Lexical Effects in Perception of Tamil Geminates

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Abstract

Lexical status effects are a phenomenon in which listeners use their prior lexical knowledge of a language to identify ambiguous speech sounds in a word based on its word or nonword status. This phenomenon has been demonstrated for ambiguous initial English consonants (one example being the Ganong Effect, a phenomenon in which listeners perceive an ambiguous speech sound as a phoneme that would complete a real word rather than a nonsense word) as a supporting factor for top-down lexical processing affecting listeners' subsequent acoustic judgement, but not for ambiguous mid-word consonants in non-English languages. In this experiment, we attempt to look at ambiguous mid-word consonants with Tamil, a South Asian language in order to see if the same top-down lexical effect was applicable outside of English. These Tamil consonants can present as either singletons (single speech sounds) or geminates (doubled speech sounds).We hypothesized that by creating ambiguous stimuli between a geminate word *kuppam* and a singleton non-word like *kubam*, participants would be more likely to perceive the ambiguous sound as a phoneme that completes the real word rather than the nonword (in this case, perceiving the ambiguous sound as a /p/ for *kuppam* instead of *kubam*). Participants listened to the ambiguous stimuli in two separate sets of continua (*kuppam*/*suppam* and *nakkam*/*pakkam*) and then indicated which word they heard in a four-alternative forced choice word identification task. Results showed that participants identified the ambiguous sounds as the sound that completed the actual word, but only for one set of continua (*kuppam*/*suppam*). These data suggest that there may be strong top-down lexical effects for ambiguous sounds in certain stimuli in Tamil, but not others.

Lexical Effects in Perception of Tamil Geminates

Because speech can sometimes be ambiguous, people rely on different cues in order to perceive speech in a way that makes sense to them. If a person hears the sentence, "I received a *kift* in the mail," for example, they might perceive the /k/ sound two different ways: they might either hear the overall word as *gift* based on the lexical context of the word and what they expect the ambiguous word to be, or they might rely on purely acoustic information to interpret the /k/ sound and then rectify their perception afterward, when they realize the word they heard does not make sense. They might even combine both of these cues, lexical and acoustic, to classify both the ambiguous sound and the word as a whole. Lexical effects refer to the way an ambiguous speech sound is perceived based on the listener's prior lexical knowledge (information relating to the words in a language) based on whether that ambiguous sound completes a word or nonword.

This effect was studied by Ganong (1980), who specifically looked at the tendency to perceive an ambiguous speech sound as a phoneme that would complete a real word rather than a nonsense word, also known as a lexical status effect. Ganong's experiment involved a continuum of stimuli with the nonword *kift* morphing into the word *gift* and a complementary set of stimuli with the word *kiss* morphing into the nonword *giss.* As the initial sound became more ambiguous, listeners were more likely to classify the same sound as a /g/ in the *kift-gift* continuum and /k/ in the *kiss-giss* continuum, because they were more likely to perceive a sound that completed a real word instead of a nonword. Ganong assumed that listeners relied heavily on lexical information and identified the word based on its lexical status (word versus nonword), placing a priority on top-down processing. This seemed to indicate that ambiguous speech recognition relied almost entirely on lexical knowledge after basic acoustic processing (hearing the stimuli) in order for listeners to make decisions about what they were hearing.

Fox (1984) replicated Ganong's experiment; his first experiment was a direct replication of Ganong's process, generating consistent results. Lexical status did seem to affect the way participants categorized sounds. He followed this up by using word-word (such as *bad* and *dad*) and nonword-nonword continua (such as *ba* and *da)*- deviating from Ganong's usage of word-nonword continua- and found that participants tended to classify ambiguous stimuli as the more frequent word (in this example, *bad* over *dad)*. Fox sorted these data by response time (slow, intermediate, or fast) and noticed that the lexical effect appeared in the slow response (responses longer than 800 ms) yet did not appear in the fast responses (responses quicker than 500 ms). Therefore, Fox suggested that listeners who responded quickly were not influenced by the lexical status of the word and relied solely on their judgement of the acoustic properties of the phonemes themselves, while listeners who responded slowly seemed to be influenced by lexical status just as in Ganong's experiment. This seemed to suggest that while there was a lexical influence on listeners perception, other factors like response time could affect how much of that lexical knowledge listeners accessed during perception.

Based on these results, Fox (1984) suggested theories to explain when listeners used lexical information relative to acoustic categorization. One of these hypotheses concerned how acoustic categorization and lexical access interact with each other in the processing hierarchy. Acoustic categorization is often categorized as bottom-up processing: listeners determine what they are perceiving based on only acoustic input, and speech processing begins at the individual phonemes. The phonemes are then combined into syllables and ultimately words. Lexical access, on the other hand, is seen as top-down processing, a process that is more knowledge-based and involves listeners' usage of preexisting information (for example, whether the phonetic sequence is a word or a non-word) in order to determine the identity of the ambiguous sound they are hearing. Fox indicated that while past speech perception models disregarded bottom-up processing and adopted top-down processing as explanatory, his speeded response results did not support this idea. While these models suggested that top-down processing aided listeners' phonetic processing, the differences Fox found between slow and fast categorization responses suggested that the listeners with the quickest responses, less than or equal to 500 ms, prioritized acoustic categorization over lexical status and therefore bottom-up processing over top-down processing when responding quickly.

Fox's (1984) results supported a time-based processing theory that faster responders resorted to acoustic analysis predominantly, while slower responders relied more on lexical access. Fox suggested that the lexical effects that arose in Ganong's (1980) experiments were corrective attempts that follow acoustic categorization. This would occur if a participant determined an ambiguous phoneme to be a certain sound, /b/, but then amended their decision to be a /p/ upon noticing that the /b/ completed a nonword instead of a word. While Ganong's work suggested that lexical knowledge was a necessity in ambiguous sound perception, Fox suggested that lexical knowledge was unnecessary at certain stages (such as when participants responded relatively quickly). Based on these arguments, further research was done to determine what speech cues participants used and how lexical influences and acoustic categorization may interact in the stages of speech processing.

One of the studies done to expand on what kind of lexical effects influenced listeners' acoustic categorization was done by Connine, Titone, and Wang (1993). They looked at a continuum where both endpoints were real words, but one word occurred with a higher frequency than the other (e.g. best and pest, with best as the more common word). They noted that listeners tended to classify ambiguous stimuli as the phoneme in the more frequently occurring word, suggesting that word and nonword distinctions are not the only cues listeners use to determine the status of ambiguous stimuli.

Another study done by Burton et al. (1989) noted a lexical effect found in the /d/-/t/ continua, but found that when they used higher quality and more natural stimuli, the effect disappeared, which brought concerns that low quality stimuli may have caused the lexical effect in the study done by Ganong (1980). Burton and colleagues suggested that the stimuli used in prior research were simplified tokens of natural speech and contained formant transitions without bursts, despite formant transitions and bursts being a significant cue for participants to identify the place of articulation. They suggested that lexical reliance may not be as important as acoustic categorization and did not always need to occur in speech perception. Pitt and Samuel (1993) also used high-quality stimuli, but unlike Burton et al. (1989), they found lexical effects in the /g/-/k/ continua but not in the /d/-/t/ continua. They argued that the conclusions drawn by Burton et al. (1989) that less natural acoustic stimuli were responsible for the lexical effect may not be accurate and consequently suggested that it was only one of the factors. Their conclusions also rejected Ganong’s stricter top-down interpretation of speech perception and proposed that there were factors like the naturalness of stimuli that could influence listeners as well.

In a similar vein, Newman et al. (1997) looked at the lexical neighborhood. In general, the lexical neighborhood looks at words that can be made by changing a single phoneme- through deletion, addition, or substitution -in the target word (Greenberg & Jenkins, 1964). Newman and colleagues specifically took into consideration a nonword- in their example, *gice* (/gals/) -and examined each end of the series to see if the phonemes at the ends were similar to other words. On the other end of the spectrum was the nonword *kice*. The phonemes in the nonword *gice* had a higher frequency of occurring in similar words (e.g. *guide*) and therefore a ‘higher density neighborhood’ compared to the nonword *kice*. When they found that participants were likely to classify ambiguous stimuli as words with higher density neighborhoods, they suggested that the stimuli items did not even need to be real words for the lexical effect to occur. Because participants were able to identify real words in the lexical neighborhood of the nonwords, they were still able to experience a lexical effect. Newman and colleagues also disagreed with the Burton et al. (1989) conclusion that lexical influences did not need to be present in speech perception. Instead, they suggested that lexical influences were integral to the process, as they arose even in nonword perception.

Newman and colleagues’ (1997) work supported the idea of acoustic and lexical cues interacting by suggesting that lexical influence was essential to ambiguous speech perception. Based on this prior research, it is clear that the work done on the interaction of top-down lexical processing and bottom-up acoustic processing has been somewhat divisive; however, there is general agreement that speech perception depends on the interaction between lexical knowledge (top-down processing) and acoustic categorization (bottom-up processing), along with theories that lexical cues may manifest in several ways in speech perception. These subsequent studies introduced cues other than solely lexical status that could have an effect on ambiguous speech perception: like time (Fox, 1984), stimuli quality (Burton et al., 1989; Pitt & Samuel, 1993), and neighborhood density (Newman et al., 1997).

Research on lexical effects in languages other than English has been generally sparse in the literature. The current study is designed to look at what kind of processing non-English participants might use to classify ambiguous phonemes in their native language. As was suggested by the prior literature, there is no consensus as to what level of interaction between top-down lexical processing and bottom-up acoustic categorization listeners use while categorizing phonemes; however, researchers have determined that there are different lexical influences at play, such as word frequency (Connine et al., 1993) and lexical neighborhood density (Newman et al., 1997).

The current study looks at yet another layer of lexical effects by considering how they might present in Tamil, a South Asian language spoken predominantly in Southern India but also Sri Lanka, Malaysia, and Singapore (Nagarajan, 1995); it aims to uncover what sort of lexical influences might occur in a non-English language. While all of the previous experiments looked at English monosyllabic words, this experiment looks at Tamil disyllabic words. The reason the syllable length increased in the study is to accommodate the presence of geminates, a phenomenon that occurs in multisyllabic words in Tamil but not in monosyllabic words in Tamil. Gemination in Tamil could offer similar phonological ambiguity that listeners may use lexical effects to classify.

Gemination involves two identical speech sounds that co-occur in either one word or across word boundaries, an example being the Tamil word *kuppam.* True geminates, such as the doubled /p/ in the Tamil word *kuppam,* contain the doubled speech sound in a single word and are perceived as a separate sound from their singleton counterparts in the same word. While singletons (single speech sounds), are present in English, true geminates are not. In Tamil, however, the addition of a geminate changes the meaning of the word and therefore alters perception of the word; this refers back to the idea of geminates being contrastive in Tamil. An example would be the words *kaattu* and *kaadu,* respectively meaning “to show” and “forest”. This is a minimal pair (only one phoneme differs between them), which indicates that the geminate’s presence changes the meaning of the word. Gemination in Tamil can mark either the difference between a word and a non-word (*kuppam* and *kubam*) or mark two separate words entirely (*kaattu* and *kaadu*) (Nagarajan, 1995).

Tamil singletons and geminates vary in two dimensions: they vary both spectrally and durationally (Figure 1). Spectral differences refer to a change in the production of the sound between the singleton and geminate version of the word, while duration refers to how long the stop closure in the geminate is compared to the singleton closure. A stop in linguistics occurs when the vocal tract is blocked, stopping airflow; the length of this closure is always longer in geminates than singletons, which is a distinguishing factor between the two (Lahiri & Hankamer, 1988), and, according to Ladefoged and Maddieson (1996), the closure duration of a long stop can be 1.5 to 3 times longer than the closure duration of a short stop in careful speech. These differences are visible in a sound spectrum, as both the amplitude and active frequencies of the sound differ when comparing a geminate and a singleton. Durational changes are reflected by a gap of silence between the doubled speech sounds, represented by a straight line with very little acoustic energy in Figure 1. The singleton, however, is noticeably missing that same gap of silence.

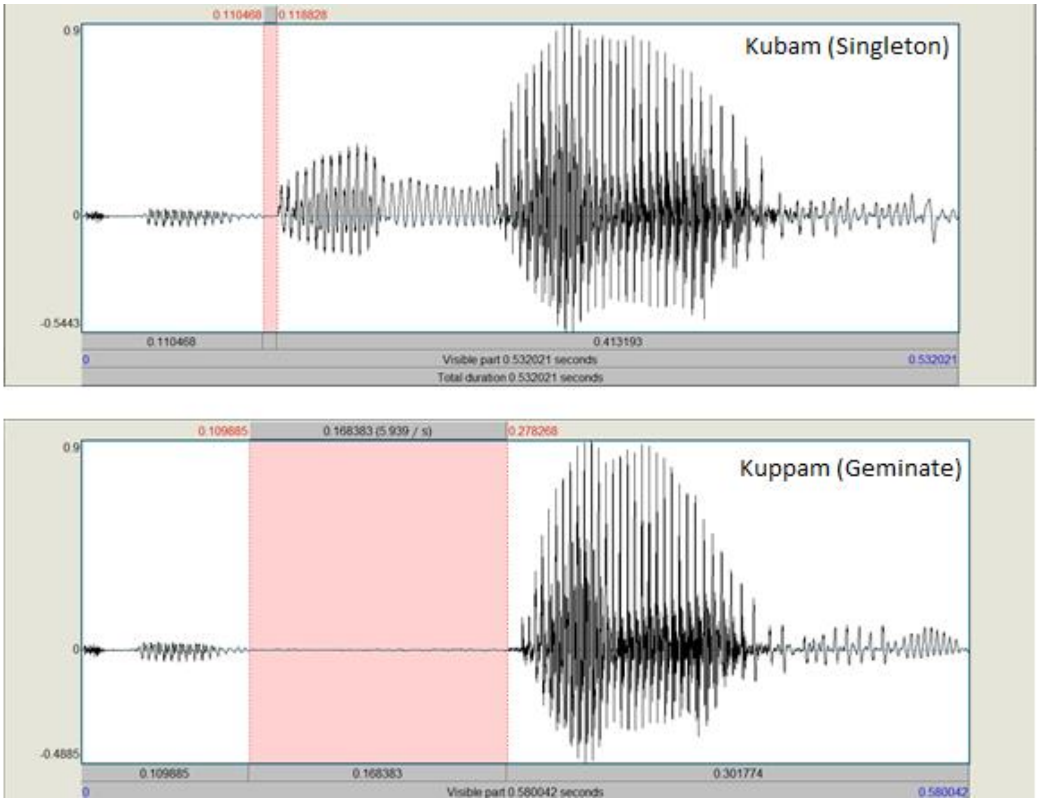

Figure 1: These graphs show the amplitude fluctuations of the Tamil words kuppam and kubam, with time on the x-axis and amplitude on the y-axis. The numbers above the waveform in the pink section represent the duration of Tamil singletons and geminates.

Figure 1 shows a singleton-geminate pair example in Tamil, *kuppam* and *kubam*; the durational difference is prominent here, as there is a pause between the /p/ sounds in *kuppam* (168 ms) that decreases in length in the alternate production of the word *kubam* (8 ms). The length of the pause in the geminate is roughly 20 times longer than the singleton. The spectral differences are also visible: after the pause in *kubam*, there is a burst of activity that represents the /b/. This burst is absent in the *kuppam* production, as there is less activity after the pause that leads into the /a/ sound. In addition, the spelling change from “pp” to “b” indicates that there is a geminate in the former word and the latter does not have the same /p/ sound. The spectral variation is as follows:

the doubled speech sound in Tamil always has a devoiced quality, while the single speech sound is produced as a voiced phoneme with the same place and manner as the geminate. In this experiment specifically, the focus is on the geminate-singleton pairs /pp/-/b/ and /kk/-/g/. Prior research suggests that participants are lexically influenced by acoustic contrasts in phonemes, but this study also aims to find out if participants are lexically influenced by the silent cue that gemination offers. This may suggest that a silent cue can induce a lexical status effect in the same way a contrast cued by acoustic evidence can.

This study takes three exploratory steps that distinguish it from previous experiments done with lexical effects. First, it looks at a language outside of English (Tamil), second, it looks at disyllabic words instead of monosyllabic words, and third, it focuses on mid-word geminates and singletons instead of word-initial singletons. Tamil was chosen due to the lack of research done with lexical influences in phonetic perception in other languages and the author's familiarity with the language.

In previous research, authors have proposed different models to account for the presence of lexical effects. There is the stricter top-down model seen in Ganong (1980), the time-dependent combination of top-down and bottom-up seen in Fox (1984), and the exploration of lexical concepts like lexical neighborhoods influencing top-down processing (Newman, 1997). Though Tamil has some different linguistic properties than English, I expect to see similar results to Ganong (1980); speakers of the language will likely interpret the ambiguous phoneme as a sound that completes a real word over a nonword. The preference of interpreting ambiguous sounds by their resulting lexical status will likely occur despite the changes made to the experiment that differentiate it from previous research.

I created four continua (*nakkam-nagam* and *pakkam-pagam* being one set and *suppam-subam* and *kuppam-kubam* being the other), each made up of seven steps, and each set of continua (either /k-g/ or /p-b/) had two geminate real words and two singleton real words. I expected that when participants listened to the ambiguous middle steps, they would report hearing the real words instead of the nonwords, regardless of whether they were a singleton or a geminate, due to preexisting lexical knowledge. If they adhere to these expectations, it may support the prioritization of top-down processing as an aid to initial acoustic processing. It will also indicate that the lexical status effect can manifest outside of English singleton consonants and that the effect may extend to Asian languages with different properties (such as gemination that depends on two cues).

Method

Participants. The participants were nine native Tamil speakers, recruited through the messaging platform Whatsapp (WhatsApp Inc., 2020). These participants were given a link to the online survey and volunteered their time for the experiment. Including the pilot and participants, 27 people in total were given the link. These participants forwarded the message to other people they knew, also through Whatsapp (WhatsApp Inc., 2020), and encouraged friends and family to do the experiment. Out of the nine participants, seven were female. None of the participants spoke only Tamil: every participant knew English as a second language, and four of the participants spoke additional languages (Hindi, Marathi, and Telegu).

Stimuli. To create the stimuli, four pairs of words were recorded in isolation by the author, a native Tamil speaker. These pairs were *nakkam-nagam*, *pakkam-pagam*, *suppam-subam*, and *kuppam-kubam*. Each pair consisted of a non-word (*kubam*, *suppam*, *pagam*, *nakkam*) and a word (*kuppam*, *subam*, *pakkam*, *nagam*) in Tamil to model the word to non-word continuum as seen in the study done by Ganong (1980). *Kuppam* means "a small village" in Tamil, *subam* means "superstition," *pakkam* means "side," and *nagam* means "fingernail." Within these four continua, two continua morphed from a geminate word to a singleton non-word (*kuppam-kubam* and *pakkam-pagam*), and two continua morphed from a geminate non-word to a singleton word (*suppam-subam*) and (*nakkam-nagam*).

These words were amplitude normalized using the acoustic editing program Praat (Boersma & Weenink, 2018). Each endpoint in the continuum was spliced such that the exact same acoustics were surrounding the geminate and singleton (for example, the acoustics from *kuppam* was used to create *kubam*). The MATLAB package STRAIGHT (Kawahara & Morise, 2011) was used to create a continuum for each pair by morphing all spectral and temporal properties of the two words. This created a set of 21 steps between the two endpoints (for example, *kuppam* to *kubam*). Each continuum started with the geminate word as the first step and ended with the singleton word as the last step.

To test for perceptual ambiguity of the steps, a pilot study was performed, testing the task performance across the continua. For the pilot (N = 16), the steps selected were 1, 8, 12, 16, 17, 19, and 21. The pilot results indicated that the ambiguous region was around steps 12-16, as this was the area where there was the most uncertainty in listener response; data analysis from the pilot revealed a sharp perceptual switch from around 13% of participants perceiving the words as singletons in step 12 to about 96% of participants perceiving the words as singletons in step 16 (this is based on the *kuppam-kubam* continuum, but the other continua showed steep inclines as well). As there was such an abrupt switch between step 12 and step 16, the steps used in the experiment were changed to give a wider range of ambiguity. The final steps used were steps 1, 12, 14, 15, 16, 19, and 21 from the original continua. Steps 1 and 21 were the endpoints, with step 1 being the geminate and step 21 being the singleton, steps 12 and 19 were close to the endpoints, and steps 14, 15, and 16 were the ambiguous in-between steps.

Each step was repeated ten times in the experiment, which meant there were 70 trials per continuum. The four geminate endpoints composed the practice trial before the experiment started. These steps were pseudo-randomized such that no single step or continua repeated more than twice in a row, and all participants received the same list of steps in the same order. The first block of the experiment contained only the /pp/ to /b/ continua (*suppam-subam*, and *kuppam-kubam*), and the second block contained only the /kk/ to /g/ continua (*nakkam-nagam*, *pakkam-pagam*). With two continua in each block, the total number of trials for the experiment was 280 (140 per block). There were four practice trials before the main experiment; this consisted of the geminate endpoints from each continuum (*kuppam*, *suppam*, *nakkam*, and *pakkam*).

Procedure. The experiment was presented via a custom created browser-based javascript experimentation framework. Participants were sent a link to the experiment via WhatsApp (WhatsApp Inc., 2020), along with a message with experiment instructions and background information; it also let them know that they could leave the experiment at any time and that their data would remain confidential. Once they clicked on the link, they were instructed to wear headphones and complete a small test to make sure they could hear a word presented through the browser. Once they had passed the test, they started the experiment. In each trial, participants heard the stimuli and then selected one of four buttons using the mouse. The screen would not change until the participant selected a response, and there was no cutoff time; however, they were encouraged to respond as quickly as possible. During the first block of trials, their four options to choose from were *kuppam*, *kubam*, *suppam*, and *subam*, all written in Tamil (Figure 2). During the second block, their four options to choose from were *nakkam*, *nagam, pakkam*, and *pagam*, also written in Tamil. Halfway through the experiment, there was a small, self-timed break that was followed by the next 140 trials. The experiment took about fifteen minutes to complete, after which the participants were shown a message in the browser thanking them for their participation. After they closed the site, they were sent a debriefing message that explained the purpose of the experiment.

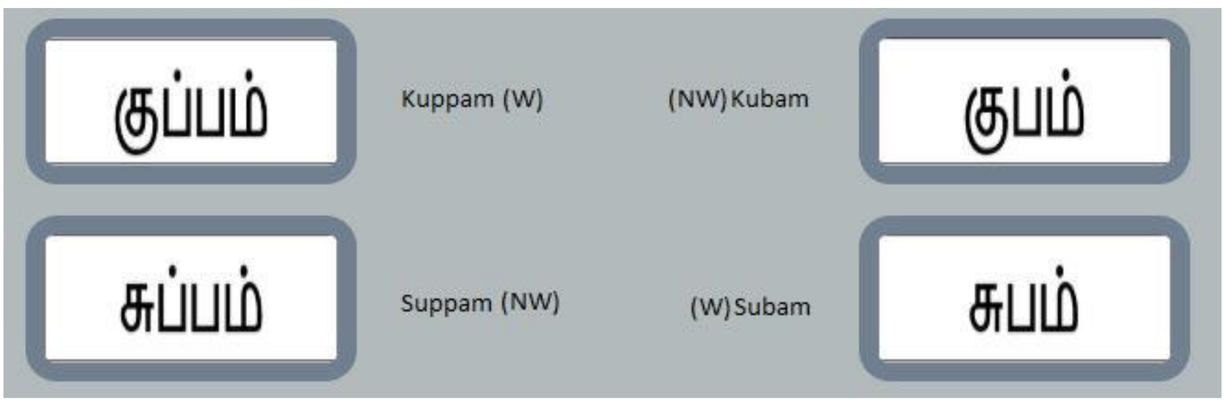

Figure 2: The four options on the screen when the listener is presented with one of the steps in the kuppam or suppam continua. They do not see the labels beside the word; these are just for reader clarity.

Results and Discussion

As noted above, the steps chosen for the main experiment were steps 1, 12, 14, 15, 16, 19, and 21. These steps were recoded as 1, 2, 3, 4, 5, 6, and 7 for the data analysis, with 1 and 7 representing the endpoints and 2-6 representing the ambiguous middle steps. Step 1 is the geminate endpoint for each continuum, and step 21 is the singleton endpoint. We expected that for the *pakkam* and *kuppam* continua, participants would perceive the geminate more often in the ambiguous area (steps 2-6), and in the *nakkam* and *suppam* continua, participants would perceive the singleton in the ambiguous area. This is based on the idea that *pakkam* and *kuppam* are both geminate words compared to *pagam* and *kubam*, which are singleton nonwords (and vice versa for *nakkam* and *suppam*). Therefore, participants will be more likely to interpret the ambiguous phonological sequences as real words instead of nonwords.

The graph in Figure 3 shows the participant responses for steps along the *kuppam* (orange line) and *suppam* continua (blue line). As expected, 98.9% of participants identified step 1 containing a geminate in both continua (1.1% singleton responses), and about 97% identified the singleton at step 7. As these were the endpoints, this indicates that participants were able to recognize the unambiguous geminate and singleton sounds in both the word and nonword context. For the *kuppam* continuum (orange), participants switched from perceiving the geminate word *kuppam* to overwhelmingly perceiving the singleton nonword *kubam* later (step 6) than they did for the *suppam* continuum (step 3). At step 3, less than half of the responses (40%) were the singleton nonword *kubam*, which increased to 60% of responses in step 4. The continuum shows a gradual increase that reflected the participants' hesitation to switch from the geminate word *kuppam* to the singleton nonword *kubam*. Conversely, in the *suppam* continuum (blue), participants identified the singleton word *subam* earlier than they did in the *kuppam* continuum: 43% of the responses were identified as the singleton by step 2, compared to only 19% in the *kuppam* continuum. By step 5 in the *suppam* continuum, participants were more consistent with the singleton identity than they were in the *kuppam* continuum, where the same consistency only occurred at step 7. This indicated that participants were more inclined to switch identification of the ambiguous sound from the geminate to the singleton earlier on in the *suppam* continuum when compared to the *kuppam* continuum. This means that participants were experiencing a lexical effect and preferred to classify the ambiguous sound as a word (*subam*).

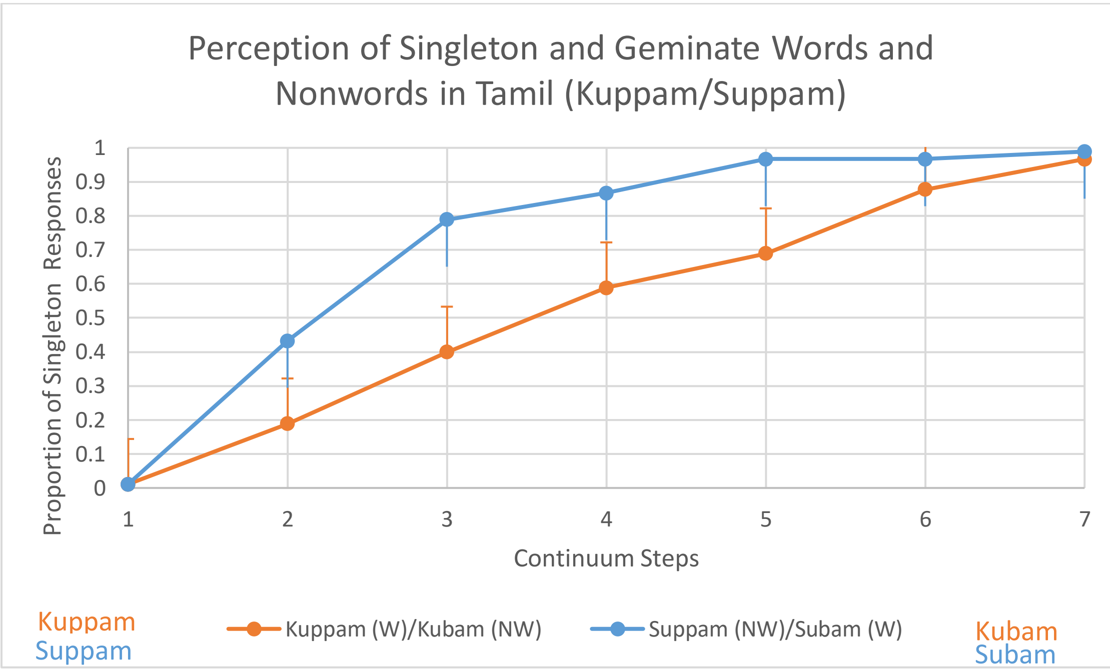

Figure 3: The data for the kuppam-kubam and suppam-subam continua. The x-axis shows the steps of the continuum, and the y-axis shows the proportion of singleton (kubam/subam) responses, averaged over all participants. Standard error is shown in the brackets.

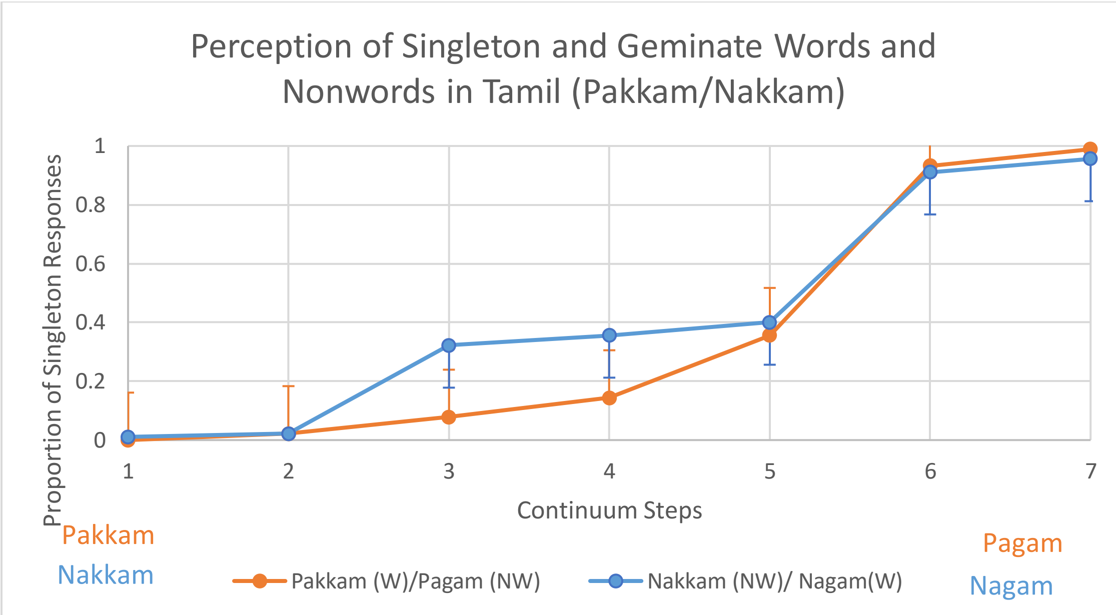

Figure 4: The nakkam-nagam and pakkam-pagam continua. The x-axis represents the steps of the continuum from 1-7, and the y-axis represents the percentage of singleton (nagam/pagam) responses. Standard error is shown in the brackets.

The *nakkam-nagam* and *pakkam-pagam* continua were graphed separately (Figure 4). We expected to see the same trend in this set of continua as we did in the *kuppam-kubam* and *suppam-subam* continua. In the *pakkam* continuum (orange line), 100% of the responses were the geminate word at step 1, and 99% of the responses were the singleton nonword at step 7. In the *nakkam* continuum (blue line), 99% of the responses were the geminate nonword at step 1, while 96% of the responses were the singleton word at step 7. As noted above, these responses are expected for the endpoints and represent the participants' certainty of the clear geminate or singleton word or nonword they hear at the endpoints. In the *pakkam* continuum, participants made the switch from 36% singleton nonword responses in step 5 to 93% singleton nonword responses in step 6; the *nakkam* continuum showed a similar trend, with participants making the switch from 40% singleton word responses in step 5 to 91% singleton word responses in step 6.

The trend in the *nakkam* and *pakkam* continua does not exactly follow the same pattern as the *kuppam* and *suppam* continua; instead, the switch to only singleton responses happened at step 6 for both *nakkam* and *pakkam*. This indicates that the ambiguous region for these continua could have been different than that of the *kuppam* and *suppam* continua. In both the *nakkam* and *pakkam* continua, the participants were more inclined to classify the ambiguous sound as a singleton at step 6 regardless of whether the singleton was a word or a nonword. This can be seen by the lack of a reliable difference between the blue and orange lines, although the relationship between the two continua are trending in the correct direction (higher singleton responses for the blue continua).

The data were analyzed using a repeated measures ANOVA test in a 2x2 design that compared the average singleton responses between two sets of continua at each individual step. The average proportion of singleton responses was calculated for each step of the continua across all nine participants for each of the four continua, and then the difference between those averages for each set was calculated (e.g. the difference in average proportion of singleton responses between *kuppam-suppam* and *nakkam-pakkam*). There was a significant main effect of continua set ($F(1, 124)=102.76$, $p<.001$)), showing that though the graphs' endpoints are similar to one another, the areas between the curves in the two graphs are considerably different. There was a significant main effect of step as well, ($F(6, 124) = 7.11$, $p<.001$)), indicating that there was a significant difference between each step. A post hoc Tukey's analysis was done for the average difference in steps between the two continua revealed that steps 3, 4, and 5 were the steps in which there were significant differences across the two continua. In the graphs for both continua, this aligns with the largest difference between the two lines in both the *kuppam-suppam* graph and the *nakkam-pakkam* graph. These significant effects suggest that while there were specific ambiguous steps (3, 4, and 5) that prompted the lexical effect, there was also a significant difference between the perception of the *kuppam-suppam* continua and the *nakkam-pakkam* continua. This indicates that the strong lexical effect present in the *kuppam-suppam* continua is not as present in the *nakkam-pakkam* continua.

General Discussion

The purpose of this study was to determine if the theoretical frameworks for speech perception in English were applicable to the lexical influences in geminate perception in Tamil. In this experiment, participants listened to ambiguous stimuli and were expected to classify these stimuli as words rather than nonwords. In the *kuppam-kubam* and *suppam-subam* continua, this meant that they were expected to classify the ambiguous stimuli as *kuppam*, the geminate word, and *subam*, the singleton word. In the *nakkam-nagam* and *pakkam-pagam* continua, this meant that they were expected to classify the ambiguous stimuli as *nagam*, the singleton word, and *pakkam*, the geminate word.

The participants in the experiment did achieve the expected results with the *kuppam* and *suppam* continua; participants switched from perceiving the geminate word *kuppam* to overwhelmingly perceiving the singleton nonword *kubam* later (step 6) than they did with the *suppam-subam* continuum (step 3). This inclination toward perception of the geminate word *kuppam* and the singleton word *subam* suggests that a lexical effect was taking place. In the *nakkam* and *pakkam* continua, participants took a similar amount of steps to switch from the geminate word to the singleton word; they went from perceiving the geminate nonword *nakkam* and geminate word *pakkam* to overwhelmingly perceiving the singleton word *nagam* and singleton nonword *pagam* at step 6 for both continua. This indicates that the same lexical effect occurring for participants listening to the *kuppam* and *suppam* continua may not be occurring for the *nakkam* and *pakkam* continua.

Based on the analysis, there was a difference between the average phoneme identification of *kuppam-kubam* and *suppam-subam*. There is a lexical effect, as participants took longer to identify the ambiguous sound as a singleton in the *kuppam-kubam* continuum, where *kuppam* was the geminate word and *kubam* was the singleton nonword than they did for the *suppam* continuum. The opposite effect was seen in the *suppam-subam* continuum, where participants identified more of the ambiguous steps as the singleton word *subam* at an earlier step. These trends follow in line with Ganong (1980)'s views of the top-down processing effect, where participants rely on the lexical status of the word to aid subsequent acoustic processing.

The same cannot be said, however, for the *nakkam-nagam* and *pakkam-pagam* continua. Despite *nakkam* being a geminate nonword and *pakkam* being a geminate word, participants identified the ambiguous steps as the similarly in both continua, steps 3-5. Though participants did behave somewhat similarly in the *nakkam* and *pakkam* continua as they did with the *kuppam* and *suppam* continua, they were still expected take more steps to switch from the geminate word *pakkam* to the singleton nonword *pagam* than they would to switch from the geminate nonword *nakkam* to the singleton nonword *nagam*. However, participants made the switch to more than 50% singleton classification at step 6 for both *nakkam* and *pakkam*, regardless of whether the singleton was a word or a nonword. These results were significantly different from the *kuppam* and *suppam* results, based on the post hoc analysis.

There are reasons for why this significant difference in perception for the two continua sets might have occurred. It could be that the spectral or durational difference between /p/ and /b/ in Tamil is more pronounced than the difference between /k/ and /g/, which might suggest that it was easier for participants to gauge when the geminate /p/ sound began to sound more like a /b/. This would enable them to make the shift earlier than they might have in the *nakkam* and *pakkam* continua. Another possibility is that the effect would have shown up if more steps between 16 and 19 had been presented for this continuum. The data suggest that the ambiguous region might not have been accurately probed for this continuum, as the singleton responses increased by 50% in one step (from 40% at step 5 and 90% at step 6). I suspect that had the correct ambiguous area been probed, participants may have overwhelmingly perceived the singleton word *nagam* at an earlier step than step 6 while still waiting until step 6 to overwhelmingly perceive the singleton nonword *pagam*.

There is also the possibility that *nakkam* could sound like a more realistic word that has a higher chance of actually existing in Tamil. Tamil exhibits diglossia, a sociolinguistic phenomenon where there is a prominent difference between the dialects of the language used: there is the everyday vernacular, which is known as the low variety, and the more formal high variety used for schooling, writing, and literature (Ferguson, 1959). While the word *nakkam* might not exist in everyday vernacular, Tamil listeners may have believed the word to exist in a different form, potentially in a formal writing setting. *Nakkam* specifically does not exist alone, but it is a part of several formal words, including the formal Tamil greeting *vanakkam.* The recognition of the nonword *nakkam* as part of a more formal real word may have swayed participants toward choosing it.

The occurrence of a lexical effect was supported by one set of continua, *kuppam* and *suppam*, yet was only partially supported by the *nakkam* and *pakkam* continua set. The existence of a lexical effect in the perception of certain phonetic sequences in Tamil does not decisively confirm the existence of the effect in other languages with gemination (as there are languages like Japanese, for example, where duration is the only cue in differentiating between a geminate and singleton word). Despite this, findings in an experiment done with Tamil listeners may still be able to predict how the effect might manifest in other languages in some ways. Because a strong lexical effect was found in at least one of the continua, this might indicate that the original conclusions drawn about lexical status (Ganong, 1980) may be applicable to non-English languages. The effect is still present despite the use of mid-word consonant manipulation, which suggests that it is not limited to word-initial consonants.

Future experiments regarding how lexical knowledge influences perception should be carried out in different languages. One idea might be to examine the effect of gemination in two different languages: Japanese, where gemination relies on only durational cues, and Tamil, where gemination relies on both durational and spectral cues. Examining the lexical effects of gemination like this may reveal different methods of processing that might be dependent on the different gemination cues between the languages; this might suggest that different gemination cues could actually determine how pervasive a lexical effect can be. Another direction future experimentation could take is to look at different sets of words within the same continua; there could be a focus on only /pp/-/b/ or /kk/-/g/. This would enable me to focus on other factors that could be involved in influencing the lexical effect. As Newman and colleagues (1997) suggested, lexical neighborhood density is able to sway listeners’ perception, and I would have to focus on certain words within the same continua to be able to look more into it. I would also like to look more into reaction times, as Fox (1984) noted that reaction times could determine the presence of a lexical effect.

One of the biggest limitations in this study was the sample size; a larger sample size is certainly needed in order to determine the strength and reliability of the lexical effects found here. If the experiment were done again, I would like to gather a larger sample of people; these subjects could potentially be recruited from Amazon mTurk, a global crowdsourcing platform through which more Tamil speakers might be able to do the experiment. Additionally, Tamil proved to be a challenging language to work with. As noted above, the diglossic nature of the language made it difficult to find words that worked in the scope of the study, and it took quite a long time to make sure the sequences used for the study were definitively considered either words or nonwords universally among the Tamil speakers in the community that I tested them with. Words that existed in the language for formal speakers with intensive Tamil education were not words that existed in the common vernacular of the daily Tamil speaker; this complication caused a setback and limited the number of usable continua. To remedy this, I would like to use more combinations of phonemes, including another geminate voiced/voiceless stop combination and the geminate affricate; this might provide more usable options that are agreed upon within the community.

Another variable that could influence the interpretation of the data is voicing in Tamil. Geminate and singleton stops vary in their voicing in Tamil; this can be seen with /pp/, a voiceless geminate consonant, and /b/, a voiced singleton consonant. This experiment did not focus specifically on this voicing difference, as it is standardized in Tamil in the regard that geminates are always voiceless and singletons always voiced. However, in order to look more into voicing as a possible factor that could influence the way Tamil listeners perceive ambiguous stimuli, I would like to use the aforementioned geminate affricates as a comparison. Tamil has a voiceless alveolo-palatal affricate, represented by the IPA symbol [t͡ɕ], and its counterpart singleton is a voiceless [s]. An example of a word-word pair where this occurs is *pachchai* ("green") and *pasai* ("sticking gum"). Because these are both voiceless compared to voiced/voiceless stop consonant pairs, it might offer further insight as to how voicing may affect Tamil listeners' perception.

Prior research suggests that several lexical influences may have an effect on the way listeners perceive ambiguous stimuli; some of these lexical effects include lexical status, lexical neighborhood density, and word frequency. In the case of lexical status, for example, English speakers favor phonemes that complete a word rather than a nonword, so they will perceive the ambiguous sound accordingly. In Tamil, listeners seem to use top-down lexical processing and adhere to this effect for certain words like *kuppam* and *suppam*, where they use their knowledge of words and nonwords in Tamil to perceive the ambiguity in the word. However, for words like *nakkam* and *pakkam*, there was more uncertainty; the lexical status effect did not replicate as strongly within this set of continua and may necessitate a reevaluation of the ambiguous area. Nevertheless, the indication of the lexical status effect in at least one of the continua suggests that manipulating phenomena like gemination that occur in non-English languages can still induce a lexical status effect that aids listeners in processing ambiguous acoustic information.

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