Stress, dispersion, and variability of Catalan, French, and Spanish vowels

Rebecca Cao
Advised by Nicholas Henriksen
University of Michigan

1. Introduction

1.1 Background

While the Romance languages share many of the same consonant phonemes, with little to no variation in their production, they differ the most in their vowel inventory (Calebrese, 2003). Not only do they have distinct vowel phonemes, but also the production of the same vowel is different. When speakers of one Romance language attempt to learn another, they struggle the most with these nuances in the vowel productions (Towell and Hawkins, 1994). This struggle is reflected in popular culture, which often mocks foreign accents, such as in the French *comédie* "Un fil à la patte" ("Cat Among the Pigeons") by Georges Feydeau. In the play, the main source of entertainment is the maiden's suitor, a South American minister of war who is known simply as "*le général*". His strong Spanish accent in French is emphasized throughout for comedic effect. Although the accent may be comical in this case, in reality many learners of foreign languages make a consistent effort to reduce their accents. Thus, the findings of this study may aid non-native speakers of Catalan, French, and Spanish to achieve more accurate vowel productions. The results of the study may be useful for native speakers of all languages, but they will be particularly useful for native speakers of one of the three languages who are learning another one of them because they will be able to compare the unique differences between their native language and the language they are acquiring.

For this project, the three Romance languages of Catalan, French, and Spanish were chosen in order to limit the scope. Of note, the three languages developed closely geographically and chronologically, thus reducing the possibility of random historical variations or foreign language influence (Alkire and Rosen, 2010). Furthermore, the languages are widely spoken in close proximity to one another, increasing the possibility that a native speaker of one would attempt to learn another. In Andorra, for example, Catalan is the official language, but citizens often speak French, Spanish, or Portuguese. Catalan was chosen instead of the other languages in the Iberian Peninsula because of the significant number of speakers (6 million in Eastern Spain and 10 million total) and its political impact. Catalonia's struggle for independence has only been heightened by the euro crisis. Moreover, Catalan is a dominant language on the Internet, the 15th most used language on Wikipedia and the 8th most used on blogs (CCRTVI). In a world in which 90% of languages have no Internet presence, that is a remarkable feat for a language ranked 88th in the world in number of speakers (Generalitat de Catalunya). The inclusion of French and Spanish is rather self-explanatory. They are the most commonly taught foreign languages in the United States. French is the official language in 29 countries and 77 million people in Europe speak French natively. In total, 335 million are able to speak French, which gives a sense of the incredible number of L2 speakers. The number of French speakers is constantly growing, leading to predictions of 1 billion speakers by the year 2060. Spanish is the official language in 20 countries and it currently has 410

native speakers. It has now superseded French as the most studied second language worldwide. Both French and Spanish are official languages of the United Nations.

In addition to exploring the effect of stress on vowel duration, this study aims to investigate how the size and nature of vowel inventories affect the duration, distribution, and variability of vowels. According to the Adaptive Dispersion Theory, there are two major trends in vowel dispersion in vowel systems. The first prediction states that the maximum range between peripheral vowels should increase with an increase in the number of vowels in the vowel inventory (Liljencrants and Lindblom, 1972). Additionally, an increase in the number of vowels should result in an increase in the distance between vowels and an expansion of the overall vowel system (Bradlow et al., 1996). The second prediction states that adjacent vowels should be roughly equidistant in identical vowel systems while becoming less distinct as the vowel inventory increases (Flemming, 2002). Adjacent vowels are those that are situated next to one another when plotted according to F1 and F2 values, for example /i/ and /e/.

Subsequent research, however, has contradicted the Adaptive Dispersion Theory. While certain larger inventories, such as German (14 vowels) and American English (11), tend to display a more peripheral vowel location than certain smaller inventories (Jongman et al., 1989), this relationship has not held up in other studies. For example, the F1 x F2 space covered by /i, e, a, o/ is similar for English, Spanish, and Greek, despite the fact that English has 11 vowel contrasts whereas the latter two have only 5. Contrary to the Adaptive Dispersion Theory, it has been proposed that the acoustic contrast between two adjacent vowels may be smaller or larger due to historical or phonological reasons rather than the number of vowels in the inventory (Recasens and Espinosa, 2006). In their 2006 study of Catalan dialects, Recasens and Espinosa found that their results supported a modified, non-strict version of the Adaptive Dispersion Theory. In the study, they found that, though intervocalic distances may not be necessarily identical across all dialects, dialects exhibiting the same vowel system size have similar degrees of overall vowel dispersion. Consequently, their findings support the Adaptive Dispersion Theory in that there is a correlation between vowel inventory size and vowel dispersion. Their results, however, do not necessarily support the hypothesis that an increase in vowel system size corresponds with an increase in the overall vowel dispersion.

Within this theoretical framework, this paper will test the two hypotheses proposed by the Adaptive Dispersion Theory for the vowel systems of Catalan, French, and Spanish. The expected outcome is that French, with 12 vowel contrasts, will have the greatest range between peripheral vowels and the least equidistant adjacent vowels. On the other hand, Spanish (5 vowel contrasts) should exhibit the smallest range between peripheral vowels and the most equidistant vowels. Finally, Catalan (7 vowel contrasts) should behave in an intermediate manner between the extremes of French and Spanish. In testing the Adaptive Dispersion Theory, it should be noted that vowel contrasts are better measured by F1 (variable related to articulatory opening and intensity) than F2 (variable related to tongue fronting and rounding).

1.2 Research questions

This project seeks to compare the common vowel phonemes of Catalan, French, and Spanish: /a, e, i, o, u/. Firstly, we will investigate the effect of stress using the measurement of duration. Due to the vowel reduction occurring in the Catalan /a, e, o/ (to [ə], [ə], and [u] respectively), these will be excluded from the study. Secondly, we will compare the bases of articulation for the three languages by plotting the F1 and F2 values of those vowels. By examining acoustic data, this study will address the following research questions:

(1) Within each language, is there an effect of word stress on vowel duration for /a, e, i, o, u/?

(2) Within each language, is the vowel duration for /a, e, i, o, u/ affected differently by word stress?

(3) Across the three languages, is there any difference in the effect of stress on vowel duration for /a, e, i, o, u/?

(4) When /a, e, i, o, u/ are in stressed position, is there any difference in their F1 and F2 values across the three languages?

(5) When plotted according to F1 and F2, is there any difference in the vowel dispersion of the languages?

(6) When plotted according to F1 and F2, is there any difference in intervowel distance of the languages?

1.3 Vowel inventories

For the purposes of this study, we will focus on the Eastern dialect of Catalan, spoken in Catalonia. The Eastern dialect exhibits 7 vowel phonemes: /a/, /e/, /i/, /o/, /u/, /ɛ/, and /ɔ/. While /ə/ exists in Majorcan Catalan, it does not exist in the Eastern dialect, only manifesting as [ə], an allophone of /a/ and /e/ during vowel reduction (Recasens and Espinosa, 2009). Similarly, /o/ experiences vowel reduction to [ɔ]. The 7 vowels of the Catalan vowel system are charted according to front-back and high-mid-low in Table 1.3.1.

Table 1.3.1. Catalan vowel system.

Catalan vowels					
	FRONT				BACK
HIGH	i				u
MID		e		o	
		ɛ		ɔ	
LOW			a		

The French vowel system is the most complex of the three languages with 12 vowel contrasts. In addition to /a/, /e/, and /i/, its front vowel inventory also includes /ɛ/ and the rounded front vowels /y/, /ø/, /œ/, and /ə/. Its back vowel inventory contains /ɑ/, /ɔ/, /o/, and /u/ (Hacquard et al., 2006). The 12 vowels of the French vowel system are charted according to front-back and high-mid-low in Table 1.3.1.

Table 1.3.2. French vowel system.

French vowels					
	FRONT				BACK
HIGH	i, y				u
MID		e, ø		o, ɔ	
		ɛ, œ	ə		
LOW			a	ɑ	

The least complex of the three languages, Spanish has 5 distinct vowel phonemes: /a/, /e/, /i/, /o/, and /u/ (Hacquard et al., 2006). The 5 vowels of the Spanish vowel system are charted according to front-back and high-mid-low in Table 1.3.1.

Table 1.3.3. Spanish vowel system.

Spanish vowels					
	FRONT				BACK
HIGH	i				u
MID		e		o	
LOW			a		

2. Methodology

2.1 Data set

The data are taken from a read corpus of utterances that were part of a sentence elicitation task designed for this study. Participants were presented a PowerPoint presentation slideshow and each slide contained a single sentence. Each sentence was read three times. The speaking task lasted approximately five minutes. In order to generate digital recordings, a Tascam portable digital recorder and Shure microphone were used. From these utterances, the target vowels were extracted. The database for this study consists of 1485 vowels (75 tokens x 3 productions x 6 speakers and 45 tokens x 3 productions x 1 speaker). The 75 tokens pertain to French and Spanish. Out of the 75, 50 come from the effect of stress comparison (i.e. Table 2.1 and 2.2) and 25 come from the vowel dispersion comparison (i.e. Table 2.4). The 45 tokens pertain to Catalan, which only includes /i/ and /u/ in the effect of stress comparison. Of the 45, 20 come from the effect of stress comparison (i.e. Table 2.3) and 25 come from the vowel dispersion comparison (i.e. Table 2.4).

2.2 Speaking task

In order to compare vowels in similar environments, each vowel was placed between the same consonants in stressed and unstressed positions. For example, the pair of words “barco” and “barato” were used to compare /a/ in stressed and unstressed position. In “barco”, /a/ is placed between /b/ and /ɾ/ and is in stressed position. In “barato”, /a/ is still placed between /b/ and /ɾ/ but is in unstressed position. This method allows for a direct comparison without additional confounding factors. The difficulty of the French language is that stress always falls on the last syllable. This was only a small challenge for /a/, /i/, /o/, and /u/ but proved to be a greater challenge for /e/. The French /e/ is only produced by the orthographic “é”, which is never followed by a consonant in stressed position. Therefore, the experiment resolves this issue by using phrases for /e/ in stressed position. For example, “regardé par les enfants” is used to produce /dep/ in stressed position. As for the unstressed counterpart, “départ” was used. For Catalan, only /i/ and /u/ were compared in stressed and unstressed positions, since /a/ and /e/ often experience vowel reduction to [ə] and /o/ to [u]. The set of manipulation conditions and lexical combinations provided in Tables 2.1-2.3 was used to compare the effect of stress on vowel duration for the three languages.

Table 2.1. Spanish speaking task.

Target vowel	Stressed	Unstressed
/a/	*b̲arco* / ‘boat’	*b̲arato* / ‘cheap’
/a/	*p̲ato* / ‘duck’	*p̲atinar* / ‘to skate’
/a/	*m̲ano* / ‘hand’	*m̲anera* / ‘way’
/a/	*c̲asa* / ‘house’	*c̲asarse* / ‘to marry’
/a/	*sábado* / ‘Saturday’	*s̲abor* / ‘flavor’
/e/	*p̲ero* / ‘but’	*p̲ersonal* / ‘personal’
/e/	*m̲enos* / ‘less’	*m̲entir* / ‘to lie’
/e/	*s̲erio* / ‘serious’	*s̲ervir* / ‘to serve’
/e/	*p̲eso* / ‘weight’	*p̲esar* / ‘to weigh’
/e/	*b̲eso* / ‘kiss’	*b̲esar* / ‘to kiss’
/i/	*p̲iso* / ‘ground’	*p̲isar* / ‘to step on’
/i/	*l̲isto* / ‘ready’	*l̲istón* / ‘ribbon’
/i/	*m̲isa* / ‘mass’	*m̲isión* / ‘mission’
/i/	*r̲itmo* / ‘rhythm’	*r̲itual* / ‘ritual’
/i/	*r̲isa* / ‘laugh’	*r̲isotada* / ‘guffaw’
/o/	*p̲ostre* / ‘pastry’	*p̲osible* / ‘possible’
/o/	*t̲orpe* / ‘clumsy’	*t̲ortuga* / ‘turtle’
/o/	*t̲oro* / ‘bull’	*tortilla* / ‘pancake’
/o/	*j̲oya* / ‘jewel’	*j̲oyería* / ‘jeweller’
/o/	*j̲oroba* / ‘hump’	*j̲orobado* / ‘hunchback’
/u/	*p̲unto* / ‘point’	*p̲untual* / ‘punctual’
/u/	*r̲uta* / ‘route’	*r̲utina* / ‘routine’
/u/	*s̲upo* / ‘he/she found out’	*s̲uperar* / ‘to surpass’
/u/	*t̲ubo* / ‘tube’	*t̲ubería* / ‘piping’
/u/	*t̲urbio* / ‘turbid’	*t̲urismo* / ‘tourism’

Table 2.2. French speaking task.

Target vowel	Stressed	Unstressed
/a/	*car* / ‘because’	*caractère* / ‘character’
/a/	*part* / ‘portion’	*partir* / ‘to leave’
/a/	*battre* / ‘to fight’	*bateau* / ‘boat’
/a/	*matte* / ‘matte’	*matin* / ‘morning’
/a/	*capital* / ‘capital’	*talon* / ‘heel’
/e/	*regardé par les enfants* / ‘watched by the children’	*départ* / ‘departure’
/e/	*austérité maintenue* / ‘maintained austerity’	*témoin* / ‘witness’
/e/	*déclaré par le gouvernement* / ‘declared by the government’	*répondre* / ‘to respond’
/e/	*condé français* / ‘French cop’	*défense* / ‘defense’
/e/	*défilé géant* / ‘gigantic parade’	*léger* / ‘light’
/i/	*pire* / ‘worse’	*pirate* / ‘pirate’
/i/	*lire* / ‘to read’	*lirette* / ‘weaving’
/i/	*mire* / ‘sight’	*miroir* / ‘mirror’
/i/	*tir* / ‘shooting’	*tirer* / ‘to shoot’
/i/	*piste* / ‘track’	*piston* / ‘piston’
/o/	*côte* / ‘coast’	*côté* / ‘side’
/o/	*l’hôte* / ‘the host’	*l’hôtel* / ‘the hotel’
/o/	*prône* / ‘sermon’	*prôner* / ‘to advocate’
/o/	*trône* / ‘throne’	*trôner* / ‘to sit on the throne’
/o/	*contrôle* / ‘control’	*contrôler* / ‘to control’
/u/	*moule* / ‘mold’	*moulin* / ‘mill’
/u/	*touche* / ‘touch’	*toucher* / ‘to touch’
/u/	*cour* / ‘court’	*courant* / ‘common’
/u/	*coupe* / ‘cut’	*couper* / ‘to cut’
/u/	*bouge* / ‘move’	*bouger* / ‘to move’

Table 2.3. Catalan speaking task.

Vowel	Stressed	Unstressed
/i/	*intrínsec* / ‘instrinsic’	*principi* / ‘beginning’
/i/	*política* / ‘politics’	*finalitat* / ‘purpose’
/i/	*cita* / ‘appointment’	*publicitat* / ‘advertising’
/i/	*límit* / ‘limit’	*limitar* / ‘to limit
/i/	*discutit* / ‘discussed’	*constitució* / ‘constitution’
/u/	*grup* / ‘group’	*ruptura* / ‘break’

/u/	*p<u>ú</u>blic* / ‘public’	*p<u>u</u>blicar* / ‘to publish’
/u/	*p<u>u</u>nt* / ‘point’	*p<u>u</u>ntual* / ‘punctual’
/u/	*com<u>u</u>ns* / ‘common’	*com<u>u</u>nicació* / ‘communication’
/u/	*res<u>u</u>m* / ‘summary’	*s<u>u</u>mari* / ‘summary’

Finally, to perform a comparison of vowel dispersion, the same vowel was placed between the same consonants in stressed position for all three languages. For example, the Spanish word “cargo”, the French word “carte”, and the Catalan word “càrrega” were used to compare the /a/ of each language in stressed position between /c/ and /ɾ/. The set of manipulation conditions and lexical combinations provided in Table 2.4 was used for this purpose.

Table 2.4. Vowel dispersion comparison.

Vowel	Spanish	French	Catalan
/a/	*b<u>a</u>rba* / ‘beard’	*b<u>a</u>rbe* / ‘beard’	*b<u>a</u>rba* / ‘beard’
/a/	*c<u>a</u>rgo* / ‘post’	*c<u>a</u>rte* / ‘card’	*c<u>à</u>rrega* / ‘career’
/a/	*m<u>a</u>lo* / ‘bad’	*m<u>a</u>l* / ‘badly’	*m<u>a</u>la* / ‘bad’
/a/	*p<u>a</u>rte* / ‘part’	*p<u>a</u>r* / ‘by’	*p<u>a</u>rc* / ‘park’
/a/	*b<u>a</u>lde* / ‘bucket’	*b<u>a</u>lle* / ‘bullet’	*b<u>a</u>la* / ‘bullet’
/e/	*s<u>e</u>rio* / ‘serious’	*pens<u>e</u>r rapidement* / ‘to think quickly’	*c<u>e</u>rcle* / ‘circle’
/e/	*r<u>e</u>sto* / ‘rest’	*malgr<u>é</u> son handicap* / ‘in spite of his/her handicap’	*pr<u>é</u>stec* / ‘loan’
/e/	*pres<u>e</u>nte* / ‘present’	*dépens<u>e</u>r n’importe quoi* / ‘spend anything’	*c<u>e</u>nt* / ‘hundred’
/e/	*p<u>e</u>ro* / ‘but’	*développ<u>e</u>r rapidement* / ‘to develop quickly’	*p<u>e</u>ra* / ‘pear’
/e/	*d<u>e</u>ntro* / ‘inside’	*regard<u>e</u>r n’importe quoi* ‘to watch anything’	*d<u>e</u>nt* / ‘tooth’
/i/	*p<u>i</u>so* / ‘ground’	*p<u>i</u>ste* / ‘track’	*p<u>i</u>sta* / ‘track’
/i/	*c<u>i</u>ta* / ‘appointment’	*s<u>i</u>te* / ‘site’	*c<u>i</u>ta* / ‘appointment’
/i/	*l<u>í</u>mite* / ‘limit’	*l<u>i</u>me* / ‘file’	*l<u>í</u>mit* / ‘limit’
/i/	*t<u>í</u>tulo* / ‘title’	*t<u>i</u>tre* / ‘title’	*discut<u>i</u>t* / ‘discussed’
/i/	*m<u>í</u>nimo* / ‘minimum’	*m<u>i</u>ne* / ‘mine’	*m<u>i</u>na* / ‘mine’
/o/	*c<u>o</u>n* / ‘with’	*c<u>ô</u>ne* / ‘cone’	*c<u>o</u>tna* / ‘rind’
/o/	*r<u>o</u>nda* / ‘circle’	*pr<u>ô</u>ne* / ‘sermon’	*fur<u>ó</u>ncol* / ‘boil’
/o/	*g<u>ó</u>ndola* / ‘gondola’	*escarg<u>o</u>t New-yorkais* / ‘New York snail’	*seg<u>o</u>ns* / ‘according’

/o/	*roncha* / ‘welt’	*trône* / ‘throne’	*ronda* / ‘round’
/o/	*donde* / ‘where’	*dos nu* / ‘nude back’	*dóna* / ‘he/she gives’
/u/	*turno* / ‘turn’	*tour* / ‘tower’	*turc* / ‘Turkish’
/u/	*curso* / ‘course’	*cour* / ‘court’	*curi* / ‘cure’
/u/	*catapulta* / ‘catapult’	*poule* / ‘hen’	*pulcre* / ‘neat’
/u/	*puro* / ‘pure’	*pour* / ‘for’	*pur* / ‘pure’
/u/	*múltiple* / ‘multiple’	*moule* / ‘mold’	*multa* / ‘fine’

2.3 Measurement

Using Praat (Boersma and Weenink, 2013), each sound file was divided into segments containing the separate sentences. From those smaller sound files, the target vowel was marked by hand and a duration script was run. For the vowels of Table 2.4, a separate script was run to extract F1 and F2 values.

2.4 Speakers

Three speakers of Spanish (2 female and 1 male), three speakers of French (2 female and 1 male), and one speaker of Catalan (female) participated in the study. Speakers’ ages ranged from 30 to 50 and they all had post-secondary education. The Spanish speakers were born and raised in Chile and Mexico. The French speakers were born and raised in Paris. The Catalan speaker was born and raised in the Barcelona region. Therefore, the effect of regional accents (within languages) should be minimal. For Catalan phonology, the Eastern dialect was used. All speakers were living in the United States at the time of recording, which took place in Ann Arbor, Michigan.

2.4 Hypotheses

Using the Adaptive Dispersion Theory as a framework, the following hypotheses are proposed. First, the null hypothesis (H0) is that all languages will show similar behavior with respect to the effect of stress on vowel duration, vowel space dispersion, and intervowel distance. That is, the change in vowel duration from stressed to unstressed position will be the same for Catalan, French, and Spanish. Moreover, the maximum range in peripheral vowels and the distance between adjacent vowels will be identical for the three languages. The first hypothesis (H1) is that, with respect to vowel duration in stressed and unstressed positions, Catalan will behave differently than French and Spanish because it is the only language that exhibits vowel reduction in unstressed position. This could potentially impact the effect of stress on the remaining vowels /i, u/. The second hypothesis (H2) is that French will have the greatest vowel space dispersion and the least consistent intervowel distance, while Spanish will have the smallest vowel space dispersion and equidistant intervowel distance and Catalan will fall somewhere in between.

3. Results

After a Praat script was used to extract the durations of /a, e, i, o, u/ using the words listed in Tables 2.1-2.3, the values were then averaged.

In Table 3.1, the mean durations of stressed and unstressed /a, e, i, o, u/ for each language are specified. The French /a/ is, on average, 37.3 milliseconds longer in stressed position. The Spanish /a/ is 32.2 longer and the Catalan /a/ is not measured due to vowel reduction in unstressed position. The two values are almost identical, though the Spanish /a/ is longer both in stressed and unstressed position. This suggests that, with regard to stress, /a/ behaves similarly in both languages. The French /e/ is 18.2 milliseconds longer in stressed position than unstressed and the Spanish /e/ is 49.9 milliseconds longer. A possible explanation for the smaller change in duration for French may be that the stressed /e/ is always found at the end of the word, leading it to be cut short. This, however, does not account for the significantly higher difference found in Spanish. Furthermore, the unstressed French /e/ at 80.1 milliseconds is longer than the unstressed Spanish /e/ at 72.2. Again, the Catalan /e/ is omitted due to vowel reduction to /ə/ in unstressed position. The Catalan /i/ exhibits the smallest change of all vowels at 5.3 milliseconds. The French /i/ is 32.4 milliseconds longer in stressed position than unstressed and the Spanish /i/ is 29.7 seconds longer. The French /o/ is 27.3 milliseconds longer in stressed position and the Spanish /o/ is 36.8 seconds longer. The Catalan /o/ is omitted due to vowel reduction to /ɔ/ in unstressed position. Finally, with regard to /u/, Catalan is 29.5 milliseconds longer in stressed position than unstressed, French is 23.3 milliseconds longer, and Spanish is 38.0 milliseconds longer.

When all five vowels are averaged, Catalan shows an overall difference of 17.3 milliseconds between stressed and unstressed position. French has a difference of 27.7 milliseconds and Spanish has a difference of 37.4 milliseconds. These values, however, must be placed in the context of percent increase. For Catalan, vowel duration in stressed position is 22.5% longer than in unstressed position. For French, vowel duration in stressed position is 34.5% longer. For Spanish, vowel duration in stressed position is 46.5% longer. Thus, while there is variability for individual vowels, overall Spanish experiences the greatest effect of stress and Catalan the smallest. Furthermore, in both stressed and unstressed positions, Spanish vowels are the longest, whereas Catalan vowels are the shortest and French vowels fall in the middle. This could be a possible influence for the different effects of stress.

Table 3.1. Mean durations of individual vowels.

Descriptive Statistics

Dependent Variable: Duration (ms)

Vowel	Language	Stress	Mean	Std. Deviation	N
a		S	114.576009389959	29.456928857809	45
	French	U	77.310048214894	15.318707657663	45
		Total	95.943028802427	29.934638391575	90
		S	126.705902854435	30.198270543270	45
	Spanish	U	94.519657415649	19.734647565571	45
		Total	110.612780135042	30.087926516709	90
	Total	S	120.640956122197	30.282370546327	90
		U	85.914852815272	19.581314421422	90

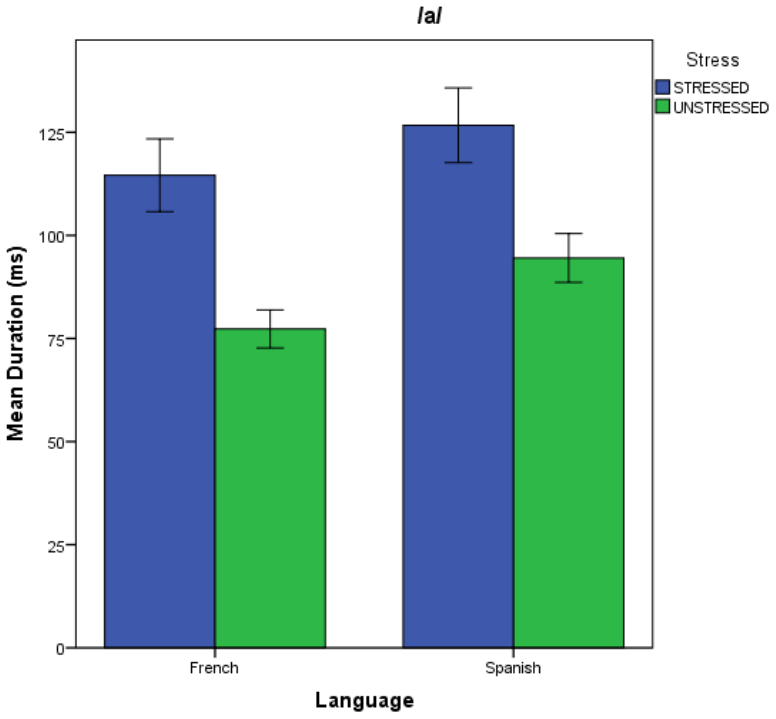
		Total	103.277904468734	30.818049297077	180
		S	98.365860417908	31.461988286396	45
	French	U	80.138026693130	19.267692489997	45
		Total	89.251943555519	27.511824466626	90
		S	122.057921269862	26.190296338568	45
e	Spanish	U	72.154819574847	15.883384520929	45
		Total	97.106370422355	33.066766850150	90
		S	110.211890843885	31.150999732038	90
	Total	U	76.146423133988	18.010327726207	90
		Total	93.179156988937	30.585886893520	180
		S	82.459448700845	12.069086377230	15
	Catalan	U	77.249371485300	19.517668478188	15
		Total	79.854410093072	16.162982384963	30
		S	112.256487143085	48.577423564317	45
	French	U	79.916176093361	24.316528586028	45
		Total	96.086331618223	41.513403541225	90
i		S	101.10566629812	21.264628344847	45
	Spanish	U	71.362269598572	15.720719092508	45
		Total	86.233967948348	23.861817996240	90
		S	103.220844146353	36.176103975442	105
	Total	U	75.869244080157	20.546362972701	105
		Total	89.545044113255	32.391562455056	210
		S	105.829814465518	26.456833515603	45
	French	U	78.512556815185	16.101584141622	45
		Total	92.171185640351	25.746415697407	90
		S	120.549313704241	37.694170938601	45
o	Spanish	U	83.657365346392	17.454285322179	45
		Total	102.103339525316	34.599631591316	90
		S	113.189564084879	33.215464965855	90
	Total	U	81.084961080789	16.896156601908	90
		Total	97.137262582834	30.815748321411	180
u		S	105.999342139068	12.829753400035	15
	Catalan	U	76.486882778291	10.559138720486	15
		Total	91.243112458679	18.935244633874	30
		S	103.516504893862	35.433123285427	45
	French	U	80.245827208602	24.685838171892	45
		Total	91.881166051232	32.540339788649	90
		S	118.538083773491	27.900349496995	45
	Spanish	U	80.503177250739	17.358060321523	45
		Total	99.520630512115	29.992117881660	90

		S	110.309015448732	30.571435374261	105
	Total	U	79.819128022331	20.054548077743	105
		Total	95.064071735532	29.978675916959	210
		S	94.229395419956	17.119927115908	30
	Catalan	U	76.868127131795	15.423277889135	30
		Total	85.548761275876	18.374317606291	60
		S	106.908935262066	35.316809345469	225
	French	U	79.224527005035	20.176813093888	225
		Total	93.066731133550	31.896417753797	450
Total		S	117.791377580031	30.197400495867	225
	Spanish	U	80.439457837240	19.127923223757	225
		Total	99.115417708635	31.416963913114	450
		S	111.217608858480	32.780340282516	480
	Total	U	79.646750840553	19.409839971587	480
		Total	95.432179849517	31.214247236452	960

For Figures 3.2-3.6, the mean values in Table 3.1 were graphed in separate charts according to vowel. The dependent variable is duration in milliseconds, the independent variable is language, and separate bars are used for stressed and unstressed positions.

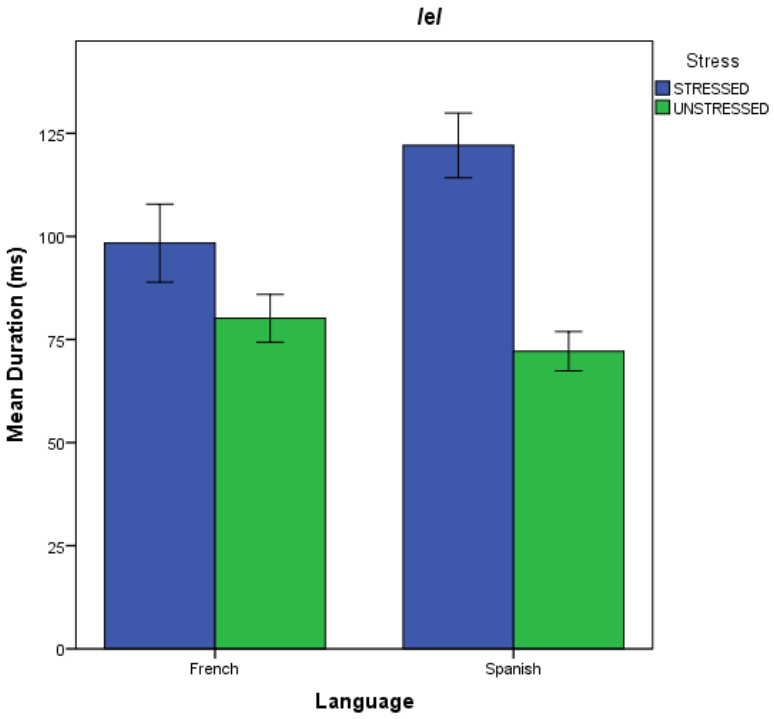
In Figure 3.2, the bars show that the effect of stress on /a/ is similar for French and Spanish. While the durations are overall longer in Spanish, the difference in duration is actually slightly greater in French. That is, the French /a/ is 48.3% longer in stressed position than in unstressed position and the Spanish /a/ is 34.1% longer. Thus, one may conclude that the French /a/ is more affected by stress than is the Spanish /a/.

Figure 3.2. Effect of stress on /a/ in French and Spanish.



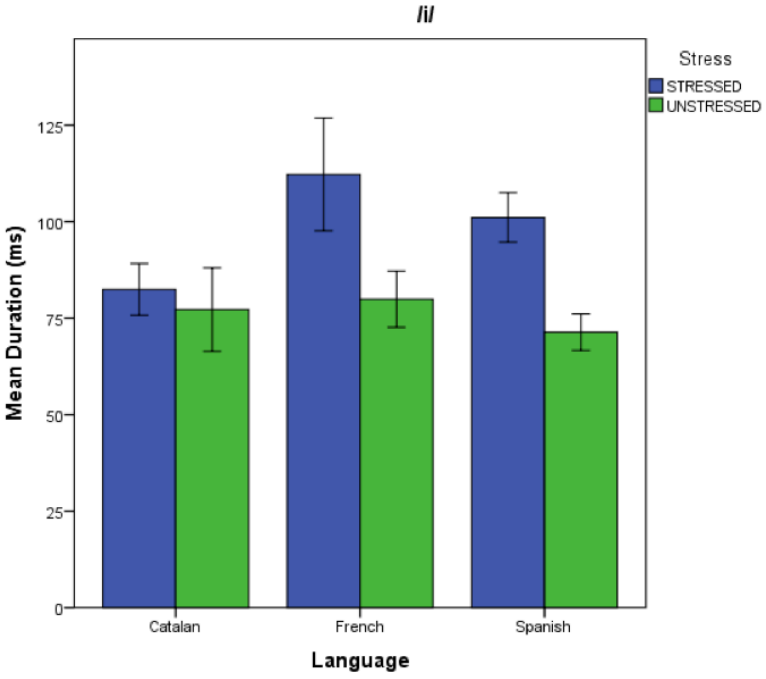
In Figure 3.3, one notes the marked difference in the effect of stress on the French and Spanish /e/. While the stressed Spanish /e/ is longer than its French equivalent, the unstressed Spanish /e/ is actually shorter than the French one. The French /e/ is only 22.8% longer in stressed position than in unstressed position, but the Spanish /e/ is 69.1% longer in stressed position. Thus, the Spanish /e/ is much more affected by stress than the French /e/.

Figure 3.3. Effect of stress on /e/ in French and Spanish.



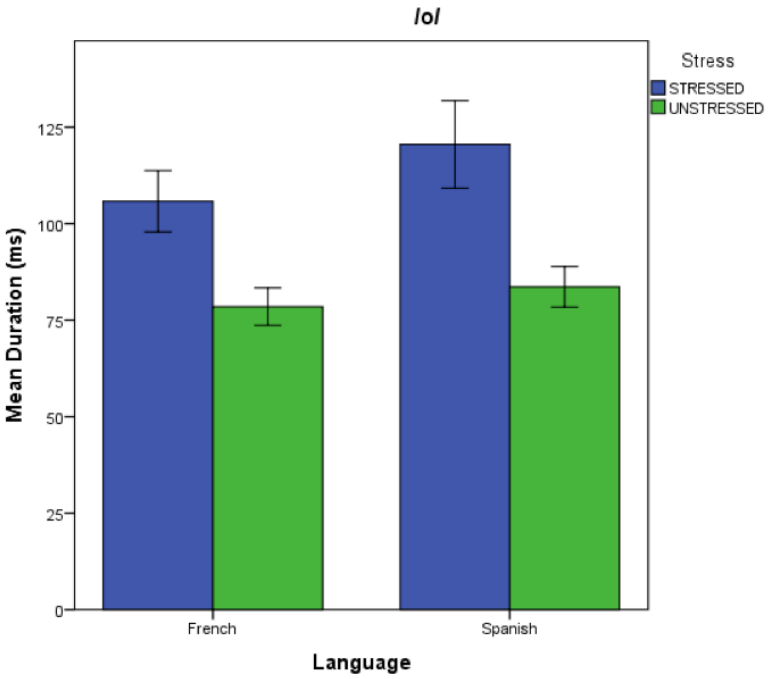
In Figure 3.4, the unique effect of stress on the Catalan /i/ is apparent. French and Spanish behave similarly, though the French /i/ is longer in both stressed and unstressed positions. On the other hand, the Catalan /i/ does not appear to have a significant difference in vowel duration between stressed and unstressed positions.

Figure 3.4. Effect of stress on /i/ in Catalan, French, and Spanish.



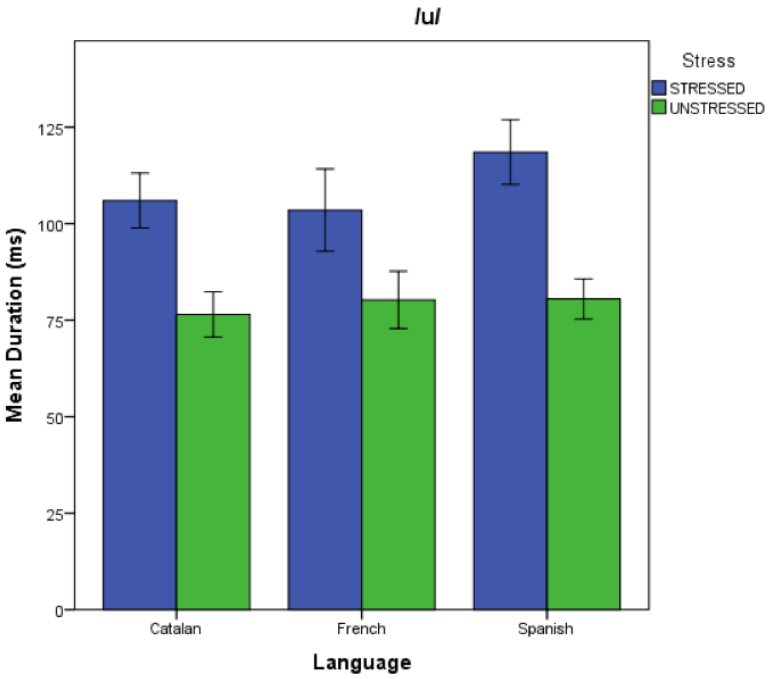
In Figure 3.5, we observe that the French and Spanish /o/ behave similarly, though the Spanish /o/ is longer in both stressed and unstressed positions.

Figure 3.5. Effect of stress on /o/ in French and Spanish.



In Figure 3.6, one can see that the effect of stress on the three languages is most consistent for /u/. Spanish shows the greatest difference with an increase of 47.2% from unstressed to stressed position, while French has the smallest difference with an increase of 29.1%. Lastly, Catalan falls in the middle with an increase of 38.6% from unstressed to stressed.

Figure 3.6. Effect of stress on /u/ in Catalan, French, and Spanish.



To obtain the data shown in Table 3.7, a Praat script was run to extract the F1 and F2 values of /a, e, i, o, u/ from the words listed in Table 2.4.

In Table 3.7, the average values of F1 and F2 for /a, e, i, o, u/ in stressed position are specified. The F1 values do not vary to a great extent except in the case of the Catalan /a/, which is much lower than the French and Spanish equivalents (1049.79 compared to 793.68 and 849.24, respectively).

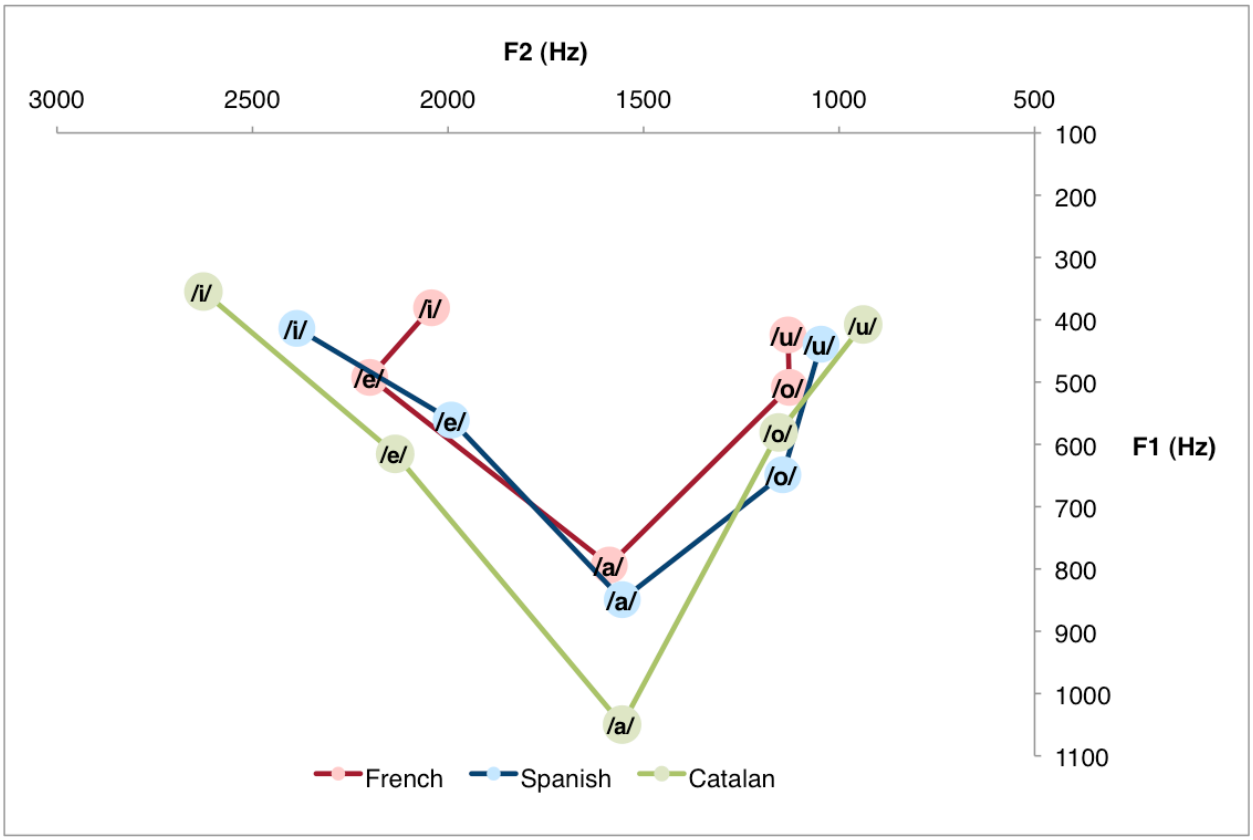
Table 3.7. Mean F1 and F2 values of /a, e, i, o, u/ for Catalan, French, Spanish.

Catalan		
Vowel	F1 (Hz)	F2 (Hz)
i	354.595691	2625.54352
e	615.203318	2135.31547
a	1049.78691	1554.92941
o	580.805503	1154.51225
u	407.461192	938.390784

French		
Vowel	F1 (Hz)	F2 (Hz)
i	380.711563	2042.12724
e	492.455026	2200.22445
a	793.679927	1587.68171
o	508.452816	1127.10175
u	424.270959	1130.8724
Spanish		
Vowel	F1 (Hz)	F2 (Hz)
i	413.7721521	2386.58618
e	560.9193427	1991.67027
a	849.2417673	1554.47715
o	648.7389681	1143.88395
u	439.1452463	1046.15531

In Figure 3.8, the F1 and F2 values for /a, e, i, o, u/ in stressed position have been plotted in order to compare the dispersion of each vowel system. For posterior vowels, there is little variation regarding /o/ and /u/ for the three languages, which is evident in their cluster in the back/high area. As one would expect, /u/ is higher than /o/. For anterior vowels, there is more variation, though /i/ is still higher than /e/ for all three languages. For the low vowel /a/, one notes the exceptionally low Catalan /a/. The other unexpected findings are the French /i/, which is more back than the French /e/, and the French /u/, which is slightly more front than the French /o/. With regard to vowel dispersion, French and Spanish have similar structures. The distance between periphery vowels is the smallest for French, with 412.97 Hz separating the F1 values of /i/ and /a/. In comparison, the Spanish /i/ and /a/ are separated by 435.47 Hz while the Catalan equivalents are separated by 695.19 Hz. Clearly, the Catalan vowel dispersion is exceptional. Its adjacent vowels are much further apart, especially /a, e/ and /a, o/.

Figure 3.8. Average F1 and F2 values for French, Spanish, and Catalan.



4. Discussion

With regard to this paper's research questions, this section will attempt to answer them using the above results.

(1) Within each language, is there an effect of word stress on vowel duration for /a, e, i, o, u/?

Yes. Figures 3.2-3.6 clearly show that there is an effect of word stress on vowel duration for the French and Spanish /a, e, i, o, u/ and the Catalan /u/. With the exception of the Catalan /i/, all vowels increase significantly in duration from unstressed to stressed position. On the other hand, the Catalan /i/ varies insignificantly from unstressed to stressed position, thus having no apparent effect of stress.

(2) Within each language, is the vowel duration for /a, e, i, o, u/ affected differently by word stress?

Yes. For example, while the Catalan /u/ is 38.6% longer in stressed position than in unstressed position, there appears to be no effect of stress on the Catalan /i/. Whereas the French /a/ is 48.3% longer in stressed position than in unstressed, the French /e/ is only 22.8% longer. Finally, whereas the Spanish /a/ is 34.1% longer in stressed position, the Spanish /e/ is 69.1% longer. One can see that, within languages and across languages, there is a great degree of variability.

(3) Across the three languages, is there any difference in the effect of stress on vowel duration for /a, e, i, o, u/?

Yes. As Table 3.1 shows, Catalan is least affected by stress and Spanish is most affected by stress. That is, for Catalan /i/ and /u/, vowel duration in stressed position is 22.5% longer than in unstressed position. For French, vowel duration in stressed position is 34.5% longer. For Spanish, vowel duration in stressed position is 46.5% longer. However, one should note that these averaged differences do not account for the variability within the languages. The Catalan effect of stress is lowered greatly by the exceptional behavior of the /i/. If one only considers the Catalan /u/, the difference between stressed and unstressed positions is 38.6%. This percentage is quite similar to the difference for French. As for Spanish, the overall difference is skewed by the extreme effect of stress on the /e/, where it is 69.1% longer in stressed position than unstressed. Disregarding the Spanish /e/, the average effect of stress would be 41.7%, which is still greater than Catalan and French, but much less extreme.

With the exception of the Catalan /i/ and the Spanish /e/, the effect of stress on vowel durations appears to be similar for Catalan, French, and Spanish.

(4) When /a, e, i, o, u/ are in stressed position, is there any difference in their F1 and F2 values across the three languages?

Yes. Table 3.7 and Figure 3.8 show that the articulation for Catalan /a/ is much lower than its French and Spanish equivalents. Whereas the posterior vowels are similarly positioned, the anterior vowels vary to a greater extent.

(5) When plotted according to F1 and F2, is there any difference in the vowel dispersion of the languages?

Yes. Figure 3.8 shows that Catalan has a much greater range (695.19 Hz) between periphery vowels than do French or Spanish. French has the smallest range at 412.97 Hz, similar to Spanish at 435.47 Hz.

(6) When plotted according to F1 and F2, is there any difference in intervowel distance of the languages?

Yes. Figure 3.8 shows that French has the least distance between adjacent vowels whereas Catalan has the largest distance between adjacent vowels. For example, the French /i/ and /e/ are separated by 193.7 Hz, whereas the Catalan /i/ and /e/ are separated by 556.1 Hz.

As for the hypotheses, the null hypothesis (H0) was that all languages would show similar behavior with respect to the effect of stress on vowel duration, vowel space dispersion, and intervowel distance. With the answers to the above research questions, H0 can be effectively rejected. The first hypothesis (H1) was that, with respect to vowel duration in stressed and unstressed positions, Catalan would behave differently than French and Spanish because it was the only language that exhibits vowel reduction in unstressed position. H1 is supported by the distinct behavior of the Catalan /i/. Whether or not this is due to the vowel reduction in /a, e, o/, this study cannot confirm that. The second hypothesis (H2) was that French would have the greatest vowel space dispersion and the least consistent intervowel distance, while Spanish would have the smallest vowel space dispersion and equidistant intervowel distance and Catalan would fall somewhere in-between. H2 is partially supported by the findings of this study. The fact that French has the least consistent intervowel distance supports H2. On the other hand, the fact that it has the smallest vowel space dispersion does not support H2. That Spanish has a small vowel space dispersion and roughly equidistant adjacent vowels supports H2. The Catalan vowel dispersion contradicts H2, as it has the largest vowel space dispersion by far and its adjacent vowels are also roughly equidistant.

Within the theoretical framework of the Adaptive Dispersion Theory, it was previously hypothesized that French would have the greatest range between peripheral vowels and the least equidistant adjacent vowels because it had the greatest number of vowels in its inventory at 12. On the other hand, Spanish was predicted to exhibit the smallest range between peripheral vowels and the most equidistant vowels because it had the smallest vowel inventory with 5. Finally, Catalan was thought to behave in a moderate manner between the extremes of French and Spanish because it had 7 vowels in its inventory. The data in Table 3.7 and Figure 3.8, however, contradict these hypotheses. Catalan has the largest range between peripheral vowels and French has the smallest. Although French appears to have the least equidistant vowels, one must note that only 5 out of its 12 total vowels were included in this study. Thus, it is difficult to determine whether adjacent vowels are equidistant. Consequently, the results of this study do not support the Adaptive Dispersion Theory in that vowel space dispersion was not found to increase with an increase in vowel inventory. This is due to the exclusion of certain vowels and As Recasens and Espinosa (2006) proposed, the

differences in vowel system dispersions may be due to historical and phonological causes and not the size of the vowel inventory.

5. Conclusion

The first purpose of the study was to examine the effect of stress on vowel duration for the vowels that Catalan, French, and Spanish have in common: /a, e, i, o, u/. In general, the findings were expected, as there was a similar effect of stress for all languages. There was a degree of variability for individual vowels in that /a, e, i, o, u/ were not affected identically by stress. For example, the Catalan /i/ was unexpected because there was no significant effect of stress and the Spanish /e/ was unexpected because it showed a much greater effect of stress than the other Spanish vowels. Overall, Spanish showed the greatest effect of stress, French showed a moderate effect of stress, and Catalan showed the smallest effect of stress. This result suggests that the vowel reduction of Catalan /a, e, o/ could affect the behavior of /i, u/ under the influence of stress. Further research would be necessary to confirm this proposal.

The second purpose of the study was to test the Adaptive Dispersion Theory by comparing the vowel dispersions of Catalan, French, and Spanish. The first prediction of the theory states that the maximum range between peripheral vowels should increase with an increase as the vowel inventory increases. Additionally, an increase in vowel inventory should result in an increase in the distance between vowels and an expansion of the overall vowel system. This prediction is contradicted by the results of this study, as Catalan had the largest vowel dispersion and French the smallest. The second prediction states that adjacent vowels should be roughly equidistant in identical vowel systems while becoming less distinct as the vowel inventory increases. This prediction is partially supported by the results of this study. There were no identical vowel systems involved in this study, thus making a comparison of identical vowel systems impossible. However, the hypothesis that adjacent vowels become less distinct as vowel inventory increases is supported by the study. For example, French (the largest vowel inventory with 12 vowel contrasts) had less equidistant adjacent vowels than Spanish (the smallest vowel inventory with 5 vowel contrasts). Yet the exclusion of the remaining 7 vowels in the French vowel system makes this observation unreliable. In order to adequately test the Adaptive Dispersion Theory, it would be necessary to compare languages with the same vowel inventories and include all vowels in the comparison.

There are a variety of ways in which this study could be improved. As only one Catalan speaker was available, the data for Catalan do not have a large enough sample size to be conclusive. The unique behavior of Catalan could be attributed to peculiarities of this particular speaker and not the general population of Catalan speakers. Thus, it would be necessary to include more Catalan speakers in order to confirm the findings of this study. Moreover, there was a gender disequilibrium in the study with 5 women and only 2 men. To improve this aspect, ideally the gender ratio would be equally balanced. With regard to the methodology of this study, the distinction between the French /r/ and the Catalan and Spanish /ɾ/ was disregarded. It is possible that the production of a vowel followed by /r/ could be affected differently than the production of a vowel followed by /ɾ/. As /ɾ/ does not exist in French, the solution would be to avoid using both /r/ and /ɾ/ in cross-language comparisons.

Additionally, the speaking task required speakers to repeat a phrase three times. Inevitably, subjects would speed up each time they voiced the same phrase. To avoid this effect, the identical phrases could be separated from one another and dispersed throughout the speaking task.

On a practical level, L2 learners of Catalan, French, or Spanish can use the results of this study to improve the accuracy of their vowel production. For example, a native speaker of French who is learning Spanish can exaggerate the effect of stress on vowel duration, as well as increase the duration of vowels in general. A native speaker of Spanish who is learning Catalan can produce a lower /a/. A native speaker of Catalan who is learning French can minimize the acoustic contrasts of adjacent vowels. One must note that the application of this study is limited to one aspect of stress, namely duration. To further expand the application of this research, one would need to examine pitch and amplitude as well (Ortega-Llebaria and Prieto, 2011).

6. Acknowledgements

This research was funded by the Honors Summer Fellowship of the University of Michigan Honors Program. The project was advised by Nicholas Henriksen, Assistant Professor of Spanish Linguistics. I thank Steven Dworkin for his guidance and Lorenzo García-Amaya for serving as a second reader. Lastly, I thank an anonymous reviewer for comments on a previous manuscript version.

7. References

(2007, June 22). *The Catalan Language Occupies Position 88*. Retrieved from http://www20.gencat.cat/portal/site/Llengcat/menuitem

Alkire, T., Rosen, C. (2010). *Romance Languages: A Historical Introduction*. Cambridge: Cambridge University Press.

Aguilera, J., Novella, A. (2009, February 10). *El català, un exemple d'èxit a Internet*. Retrieved from http://blogs.ccrtvi.com/espaiinternet.php?itemid=24990.

Boersma, P., Weenink, D. (2014). Praat (Version 5.3.68) [Software]. Available from http://www.fon.hum.uva.nl/praat/

Bradlow, A.R., Torretta, G.M., Pisoni, D.B. (1996). Intelligibility of normal speech I: global and fined-grained acoustic-phonetic talker characteristics. *Speech Communication* 20, 255-272.

Calebrese, A. (2003). On the Evolution of the Short High Vowels of Latin into Romance. *Romance Linguistics* 2002, 63-94.

Flemming, E.S. (2002). *Auditory Representations in Phonology*. New York and London: Routledge.

Hacquard, V., Walter, M., Marantz, A. (2006). The effects of inventory on vowel perception in French and Spanish: An MEG study. *Brain and Language* 100, 295-300.

Jongman, A., Fourakis, M., Sereno, J.A. (1989). The acoustic vowel space of modern Greek and German. *Language and Speech* 32, 221-248.

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

Ortega-Llebaria, M. and Prieto, P. (2011). Acoustic correlates of stress in Central Catalan and Castilian Spanish. *Language and Speech* 54, 1-25.

Recasens, D., Espinosa, A. (2006). Dispersion and variability in Catalan vowels. *Speech Comm.* 48, 645-666.

Recasens, D., Espinosa, A. (2009). Dispersion and variability in Catalan five and six peripheral vowel systems. *Speech Communication* 51, 240-257.

Towell, R., Hawkins, R. (1994). Approaches to Second Languages Acquisition. Bristol: Multilingual Matters Ltd.