The Perception of the Vowel Continuum in British and US English Speakers

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Abstract

In this paper, the perception of the /æ/-/ɛ/ vowel continuum was analysed in British and United States English speakers by testing their word identification across the pan-pen continuum. A clear difference was found between the two speaker groups, with the U.S. speakers continuing to perceive 'pan' beyond the British speakers, presumably due to /æ/-tensing in U.S. dialects, particularly before nasal codas. It was found that the amount of /æ/-tensing across phonetic environments in a U.S. speaker's dialect as well as their exposure to British English affected how they perceived the continuum. The results prove Bell-Berti's (1979) argument that speech production and perception are closely related, and the steep drop in perception from 'pan' to 'pen' displayed by both speaker groups may prove that vowel perception is categorical, in contrast to popular opinion, though a discrimination task would have to be run before any reliable claim can be made.

Keywords: Vowels, Perception, U.S. English, British English, Sociolinguistics, Sociophonetics, Dialectology

Papers from the Lancaster University Postgraduate Conference in Linguistics and Language Teaching, Vol 11–12. Papers from LAEL PG 2016–2017
Edited by Márton Petykó, Olena Rossi, and Shuo Yu

1. Introduction

1.1. British and United States English Short-a Pronunciation

The production of short-a by British and United States speakers is one of the key linguistic features that differentiates the dialects of these two countries. In England during the Great Vowel Shift, the short-a or TRAP vowel was fronted and raised to [æ] (Lass 2000). Then in the early twentieth century, the short-a vowel in Britain was lowered again to a fully open [a] sound (Wells 1997).

Across the United States, short-a configuration is complex. U.S. speakers follow a system of /æ/-tensing (fronting and raising) which varies depending on dialect, according to Labov et al. (2006).

The first system is the nasal system where there is a wide acoustic separation between vowels that occur before nasals and vowels that do not. Short-a is more tensed before nasals than before other consonants in this system. The nasal system is concentrated in New England, New Jersey outside the New York City area, and across the Midland, particularly the large cities of Pittsburgh, Columbus and Indianapolis.

The second is the raised /æ/ system where all short-a vowels are tensed. They then develop a second mora and glide inwards ([ɛə], [eə], [iə]). It is one of the triggering events of the Northern Cities Vowel Shift and is dominant in the Inland Northern area of the United States. Labov found that for many speakers in this area, the second mora consists of a second steady state instead of an inglide. As a result, the short-a tends to break in to two morae of equal length, with one in mid front position and the other in low front or central position.

The third system of /æ/-tensing in the U.S. is the Southern breaking system that occurs in Southern American English. This is when the vowel begins in a low front position, is then followed by a [j] and then returns to a position not far acoustically from the origin. It is most favoured by nasal codas, with /n/ showing the highest percentage of breaking.

The fourth is the short-a split system which occurs in New York City and the Mid-Atlantic. In New York City, short-a is tensed before voiceless fricatives, voiced stops and nasals whereas in the Mid-Atlantic, short-a is tensed before nasals and voiceless fricatives apart from /ʃ/. It is referred to as a split system because the variations of short-a in these areas can become distinct phonemes.

The final system is the continuous short-a system, the most common short-a configuration in the West and the Midland. It is a continuum of allophones of the short-a vowel from low

front to mid position. The most conservative phonetic environments where short-a is lowest is before voiceless velars, and the most advanced where short-a is highest is before nasal codas. From these five systems, it can be deduced that for all speakers in the United States, short-a undergoes a process of tensing before nasals in closed syllables.

What is clear to see from previous research is that short-a production is markedly different between British and United States English Speakers, with British speakers far more likely to produce a more open short-a vowel than U.S. speakers, particularly before nasal codas. This experiment will seek to find if this difference in short-a production between British and United States English speakers is reflected in their perception of the /æ/-/ɛ/ vowel continuum, specifically the pan-pen continuum.

1.2. The Relationship between Vowel Production and Perception

Before being able to make a hypothesis on how British and United States speakers will perceive the pan-pen continuum, it is first necessary to consider the relationship between a speaker's vowel production and that same speaker's perception. There are numerous studies that support the claim that an individual's production and perception are closely related. Bell-Berti et al. (1979) found that speaker differences in the production of the /i/ vowel were strongly linked to differences in their perception of /i/. This finding was taken as evidence for a shared mechanism mediating the production and perception of vowels. There are less sociolinguistic investigations on the relationship between vowel production and perception, though there is one notable study that is closely related to this current experiment in terms of its aim, the subjects investigated and the experimental methods implemented. Fridland & Kendall (2012) examined how speakers in the U.S. perceived the /e/-/ɛ/ vowel continuum. Southern speakers, who typically display /e/ centralization and /ɛ/ peripheralization due to the Southern Vowel Shift (Feagin 1986; Labov et al. 2006; Thomas 2001) sustained a longer /e/ perception along the continuum than Westerners and Northerners, whose vowel production along this continuum are not dissimilar. Results also suggested that vowel perception depends on both the speaker's own production of speech and what that speaker is exposed to in their region. For example, Southerners who actively engaged in the Southern Vowel Shift displayed a longer /e/ perception than Southerners who did not, though these non-shifters still displayed a longer /e/ perception than Northerners and Westerners, presumably due to exposure to vowel shifters in their region. It is therefore important in this experiment to consider that a speaker's

dialect may not be similar to those that live in their region, which could influence their perception of the /æ/-/ɛ/ continuum. Unfortunately however, due to time constraints, speakers were not recorded in this study and assumptions had to be made on the participant's dialect based on region of origin.

It is also worth noting that if a U.S. speaker has spent an extended period of time in the U.K., their perceptual boundaries may have shifted towards a more British perception of the /æ/-/ɛ/ continuum. As will be seen in the "Participants" section, many of the U.S. speakers in this experiment lived in the U.K. for at least eight months, and thus results may be affected. Literature supports this proposal: Clarke & Garret (2004) and Nygaard (et al. 2005) found that listener perception adapts rapidly to foreign-accented speech while Clarke & Luce (2005) discovered that listeners shift their Voice Onset Time categorization boundary for stop consonants to match a speaker's production after less than two minutes with that speaker.

Furthermore, Clopper & Pisoni (2007) and Sumner & Samuel (2009) (as well as Fridland & Kendall (2012)) have found that speaker perception depends on the production of the individual and the dialect of the speakers around them.

Based on the findings of previous research, it is hypothesized that in this experiment, speakers from the U.S. who in most cases display /æ/-tensing before nasal codas will maintain a longer 'pan' perception along the pan-pen continuum than British speakers whose production of short-a before nasal codas is more open, close to the cardinal vowel /a/. Additionally, in the case that a U.S. speaker has spent a significant amount of time in the United Kingdom, it is possible that the speaker's pan-pen perception will be affected. If the perception of the pan-pen continuum is proven to be different between British and U.S. speakers, it would support the claim of Bell-Berti et al. (1979) that a speaker's production and perception are correlated.

1.3. The Perception and Categorization of Vowels

Liberman et al. (1957) was the first to introduce the concept that speech sounds, in particular consonants, are perceived categorically. In his experiment, 14 synthetic stimuli were produced that varied along a particular acoustic continuum, being the direction and extent of the second formant (F2) transition. The first formant (F1) was kept consistent with a rising transition, a marker for voiced stops (Delattre et al. 1955). It was found that in an identification task, participants displayed clear categorical boundaries between the consonants /b/, /d/ and /g/. The shift in perception from one consonant to another along the continuum was abrupt, indicating

that the phoneme boundaries were stable and sharp. In one-step, two-step and three-step discrimination tasks, participants found it easier to discriminate stimuli that lay on either side of a phoneme boundary than stimuli within the same category. Figure 1 shows the results of Liberman's identification and discrimination experiments.

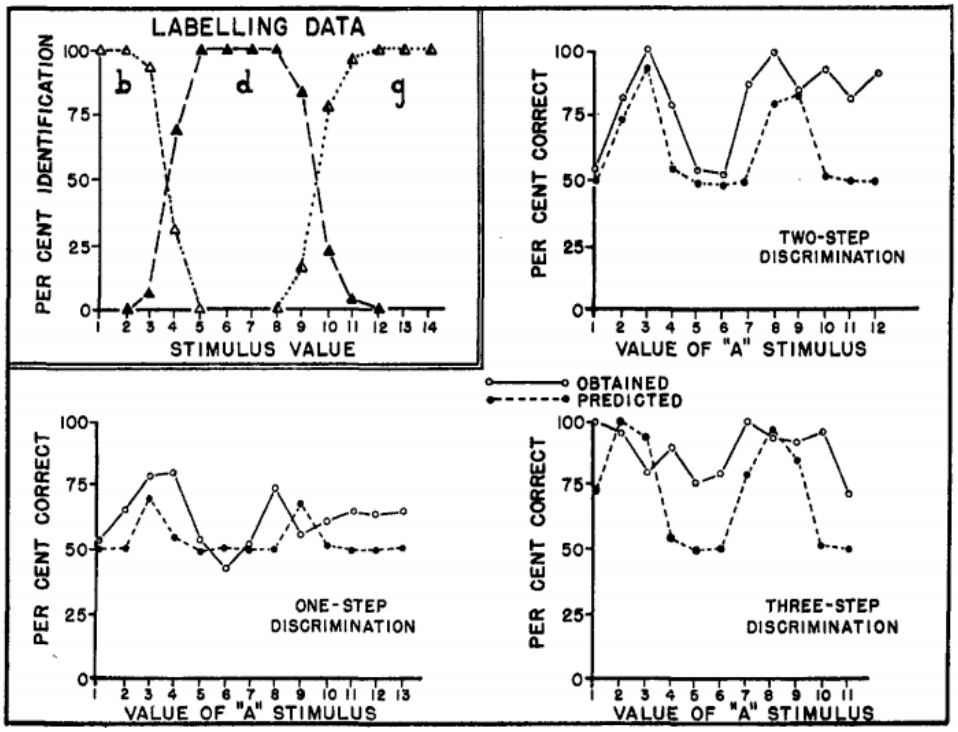

Figure 1: The results of Liberman's experiment. (Liberman et al. 1957)

Fry et al. (1962) proposed that the boundaries between vowel phonemes are less sharply defined than consonants. In his vowel phoneme identification task, speakers displayed a gradual shift in the perception of one vowel to another compared to Liberman's experiment where shifts were sudden. Moreover, speakers performed consistently above chance in the one-step, two-step and three-step discrimination tasks, meaning that participants were able to discriminate vowel stimuli even a step apart, regardless of where they lay in relation to phoneme boundaries. Figures 2 and 3 show the results of Fry's identification and discrimination experiment.

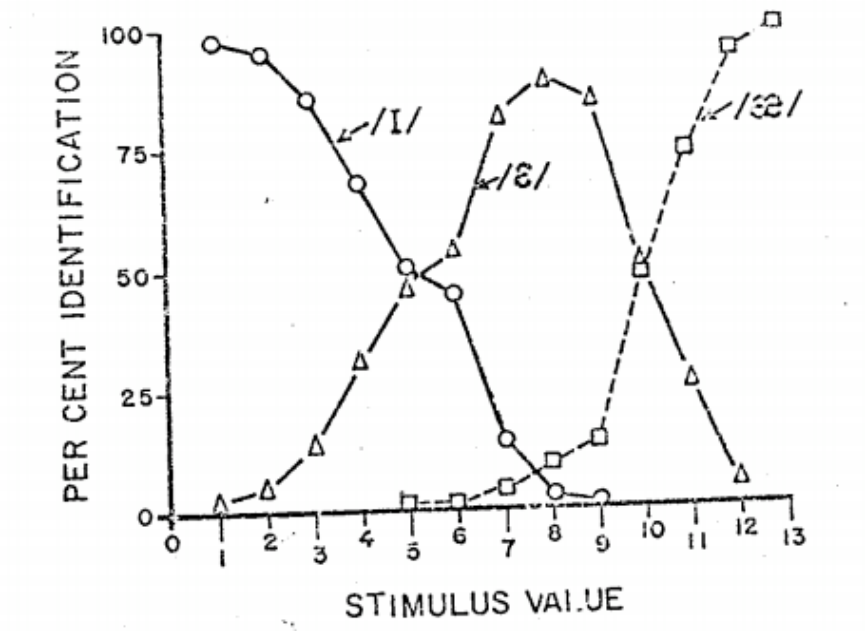

Figure 2: ***The results of Fry's identification experimen (Fry et al. 1962)***

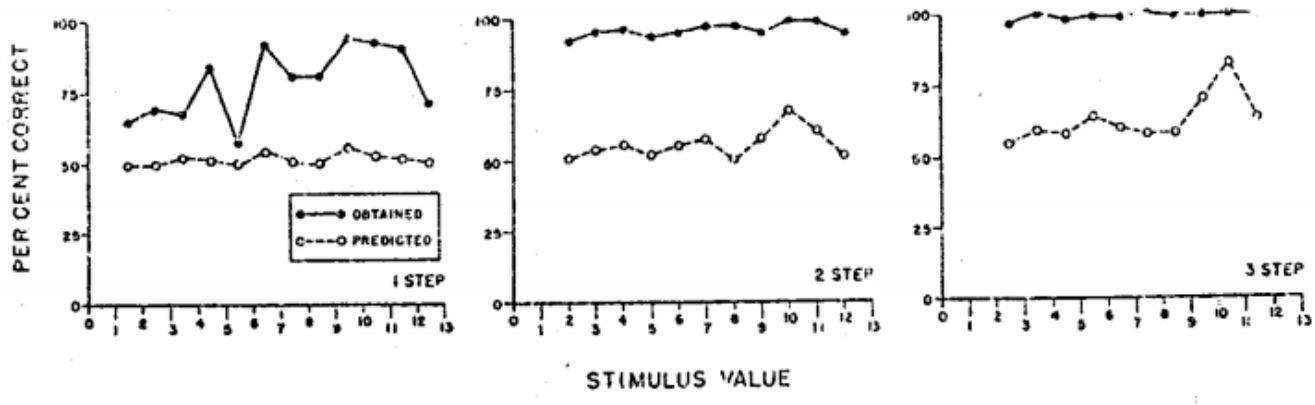

Figure 3: ***The result of Fry's discrimination experiment (Fry et al.1962)***

If previous literature is to be assumed true, participants in this study would be expected to show a more continuous, rather than categorical, perception of the /æ/-/ɛ/ vowel continuum in this experiment. However, should speakers collectively show an abrupt shift from perceiving 'pan' to 'pen', it could be argued that perhaps vowel categorization is sharper than previously believed. This experiment however cannot prove that vowels are perceived categorically since

a discrimination task would have to be run in order to provide any credible arguments on vowel perception. Due to time constraints, this was not possible.

2. Method

2.1. Participants

Fourteen participants took part in the study. Seven were native speakers of Standard Southern British English aged 21-35 (mean = 24.7 years), two of the seven British speakers were female and five were male. They were all raised in the South of England and had lived in Oxford for at least eight months. The other seven participants were native speakers of United States English aged 18-21 (mean = 20.4 years). Two of them were male and five were female. They were all raised in the U.S.; two in Massachusetts, one in Michigan, one in Maryland, one in Iowa, one who had lived for over three years in Massachusetts and Illinois, and one who moved frequently between Massachusetts, North Carolina and Pennsylvania. They had all lived in Oxford for at least eight months, apart from one speaker, participant 1, who had been living in the country for 4 days on the day of her experiment. Table 1 shows the U.S. participants, their region of origin, and assumed dialect based on region according to Labov et al. (2006).

Table 1: ***Names of the U.S. speakers, their region of origin and assumed dialect (Labov et al. 2006)***

Participant	***Region of Origin***	***Assumed Dialect***
1	*Highland and Livonia, Michigan*	*Inland Northern American English*
2	*Middleborough, Massachusetts*	*Northeastern New England English*
3	*Worcester, Massachusetts*	*Northeastern New England English*
4	*Hagerstown, Maryland*	*Western Pennsylvania English*
5	*Des Moines, Iowa*	*Midland American English*
6	*- Sherborn, Massachusetts*	*- Northeastern New*

	- Charlotte, North Carolina *- Kennett Square, Pennsylvania*	*England English* *- Southern American English* *- Mid-Atlantic American English*
7	*- Martha's Vineyard, Massachusetts* *- Chicago, Illinois*	*- Southeastern New England English* *- Inland Northern American English*

2.2 Materials

Each participant took part in a word identification task, listening to 100 synthetic stimuli ranging across the pan-pen continuum (10 unique stimuli multiplied by 10 and played in random order). The stimuli were created with the IPOX Speech Synthesizer (Dirksen & Coleman 1995) which is able to generate synthetic words using a phonemic input. Initially two sound files were created; a "pan" .wav file, which would be stimulus 1, and a "pen" .wav file, which would be stimulus 10. The files were 16-bit sound files sampled at 11025Hz. The /æ/ vowel in stimulus 1 had an F1 value of 838 Hz, an F2 value of 1560 Hz, an F3 value of 2430 Hz and an F4 value of 3300 Hz. The /ɛ/ vowel in stimulus 10 had an F1 value of 620 Hz, an F2 value of 1660 Hz, an F3 value of 2430 Hz and an F4 value of 3300 Hz. Eight more stimuli were then created that moved in equal steps across the acoustic continuum from stimulus 1 to 10. This process was carried out by creating a parameter file of stimulus 1 and 10 through IPOX, duplicating the stimulus 1 parameter file eight times and then adjusting the formant values so that there were 10 parameter files moving in uniform steps from stimulus 1 to 10. These parameter files were then converted back to .wav files, giving 10 sound files ranging across the pan-pen continuum. These sounds were then embedded in to a word identification task, run on a computer using a Praat script (Boersma & Weenink 2016). The script played the ten sound files five times in random order, giving 50 stimuli, asking the listener to identify whether they heard the word "pan" or "pen", to which they would respond by pressing a button on the keyboard with their right hand. The script was then run a second time with the participant using their left hand, meaning each listener heard 100 stimuli.

Participants were required to answer with their right hand in the first block and then their left hand for the second block to reduce any bias towards a particular answer since there is evidence that language dominance in the right or left hemisphere of the brain is linked to handedness (Knecht et al. 2000).

2.3. Procedure

Before the task begun, each participant was required to fill out a questionnaire on his or her language background in order to confirm that they were native English speakers and to extract information on where they were raised in the U.K. or U.S. The participant was then sat in a soundproof room in front of a computer screen and keyboard, and was told that they would hear a block of fifty words through headphones that would sound like the word "pan" or "pen". After hearing each sound, they would have to identify which word they heard. The screen showed the word "pan" on the left hand side and "pen" on the right as shown in Figure 4, and participants were required to press the letter "Q" on the keyboard with their right index finger if they heard the word "pan" and the letter "W" with their right middle finger if they heard the word "pen".

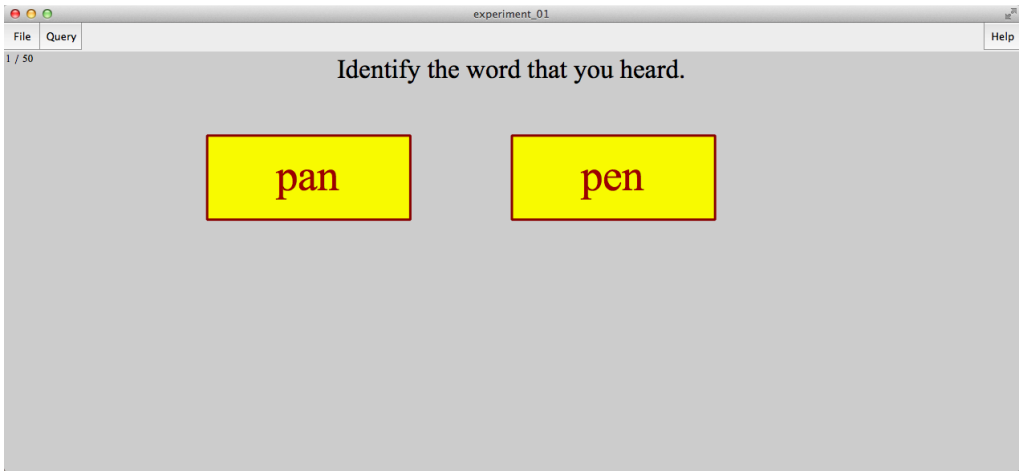

Figure 4: ***A screenshot of the first block of the identification task***

It was specified to the participant that there was no right or wrong answer to each stimulus and that they must choose their answer as quickly as possible, in order to force the participant in to acting on instinct as to which word they heard, reflecting normal communication as realistically as possible. Once the block was over, participants then re-sat the test, this time by pressing the letter "Q" with their left middle finger if they heard the word "pen" and the letter "W" with their left index finger if they heard the word "pan". Moreover, in the second block,

"pen" was on the left hand side of the screen and "pan" was on the right as shown in Figure 5. A shorter block of 25 stimuli was run before the main experiment in order for participants to familiarize themselves with the task and to test sound volume.

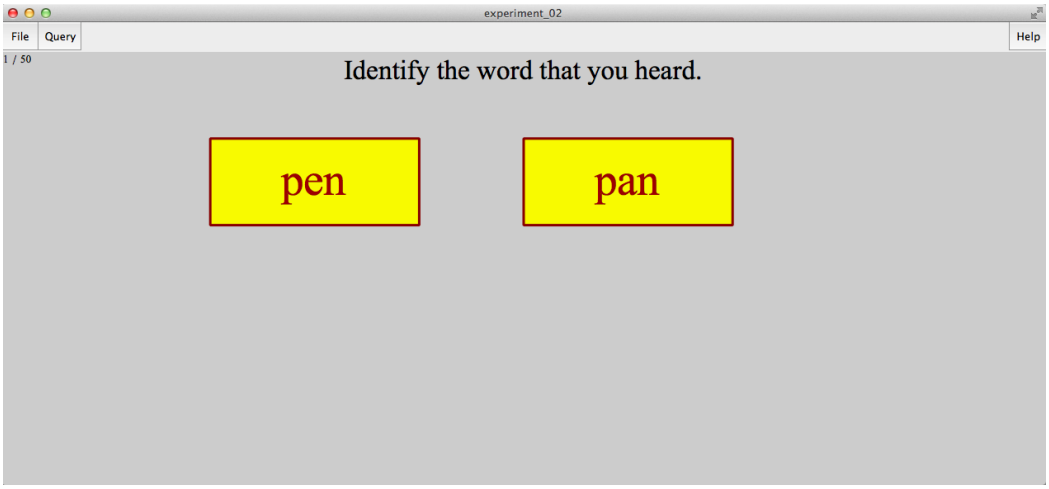

Figure 5: ***A screenshot of the second block of the identification task***

2.4. Analysis

The responses of each participant were collected to a table on Praat and saved as a comma-separated file. Responses that had reaction times above 1.5 seconds were removed due to the fact that they often yielded unusual responses and were thus deemed to not be instinctive. Since the majority of responses were below 1.5 seconds, it seemed suitable to remove these anomalies from the final results. Additionally, responses with reaction times below 0.16 seconds were removed since it is not possible to respond to visual stimuli faster than this (Kosinski 2008). Answers given below this reaction time indicate that a speaker answered too soon before cognitively processing what they heard. In total, 62 responses were omitted from the results out of 1400. The percentage of "pan" and "pen" responses were calculated for each individual and then for both speaker groups.

3. Results

Figure 6 and Table 2 show the results of the experiment for the British and United States English speaker groups. In Figure 6, across the x-axis is stimulus 1-10, and across the y-axis is the overall percentage of "pan" responses to each stimulus. The blue line represents the British English speaker group and the red line represents the United States English speaker group.

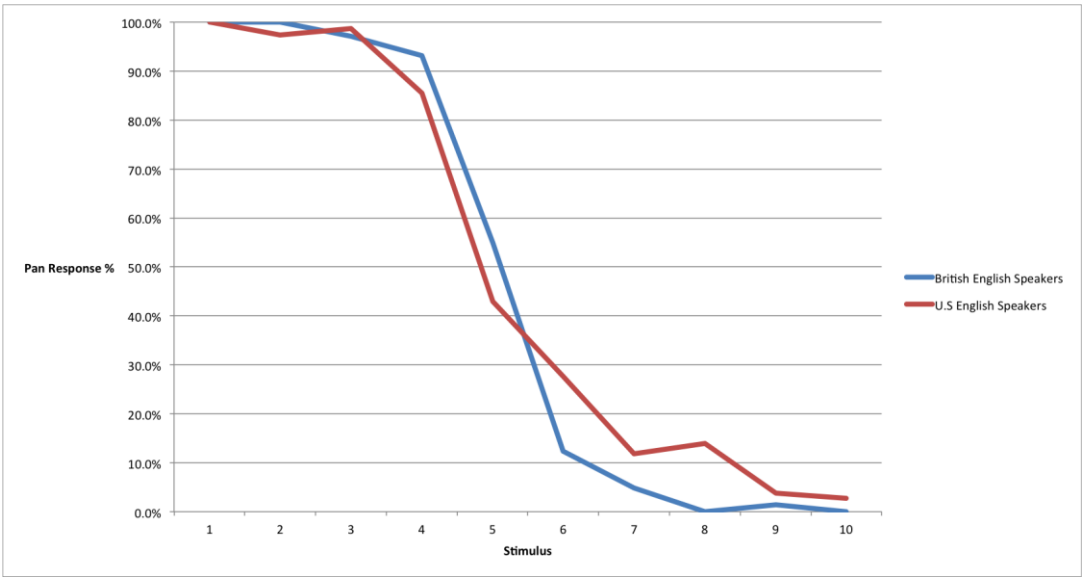

Figure 6: The percentage of "pan" responses by the British and U.S. speaker groups (Graph)

Table 2: ***The percentage of "pan" responses by the British and U.S. speaker groups***

		Stimulus									
		1	2	3	4	5	6	7	8	9	10
Speaker Group	British English	100%	100%	97.1%	93.1%	54.9%	12.4%	4.9%	0%	1.4%	0%
	U.S. English	100%	97.4%	98.7%	85.5%	42.9%	27.6%	11.8%	13.9%	3.8%	2.7%

The results show that from stimulus 1-4, both the British English and United States English speaker groups performed above chance, identifying the word "pan" over 85% of the time. At stimulus 5, there was a steep drop in the perception of "pan" for both groups who performed at chance: The British speakers identified "pan" 54.9% of the time and the U.S. speakers identified "pan" 42.9% of the time. By stimulus 6, both speaker groups performed above chance, with the British speakers identifying "pan" 12.4% of the time (meaning they identified "pen" 87.6% of the time) and the U.S. speakers identifying "pan" 27.6% of the time (meaning

they identified “pen” 72.4% of the time). At stimulus 6-8, the United States English speaker group displayed a significantly higher percentage of “pan” responses than the British English speaker group (15.2% more at stimulus 6, 6.9% more at stimulus 7 and 13.9% more at stimulus 8) and at stimulus 7-8, the United States English speaker group still responded with “pan” over 10% of the time (11.8% and 13.9% respectively) while less than 5% of the British English responses were “pan” (4.9% and 0% respectively). At stimulus 9-10, only 1 out of 139 responses by all British speakers was “pan”, while 5 out of 155 U.S. speaker responses were “pan”. The main finding from these results is that both the British English and United States English speaker groups sharply dropped in their perception of “pan” at stimulus 5, but from stimulus 6 onwards, United States English speakers perceived “pan” significantly more than the British English speakers.

It is crucial to examine the results of the individual U.S. participants to investigate if particular speakers influenced the U.S. group results considerably from stimulus 6 onwards. Additionally, one should analyze the variation within the British English speaker group to ensure that the overall pattern seen in the British group is consistent amongst the individual speakers. Table 3 and Figure 7 shows the results of the individual U.S. speakers. There appears to be one U.S. speaker who consistently identified “pan” well above the group average across stimulus 6, 7 and 8. Participant 1 identified “pan” 50% of the time at stimulus 6 (22.4% above the average), 44.4% of the time at stimulus 7 (32.6% above the average), and 20% of the time at stimulus 8 (6.2% above the average).

Table 3*: The percentage of “pan” responses by the individual U.S. speakers*

	1	2	3	4	5	6	7	8	9	10
1	100%	100%	100%	100%	42.9%	50%	44.4%	20%	20%	0%
2	100%	90%	100%	70%	11.1%	10%	0%	0%	0%	0%
3	100%	100%	100%	100%	57.1%	44.4%	11.1%	0%	0%	0%
4	100%	90%	100%	90%	50%	30%	0%	30%	0%	0%
5	100%	100%	100%	80%	20%	0%	0%	0%	0%	10%
6	100%	100%	100%	70%	60%	20%	20%	20%	10%	20%
7	100%	100%	90%	87.5%	33.3%	22.2%	10%	20%	0%	0%

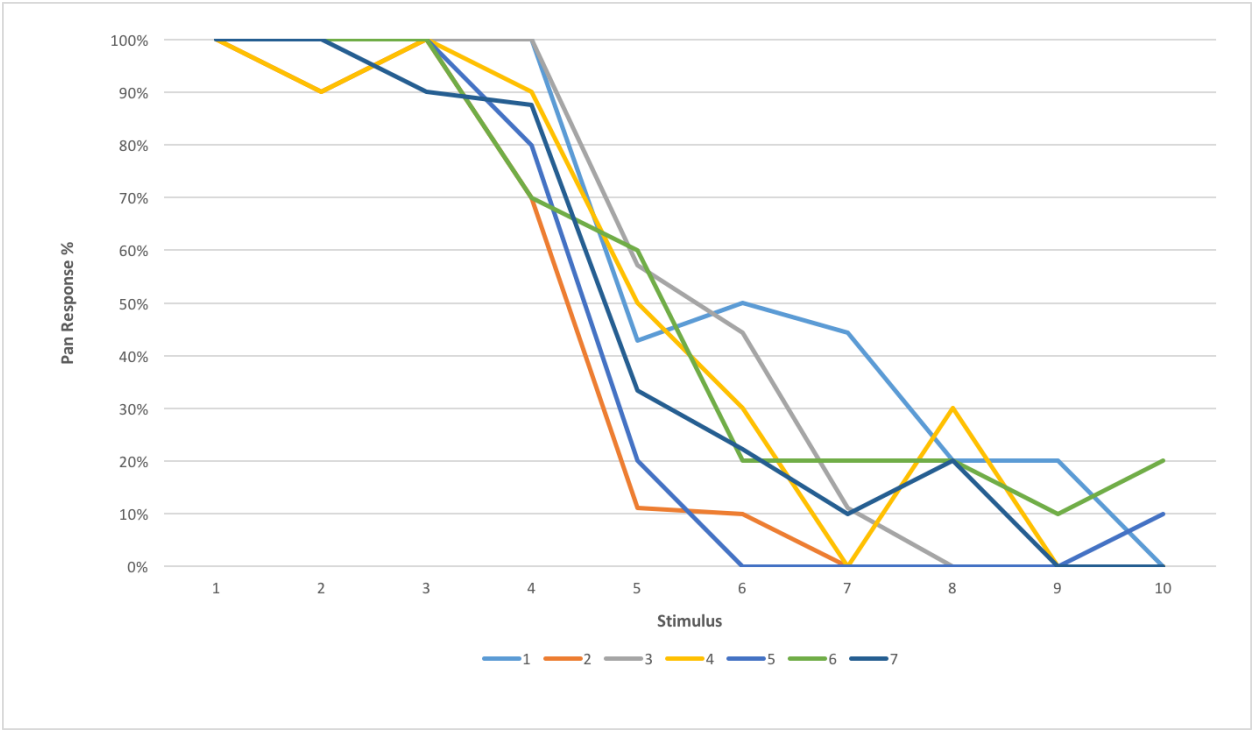

Figure 7: ***The percentage of "pan" responses by the individual U.S. speakers (Graph)***

However, removing participant 1's results does not dramatically alter the results for stimulus 6 (24.2%), 7 (7.5%) and 8 (13.0%): The U.S. English speaker group still displays a markedly higher percentage of "pan" responses than the British speaker group. Each U.S. speaker identified "pan" above the group average at some point from stimulus 6-10, apart from participant 2 who always identified "pan" below the average from stimulus 6 onwards. This indicates that beyond stimulus 5, almost the entire U.S. speaker group perceived "pan" more than the British English group whose "pan" perception never increased beyond 5%. From stimulus 7-10, only three of the seven British speakers perceived "pan" at any time with four "pan" responses in total whereas six of the seven U.S. speakers perceived "pan" with 25 "pan" responses in total. Thus it is clear that the United States English speaker group perceived "pan" significantly more than the British English speaker group in the second half of the pan-pen continuum. Table 4 and Figure 8 show the results of the individual British English speakers.

Table 4: ***The percentage of "pan" responses by the individual British speakers***

	1	2	3	4	5	6	7	8	9	10
1	100%	100%	100%	89%	63%	20%	0%	0%	0%	0%
2	100%	100%	90%	90%	30%	10%	0%	0%	0%	0%
3	100%	100%	100%	100%	90%	50%	0%	0%	0%	0%
4	100%	100%	100%	100%	63%	11%	0%	0%	0%	0%
5	100%	100%	100%	90%	44%	0%	10%	0%	10%	0%
6	100%	100%	90%	89%	80%	0%	10%	0%	0%	0%
7	100%	100%	100%	100%	40%	20%	11%	0%	0%	0%

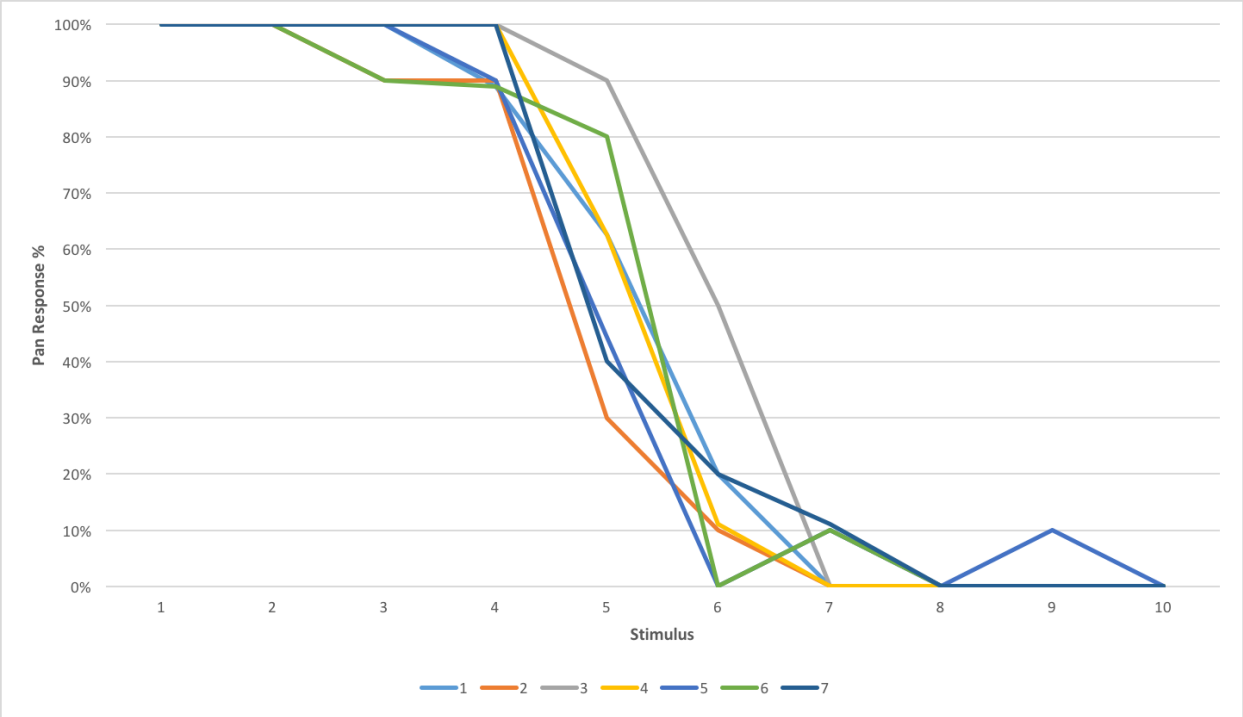

Figure 8: ***The percentage of "pan" responses by the Individual Speakers (Graph)***

The table and graph confirm that there was not much inter-group variation within the British Group. Apart from speaker 3 whose drop in "pan" perception starts at stimulus 6, every other speaker's "pan" perception drops at stimulus 5, indicating that the pattern shown in Figure 6 for the British speakers is uniform across six out of seven British speakers. Furthermore, beyond stimulus 6, the perception of "pan" across the listeners was minimal, unlike the U.S. English group.

4. Discussion

The results show that both the British and U.S. speaker group's drop in "pan" perception occurred at the same stimulus. This was an unanticipated result since it was expected that the /æ/-tensing before nasal codas by United States English speakers would cause them to perceive "pan" for longer across the pan-pen continuum than the British English speakers. However, it is worth noting that the U.S. participant who had the highest percentage of "pan" responses at stimulus 6 and 7 (50% and 44.4% respectively) was participant 1 who had only lived in England for four days at the time of the experiment, compared to the other participants who had been living in England for at least eight months. It is possible that extensive exposure to British English speakers may have caused the other six speakers to adjust their perceptual boundary between /æ/ and /ɛ/, having a more British perception of the pan-pen continuum than the U.S. speaker who had only lived in England for a limited time. It is also possible that the U.S. speakers dropped in their "pan" perception earlier than expected due to an unconscious assumption that they were listening to British speech. Since the experiment was run by a British phonetician in England, U.S. participants may have assumed that the synthetic speech they were listening to was British, and adjusted their perceptual vowel boundaries accordingly. Niedzielski (1999) found that altering the national identity of a speaker as indicated on an answer sheet changed the perception of vowel categories. Though the national identity of the synthetic speech was never specified, the environment and location of the experiment, as well as the presence of open British /æ/ in the stimuli may have led to a subconscious assumption that the participant was listening to British speech.

Although the U.S. English speakers display a sharp drop in "pan" perception earlier than expected, the drop was not as great as the British English speakers, and the U.S. speakers continued to perceive "pan" significantly more than the British speakers to the end of the continuum. This is likely due to two reasons: The first is that although the U.S. speakers may

have shifted their perceptual boundaries, it is not a firmly established, fully shifted boundary and at times, the U.S. speakers were still susceptible to hearing “pan” past stimulus 6. The second reason is that in some U.S. dialects, /æ/ before nasal consonants is often tensed beyond /ɛ/, towards the higher /e/ and even /ɪ/ (Labov et al. 2006). It is therefore unsurprising to observe the U.S. speakers continuing to hear “pan” at the end of the /æ/-/ɛ/ continuum.

The individual variation of the U.S. participants can also be explained with relation to the assumed dialect of each speaker. Speakers of dialects that tense /æ/ in more phonetic environments displayed “pan” perception the most across the pan-pen continuum: The U.S. speakers who perceived “pan” consistently at 10% or above from stimulus 1-8 were participant 1, 6 and 7. According to Labov et al. (2006), participant 1 came from an area where Inland Northern American English is spoken, a dialect with the raised /æ/ system where all short-a vowels are tensed. Participant 7 also spent time in an area where Inland Northern American English is spoken; Chicago, Illinois, and it appears to have affected her perception of the /æ/-/ɛ/ continuum, causing it to be markedly different to the other speakers who lived in Massachusetts, perceiving “pan” much later in the continuum than them. Participant 6 spent four years in Charlotte, North Carolina where the Southern American English dialect is prominent, and most /æ/ vowels are tensed due to the Southern Breaking system. She also spent three years in Kennett Square, Pennsylvania, where Mid-Atlantic American English is spoken. This dialect has a short-a split system where /æ/ is tensed before nasals and all voiceless fricatives apart from /ʃ/. The other four speakers originated from areas with dialects that have the nasal system where short-a is only tensed before nasals: Participant 2 and participant 3 were raised in an area where Northeastern New England English is spoken, participant 4 originated from a region where Western Pennsylvania English is spoken and participant 5 came from an area where Midland American English dominates. These three dialects have the nasal system which has the least occurrences of /æ/-tensing. It is therefore likely that the more accustomed a listener was to /æ/-tensing across phonetic environments, the more they perceived “pan” along the continuum.

The final point to discuss is whether any claim can be made that the vowel continuum was perceived categorically. Compared to Fry’s et al. (1962) vowel identification results, the graph from this experiment shows a steeper and more sudden shift in the perception of one vowel to another. In his experiment (see Figure 2) there were 8 synthetic stimuli between the /ɪ/ and /ɛ/ vowel, and the decrease in /ɪ/ perception was far more gradual and continuous, decreasing from 100% to 95%, then 80% to 70%, 50% to 48%, then 15% to just above 0% by stimulus 8.

The results of the current experiment are to the contrary, with a sharp drop in "pan" perception, especially for the British English speaker group, falling from 93.1% at stimulus 4 to 12.4% at stimulus 6. There are a couple of possible reasons why the results of these two studies differ: Firstly, in Fry's experiment, participants were asked to identify phonemes, not words. Sachs & Klatt (1969) found that the Phoneme Boundary Effect was observed across the /ɑ/ - /æ/ continuum only in word context by U.S. speakers ("bottle" /bɑdəl/ vs battle /bædəl/), meaning that subjects were able to discriminate stimuli in the middle of the continuum easier than on the edges. In contrast, isolated vowel stimulus pairs were differentiated equally well over the entire continuum. Their results indicated that the perceptual boundaries between vowels are more defined in word context than in isolation. Secondly, Fry's results may contradict the findings of this experiment because the quality of speech synthesis has improved since 1962. The machine that Fry used, "Alexander" was a formant-type analogue speech synthesizer with four formant generators, of which only two were used in his experiment (Fry et al. 1962). The IPOX speech synthesizer used in this study generates six formant frequencies (including nasal zero frequency), five source parameters, three formant bandwidths and six parallel branch amplitudes (Dirksen & Cole 1995), all of which assist in making the speech sound more authentic.

Regardless if these elements factor in to the difference between the present study and Fry's paper, the results of this experiment suggest that perhaps vowel perception isn't as continuous as previously believed, motivated further by the fact that the patterns we see are consistent across most of the individual speakers, though a discrimination task would have to be run before any reliable claim can be made.

5. Conclusion

This study has found that the difference in short-a production between British and United States English speakers, especially before nasals, leads to a contrast in the perception of the pan-pen continuum between these two speaker groups, but not in the expected manner: The U.S. speaker group did not collectively drop in their perception of "pan" later than the British English speaker group, however after the initial fall in "pan" perception, the U.S. speakers still perceived "pan" beyond the phoneme boundary, significantly more so than the British English speakers, with speakers exposed to /æ/-tensing most frequently across phonetic environments more likely to perceive "pan" a larger percentage of the time further along the continuum. The

results confirm the findings of Bell-Berti et al. (1979) that speech production and perception are closely related. It is also suggested in this study that extensive exposure to the British English dialect by the majority of the U.S. speakers, and perhaps the subconscious assumption that the synthetic speech was British, caused the U.S. speakers to shift their perceptual boundary towards /æ/, though the greater percentage of "pan" perception by the U.S. speakers at the later stages of the continuum suggest that these phoneme boundaries had not fully shifted nor were they as sharply defined as the British speakers' perceptual boundary. It would thus be interesting to test U.S. speakers who have not been as exposed to British speakers to determine if lack of exposure to British English does lead to having the expected higher phoneme boundary, closer to /ɛ/. In turn it would be fascinating to investigate the pan-pen perception of British English speakers who have been living in the U.S. for a considerable period of time, especially in areas with the raised /æ/ system such as the Northern cities (including Rochester New York, Cleveland Ohio, Detroit Michigan, Chicago Illinois and Madison Wisconsin), to see if extensive exposure to the United States English dialect would induce a shift in their phoneme boundary between /æ/ and /ɛ/ to a higher position, offering more of an insight in to the effect of dialect exposure to speech perception. In addition, with less strict of a time constraint, it would have been useful to record the speakers' speech instead of assuming the speaker's dialect based on region of origin. By recording the speakers, considerations could have been made on how the dialect of their region as well as their own speech contributed to their perception of the /æ/-/ɛ/ continuum.

A necessary addition to add to this study is a discrimination task to explore the possibility that vowels are perceived categorically, contrary to popular opinion (Fry et al. 1962). If it is found that speakers do find it easier to discriminate the vowels towards the middle of the continuum than the periphery in word context, the next step would be to test the discrimination of these synthetic vowels outside of word context. Though previous literature suggests that isolated vowels would be discriminated equally across the continuum and not categorically (Fry et al. 1962; Sachs & Klatt 1969), an experiment run with better quality speech synthesis could yield contrasting results, and the argument that vowels are perceived continuously may yet be proved wrong.

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