependent $F1$ and $F2$ variability since it lacks a well defined articulatory target (Recasens and Espinosa, 2006).

1.5. Summary of research questions

Vowel location and variability, and vowel space dispersion, will be explored in the Catalan dialects with five or six peripheral vowels Felanitxer, Gironí, Sitgetà and Rossellonès. In the first place, we will ascertain whether mid vowel pairs have undergone complete or incomplete neutralization, thus giving rise to mergers or to near-mergers. The precise $F1 \times F2$ location of mid vowels subjected to neutralization and the symmetrical arrangement of mid front and mid back vowels will also be investigated. Several predictions of the adaptive dispersion theory will be examined, i.e., whether, in comparison to the systems with seven peripheral vowels of Majorcan and Eastern, those with five or six peripheral vowels exhibit lesser overall system dispersion, shorter acoustic distances between point vowels and more individual vowel variability.

2. Method

2.1. Data recording and segmentation

The Catalan stressed vowels /i, e, ɛ, a, ɔ, o, u/ were read seven times by speakers of Felanitxer, Gironí, Sitgetà and Rossellonès in the meaningful sentences listed in Table 2 and used in our previous study Recasens and Espinosa (2006). In addition, speakers of Felanitxer read the sentences with the stressed vowel /ə/ also included in the table. The two members of the mid vowels pairs /e/–/ɛ/ and /o/–/ɔ/ were recorded by speakers of all four dialects independently of whether subjected to neutralization or not.

For each context condition, the two consonants flanking the stressed vowels agree in place of articulation and/or in overall articulatory configuration. They are labial (and thus, involve lip closing and no lingual activity), dental and alveolar except for /l, r/ (and thus, are produced with a front lingual closure or constriction and moderate tongue dorsum raising), alveolopalatal (and therefore, are articulated with tongue blade and predorsum), and dark /l/ or the trill /r/ (and thus, are specified for apicoalveolar central contact and some predorsum lowering and postdorsum retraction). Catalan dialects agree with respect to the articulatory implementation of these contextual consonants, except for /l/ which is probably darker in Majorcan and Eastern than in Rossellonès (Recasens, 1996, p. 306). Due to lexical restrictions, several CVC sequences were not perfectly symmetrical but quasi-symmetrical such that the target vowel could be flanked by consonants which were articulatorily close but not identical. Thus, labiovelar /w/ and labiodental /f, v/ could act as a contextual consonant in the labial condition, and the consonant preceding or following the target vowel could be /t, s, j/ in the alveolopalatal condition and /t, d, s/ in the /l, r/ condition.

No data could be gathered for /e/ followed by /l, r/ in Rossellonès because this dialect has no words with the stressed sequences /el, er/. A few words from the sentence list used in Recasens and Espinosa (2006) had to be changed: in Gironí, sola “alone (fem.)” was replaced by cosa “thing” because Gironí speakers produce /ɔ/ as [o] in the former word (see sentence 29a in Table 2); in Rossellonès, ten words had to be replaced due to the absence of specific lexical items in this dialect (see sentences 6a, 10a, 13a, 17a, 18a, 20a, 25a, 29b, 30a and 31a in Table 2). The replacement of sola by cosa is justified on the basis that both /k/ and /l, r/ should cause the target vowel /ɔ/ to keep a low tongue predorsum and a narrow pharyngeal constriction and, therefore, to exhibit a considerable low $F2$ frequency. In the list of sentences, the target words occupy the sentence final position where phrasal stress is supposed to fall in Catalan, except for sentence 29a where cosa receives presumably secondary sentence stress. Moreover, target vowels occur in CV(C) syllables, and occupy the word medial position except for /ɛ/ in sentence 19.

Four native speakers of Felanitxer, Sitgetà and Rossellonès, and five native speakers of Gironí, of about 25–45 years of age and born and presently living in their respective dialectal region were asked to read all sentences of the table from a paper list as naturally as possible at a comfortable rate. Speakers of Gironí, Sitgetà and Rossellonès were all males, and those of Felanitxer were split into two males and two females.

Recordings took place in a quiet office in the region where speakers were born and are presently living, i.e., in Girona (Gironí), Palma de Mallorca (Felanitxer), Sitges (Sitgetà) and Perpinyà (Rossellonès). They were carried out by the first author on a DAT TCD-D8 portable digital recorder at a 48 kHz sampling frequency with a Shure SM58 dynamic vocal microphone. The speech material was sampled at 10 kHz and processed with the Computerized Speech Lab (CSL) analysis system of Kay Elemetrics. Overall, 3416 vowel realizations were analyzed, i.e., 7 vowels (8 in Felanitxer) $\times$ 4 consonant contexts (3 for /e/ in Rossellonès) $\times$7 repetitions $\times$17 speakers.

Vowel segmentation and formant measurements were performed on spectrographic displays. The vowel segmentation criteria covered all consonant context conditions. Vowel onset and offset were taken to occur at the edges of the vowel transitions which coincided with the following events: the first glottal pulse following a burst after the stop consonant realizations [p, t, d, k] and the end of vowel formant structure before the stops [p, t] and the affricates [dz, dʒ]; the offset of the frication noise for the preceding fricatives or affricates [f, s, ʒ, tʃ], and the onset of the frication noise for following [f, v, s, z]; the onset of the first

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Table 2
Catalan sentences in orthographic notation with words including the vowels subjected to analysis

Labial context		
1. /i/ Encén la **pi**pa	['pipə]	"Light on the pipe"
2. /e/ Crec que té **fe**bre	['feβɾə]	"I think he/she has a fever"
3. /ɛ/ Té mal al **pe**u	[pɛw]	"His/her foot aches"
4. /a/ Li cau la **ba**va	['baβə]	"He/she is drooling"
5. /ɔ/ Es fa la **po**bra	['pɔβɾə]	"He/she pretends to be poor"
6. /o/ La proa i la **po**pa	['popə]	"The bow and the stern"
6a. /o/ Ha caigut al **po**u	[pow]	"He/she has fallen in the well"
7. /u/ La cuina no **bu**fa	['bufə]	"The kitchen is not working"
8. /ə/ Posem-hi **pe**bre	['pəβɾə]	"Let us add some pepper"
Dental, alveolar context		
9. /i/ Ves a la **ci**ta	['sitə]	"Turn up for the appointment"
10. /e/ Ha romput el **te**st	[test]	"He/she has broken the flowerpot"
10a. /e/ D'anys en fa **se**tze	['sedzə]	"He/she is sixteen year old"
11. /ɛ/ D'anys en té **se**t	[sɛt]	"He/she is seven years old"
12. /a/ Beu-te la **ta**ssa	['tasə]	"Drink what is in the cup"
13. /ɔ/ Caigué dins d'un **so**t	[sɔt]	"It fell inside a hole"
13a. /ɔ/ Una bona **do**t	[dɔt]	"A good dowry"
14. /o/ El pis de **so**ta	['sotə]	"The downstairs floor"
15. /u/ L'han ben fo**tu**da	[fu'tuðə]	"They have really harmed her"
16. /ə/ És petit**e**ta	[pəti'tətə]	"She is very small"
Alveolopalatal context		
17. /i/ Ven la motx**i**lla	[mu'tʃiʎə]	"Sell the rucksack"
17a. /i/ Els papers els **gi**ta	['ʒitə]	"He/she trows the papers away"
18. /e/ Una cosa molt **lle**tja	['ʎedʒə]	"A very ugly thing"
18a. /e/ Va a Mars**e**lla	[mər'seʎə]	"He/she goes to Marseille[a]"
19. /ɛ/ Ell recull **e**stris	[rəku'ʎɛstris]	"He picks up the tools"
20. /a/ Això no enll**a**ça	[ən'ʎasə]	"This does not work"
20a. /a/ El ganivet **ta**lla	['taʎə]	"The knife can cut"
21. /o/ Actua la Ll**o**ll	[ʎoʎ]	"Lloll[b] is acting"
22. /ɔ/ Ven a la ll**o**tja	['ʎɔdʒə]	"She/he sells at the market"
23. /u/ En Ramon Ll**u**ll	[ʎuʎ]	"Ramon Llull[c]"
24. /ə/ Compleix la ll**e**i	[ʎəj]	"He/she obeys the law"
/l, r/ context		
25. /i/ Sempre pren t**i**l.la	['tilə]	"He/she always drinks herbal tea"
25a. /i/ Un riu dit S**i**l	[sil]	"A river named Sil[d]"
26. /e/ Encén la t**e**le	['tele]	"Switch the TV on"
27. /ɛ/ Mira el c**e**l	[sɛl]	"Look at the sky"
28. /a/ Neteja la s**a**la	['salə]	"Clean up the hall"
29. /ɔ/ No estiguis s**o**la	['sɔlə]	"Do not be alone"
29a. /ɔ/ Una c**o**sa molt lletja	['kɔzə]	"A very ugly thing"
29b. /ɔ/ Ell va de d**o**l	[dɔl]	"He is wearing a mourning suit"
30. /o/ Compra't la t**o**rre	['torə]	"Buy the tower"
30a. /o/ Viu a D**o**rres	['dorəs]	"He/she lives in Dorres[a]"
31. /u/ Així ho tit**u**la	[ti'tulə]	"He/she gives it this name"
31a. /u/ Una grossa gand**u**la	[gən'dulə]	"A large couch"
32. /ə/ És bona t**e**la	['tələ]	"It is a good fabric"

Target words are presented in Eastern Catalan phonetic transcription, except for those words with stressed /ə/ which occur in Majorcan Catalan only.
[a] Place names.
[b] Name of a Catalan actress.
[c] Name of a Catalan philosopher.
[d] Name of a Spanish river.

short occlusion corresponding to the first tongue alveolar contact for following [r]; the temporal point where the vowel formant transition endpoints meet with the lower intensity formants of the approximants [β, ð, j, w] or of the laterals [l, ʎ].

*F*1, *F*2 and *F*3 frequency values were measured at vowel midpoint by the first paper author placing a cursor in the middle of the formants. Whenever spectrographic readings were judged not to be reliable enough, formant frequencies were double checked on LPC spectral displays obtained with a 25 ms full-Hamming window and 14 coefficients.

The reliability of the formant frequency data was checked using the method applied by Peterson and Barney (1952). The second paper author took *F*1 and *F*2 frequency measurements of 50 tokens selected at random applying the same methodological criteria described above. The average

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difference between all pairs of $F1$ and $F2$ frequency measures taken by the two experimenters was then computed. The resulting means were 18.6 Hz for $F1$ and 23.6 Hz for $F2$, and the corresponding standard deviations were 16.9 Hz ($F1$) and 19.1 Hz ($F2$). Out of the 50 differences for the individual tokens, 48 differences in $F1$ frequency and 44 differences in $F2$ frequency turned out to be smaller than ±3 sd from the average difference. The remaining eight differences exceeded the ±3 sd threshold by about 10 Hz only. In view of the results from this reliability check, we can be confident that the originary formant measures were accurate enough.

2.2. Data normalization

In order to perform comparisons among dialects, formant frequency data for vowels were submitted to the same speaker normalization procedure used in Recasens and Espinosa (2006), i.e., the CLIH or constant logarithm interval hypothesis formulated in Nearey (1978), and referred to as CLIH_{i4} in Adank (2003) and as NEAREY1 in Adank et al. (2004). Data normalization needs to be carried out because formant frequencies are influenced by speaker-dependent differences in vocal anatomy.

The normalization formula is $\mathrm{CLIH} = F^{*}_{N[\mathrm{V}]\mathrm{S}} = G_{N[\mathrm{V}]\mathrm{S}} - G_{N[\cdot]\mathrm{S}}$, where $F^{*}_{N[\mathrm{V}]\mathrm{S}}$ is the measurement in Hz of the Nth formant of vowel V for subject S, $G_{N[\mathrm{V}]\mathrm{S}}$ stands for the natural logarithm of the same formant for the vowel under analysis, and $G_{N[\cdot]\mathrm{S}}$ corresponds to the average of the natural logarithms of the same formant over all system vowels. For a given formant, we computed the natural logarithm for each vowel and averaged all resulting logarithms. The difference between this resulting average and the natural logarithm for each vowel was taken to be the vowel normalized value. A possible problem with this normalization method, namely, that the value of the correction factor could be affected by dialect-dependent differences in vowel quality and/or vowel system size, should have little effect on the output of the transformation procedure. This is so since vowels common to all Catalan dialects exhibit a similar quality, and the presence of schwa in Felanitxer is expected to have little or no effect on the normalized outcome (analogously to Majorcan, as shown in Recasens and Espinosa, 2006).

In order to make sure that CLIH did not transform the formant frequency values inadequately, Lobanov's normalization method was also applied to the formant data set (see Adank, 2003, 2004 regarding the adequacy of the two normalization procedures). Lobanov's normalization formula is $(F_{i\mathrm{V}} - \mu_i)/\sigma_i$, where the mean formant frequency across all system vowels is subtracted from the formant value for a given vowel and the result is divided by the grand mean standard deviation.

Formant frequency normalization was performed for each vowel and each speaker, both on the means across all 28 tokens ($28 = 7$ repetitions $\times$ 4 consonant contexts) and on the means across tokens for each contextual condition. The contextual values were used for the calculation of vowel space dispersion and of possible formant frequency differences between pairs of mid vowels subjected to neutralization (see Sections 2.3 and 2.4). CILH normalization values were computed for the four minor dialects while those for Majorcan and Eastern were taken from Recasens and Espinosa (2006); Lobanov normalization values were computed for all six dialects.

2.3. Data analysis

Dialect-dependent differences in vowel space dispersion were estimated using several measures, i.e., mean Euclidean distances and mean formant ranges. Calculations were performed for the unnormalized and for the CILH and Lobanov normalized formant frequency data. Using normalized data for estimating systemic dispersion compensates for possible speaker-dependent differences and for the overestimation of the role of $F2$ vs. $F1$ in dispersion, while approximating perceptual dispersion better than if unnormalized data were used. Vowel dispersion for Felanitxer was processed using normalized data only.

Mean Euclidean distances were obtained by averaging the $F1$ and $F2$ frequency distances between all seven peripheral vowels and the 'centroid' or grand mean across the $F1$ and $F2$ values for all vowels. Formant values for the mid high and mid low correlates /e, ɛ, o, ɔ/ were used for the calculation of the mean Euclidean distances in the case of all dialects including those where mid vowels undergo complete merging or near-merging. Given the method of dispersion calculation of the present study, using values for /E/ and/or /O/ (e.g., by averaging /e/ and /ɛ/ and/or /o/ and /ɔ/) would have rendered the average distance from the centroid and the vowel system dispersion score higher for five and six vowel systems than for seven vowel systems. The vowel /ə/ of Felanitxer and Majorcan was not included in the computation procedure. In order to allow for maximal within-vowel dispersion, mean Euclidean distances were derived from 28 distances between the four contextual means for each vowel and the centroid (see also Bradlow et al., 1996).

Analogously to other studies in the literature (see Section 1), vowel space dispersion for all dialects was also calculated using the formant frequency values of the three common point vowels /i/, /a/ and /u/. The method of dispersion calculation was the one described above.

Formant ranges for each dialect were computed using the average vowel formant frequencies across speakers. The $F1$ ranges were obtained by subtracting the (minimal) $F1$ frequency for /i/ from the (maximal) $F1$ frequency for /a/. The $F2$ ranges equalled the difference between the (maximal) $F2$ frequency for /i/ and the (minimal) $F2$ frequency for /u/. Again, formant ranges for Felanitxer were analyzed using the normalized data only.

In order to account for the fact that the perception of quality for /i/ and, less so, for the other front unrounded vowels is associated with $F2$ and $F3$ rather than with $F2$

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alone (Fant, 1973), vowel space dispersion and formant ranges were also calculated with frequency values for $F2'$. $F2'$ was computed for all vowels of all dialects applying the following formula presented in Bladon (1983). In the formula, $F4$ was assigned a fixed value of 3500 Hz.

$$F2' = (F2 + C^2(F3 \times F4)^{1/2})/(1 + C^2),$$
$$\text{where } C = [12 \times F2 \times 67 \times F2(1 - F1^2/F2^2) \times (1 - F2^2/F3^2) \times (1 - F2^2/F4^2)] \times [1400 \times (F4 - F3)^2 \times (F3 \times F4/F2^2 - 1)]^{-1}.$$

The degree of context-dependent variability was evaluated for the unnormalized $F1$, $F2$, $F2'$ and $F3$ data of each vowel across speakers of each dialect. For that purpose, we averaged the corresponding speakers' means for each contextual condition and then calculated the standard deviation over the four contextual means. No variability data will be presented for Felanitxer since it is not advisable to pool together the unnormalized formant frequency data for male and female speakers. Contextual variability was evaluated for $F2'$ so as to take into account the perceptual quality of the front vowels, as well as for $F3$ since this formant may exhibit a specific articulatory affiliation. Thus, for example, in the case of /i/ and to a large extent of /e, ɛ/, $F3$ is front cavity dependent while $F2$ is a half wavelength of the back cavity, and both $F1$ and $F2$ vary with changes in the size of the dorsopalatal constriction (Fant, 1973). In this case, tongue dorsum lowering and retraction as a function of consonants such as dark /l/ would yield a decrease in $F1$ and $F2$, while a decrease in front cavity size as a function of dentoalveolars and other consonants would cause $F3$ to rise.

2.4. Statistical analysis

Formant frequency differences between two mid vowels which were supposed to undergo neutralization were tested statistically so as to find out whether the vowels in question were the same or not. The CILH normalized $F1$ and $F2$ data for /e/ and /ɛ/ and for /o/ and /ɔ/ were submitted to separate RM ANOVAs with the two independent variables 'vowel' and 'consonant context'. The number of ANOVAs was 16 (2 formants × 2 vowel pairs × 4 dialects). Each speaker contributed one averaged score per condition and

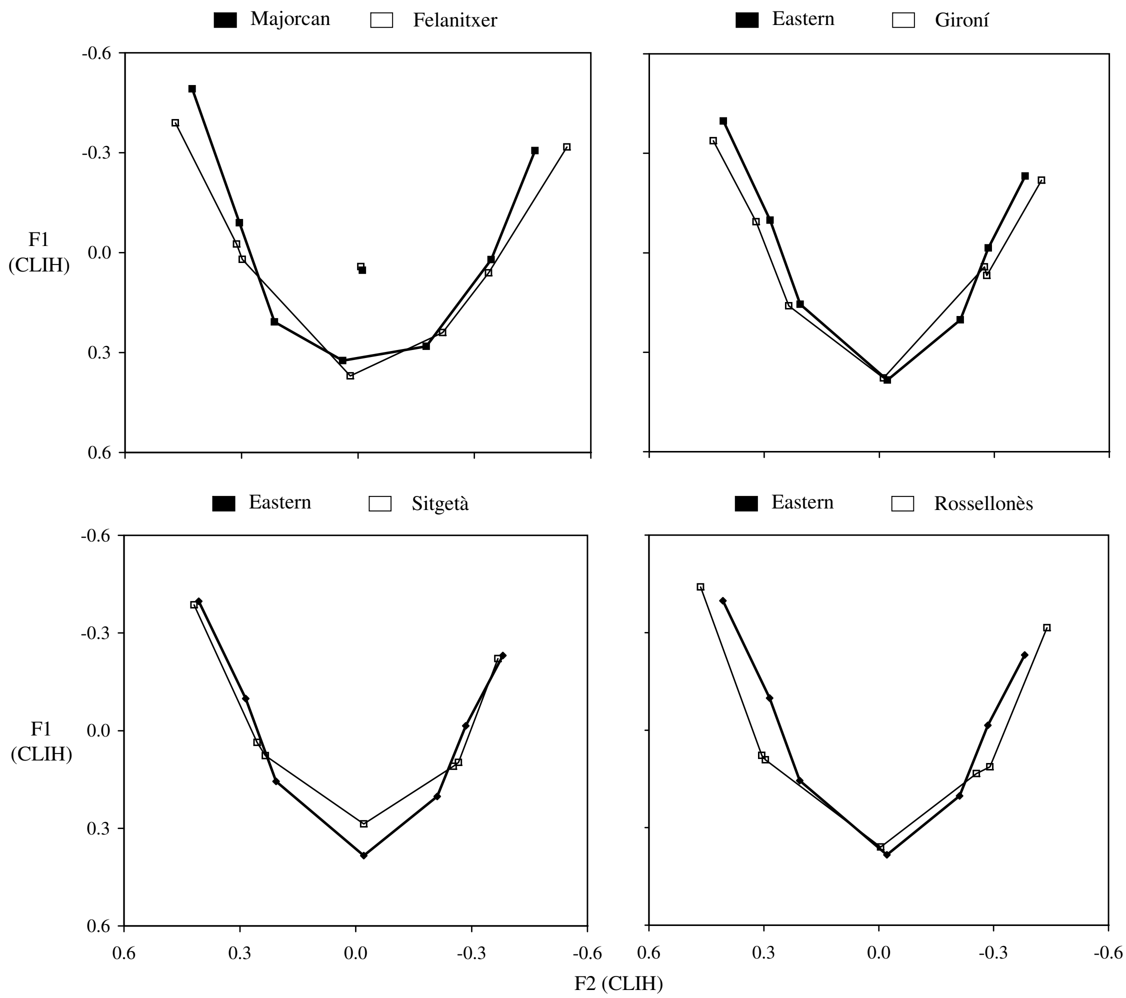

Fig. 1. Normalized $F1 \times F2$ values for the vowels of Felanitxer and Majorcan (top left), and of Gironí, Sitgetà and Rossellonès and Eastern (remaining graphs). The CILH normalization procedure has been used.

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Huynh–Feldt corrected degrees of freedom were performed on the main effects and interactions (Max and Onghena, 1999). Bonferroni post hoc tests were run on the significant main effects involving more than two levels of an independent variable. The degree of significance was set at $p < 0.05$. In view of the reduced size of the data samples subjected to statistical analysis in the RM ANOVAs, significant effects exhibiting a level of significance between 0.05 and 0.01 will be accepted with caution.

Vowel space dispersion and mean range values were also submitted to statistical analysis by means of RM ANOVAs with 'dialect' and 'consonant context' as independent variables ($p < 0.05$). In this case, statistical tests were run on the CILH and Lobanov normalized formant frequency data for all dialects, and on the corresponding unnormalized data for Gironí, Sitgetà, Rossellonès and Eastern.

Moreover, in order to find out whether there was any relationship between vowel space dispersion and vowel duration, we averaged all vowels' durations for the individual speakers of the four minor Catalan dialects of interest and correlated the resulting means with the corresponding unnormalized and normalized mean Euclidean distances. Values for /e, ɛ, o, ɔ/ always included those dialects where mid vowels undergo complete merging or near-merging. Data for Felanitxer /ə/ were excluded from the averaging procedure. Correlation values for Majorcan and Eastern may be found in Recasens and Espinosa (2006).

3. Results

3.1. Mid vowel neutralization

Figs. 1 and 2 display the normalized $F1 \times F2$ vowel spaces for the four minor dialects Felanitxer, Gironí, Sitgetà and Rossellonès overlaid onto those for the major dialects they belong to. Tables 3 and 4 present the unnormalized and normalized mean formant frequency values across all tokens of each vowel for each individual speaker of the four minor Catalan dialects. Table 5 reports the averages of the speakers' mean formant frequencies appearing in Tables 3 and 4.

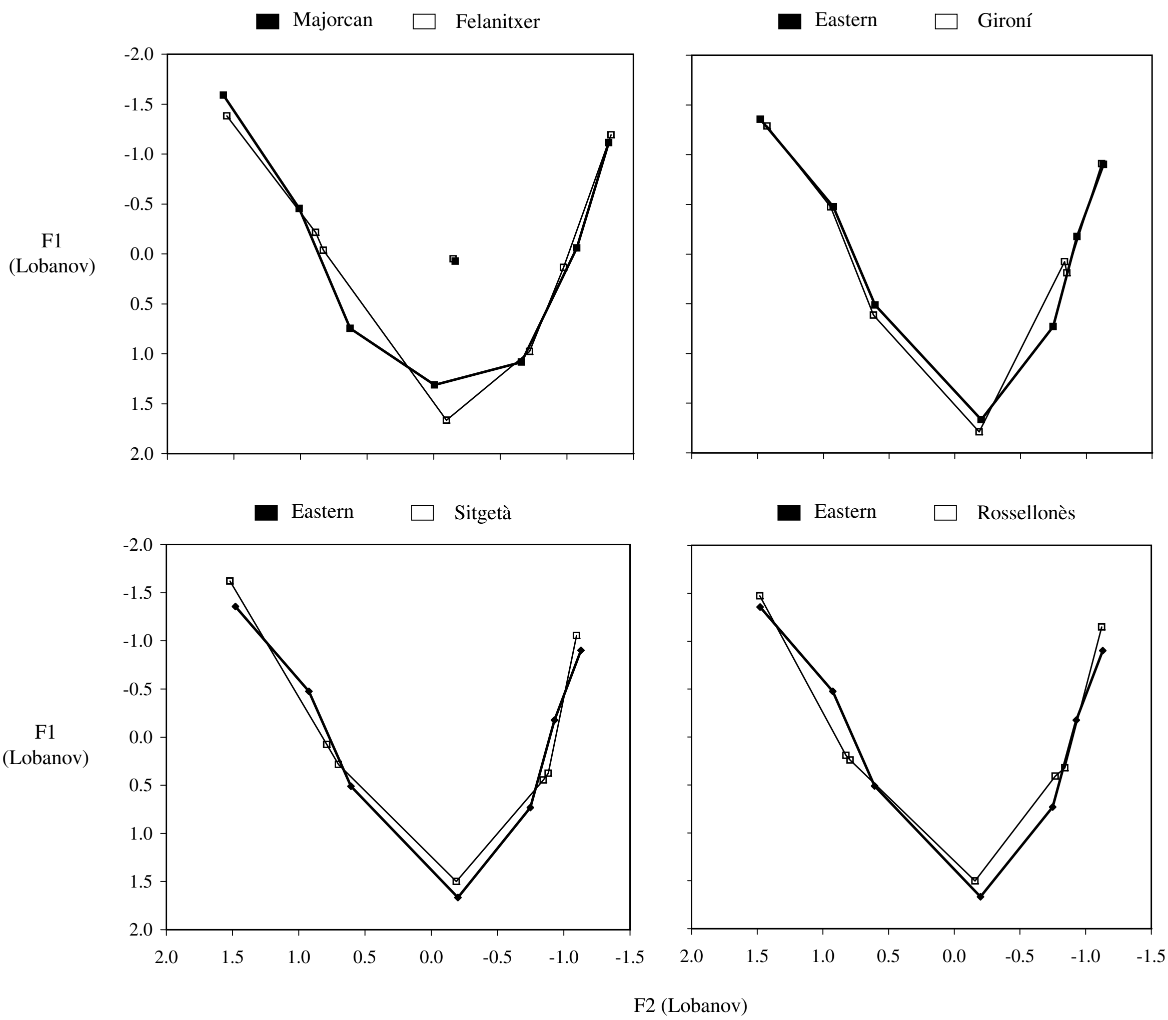

Fig. 2. Normalized $F1 \times F2$ values for the vowels of Felanitxer and Majorcan (top left), and of Gironí, Sitgetà and Rossellonès and Eastern (remaining graphs). Lobanov's normalization method has been used.

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Table 3
Unnormalized $F1$, $F2$ and $F3$ frequencies for the vowels of Felanitxer, Gironí, Sitgetà and Rossellonès according to the individual speakers of each dialect

	Felanitxer				Gironí				Sitgetà				Rossellonès			
		$F1$	$F2$	$F3$		$F1$	$F2$	$F3$		$F1$	$F2$	$F3$		$F1$	$F2$	$F3$
i	FA	306	2478	2959	MA	366	2099	2627	DJ	286	2146	2780	PY	282	2175	3046
e		516	2061	2694		459	1791	2439		496	1726	2428		438	1928	2500
ɛ		552	2034	2682		590	1626	2454		513	1709	2418		496	1801	2450
a		766	1449	2435		712	1311	2476		653	1252	2381		648	1288	2363
ɔ		677	1072	2255		504	1075	2235		558	1013	2284		532	991	2460
o		589	960	2230		496	1115	2301		563	983	2292		513	968	2447
u		370	794	2446		392	1023	2446		365	961	2190		309	783	2597
ə		562	1390	2501												
i	FB	350	2019	2456	PE	346	2188	2762	JD	355	2088	2661	PA	299	2229	2851
e		479	1764	2429		449	1977	2591		505	1834	2526		516	1840	2542
ɛ		487	1718	2424		589	1809	2520		518	1774	2490		508	1854	2554
a		679	1387	2374		681	1411	2570		630	1425	2330		683	1290	2261
ɔ		664	1149	2302		516	1156	2473		533	1130	2142		519	1026	2399
o		541	1021	2294		525	1125	2518		524	1123	2167		519	986	2363
u		385	833	2296		381	993	2393		400	1028	2299		345	918	2499
ə		509	1424	2423												
i	FC	416	2724	3273	JO	349	2163	2699	RR	338	2038	2621	JL	285	1991	2652
e		559	2232	3157		437	1947	2626		531	1758	2548		465	1696	2330
ɛ		612	2186	3082		541	1852	2555		551	1739	2493		465	1710	2322
a		846	1664	2536		689	1464	2389		671	1306	2540		583	1336	2224
ɔ		780	1336	2356		518	1078	2396		560	1051	2455		484	1007	2210
o		628	1138	2614		539	1068	2390		546	1033	2501		471	976	2105
u		426	884	2972		412	921	2489		415	943	2335		325	885	2217
ə		603	1565	2885												
i	FD	463	2564	3105	FR	324	2346	2809	VR	367	2167	2691	GD	285	2102	2862
e		643	2291	3208		410	2128	2782		510	1855	2613		517	1784	2467
ɛ		658	2274	3174		504	1919	2742		544	1799	2590		492	1809	2416
a		982	1748	3083		683	1492	2597		666	1499	2502		647	1426	2259
ɔ		732	1360	3103		461	1049	2388		545	1156	2620		505	1159	2205
o		626	1261	3253		485	1024	2306		537	1147	2609		497	1118	2170
u		453	1122	3243		373	861	2523		403	987	2598		324	926	2317
ə		674	1721	3278												
i					JR	331	2266	2980								
e						434	2064	2843								
ɛ						606	1901	2774								
a						744	1466	2440								
ɔ						511	1181	2246								
o						530	1154	2264								
u						375	1034	2403								

A first thing to notice is that the normalized vowel spaces obtained using the CILH method in Fig. 1 and Lobanov's method in Fig. 2 do not differ substantially from each other. A comparison between the normalized $F2$ values for the minor and major dialects overimposed in the graphs reveals that a slightly better match is achieved with the latter normalization method than with the former.

The graphs in the two figures also show that those mid vowels which are supposed to undergo neutralization lie much closer to each other than the corresponding cognates in major dialects where no neutralization occurs. This is indeed the case for the pair /e/–/ɛ/ in Felanitxer vis-à-vis Majorcan, for /o/–/ɔ/ in Gironí with respect to Eastern, and for /e/–/ɛ/ and /o/–/ɔ/ in Sitgetà and Rossellonès with respect to Eastern.

Another observation is that the two members of a mid vowel pair undergoing neutralization do not exhibit exactly the same formant frequencies. Moreover, in spite of being extremely small, formant frequency differences between two neutralizing mid vowels conform to the same pattern as those occurring between mid vowels in dialects where the neutralization process has not taken place. Indeed, /e/ has a slightly lower $F1$ and a slightly higher $F2$ than /ɛ/ in Felanitxer, Sitgetà and Rossellonès, while /o/ has a slightly lower $F1$ and $F2$ than /ɔ/ in Sitgetà and Rossellonès but not in Gironí.

ANOVAs indicate that those formant frequency differences are generally non-significant. Statistical comparisons between /e/ and /ɛ/ yielded non-significant results for $F1$ and $F2$ in Felanitxer and Rossellonès. In Sitgetà, the formant frequency differences between the two mid front vowels were significant both for $F1$ ($F(1,3) = 20.87$, $p = 0.020$) and for $F2$ ($F(1,3) = 10.90$, $p = 0.046$) although their size is extremely small, i.e., 21 Hz for $F1$ and 38 Hz for $F2$ (see Table 5). On the other hand, differences between /o/ and /ɔ/ were statistically non-significant for $F1$ and $F2$ in Gironí and Sitgetà, and for $F1$ in Rossellonès. The $F2$ contrast between the two mid back rounded vowels achieved

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Table 4
CILH normalized $F1$, $F2$ and $F3$ frequencies for the vowels of Felanitxer, Gironí, Sitgetà and Rossellonès according to the individual speakers of each dialect

	Felanitxer				Gironí				Sitgetà				Rossellonès			
		*F*1	*F*2	*F*3		*F*1	*F*2	*F*3		*F*1	*F*2	*F*3		*F*1	*F*2	*F*3
i	FA	−0.533	0.553	0.163	MA	−0.296	0.415	0.081	DJ	−0.506	0.474	0.151	PY	−0.452	0.493	0.180
e		−0.011	0.369	0.069		−0.068	0.256	0.007		0.044	0.256	0.016		−0.011	0.372	−0.017
ɛ		0.054	0.355	0.064		0.183	0.160	0.013		0.077	0.247	0.011		0.112	0.304	−0.038
a		0.383	0.016	−0.033		0.371	−0.055	0.022		0.318	−0.065	−0.004		0.381	−0.031	−0.074
ɔ		0.259	−0.285	−0.109		0.026	−0.254	−0.081		0.161	−0.277	−0.046		0.183	−0.293	−0.033
o		0.120	−0.396	−0.120		0.010	−0.218	−0.051		0.170	−0.306	−0.042		0.147	−0.317	−0.039
u		−0.345	−0.586	−0.028		−0.226	−0.304	0.010		−0.264	−0.329	−0.087		−0.360	−0.528	0.021
ə		0.072	−0.026	−0.006												
i	FB	−0.356	0.394	0.034	PE	−0.341	0.403	0.082	JD	−0.317	0.374	0.117	PA	−0.451	0.486	0.135
e		−0.042	0.259	0.023		−0.081	0.302	0.018		0.036	0.244	0.065		0.096	0.294	0.021
ɛ		−0.027	0.232	0.021		0.192	0.213	−0.010		0.061	0.211	0.051		0.081	0.302	0.026
a		0.306	0.019	0.000		0.337	−0.035	0.010		0.257	−0.008	−0.016		0.377	−0.061	−0.096
ɔ		0.283	−0.170	−0.031		0.059	−0.235	−0.029		0.089	−0.240	−0.100		0.102	−0.290	−0.037
o		0.079	−0.288	−0.034		0.077	−0.262	−0.011		0.073	−0.246	−0.088		0.102	−0.330	−0.052
u		−0.261	−0.492	−0.034		−0.243	−0.387	−0.061		−0.199	−0.335	−0.029		−0.307	−0.401	0.004
ə		0.019	0.045	0.020												
i	FC	−0.354	0.522	0.141	JO	−0.334	0.415	0.075	RR	−0.404	0.409	0.048	JL	−0.409	0.417	0.147
e		−0.059	0.323	0.105		−0.109	0.310	0.048		0.050	0.261	0.020		0.080	0.256	0.018
ɛ		0.033	0.302	0.081		0.103	0.260	0.020		0.087	0.250	−0.002		0.082	0.265	0.014
a		0.357	0.029	−0.114		0.346	0.025	−0.047		0.284	−0.036	0.017		0.308	0.018	−0.029
ɔ		0.275	−0.190	−0.188		0.060	−0.281	−0.044		0.103	−0.253	−0.017		0.121	−0.265	−0.035
o		0.058	−0.351	−0.084		0.101	−0.291	−0.046		0.077	−0.271	0.001		0.094	−0.297	−0.084
u		−0.329	−0.604	0.044		−0.168	−0.439	−0.006		−0.198	−0.362	−0.067		−0.276	−0.394	−0.032
ə		0.018	−0.032	0.015												
i	FD	−0.319	0.398	−0.024	FR	−0.331	0.484	0.083	VR	−0.312	0.395	0.033	GD	−0.459	0.393	0.186
e		0.010	0.285	0.009		−0.096	0.386	0.073		0.016	0.239	0.004		0.136	0.229	0.038
ɛ		0.033	0.278	−0.002		0.110	0.283	0.059		0.081	0.208	−0.005		0.086	0.243	0.017
a		0.434	0.015	−0.031		0.414	0.031	0.004		0.284	0.026	−0.040		0.360	0.005	−0.051
ɔ		0.140	−0.236	−0.025		0.022	−0.321	−0.080		0.083	−0.234	0.006		0.113	−0.203	−0.075
o		−0.017	−0.312	0.023		0.072	−0.346	−0.114		0.068	−0.242	0.002		0.097	−0.239	−0.090
u		−0.339	−0.429	0.019		−0.191	−0.518	−0.025		−0.220	−0.392	−0.002		−0.332	−0.427	−0.025
ə		0.058	−0.001	0.030												
i					JR	−0.389	0.402	0.156								
e						−0.116	0.309	0.109								
ɛ						0.218	0.227	0.084								
a						0.421	−0.034	−0.044								
ɔ						0.047	−0.249	−0.127								
o						0.083	−0.272	−0.119								
u						−0.264	−0.382	−0.059								

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Table 5
Unnormalized (top) and CILH normalized (bottom) $F1$, $F2$ and $F3$ frequencies for the vowels of Felanitxer, Gironí, Sitgetà and Rossellonès across speakers

	Felanitxer			Gironí			Sitgetà			Rossellonès		
	$F1$	$F2$	$F3$	$F1$	$F2$	$F3$	$F1$	$F2$	$F3$	$F1$	$F2$	$F3$
	Males											
i	328	2249	2708	343	2213	2776	337	2110	2688	288	2124	2853
e	498	1913	2561	438	1981	2656	511	1793	2528	484	1812	2460
ɛ	518	1873	2551	566	1822	2609	532	1755	2497	490	1794	2435
a	723	1418	2401	702	1429	2494	655	1370	2440	640	1335	2277
ɔ	670	1113	2281	502	1108	2348	549	1088	2371	510	1046	2320
o	564	991	2264	515	1097	2356	543	1071	2388	500	1012	2271
u	378	813	2361	387	966	2451	395	980	2356	326	878	2401
ə	534	1408	2460									
	Females											
i	437	2650	3194									
e	597	2259	3181									
ɛ	633	2227	3125									
a	909	1703	2789									
ɔ	758	1348	2701									
o	627	1195	2909									
u	439	993	3152									
ə	636	1638	3074									
i	−0.391	0.467	0.078	−0.338	0.424	0.095	−0.385	0.413	0.087	−0.443	0.447	0.162
e	−0.026	0.309	0.051	−0.094	0.313	0.051	0.037	0.250	0.026	0.075	0.288	0.015
ɛ	0.023	0.292	0.041	0.161	0.229	0.033	0.076	0.229	0.014	0.090	0.278	0.005
a	0.370	0.020	−0.044	0.378	−0.013	−0.011	0.286	−0.021	−0.011	0.356	−0.017	−0.062
ɔ	0.239	−0.220	−0.088	0.043	−0.268	−0.072	0.109	−0.251	−0.039	0.130	−0.263	−0.045
o	0.060	−0.336	−0.054	0.068	−0.278	−0.068	0.097	−0.266	−0.032	0.110	−0.296	−0.066
u	−0.318	−0.528	0.001	−0.218	−0.406	−0.028	−0.220	−0.354	−0.046	−0.319	−0.438	−0.008
ə	0.042	−0.003	0.015									

Unnormalized data for the male and female speakers of Felanitxer have been averaged separately.

significance in Rossellonès ($F(1,3) = 62.26$, $p = 0.004$) though, as shown in Table 5, its size is only 34 Hz large. Moreover, it should be noticed that if the significance threshold was set at 0.01 instead of at 0.05, only one out of the three differences referred to above would reach significance, i.e., the $F2$ frequency difference between /o/ and /ɔ/ in Rossellonès. In view of the small magnitude of the significant formant frequency differences between /e/ and /ɛ/ in Sitgetà and between /o/ and /ɔ/ in Rossellonès, it may be claimed that these vowel pairs behave as near-mergers and therefore, that its members cannot be distinguished perceptually while being perhaps not entirely identical in production. The perceptual identity between the mid vowels of interest is consistent with the observation that the size of the $F1$ and $F2$ differences involved does not exceed one JND (see Section 1.1).

As expected, those mid high and mid low vowels which do not undergo neutralization, i.e., /o/ and /ɔ/ in Felanitxer and /e/ and /ɛ/ in Gironí, are located far apart from each other and turned out to be highly significant both for $F1$ and for $F2$.

3.2. Mid vowel location

The vowel spaces of the minor Catalan dialects in Figs. 1 and 2 also show that the mid vowels subjected to neutralization occupy a different location in the $F1 \times F2$ plane depending on whether the vowel system has five or six peripheral vowels.

In systems of six peripheral vowels, the vowel outcome of the neutralization process lies close to the vowels /e/ or /o/ of the corresponding major dialect. Thus, /E/ in Felanitxer lies closer to /e/ than to /ɛ/ of Majorcan, and /O/ in Gironí lies closer to /o/ than to /ɔ/ of Eastern. Moreover, Felanitxer /E/ and Gironí /O/ are slightly lower than Majorcan /e/ and Eastern /o/, respectively, and therefore, are located somewhere between the mid high and mid low vowels.

As for five vowel systems, /E/ and /O/ in Sitgetà and Rossellonès occupy a lower position than /E/ in Felanitxer and /O/ in Gironí, thus approaching the mid low vowels /ɛ/ and /ɔ/ of the Eastern dialect.

3.3. Symmetry and optimality

Inspection of the five vowel systems of Sitgetà and Rossellonès in Figs. 1 and 2 indicate that mid front /E/ and mid back /O/ share a similar $F1$ frequency, thus suggesting that front and back vowels of the same height are arranged symmetrically along the $F1$ dimension. Moreover, $F1$ is slightly higher for the back vowel cognate than for the

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front one in accordance with a general trend reported for other languages (see Section 1.2).

As for the systems with six peripheral vowels, it appears that the neutralization of a given mid vowel pair may cause the members of the other mid vowel pair to approach one another. Thus, mid low /ɔ/ and mid high /o/ are nearer in Felanitxer than in Majorcan, thus suggesting that the neutralization between /e/ and /ɛ/ has caused the two mid back vowels to move closer to each other than they were originally. We could take this finding as tentative evidence in support of an on-going mid vowel merging process triggered by the previous merging of the other mid vowel pair. This scenario is essentially in agreement with the hypothesis that mid front and mid back vowel merging may occur sequentially, as suggested for Rossellonès elsewhere (see Section 1.2).

In Gironí, however, the two mid front vowels /e/ and /ɛ/ occupy the same position as their Eastern cognates in spite of the fact that /o/ and /ɔ/ undergo neutralization in the former dialect but not in the latter. In this particular case, the neutralization of the mid back pair does not seem to affect the $F1$ distance between the two mid front vowels. This finding is in agreement with the notion that vowel systems drive towards optimality rather than towards a symmetrical arrangement between front and back vowels. Indeed, the prediction that contrasting mid vowels ought to approach each other in unoptimal six vowel systems lacking the mid front vowel contrast (Felanitxer) but not in optimal six vowel systems lacking the mid back vowel contrast (Gironí) is borne out by the data. Another factor which may prevent Gironí from becoming a five vowel system could be the pressure from the prestigious Eastern Catalan variety to which Gironí belongs to.

3.4. Dispersion

3.4.1. Overall vowel space

If overall vowel space dispersion is related to vowel system size, the expected trend is for dispersion to be greater in the system with seven peripheral vowels of Majorcan than in that with six peripheral vowels of Felanitxer, and for the seven vowel system of Eastern than for the five or six vowel systems of Gironí, Sitgetà and Rossellonès.

Dispersion values for the unnnormalized and normalized formant frequency data in Table 6 do not generally support this hypothesis whether $F1$ is paired with $F2$ or with $F2'$. In fact, vowel space dispersion may increase with a decrease in the number of vowel units when the unnormalized formant frequencies are taken into consideration, i.e., in Gironí and Rossellonès vs. Eastern. A similar scenario holds for the normalized formant frequency values whether computed using the CILH or Lobanov's normalization methods.

Some comparisons were in agreement with the ADT hypothesis. Thus, values for the "dispersion (a)" condition at the top of the table may be higher for Majorcan than for Felanitxer ($F1 \times F2$ and $F1 \times F2'$ values using Lobanov, and $F1 \times F2'$ values using CILH), for Eastern vs. Gironí ($F1 \times F2$ values using Lobanov), for Eastern vs Sitgetà (values for all conditions) and for Eastern than Rossellonès ($F1 \times F2$ and $F1 \times F2'$ values using Lobanov). A small subset of these dialect-dependent differences were consistent with the ADT hypothesis when data for /i, a, u/ were subjected to analysis, i.e., four differences for Eastern vs. Sitgetà and one difference for Majorcan vs. Felanitxer (see "dispersion (b)" condition in the table). However, ANOVAs run on most of these dialectal differences yielded a non-significant effect of 'dialect' and a non-significant 'dialect' × 'consonant context' interaction, meaning that vowel space dispersion is largely unrelated to the number of units in the vowel system. Significant effects hold for the "dispersion (a)" condition only. A barely significant 'dialect' effect was found to hold when the Lobanov $F1 \times F2$ dispersion values were compared for Felanitxer vs. Majorcan ($F(1,7) = 6.64$, $p = 0.037$) and for Sitgetà vs. Eastern ($F(1,7) = 6.87$, $p = 0.034$), and when the Lobanov $F1 \times F2'$ values were compared for Rossellonès vs. Eastern ($F(1,7) = 7.35$, $p = 0.030$). Differences in vowel space dispersion for Gironí vs. Eastern and for Rossellonès vs. Eastern using Lobanov $F1 \times F2$ data yielded no main 'dialect' effect and a significant 'dialect' × 'consonant context' interaction ($F(3,24) = 3.75$, $p = 0.024$; $F(3,21) = 4.26$, $p = 0.017$). In this case, a trend is observed towards greater dispersion in Gironí and Rossellonès than in Eastern in the context of /l, r/, and in Eastern than in the two other dialects in the alveolopalatal context condition (and possibly in the labial and dental and alveolar contexts as well).

Correlation values between mean Euclidean distances and vowel durations across dialects were extremely low, i.e., $r < 0.3$, both for the unnormalized and the normalized formant frequency data, and for all minor and major dialects under analysis. It may be thus ascertained that system dispersion varies independently of vowel duration.

3.4.2. Point vowels

Judging from the data presented in Table 6, the ADT claim that the $F1$ distances between point vowels should decrease with the number of system vowels could find some support if we compare Gironí, Sitgetà and Rossellonès with Eastern. Indeed, according to the table, there is a trend for Gironí, Sitgetà and Rossellonès to exhibit smaller $F1$ distances than Eastern both when the unnormalized and CILH data are taken into consideration. However, ANOVAs yielded a non-significant effect of 'dialect' and a non-significant 'dialect' × 'consonant context' interaction for the $F1$ distances just referred to. On the other hand, $F1$ ranges for the CILH normalized values turned out to be significantly smaller in Felanitxer than in Majorcan in all consonant contexts except for /l, r/ (a 'dialect' × 'consonant context' interaction was obtained in this case; $F(2.9, 20.7 = 4.34$, $p = 0.016))$. $F1$ normalized values using the Lobanov normalization procedure were found to be larger, not smaller, for the minor dialects than for the major dialects they belong to, i.e., for Gironí, Sitgetà and

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Table 6
(Top) Vowel space dispersion values for the minor dialect Felanitxer and the major dialect Majorcan, and for the minor dialects Gironí, Sitgetà and Rossellonès and the major dialect Eastern. (Bottom) Corresponding mean formant ranges

	$F1 \times F2$			$F1 \times F2'$		
	Hz	CILH	Lobanov	Hz	CILH	Lobanov
Dispersion (a)						
Felanitxer		0.417	1.368		0.443	1.337
Majorcan		**0.406**	**1.395**		**0.451**	**1.375**
Gironí	452	0.377	1.279	626	0.441	1.274
Sitgetà	398	0.343	1.269	503	0.384	1.244
Rossellonès	443	0.407	1.274	584	0.454	1.230
Eastern	**403**	**0.368**	**1.294**	**508**	**0.407**	**1.265**
Dispersion (b)						
Felanitxer		0.541	1.856		0.547	1.774
Majorcan		**0.513**	**1.769**		**0.557**	**1.760**
Gironí	516	0.478	1.739	706	0.537	1.736
Sitgetà	462	0.441	1.778	603	0.487	1.785
Rossellonès	509	0.524	1.752	742	0.593	1.799
Eastern	**473**	**0.473**	**1.725**	**604**	**0.515**	**1.713**

	Hz			CILH			Lobanov		
	$F1$	$F2$	$F2'$	$F1$	$F2$	$F2'$	$F1$	$F2$	$F2'$
Formant ranges									
Felanitxer				0.761	0.994	0.994	2.981	2.845	2.496
Majorcan				**0.813**	**0.873**	**1.055**	**2.802**	**2.835**	**2.825**
Gironí	359	1246	1748	0.716	0.830	1.028	2.973	2.535	2.518
Sitgetà	319	1130	1526	0.689	0.763	0.935	3.006	2.577	2.629
Rossellonès	353	1246	1894	0.799	0.885	1.144	2.932	2.581	2.752
Eastern	**395**	**1118**	**1488**	**0.780**	**0.772**	**0.928**	**2.880**	**2.569**	**2.561**

Dispersion has been computed for all system vowels including the mid vowel pairs subjected to neutralization (dispersion (a) condition) and for /i, a, u/ only (dispersion (b) condition).

Rossellonès than for Eastern and for Felanitxer than for Majorcan.

Regarding $F2$, formant frequency distances between point vowels were generally larger, not smaller for Felanitxer than for Majorcan and for Gironí, Sitgetà and Rossellonès than for Eastern. Smaller ranges for Sitgetà than for Eastern (CILH) and for Gironí than for Eastern (Lobanov) turned out to be non-significant. As for $F2'$, smaller ranges for Felanitxer vs. Majorcan (CILH, Lobanov) and for Gironí vs. Eastern (Lobanov) turned out to be also non-significant.

3.5. Variability

3.5.1. F1, F2, F2′, F3

Fig. 3 shows standard deviations for each vowel computed over the $F1$ and $F2$ contextual means. In each graph, the contextual variability for the vowels of each of the three minor dialects Gironí, Sitgetà and Rossellonès is compared with that for the vowels of the major dialect Eastern Catalan. Two mid vowel variability measures are reported, i.e., separate values for /e/ and /ɛ/ and for /o/ and /ɔ/, and joint variability values for /E/ and /O/.

Variability differences among system vowels are similar in all dialects. Standard deviations in $F2$ frequency are less for front vowels than for back vowels, and vary in the progression /ɛ/ > /e/ > /i/ and /u/ > /o, ɔ/ as a general rule. Low /a/ and mid back rounded vowels exhibit a similar degree of $F2$ variability. There is also a trend for $F1$ variability to increase with vowel opening mostly for front vowels and /a/.

Formant frequency variability data for mid front vowels are not in support of the ADT hypothesis. Thus, /E/ of Sitgetà is not more variable than /e/ and /ɛ/ of Eastern, and /E/ in Rossellonès is more variable than Eastern /e/ regarding both $F1$ and $F2$ but not than Eastern /ɛ/ regarding $F2$.

As for the back vowel series, $F1$ appears to be more variable for /O/ in Rossellonès and perhaps Gironí (but not in Sitgetà) than for /o/ and /ɔ/ in Eastern. The $F2$ scenario is in agreement with the ADT hypothesis in that /O/ in Gironí and Rossellonès is far more variable than /o/ and /ɔ/ in Eastern. It should be observed, however, that $F2$ and $F1$ of the other back vowels /u/ and /a/ are also more variable in Gironí and Rossellonès than in Eastern.

Contextual variability data for $F2'$ (not shown) agree essentially with those for $F2$ just described. Contextual variability data for $F3$ (Fig. 4) are in disagreement with the ADT hypothesis since variability for mid front vowels is basically the same for Eastern than for Rossellonès and greater for Eastern than for Sitgetà, while variability for mid back rounded vowels is greater for Eastern than for all three other dialects.

3.5.2. F1 × F2 ellipses

Dialect-dependent trends in contextual variability may also be analyzed through inspection of the ellipses

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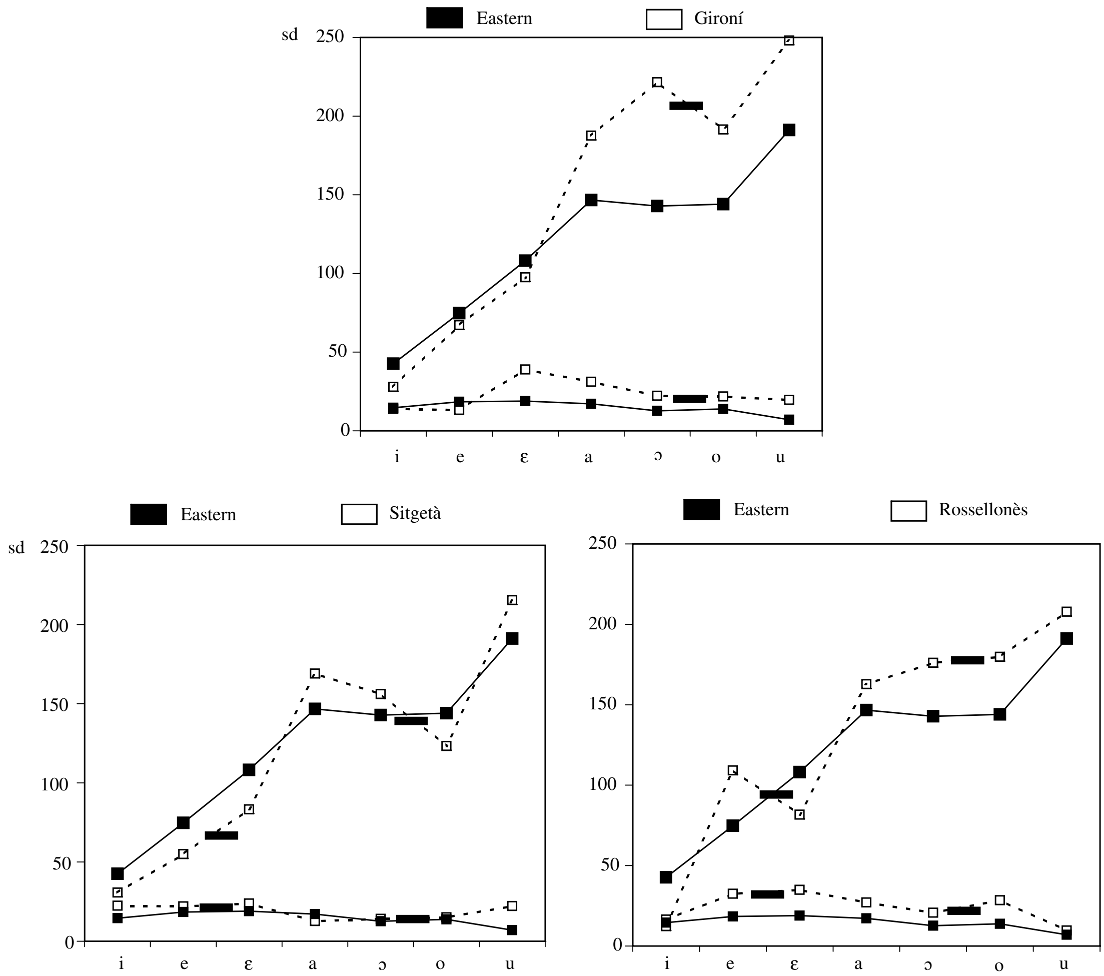

Fig. 3. Degree of contextual $F1$ and $F2$ variability expressed in standard deviation values for the vowels of Gironí, Sitgetà and Rossellonès and for those of Eastern. Mid vowels subjected to neutralization have been assigned a single standard deviation (see thick trace) and two standard deviations for each member of the vowel pair.

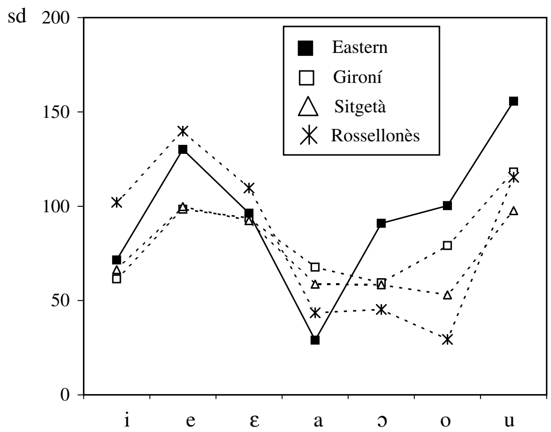

Fig. 4. Degree of contextual $F3$ variability expressed in standard deviation values for the vowels of Gironí, Sitgetà and Rossellonès and for those of Eastern.

encompassing the mean $F1 \times F2$ values for each vowel in each context condition across repetitions and speakers (see Fig. 5). Ellipses for the mid vowels undergoing neutralization have been displayed separately for the mid high and mid low correlates. They overlap almost entirely and therefore, may be jointly considered to correspond to /E/ and /O/.

Graphs in the figure reveal that mid front vowels and, to a large extent, /a/ undergo simultaneous consonant-dependent changes in $F1$ and $F2$ frequency, i.e., $F1$ decreases and $F2$ increases as we proceed from contextual consonants produced with tongue dorsum lowering and retraction (/l, r/) and lip closing and rounding (labials), to those produced with more or less tongue dorsum raising and fronting (dentals, alveolars, alveolopalatals). On the other hand, C-to-V effects for the back rounded vowels /ɔ, o, u/ involve mostly variations along the $F2$ dimension, i.e., $F2$ increases with tongue body fronting in the neighbourhood of alveolopalatal and dental and alveolar consonants.

The $F1 \times F2$ ellipses for mid front /E/ in Sitgetà and Rossellonès show that this vowel is slightly more variable than Eastern Catalan /e/ while exhibiting a similar degree of variability to Eastern Catalan /ɛ/. On the other hand, mid back /O/ in Gironí and Rossellonès, but not in Sitgetà, appears to be more variable than both /o/ and /ɔ/ in

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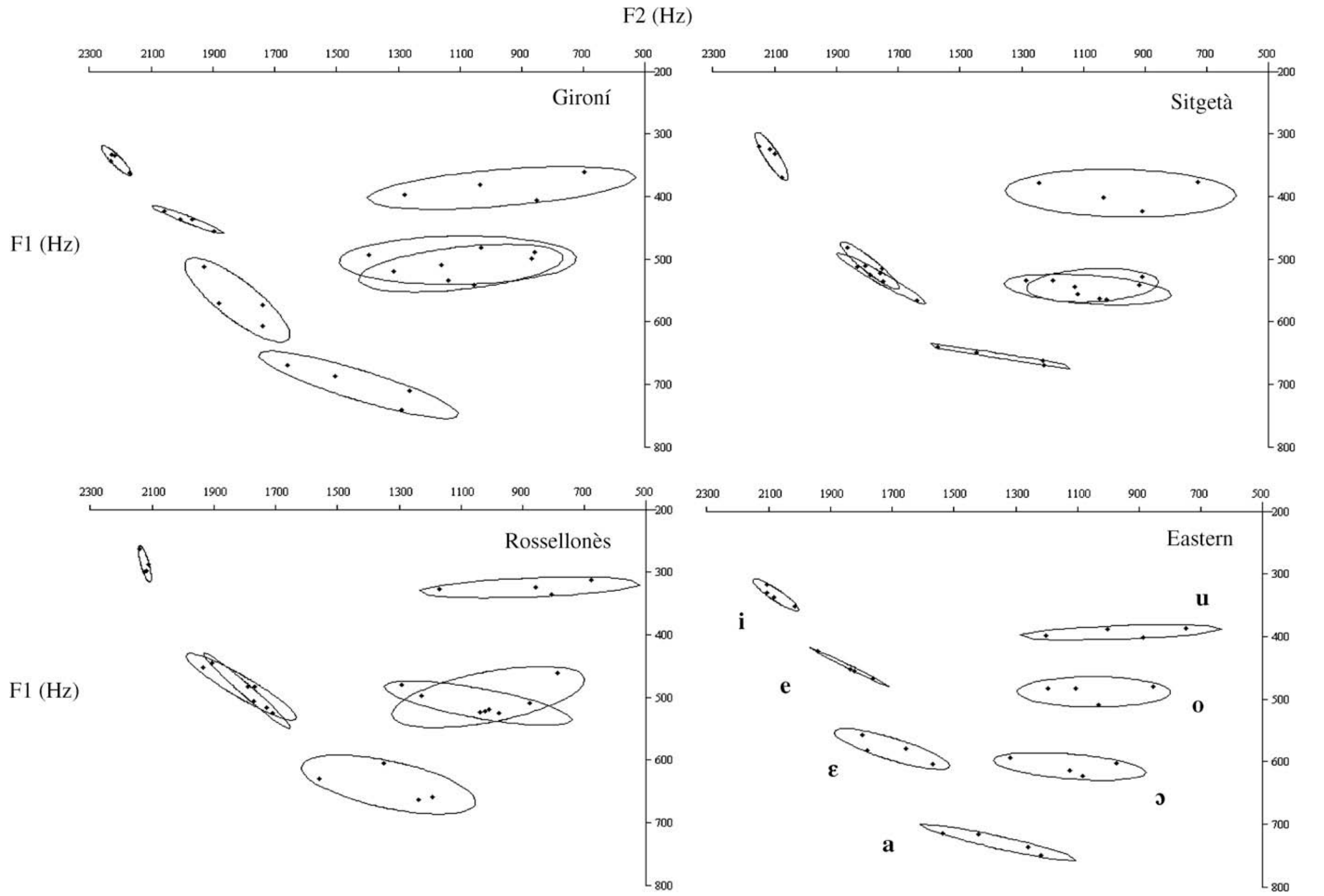

Fig. 5. $F1 \times F2$ ellipses for the vowels of Gironí, Sitgetà, Rossellonès and Eastern as a function of four consonant context conditions: labial; dental and alveolar; alveolopalatal; /l, r/. Ellipses with radii of two standards deviations have been drawn along axes oriented along the principal components of each vowel cluster.

Eastern. As pointed out in Section 3.5.1., this dialect-dependent variability difference is mostly associated with $F2$ and applies to the other back vowels /a/ and /u/ as well.

In summary, the data presented here yield partial confirmation of the ADT hypothesis that the presence of a smaller number of vowels in a vowel system should result in more individual vowel variability. Standard deviations and ellipses support this hypothesis for mid back vowels to some extent but not for mid front vowels.

4. Discussion

Data for four minor Catalan dialects (Felanitxer, Gironí, Sitgetà, Rossellonès) reveal that the high and low members of mid vowel pairs undergoing neutralization exhibit very small, essentially non-significant differences in $F1$ frequency conforming to the same formant frequency differences occurring in dialects where neutralization has not taken place (Majorcan, Eastern). In view of the small size of these $F1$ differences, it has been assumed that the vowels of the mid vowel pairs in question are neutralized perceptually and, therefore, can be treated as near-mergers. We believe that small $F1$ differences between the two mid high and mid low vowel cognates should be related to the influence of the prestigious Eastern Catalan dialect spoken in Barcelona to which Gironí and Sitgetà belong to. Moreover, specific lexical items may have contributed more than others to this scenario perhaps since the speech material was elicited using a reading task.

Our data suggest that mid vowel merging has been achieved through a two-stage neutralization process. Firstly, one mid vowel pair gets neutralized either through approximation of one vowel to another as for /ε/ towards /e/ in Felanitxer, or else through mutual approximation as for /o/ and /ɔ/ in Gironí. These two actions lead to a six vowel system where, at least for the Catalan dialects under analysis, the neutralization outcome may occupy a relatively high position within the mid vowel space. At a second stage, the other mid vowel pair undergoes neutralization, as in Rossellonès where mid front vowels ceased to oppose each other after mid back vowels did, and the two mid vowels of the outcoming five vowel system appear to acquire a higher $F1$ frequency than /E/ or /O/ of a six vowel system. Possible evidence for the implementation of this second vowel shift may be found in Felanitxer where the neutralization between /e/ and /ε/ through merging by

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approximation appears to have caused /o/ and /ɔ/ to approach each other through a simultaneous downward and upward $F1$ movement. Several aspects about the sound changes just discussed may be attributed to a trend towards symmetry not only regarding phonemic inventory (i.e., consecutive neutralization of the mid front and mid back vowel pairs) but also formant frequency location (i.e., similar placement of mid vowels agreeing in degree of height along the $F1$ frequency dimension). Another finding is more consistent with the hypothesis that unbalanced vowel systems may differ regarding optimality and, therefore, that unoptimal systems ought to undergo restructuring, i.e., a preference for the six vowel system of Felanitxer over that of Gironí to approximate the two contrasting mid high and mid low vowels. The fate of a presumable on-going neutralization process between /o/ and /ɔ/ in Felanitxer but not between /e/ and /ɛ/ in Gironí needs to be investigated in future studies using data for next generations of speakers of these two dialects: the optimality principle will prove to hold in case that merger takes place in the former dialect but not in the latter; on the other hand, the finding that merger operates on the two dialects will be in support of the role of systemic symmetry. Regarding the relationship between symmetry and optimality, it should be also noticed that optimal systems may drive towards symmetry, as exemplified by Rossellonès where the optimal but asymmetrical six vowel system /i, e, ɛ, a, O, u/ was replaced by the more symmetrical system /i, E, a, O, u/.

The prediction of the adaptive dispersion theory (ADT) that $F1 \times F2$ spaces and formant frequency distances between point vowels ought to be larger for more crowded vowel systems than for less crowded ones has not been confirmed. Most instances where smaller vowel systems were less disperse than larger vowel systems turned out to be non-significant. It was also found that vowel system dispersion proceeds independently of vowel duration.

The ADT claim that individual vowel variability should be inversely dependent on vowel system size has not been clearly confirmed either. Thus, mid back rounded vowels turned out to be more variable in Gironí and Rossellonès than in Eastern, but the same trend was found to hold for other non-mid back vowels as well.

In summary, the present study provides some evidence in support of a symmetrical arrangement between mid front and mid back vowels agreeing in height, as well as of a trend for unoptimal systems to drive towards optimality. Little or no support was found for the ADT predictions regarding vowel space dispersion and individual vowel variability as a function of the number of system vowels. This finding is consistent with Livjn (2000) in revealing that ADT may work out for vowel systems differing considerably in number of vowels but not for vowel systems of a similar size. In agreement with Recasens and Espinosa (2006), it appears to be in support of the notion that the acoustic characteristics of vowel spaces may not only be associated with vowel system size but also with dialect-specific trends in vowel production.

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