Lend Me Your Ears: Otitis Media and Aboriginal Australian languages

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Abstract

Language change is influenced by linguistic and non-linguistic factors, but some of these factors have more evidence than others. Aboriginal Australian languages have very unique phonemic inventories, showing a generalized lack of high vowels and fricatives (sounds such as [s], [f], th [θ] or [ð]) (Gasser and Bowern 2013). In addition, Aboriginal Australian populations have high rates of chronic middle ear infections such as chronic otitis media (COM) (Chr 2004). These chronic middle ear infections result in partial deafness in high frequencies (Chr 2004). It has been hypothesized that this partial deafness caused a loss of fricatives in Aboriginal Australian languages between the acquisition and transmission of language in a population that cannot distinguish between the sounds in question (Butcher 2006). In this thesis, I investigate the assumptions behind this hypothesis which follow in a previous body of literature that links linguistic properties to other biological and cultural factors (Roberts and Winters 2013). Using comparative methods, phonological research, and mixed effects modelling, I show that the historical, phonological, and general medical prerequisites for Butcher's 2006 hypothesis are insufficient to fully explain the unique phonemic inventories of Australian languages and cannot be generalized in a broader linguistic context.

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1 Introduction

1.1 Australian language change and otitis media

Language change is influenced by linguistic and non-linguistic factors, but some of these factors have more evidence than others. The phonologies of Aboriginal Australian languages show a different phonemic inventory than most languages in their general lack of phonemic fricatives (sounds such as [s], [f], th [θ] or [ð]) (Gasser and Bowern 2013). Gasser and Bowern 2013 show that several Australian languages have do in fact have fricatives. However, according to data from the World Atlas of Language Structures (WALS), Australian languages do stand out as being less likely to have fricatives (Maddieson 2013). In his 2006 paper about the phonologies and phonotactics of Aboriginal Australian languages, Andrew Butcher posited a 'place-of-articulation imperative' influencing the consonant inventory (Butcher 2006). Butcher then hypothesized that this place-of-articulation imperative was itself the result of the selective deafness caused by chronic middle ear infections (otitis media) which then prompted a loss or lack of development of fricatives in Aboriginal Australian languages (Butcher 2006).

I hypothesize that the prevalence of chronic otitis media (COM) in Aboriginal Australian populations and the resulting partial deafness did not influence the presence or number of fricatives in Aboriginal Australian languages. For hearing loss as a result of COM to impact language change to such an extent that a large language group shows a general lack of fricatives, it would be expected that there is some correlation between COM and phonemic inventories lacking fricatives. But, as any teacher, student, or statistician knows, correlation does not equal causation. In order to argue for a causal relationship, there would need to be much more concrete historical and phonological evidence for COM causing a influencing fricatives that takes into account changes in population, sanitation, and surviving evidence of otitis media around the globe.

There are two variables of interest when investigating this hypothesis: the absence of fricatives, and the presence of chronic otitis media in the language population. In theory, since COM causes selective deafness in "the low frequency end of the scale (under 500 Hz), [and] may also affect the upper end of the scale (above 4000 Hz)," fricatives which make up the audio frequencies of around 4000 Hz would not be distinguishable from each other or from stops with the same place of articulation (Butcher 2006; Gordon, Barthmaier, and Sands 2002). If the hearing ability of a population influences language development and change, then if a language population with fricatives has a generation that cannot distinguish between the fricative and stop phonemes, the generation will not acquire fricatives in their phonemic inventory and would not transmit fricatives which would cause, in a few generations, a complete loss of fricatives (explored more in section 2.2). If there are no fricatives, then this same mechanism would prevent a language from developing fricatives through the same mechanism (Bowern 2018).

When researching this question, even preliminary data shows several languages which refute this hypothesis. For example, according to the World Health Organization (WHO) Indian populations, specifically Tamil speakers, have at least a 7.8% prevalence of chronic otitis media which is very high and considered a serious health concern (Chr 2004). However, while Tamil has a low number of phonemic fricatives, there is a very regular pattern of allophonic fricatives and does not seem to be have either lost or be on the way to losing them [1] (Keane 2004). Similarly, non-Aboriginal languages lacking fricatives, such as Hawai'ian (which has only [h]), have been studied and there are no hypotheses to explain the lack of fricatives beyond systematic sound change, nor is there any evidence to support chronic otitis media in this population which would cause the loss of fricatives (Schütz 1994; Chr 2004). When the available data of rates of otitis media and population con-

[1] Although it does have many places of articulation which is another part of Butcher's claim (Butcher 2006)

sonant inventories were compiled, the resulting p and R^2 values were very high, which does not indicate a correlation or a causal relationship.

This thesis predicts that the prevalence of otitis media is not the cause of the unusual consonant inventories of Aboriginal Australian languages; its presence does not influence the course of language change in these languages, which could be a result of other factors such as social selection pressures, high frequency of allophonic variation not captured in phonemic analyses, or high rates of lexical replacement obscuring sound changes (Bowern 2018). Should my hypothesis be proved correct (and Butcher's proved incorrect), there should be some other plausible reason for there to be a lack of fricatives. This reason could be that fricatives were lost earlier than the earliest evidence of otitis media, there is some other reason for the lack of fricatives, or that the ancestral language, while odd, was perfectly natural to not have fricatives in a language because of the varieties of phonetic inventories. For the last reason to be true, my hypothesis predicts that Andrew Butcher's hypothesis and line of reasoning must have some irreparable hole that cannot be explained or supported. In addition, Butcher (2006)'s hypothesis does not account for the presence of phonemic and allophonic fricatives in different subfamilies of Australian languages or how other non-linguistic factors could affect language change Bowern (2018).

1.2 Explanation of Butcher's hypothesis

The unusual phonemic inventory of "Standard Average Australian" is a topic of interest to Butcher 2006 who examines the phonologies of Aboriginal Australian languages and attempts to generalize patterns of phonological change in these languages. Butcher claims the phonological structure of many of these languages including VC(V) syllable structure as opposed to CV(C), and a lack of close (high) vowels, voicing contrasts, and manner-of-articulation contrasts is due to an overarching 'place-of-articulation' imperative which requires a distinction in place of articulation to differentiate syllables (Butcher

2006). “It appears that there is an overwhelming imperative to preserve the rich system of place of articulation distinctions” as opposed to constraining speech to minimize the ‘economy of effort’ (Butcher 2006). This ‘imperative’[2] is proposed to account for the distinct places of articulation and resistance to place assimilation of consonants in connected speech in Australian languages (Butcher 2006).

Butcher’s work is heavily based on Recasens’ 1989 work dealing in coarticulatory effects and anticipatory place of articulation assimilation which “argued that anticipatory coarticulation reflects planning of the speech sequence” (Butcher 2006). Recasens relevant conclusions showed that anticipatory place of articulation assimilation was “more tightly controlled” due to the speech planning (Recasens 1989). Butcher’s hypothesis follows the logic that if there is evidence for preplanned speech, as in Recasens 1989, and contradictory evidence for no place of articulation assimilation in Australian languages , then there must be a reason for the distinct consonants in Australian languages, which leads to the necessity for the ‘imperative’ (Butcher 2006).

The main linguistic intuition both Butcher’s 2006 and Recasens’ 1989 papers rely on is that of the linguists who are interpreting the speech sounds of the Aboriginal languages in question since most other pieces of data used as evidence are quantifiable (such as computer-calculated formants or visible ink-markings). Both papers provide evidence in the form of field-work data to support phonological statements about places of articulation and vowels (Butcher 2006; Recasens 1989).The few vowels in Aboriginal Australian languages are shown to have F_1 frequencies between 450 and 800 Hz, generally the range of mid vowels (however in Butcher’s (2006) paper only data from Warlpiri was shown with [a], [i], and [u] closer in frequency to [ɐ], [e], and [o] respectively which is not actually representative of all Australian languages) (Butcher 2006).This becomes important when Butcher hypothesizes about

[2]This is a very loaded term and implies more of a necessity than evidence allows

mechanisms for language change (Butcher 2006).

Butcher's 2006 paper gives phonological details about Aboriginal Australian languages and several pieces of evidence for categorizing these languages as changing syllable structures from CV(C) to VC(V) and vice versa. This syllable structure was itself proposed to be evidence for a place of articulation imperative which accounted for the lack of anticipatory assimilation (Butcher 2006). But what mechanism caused this 'imperative'? In the conclusion of his paper, Butcher suggests the idea that chronic middle ear infections (otitis media) in Aboriginal infants causes deafness in very high and very low frequencies which could account for the lack of high vowels and the need for several places of articulation for consonant/syllable contrast. The 'high' vowels in Australian languages have been shown by Butcher 2006 to have the frequencies of mid vowels, and canonically fricatives have a frequency around 4000 Hz (Gordon et al. 2002). Butcher (2006) claims that in Aboriginal Australian languages, both high vowels and fricatives, which have high frequencies, are generally absent in the phonemic inventories although Gasser and Bowern (2013) show that is not entirely the case. Selective deafness of high frequencies would then affect vowel height and fricatives, although Butcher does not specify whether affricates or other phoneme distinctions would be similarly affected by this kind of hearing loss. In addition, Butcher seems to assume that this kind of change would be in about one generation which is not generally seen in most models of language change (Butcher 2006; Bowern 2018).

1.3 Hypothesis

In this essay I will investigate whether the selective deafness caused by chronic middle ear infections (otitis media) prompted a loss of fricatives in Aboriginal Australian languages leading to the generalized assumption that Aboriginal Australian languages do not have any fricatives. This hypothesis was first posited by Andrew Butcher in his 2006 paper about the phonologies and phonotactics of Aboriginal Australian languages which covered the general lack of fricatives, a possible VC(V) syllabic structure, and a ‘place-of-articulation imperative’ influencing the consonant inventory (Butcher 2006). Butcher then claimed that it was the selective deafness caused by otitis media and the resulting loss of fricatives that created the place-of-articulation imperative in Aboriginal Australian languages (Butcher 2006). As a generalization, a “large group of speakers in a speech community operates with an atypical auditory system over many generations, then the phonology of the language(s) spoken by such a community might also over time be influenced by the particular properties of that common auditory system”(Butcher 2018).

Butcher’s hypothesis, while medically and linguistically fascinating, is difficult to investigate directly and requires a multifaceted, interdisciplinary approach. Even if auditory and phonological systems are unique to individual populations, that kind of reasoning assumes no overarching global trends such as would be investigated in a larger collection of phonological inventories. In addition, this contradicts the conclusions in Bowern et al. 2011 that Australian languages are not in fact very different from other world languages when it comes to language change and transmission.

Aboriginal Australian languages are not the only languages to lack fricatives (although it is the largest group) and even among the Aboriginal Australian language family, not all the languages lack fricatives (Maddieson 2013; Gasser and Bowern 2013). These outliers to Butcher’s generalization pose a relevant area of inquiry to compare these consonant inventories. The phonemic inventories of Aboriginal Australian languages, which have been shown by Gasser and Bowern to vary across language sub-groups, can be reconstructed at different ancestral nodes in order to estimate when (if ever) fricatives were lost in this family. Similarly, non-Australian languages lacking fricatives, such as Hawai’ian (which has only [h]), have been studied and there are no hypotheses to explain the lack of fricatives beyond systematic sound change, nor is there any evidence to support chronic otitis media in this population which would cause the loss of fricatives (Schütz 1994; Chr 2004).

Whether otitis media causes language change can also be investigated by comparing Aboriginal populations to populations of other language speakers who also have high rates of chronic otitis media and selective deafness.

I hypothesize that the prevalence of chronic otitis media in Aboriginal Australian populations and the resulting partial deafness did not directly influence the development of fricatives in Aboriginal Australian languages. This hypothesis predicts that the prevalence of otitis media is not the cause of the odd consonant inventories of Aboriginal Australian languages, and does not majorly influence the course of language change in these languages. Should my hypothesis be proved correct (and Butcher's proved incorrect), there should be some other plausible reason for there to be a lack of fricatives. This reason could be that fricatives were lost earlier than the earliest evidence of otitis media, there is some other reason for the lack of fricatives, or that the ancestral language, while odd, was perfectly natural to not have fricatives in a language because of the varieties of phonetic inventories. For the last reason to be true, my hypothesis predicts that Andrew Butcher's hypothesis and line of reasoning must have some irreparable hole that cannot be explained or supported, or doesn't take into account trends in fricative development in infants (Vilain, Dole, Lœvenbruck, Pascalis, and Schwartz 2018).

1.4 Outline

The remainder of this paper is organized as follows. Section 2 gives account of previous work in several areas related to this topic including non-linguistic forces of language change, phonological studies of Aboriginal Australian languages, and the medical and auditory outcomes of middle ear infections. Next, languages of comparative phonologies and rates of otitis media, historical comparisons, and a mixed-effects model of phonemes and fricatives are described in Section 3. The results and analysis of these comparisons are investigated in Section 4 and Section 5. Finally, Section 6 gives the conclusions of this analysis and how they relate to the broader study of causal relationships between social and linguistic factors.

2 Background

2.1 Generalized phonemic inventory of Aboriginal Australian languages

The paper *Revisiting Phonotactic Generalizations in Australian Languages* by Emily Gasser and Claire Bowern explores the question of whether the near-uniform phonemic inventories of Australian languages corresponds to near-uniform phonologies and phonotactics as a type of hypothesized "lexical diffusion and linguistic convergence" (Gasser and Bowern 2013). Australian languages have "Little variation in inventory, Similar cognates across the country, [and] Similar changes in different subgroups" (Bowern 2018).

The main lanugage family of Australia is the Pama-Nyungan family which is proposed to have originated around 6-7 thousand years ago and spread all throughout Australia (Bouckaert, Bowern, and Atkinson 2018).

The inventory sizes, composition, phoneme frequency, and positional markedness of Australian languages were compiled by creating wordlists from a database of lexical items from Australian languages with a standardized orthography that was then converted into a set of symbols to be coded. Gasser and Bowern (2013) were able to use morphophonemic lenition rules observable in a standardized orthography to study phonemic patterns. In creating these wordlists and standardizing the coding of lexical items, the authors of this paper ran into problems in relying on transcriptions (distinguishing Australian sounds).

This paper was able to confirm a general similarity of phonemic inven-

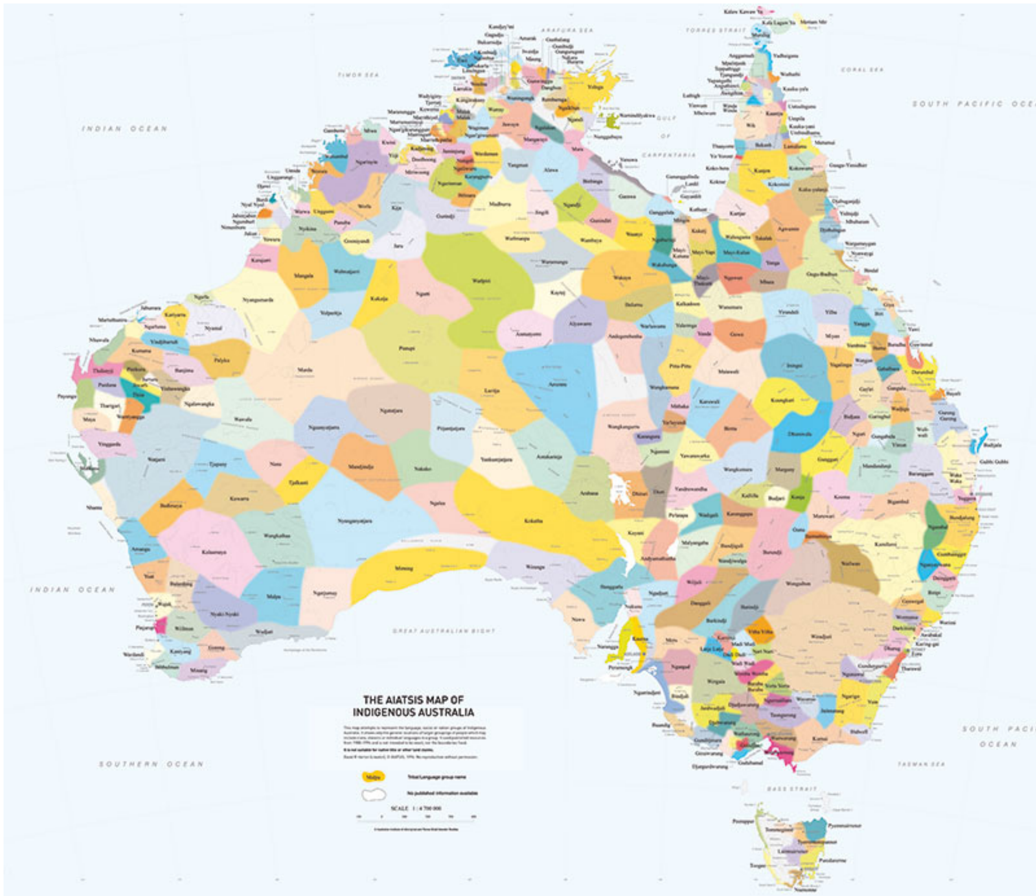

Figure 1: Map of indigenous Australian languages (AIA 2014)

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tories in that most languages share the consonants [p, t, k, m, n, ŋ, ɾ, w, j] and the vowels [i, u, a] (Gasser and Bowern 2013). However, there is a clear variation in the existence in certain consonants and certain sounds (such as laminal vs dental sounds). In addition, Gasser and Bowern found that although there is a stereotype that Australian languages have only three vowels [i, u, a], only 13% of all the languages they investigated had only those three vowels. A length distinction in these vowels is common, making at least 6 contrastive vowel sounds. There is also considerable variation in the frequencies of phonemes within similar inventories and the phonotactics that govern when certain phonemic contrasts are neutralized, suggesting a hierarchy of place of articulation for initial consonants which tentatively confirms previous work on initial consonant neutralization (Gasser and Bowern 2013).While the “standard” inventory does not have voicing distinctions or fricatives or laminals (instead of lamino-dentals), there is variation across all Aboriginal Australian languages (Bowern 2018).

	Labial	Lamino-dental	Apico-alveolar	Retroflex	Palatal	Velar
Nasal	m	n̪	n	ɳ	ɲ	ŋ
Stop	p	t̪	t	ʈ	c	k
Liquid		l̪	l ɹ r	ɭ	ʎ	
Glide	w		j			

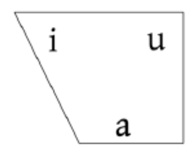

Figure 2: “Standard Average Australian” Phonemic Inventory from Gasser and Bowern (2013).

The methods used in this paper (Gasser and Bowern 2013) summarizing a generalized phonemic inventory seem fairly straightforward and applicable for the questions posed in my thesis. Quantitative results were collected from more qualitative data that both confirmed and disproved previous generalizations about Aboriginal Australian languages which is helpful for the further study of Aboriginal Australian languages. Clarifying the generalizations made about Australian languages makes further research more specific and less likely to make false assumptions.

2.2 Causal approaches to language change

There are several studies which investigate the difference between correlation and causation of factors possibly responsible for language change. Roberts (2019) describes a system of determining whether a factor is causally related

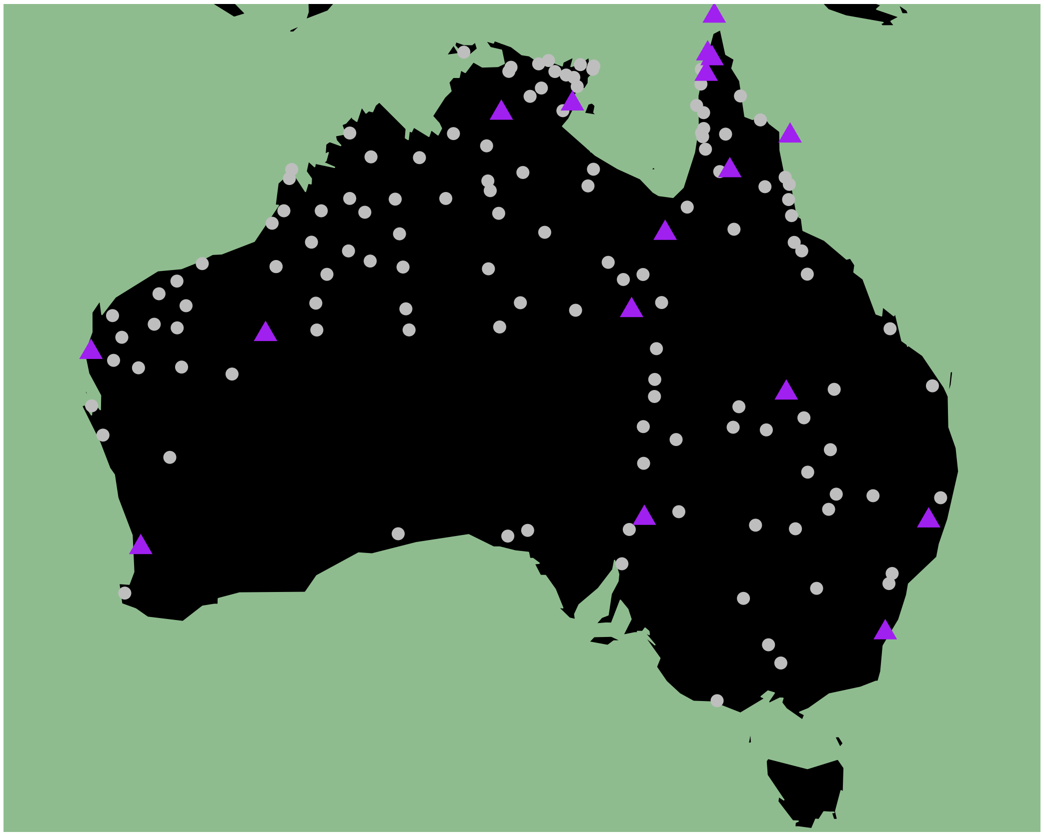

Figure 3: Presence of fricatives in Aboriginal Australian phonemic inventories from Bowern (2018).

or merely correlated to language change, since "[the] goal of evolutionary approaches to linguistics is to explain similarities and differences between languages" (Roberts 2019). He says that the point of such investigation is to "test hypotheses involving adaptation, and also to spot new patterns that might be explained by adaptation" (Roberts 2019).

Factors proposed to be responsible for language change range from obvious forces like the social structure of a culture influencing honorifics, to those less intuitive and more ridiculous like those that "[suggest] that the distribution of languages that use lexical tone across the world could be predicted by humidity" (Everett, Blasi, and Roberts 2015; Roberts 2019). Roberts and Winters (2013) also posits "a link between areas with a prevalence of a recently mutated genotype and populations with tonal languages." The logic behind this kind of theoretical analysis is based in "the idea of trying to explain properties of language as being adapted to external climatic influences goes back a long way" (Roberts 2019).

But when looking at non-linguistic forces of language change, how do we determine whether a factor is in fact causally linked to a linguistic characteristic? If otitis media causes a loss or lack of development of fricatives, there should be historical causal evidence backed up by theories of language acquisition/development/change which also shows correlation across languages.

Butcher (2006)'s hypothesis falls in the same class of theories that Roberts (2019) describes, since it tries to quantify how patterns in historical events and population pressures can influence language change.

The percentage of a population that would need to be affected (in this case unable to hear fricatives) in order to influence language development has been found to be between around 17% and 30%, however this is a general model that doesn't take into account more specific population effects (Niyogi and Berwick 2009).

However, "[as] every researcher knows, discovering a simple correlation is not the same as proving a causal link" (Roberts 2019). There are several steps that can be taken to clarify whether a correlation is indeed a causal link (Roberts 2019). These steps include breaking down the link into smaller links, considering alternative ways these smaller links could be connected, and putting it into a larger context (Roberts 2019). In addition, it is suggested that deconstructing the main problem into sub-hypotheses could add further clarity and structure to the argument a researcher is trying to make (Roberts 2019). Butcher (2006)'s original hypothesis does not take into account other sub-hypotheses, or that his hypothesis could be a sub-hypothesis of a larger hypothesis of language change.

If Butcher's hypothesis is correct, then other paleopathological factors should be investigated when determining forces of linguistic change in other languages and language families. If not, then the scope of investigation should be broadened to look at other linguistic and non-linguistic forces for fricative loss or non-development.

To test this, the correlation between high rates of otitis media and a lack of fricatives in Aboriginal Australian languages can and should be modeled statistically if possible to determine the robustness of the link which could give more quantitative evidence for a causal link (Roberts 2019). While "[recent] studies have been uncovering some surprising links between cultural traits...[such as] between chocolate consumption and the number of Nobel laureates a country produces...between the number of phonemes in a language and distance from East Africa," these links are only statistical correlations (Roberts and Winters 2013). These new large-scale correlative studies "are possible because of recently available, large-scale databases" such as WALS or PHOIBLE (Roberts and Winters 2013). However, "[the] inter-connectedness of cultural traits that we demonstrate raises problems for the usefulness of statistical analyses as independent sources of knowledge" (Roberts and Winters 2013).

There are several problems with assuming correlations between cultural and linguistic phenomena (Roberts and Winters 2013). These include *Galton's Problem* which stipulates that traits must be controlled for "diffusional and historical associations" which could heavily influence the correlational values between traits (Roberts and Winters 2013). The second problem is the reliance of linguistic data on just a few individuals to code and interpret (Roberts and Winters 2013). The last problem is that large sets of data can be incomplete which may increase the amount of statistical noise. This obfuscates the significance of correlations between variables (Roberts and Winters 2013). While my thesis will attempt to minimize the effect of these problems by taking into account language families and general language data as opposed to just individuals, the data available to run a statistical correlation test is neither small enough nor robust enough to have any clear conclusions.

2.3 Medical and observed cognitive outcomes of otitis media

2.3.1 Epidemiology of otitis media

Otitis media is an infection of the middle ear (Aithal, Aithal, and Pulotu 1995). Much of the clinical data about otitis media deals with chronic suppurative otitis media (CSOM) which has several definitions (Roland 2002). Chronic suppurative otitis media involves an infection with a pus-filled ear discharge and occasionally a rupture of the tympanic membrane (Roland 2002). Chronic otitis media (not suppurative) is usually dry, without discharge (Roland 2002). But these definitions are not standardized and could refer to middle ear infections with or without discharge or an intact tympanic membrane (Bluestone 1998).

Otitis media has been linked to risk factors such as "lack of breastfeeding, overcrowding, poor hygiene, poor nutrition, passive smoking, high rates of nasopharyngeal colonization with potentially pathogenic bacteria and inadequate and unavailable health care" (Bluestone 1998). CSOM generally develops from acute otitis media (AOM) from a respiratory infection, or otitis media with effusion (OME) (Bluestone 1998). Both of these precursor conditions can occur due to viral infections and can be complicated by preexisting conditions such as a eustachian tube dysfunction or malformation (Bluestone 1998).

CSOM is a painful condition that can be easily treated with antibiotics (in the case of bacterial OM) and has been shown to contribute to hearing loss[3] (Chr 2004).

[3] Hearing loss due to CSOM in many of these epidemiological studies is measured in decibels for *loudness*, not Hz for frequency (Bluestone 1998).

2.3.2 Historical 'proof'

In a more recent presentation, Butcher (2012) explains that there is skeletal evidence for chronic otitis media, namely staining of the skull near the ear in ancient skulls and the presence of aural exostoses (DiBartolomeo 1979).[4] [5] (See Appendix). These skulls are of unknown ages (although Butcher assumes some would be at least 10,000 years old), which could fall before "5,000 years ago" which is approximately the reconstructed age of contemporary Australian linguistic diversity (Butcher 2012; Bouckaert et al. 2018; Bowern et al. 2011). This cannot be relied upon especially since most of Butcher's other evidence comes from contemporary studies of Australian language and the hearing status of the speakers (Butcher 2012). Similar skeletal evidence has also been found in up to 20% of skulls studied from Eastern Europe dating between 900 and 1300 CE (Krenz-Niedbała 2017). This skeletal evidence for otitis media in European countries such as Poland where phonemic fricatives are present clearly shows that it is possible to have high historical rates of otitis media that does not in fact affect the acquisition or loss of fricatives in a language population (Krenz-Niedbała 2017; Moran and McCloy 2019).

In addition, since "/v/ and /z/ appear very late in the development of speech production," it makes sense that Australian languages could lack fricatives just as a result of sound change or how language developed as opposed to being a direct result of an unknown rate of hearing loss (Vilain et al. 2018).[6]

[4]Aural exostoses are results of continued contact with a liquid (presumably puss-y discharge)

[5]Without even taking into account this kind of skeletal evidence, there is also a possibility of "Genetic susceptibility to chronic otitis media" (MacArthur, Wilmot, Wang, Schuller, Lighthall, and Trune 2014). This could be the focus of an entirely new study linking genes to rates of otitis media which is a cyclical argument for nonlinguistic factors for language change, similar to studies about genetic factors for tonal languages.

[6]Butcher does not specify what rate of OM-facilitated hearing loss would be necessary to have an effect on linguistic structure, however Bromham et al. 2015 concludes that

2.3.3 Cognitive outcomes of otitis media

There is some evidence to suggest that otitis media has long-term effects on cognitive and language development as discussed by Williams and Jacobs 2009. The statistics and data used in their paper were focused on Aboriginal and non-Aboriginal Australian children on mainland Australia and the Torres Strait islands. The paper concludes that otitis media negatively affects cognitive and educational development including speech and language problems (Williams and Jacobs 2009; Leach and Morris 2017). However, these negative cognitive outcomes causes a difficulty in hearing and concentrating which could hinder language development as opposed to actual cognitive processing (Williams and Jacobs 2009). Finally, this paper also concludes that children in Indigenous populations have a pattern of earlier onset of otitis media (before 12 months old) and are at a higher risk of negative outcomes than non-Indigenous children (Leach and Morris 2017).

The paper explored both cognitive outcomes and educational outcomes and discovered that auditory processing skills were most negatively affected, possibly due to asymmetry in hearing levels of ears which impacts binaural hearing and makes distinguishing specific sounds from background difficult (Williams and Jacobs 2009). There is conflicting data and no clear conclusion about the impact of otitis media on language acquisition (Williams and Jacobs 2009). Overall though, there is a consensus that "episodes of hearing loss in infancy can change perceptual capabilities, and this can in turn affect language learning," but there was little evidence to support affected speech (Williams and Jacobs 2009).

The educational outcomes impacted by otitis media were much smaller and more speculative. It was found in later studies that Aboriginal children with otitis media had difficulty distinguishing English consonant pairs that

larger populations show greater language change which suggests that a large part of the Aboriginal Australian population would need to have hearing loss due to OM.

differed by a few distinctive phonetic features [7] which meant that the above cognitive outcomes become educational problems specifically when learning English, since English is the main language in the classroom (Aithal, Yonovitz, and Aithal 2008; Williams and Jacobs 2009).

This paper found that among research on otitis media, the age at which otitis media was contracted was a huge factor (Williams and Jacobs 2009). Children who developed otitis media before 12 months are at higher risk for long-term consequences (Williams and Jacobs 2009). However, this paper noted that differences in otitis media studies could be due to nonstandardized definitions of otitis media and how hearing loss was measured (Williams and Jacobs 2009).

These findings provide indirect evidence in favor of Butcher's hypothesis, since if children cannot hear contrasts, they will merge sounds which would prevent the development of fricatives. However, regardless of actual hearing ability, a "child will have difficulty in perceiving the sounds not present in [their] language (fricatives and affricates)," so this evidence is not at all conclusive (Aithal et al. 2008). If the high rate of otitis media (around 33%) is in the total Aboriginal Australian population and leads to hearing loss in all of those individuals, then it could be possible for language to be effected (Chr 2004; Niyogi and Berwick 2009). However, later in this thesis I will investigate whether this holds for all populations (whether the rate of otitis media can predict different linguistic phenomena around the world).

2.4 No fricatives predating otitis media

Butcher claims that there is other anthropological evidence for otitis media, and thus fricative loss, in Aboriginal Australian populations before the coming of English colonists. If otitis media came with colonization, then there is historical evidence that there were no fricatives before the introduction of oti-

[7] Such as manner of articulation, place of articulation, nasality, etc.

tis media (Troy 1990). If not, it is unclear whether there is enough evidence to accurately place the introduction of otitis media and the loss or lack of development of fricatives in Aboriginal Australian languages. Butcher uses first-hand accounts to show there were at least upper-respiratory infections when colonists arrived, but this is not necessarily otitis media, nor are primary accounts representative of the entire indigenous population of Australia (Butcher 2012).

If the rate of otitis media in Aboriginal Australian populations has continually influenced the phonemic inventory, then historical data should show evidence of middle ear infections in the population and an inability to hear fricatives. Butcher suppports this claim primarily with historical sources such as the notes and journals written by British colonists and missionaries, as well as population data from the early colonies in New South Wales discussed by Troy (1990) who very thoroughly tracks and summarizes the historical context of English colonial contact with Aboriginal Australians in New South Wales. The linguistic data includes lexical inventories of Aboriginal languages and innovations due to English analyzed according to time period (Troy 1990). Since Troy's data comes from written records that can be physically analyzed, it is a fairly good source of evidence, and the inclusion of all the pieces of data looked at gives greater credibility to the conclusions of the paper.

However, the main linguistic intuition Troy (1990) relies on is that of the original colonists of New South Wales which relies on the colonists' abilities to hear and accurately transcribe the sounds of the Aboriginal language and that of the Aboriginal people speaking English (Troy 1990). All of Troy's analyses depend on this data being accurate transcriptions, and as Troy herself states, "any attempted description of Aboriginal linguistic output. . . is entirely based on the literate colonists' perceptions of it" (Troy 1990). This kind of data is not wholly reliable when constructing an entire hypothesis of language change and development.

The contact and influence of English colonists was not limited to just documenting the language. Colonists could have highly influenced the development of Butcher's thesis since the highest prevalence of otitis media in Aboriginal Australian languages is in areas with "poor hygiene and overcrowding" possibly as a result of Aboriginal Australian populations being forced to live in missions (Wiertsema and Leach 2009).

2.5 Fricatives in language development

Previous studies have used similar "random-sampling and mixed-model approaches [that] point to a clear influence of place of articulation on obstruent voicing rates, even after controlling for relatedness and region" (Everett 2018). For example, it has been discovered that "infants at 6 or 9 months of age seem to be unable to categorize /v/ or /z/ consonants, which are largely absent from their productive inventories" (Vilain et al. 2018). Fricatives in general seem to be some of the last phonemes acquired by infants in early childhood language development which could point to developmental causes for no fricatives in a language's phonemic inventory (Vilain et al. 2018).

Recent studies have shown that fricatives, in particular labio-dental fricatives, are "overwhelmingly absent in languages whose speakers live from hunting and gathering, because the associated heavy-wear diet induces an edge-toedge bite that makes the articulation of labiodentals effortful" (Blasi, Moran, Moisik, Widmer, Dediu, and Bickel 2019). If this is in fact the case, then there are other physiological factors that cannot be ignored when determining the cause of non-fricative languages.

If these physiological factors affected between 14% and 30% of the population, then it could be that a variation in language could be selected and transmitted to future generations (Niyogi and Berwick 2009).[8] (See Appendix for language transmission graphic).

[8] Though probably not in the one generation that Butcher mainly proposes.

3 Comparing language inventories

3.1 Rationale for finding comparative languages

In exploring the probability of a causal relationship between the prevalence of otitis media in Aboriginal Australian populations and the absence of fricatives in these languages, it seems intuitive to compare the "standard" phonemic inventory of Aboriginal Australian languages to the inventories of languages with neither fricatives nor a high rate of otitis media, and languages with both fricatives and a high rate of otitis media.

The "standard" phonemic inventory of Aboriginal Australian languages, compiled by Gasser and Bowern by sampling all major non-Pama-Nyungan language families and Pama-Nyungan subgroups, shows three phonemic vowels and a number of phonemic consonants that mainly differ in place of articulation, rather than manner (Gasser and Bowern 2013). And of course, there are no phonemic fricatives.

The World Atlas of Language Structures online (WALS) identifies 49 languages as lacking any fricatives, 29 of which are Aboriginal Australian languages (Maddieson 2013). While a convenient source for large-scale linguistic data, WALS suffers from one of the problems identified by Roberts and Winters (2013). WALS "highlight[s] the geographic distribution of typological diversity around the globe," the broad-level identification of languages lacks fine details and can lead to incorrect generalizations (Roberts and Winters 2013). These generalizations are also based on assumptions that are not entirely accurate or standardized between the languages. Some of the identified languages when identified in another source have just a limited number of phonemic fricatives or have allophonic fricatives. Yet another group of languages seem entirely misidentified, as outside research shows completely contradictory phonemic inventories, as is the case with the Inuit language of Aleut.

The list of languages without fricatives was cross-referenced with a list

	No Fricatives	Fricatives
Otitis Media	Australian Aboriginal languages	Greenlandic Apache Navajo
No Otitis Media	Hawai'ian Gilbertese Waorani Dinka Lango	Others (such as English or other European languages)

Table 1: Table of languages compared in this thesis showing a clear spread of languages with and without fricatives and otitis media.

of languages from another database. PHOIBLE is another online database which collects language details such as which specific phonemes are present (Moran and McCloy 2019). PHOIBLE contains "cross-linguistic phonological inventory data, which have been extracted from source documents and tertiary databases" and "includes 3020 inventories that contain 3175 segment types found in 2186 distinct languages" (Moran and McCloy 2019).

In order to find a correlation between the absence of fricatives and a high rate of otitis media, statistics on the rate of otitis media in different populations were compared with language populations. Several epidemiological studies, such as those from the WHO and the International Journal of Pediatric Otorhinolaryngology, quantified the rate of otitis media in world populations. (see Appendix I)[9]

[9]The tables showing rates of otitis media from two different sources do mostly concentrate on children (which is when contraction of OM would influence language acquisition) but does not go into how much of the population would have some sort of hearing loss.

3.1.1 No fricatives with no otitis media

The first group of languages to be compared are those found to have a phonemic inventory with no fricatives and cross-referenced to have a low rate of otitis media in the population. This allows for discussion of general patterns.

1. Hawai'ian and Gilbertese

Many languages in the Pacific Ocean (such as Micronesian or Polynesian languages) have allophonic fricatives or one singular fricative. The Micronesian language Kiribati (also called Gilbertese since it is spoken in the Gilbert Islands, Fiji, etc) has one labiovelar fricative that can also be a flap or approximant depending on the context. There are also allophonic fricatives (such as /t/ being pronounced as [s] as in [kiribas]). Hawaiian, by contrast, has only one phonemic fricative [h] and an otherwise very small phonemic inventory (five vowels and eight consonants). (Schütz 1994)

a) Statistics on otitis media

The available data for rate of otitis media in the Pacific Islands, such as Hawai'i and the Gilbert Islands where these langauges are spoken, shows that the prevalence of OM is about 3.4% of the population (Monasta, Ronfani, Marchetti, Montico, Vecchi Brumatti, Bavcar, Grasso, Barbiero, and Tamburlini 2012).

b) Phonemic inventory

	Bilabial	Apical	Velar	Velarized-Labial
Stop	b [p]	t	k	bw [p^w]
Nasal	m	n	ng [ŋ]	mw [m^w]
Flap/Fricative		r		w [β^w]

Table 2: Gilbertese (Kiribati) phonemic inventory from Blevins and Harrison (1999).

c) Possible hypotheses for lack of fricatives

	Bilabial	Apical	Velar	Glottal
Stop	p		k	ʔ
Fricative				h
Nasal	m	n		
Glide	w	l		

Table 3: Hawai'ian phonemic consonant inventory from Schütz (1994).

The loss of fricatives in Polynesian languages like Gilbertese and Hawai'ian have been studied along with other sound changes in papers such as Grace (1985) who posits a dissimilation of voice and other predictable sound changes which arose in unrelated subgroups of Proto-Polynesian.

2. Waorani Language

According to WALS, there are a few indigenous languages in South America that also do not have any fricatives (Maddieson 2013).One such language is Waorani which is spoken in the Amazon Rainforest. According to Fawcett, Waorani is a language isolate, meaning that it is not related to any other language (Fawcett 2012). It has twelve consonants which is a much smaller inventory than most other languages (Moran and McCloy 2019). There are nasals and voicing distinctions in the stops, but no fricatives and no affricates (Moran and McCloy 2019).

a) Statistics on otitis media

What data available about the rate of otitis media in populations in the Amazon Rainforest, such as the rainforest of Ecuador where Waorani is spoken, shows that the prevalence of OM is about 1.7% of the population (Monasta et al. 2012).

b) Phonemic inventory

	Bilabial	Alveolar	Palatal	Velar
Voiceless Stop	p	t		k
Voiced Stop	b	d		g
Nasal	m	n	ɲ	ŋ
Approximant			j	w

Table 4: Phonemic inventory of the Waorani language of South America from Saint and Pike (1962).

c) Possible hypotheses for lack of fricatives

As this is a language isolate, there is no data for comparison about language change.

3. South Sudanese languages

Dinka, a Nilo-Saharan language spoken in South Sudan, is correctly identified as having no fricatives. This is a tonal language with four tones, seven phonemic vowels, and like the "Standard Average Australian" inventory, shows many consonants that differ in place of articulation with no fricatives.

Another South Sudanese language, Lango, was similarly categorized as having no fricatives. This is an Eastern Nilotic language which in comparison to the languages described above, has a large vowel inventory and relatively small consonant inventory. In addition, Lango has alveolo-palatal affricates which, while not true fricatives, share similar acoustic properties. This calls into question the exact criteria of WALS's determination of what counts as a fricative, but also provides an interesting comparison to languages that have neither true fricatives nor affricates.

a) Statistics on otitis media

Like the above language populations, there is only generalized data for rates of OM, and the data available for South Sudan shows a rate of about 4.4% (Monasta et al. 2012).

b) Phonemic inventory

	Bilabial	Dental	Apical	Palatal	Velar	Glottal
Voiceless Stop	p	t̪	t	c	k	[ʔ]
Voiced Stop	b	d̪	d	ɟ	ŋ	
Nasal	m	n̪	n	ɲ	ŋ	
Glide	w		l	j	ɰ	
Trill			r			

Table 5: Dinka phonemic inventory (Norton 2014)

	Bilabial	Alveolar	Alveolo-palatal	Palatal	Velar
Voiceless Stop	p	t			k
Voiced Stop	b	d			g
Voiceless Affricate			tɕ		
Voiced Affricate			dʑ		
Nasal	m	n		ɲ	ŋ
Approximant		l		j	w
Flap		ɾ			

Table 6: Phonemic inventory of Lango (South Sudan) (Moran and McCloy 2019)

3.1.2 Fricatives with otitis media

On the other side, there are several populations in the world identified as having high rates of otitis media. These populations are broadly "indigenous", including Aboriginal Australians, Native Americans, and Pacific Islanders. Some sources, including a study from the World Health Organization (WHO), include African countries such as Tanzania and Asian countries such as India among the countries with the highest rates of otitis media (Chr 2004). The International Journal of Pediatric Otorhinolaryngology (IJoPO) refines the broad populations as specifically including the Apache and Navajo populations and Greenlandic Inuits (Bluestone 1998).

1. Greenlandic

Greenlandic is an Eskimo-Aleut language related to the misidentified fricativeless Aleut language which has less distinction in place of articulation and also contains both voiced and voiceless fricatives.

a) Statistics on otitis media

According to the IJoPO, the Greenlandic Inuit population has a rate of otitis media between 7 and 12%.

b) Phonemic inventory

	Labials	Coronals	Palatals	Velars	Uvulars
Plosives	p	t		k	q
Nasals	m	n		ŋ	
Fricatives	v	s		ɣ	ʁ
Approximants		l	j		

Table 7: Greenlandic Phonemic Inventory from Moran and McCloy (2019)

c) Any evidence of phonological change

Fortescue (1986) shows that Greenlandic lost fricatives through regular sound changes that are shared with other languages and dialects of the same family but are not predicated on non-linguistic sound changes.

2. Native American Languages: Apahce and Navajo

a) Statistics on otitis media

According to the IJoPO, Apache and Navajo have a fairly high rate of otitis media: between 4 and 8% (Bluestone 1998). This high rate of otitis media could be related to the high rate of otitis media in other indigenous populations possibly due to being forced to live on reservations.

b) Phonemic inventory

	Bilabial	Alveolar	Palato-alveolar	Velar	Glottal
Stops	p	t^h t t’		k^h k k’	ʔ
Affricates		ts^h ts ts’	$tʃ^h$ tʃ tʃ’		
Nasals	m	n			
Fricatives		s z	ʃ ʒ	x ɣ	h
Laterals		ɬ l			
Lateral Affricates		tɬ tl tɬ’			
Approximants	w		j		

Table 8: Apache Phonemic Inventory from Gordon et al. (2001)

	Bilabial	Alveolo-Palatal	Palato-Velar	Glottal
Voiceless Unaspirated Stops	b [p]	d [t]	g [k]	
Voiceless Aspirated Stops			k [k^h] kw [kw^h]	
Voiceless Glottalized Stops		t’ [tʔ]	k’ [kʔ]	’ [ʔ]
Voiced Spirants		z zh	gh	
Voiceless Spirants		s sh [ʃ]	h(x) hw	h
Voiced Laterals		l		
Voiceless Laterals		ɬ		
Voiceless Unaspirated Affricates		dz j dl		
Voiceless Aspirated Affricates		ts ch tl	t (tx)	
Voiceless Glottalized		ts’ ch’ tl’	t’	
Nasal	m	n		

Table 9: Navajo Phonemic Inventory with standard orthography from Young and Morgan (1980)

3.2 Statistical methods

Data on the language characteristics from populations with percentages of the rates of otitis media was collected using epidemiological studies from the

WHO (Chr 2004) and the International Journal of Pediatric Otolaryngology (Bluestone 1998). The sources consulted to create these studies to determine the language of the population assessed for prevalence of otitis media. Where a distinct language was not specified, the official or most commonly spoken language in the country or region was used as the language for data purposes.[10]

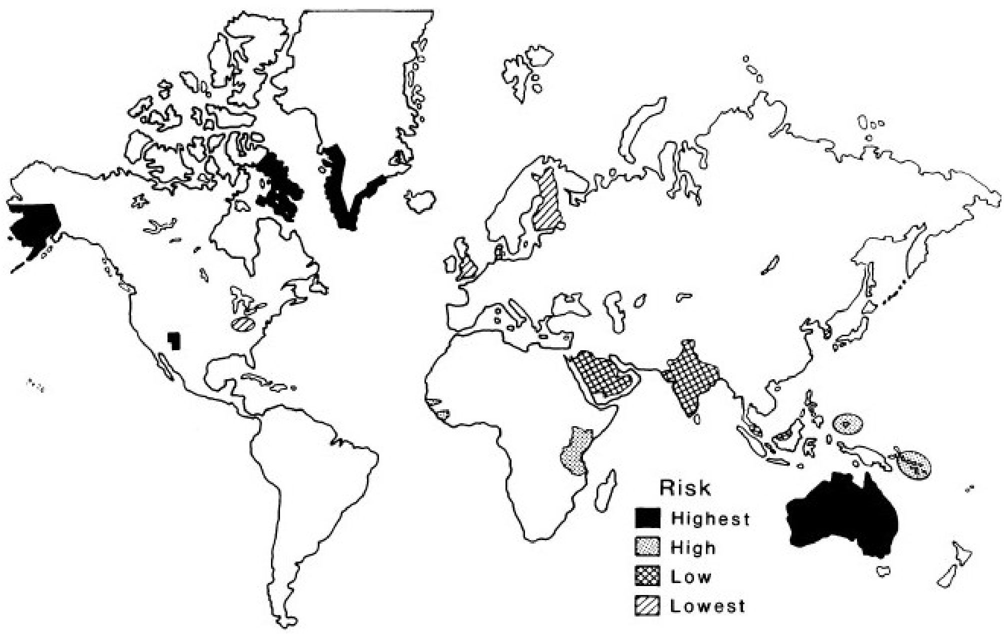

Figure 4: "Areas of the world in which there are prevalence data available for chronic suppurative otitis media (CSOM) in children" (Bluestone 1998).

These languages were searched in the PHOIBLE database where the consonant and vowel inventories were collected (Maddieson 2013; Moran and McCloy 2019). Other language datapoints such as presence of phonemic fricatives, voicing distinctions, and contrastive fricative/plosive pairs were

[10]Similar to the use of a broader otitis media statistic when no population-specific data was known, this practice is problematic since it does not take into account language differences in a population that could have a more narrow result.

also collected. Where language data was not available in PHOIBLE, external sources were consulted such as grammars of the languages and the number of consonants etc. was manually calculated. This data was organized in an Excel spreadsheet which was imported into RStudio as a dataframe.The dataframe was then analyzed to determine correlation values, linear models, and mixed effects models of factors (R Core Team 2013). Maps and modeling was possible using "dplyr" (Wickham, François, Henry, and Müller 2019), "maps" (Becker, Minka, and Deckmyn 2018), "ggplot2" (Wickham 2016), "ggmap" (Kahle and Wickham 2013), "rgdal" (Bivand, Keitt, and Rowlingson 2019), "lmerTest" (Kuznetsova, Brockhoff, and Christensen 2017), and "lme4" (Bates, Mächler, Bolker, and Walker 2015) .

Linear regression models relating the presence or absence of fricatives conditioned by the rate of otitis media and language family were coded. In addition, a cor.test was performed on each combination of rate of otitis media (rOM) and the other factors. The resulting p-values and correlation coefficients from this Spearman's rho test were recorded in tables (see the Results section) (Bivand et al. 2019; Kuznetsova et al. 2017). These p-values were not different enough from the lmer p-values to also chart.

In addition to linear regression models, the rate of otitis media was modelled using mixed (fixed and random) effects. The language family of each population was always coded as a random effect with the number of consonants, presence of phonemic affricates, voicing contrasts, an r-d distinction, p-f distinction, k-x distinction, and t-s distinction as fixed effects.

The models were fitted several times. The first fit had rate of otitis media as the response variable, and phonemic fricatives as an explanatory variable. This fit was repeated with 'country' as an additional random effect. The next two were like the first, but the number of fricatives was the explanatory variable. The last two had the number of fricatives as the response variable and rate of otitis media as an explanatory variable. Each of these models were graphed (see Appendix) with the fitted values (how well the data fit the model) on the x-axis and the residuals (how far away from the model the data was) on the y-axis.

The last four fixed effects (an r-d distinction, p-f distinction, k-x distinction, and t-s distinction) are useful to specify which common stop-fricative distinctions are affected by the rate of otitis media, as well as investigating whether the hearing loss affecting fricatives also affects stop-trill distinctions like r-d which involves the same difference of frequencies with the same voicing and place of articulation.

The preliminary results did not show any clear correlation, so additional data was added by going back to the lists from WALS of languages that have no fricatives (Maddieson 2013). The specific language datapoints were once again found using PHOIBLE or other sources (Moran and McCloy 2019). The rates of otitis media for the countries/areas where the non-fricative languages are spoken were found by searching for scholarly articles about the otitis media rates for certain language speakers. Where no studies existed, the general/estimated rates of otitis media in world regions was used according to Monasta et al. (2012). However, it should be noted that this rate can be highly variable in a geographic population area, so while this is the best estimate available, it is not entirely reliable.

4 Statistical results

When the rate of otitis media in a language population was plotted against the number of fricatives in the language, it is clear that there are very few exceptional language populations with a rate of otitis media greater than 10%. The high rate of OM in Aboriginal Australian populations is only comparable to a few other outlier language populations which do not at all pattern together in the number of fricatives. The populations in question, Eskimo-Aleut, 'Standard' Australian, Inuktitut, and Greenlandic, are all indigenous populations that have more overcrowding and poor sanitation due to European colonization pressures and less access to health care (Bowern 2018).

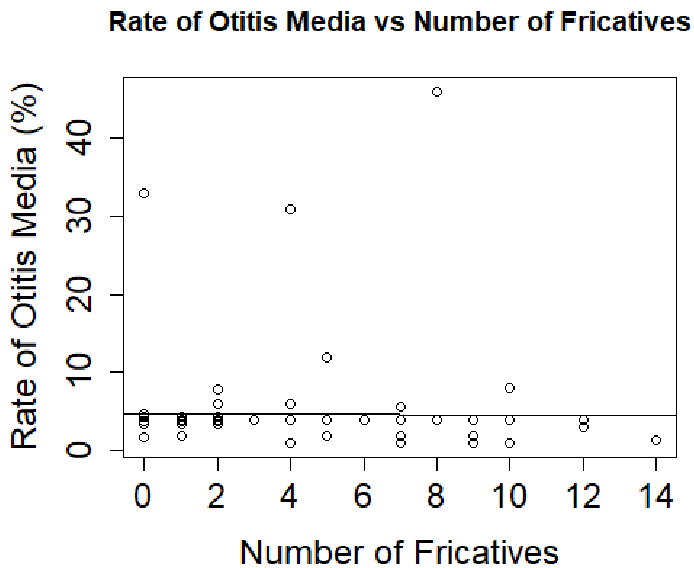

Figure 5: Scatterplot showing each language/OM population. The languages were graphed as the rate of otitis media vs the number of fricatives in the language (input from R). The outliers seen with OM rates above 10% are Eskimo-Aleut, 'Standard' Australian, Inuktitut, and Greenlandic.

The linear model of the presence of phonemic fricatives and the rate of otitis media in a population had a p-value of 0.3784 which is not small enough to reject the null hypothesis. The correlation between these two factors was -0.1158 indicating a very small negative correlation between the presence of phonemic fricatives and the rate of otitis media.

The linear model of phonemic fricatives and language family was also calculated and the overall p-value was found to be p ¡ 0.001 which makes sense because related languages tend to have similar phonemic inventories. However, this could be a somewhat skewed statistic since some of the languages in the dataset were the only ones sampled from their respective language families.

The last linear model was of the number of fricatives in a language and the rate of otitis media. This model had a very large p-value: 0.8129. This suggests that the null hypothesis (that there is no causal relationship between OM and the number of fricatives in a language) is correct. The correlation value here was even smaller than that of phonemic fricatives and OM: -0.0312.

Fixed Effects	rOM
Number of Fricatives	−0.0347
Presence of Phonemic Fricatives	−0.1136
Number of Consonants	0.0088
R-D Distinction	−0.2023
P-F Distinction	−0.2621
K-X Distinction	0.1442
T-S Distinction	−0.1539
Voicing Contrast	−0.0056
Phonemic Affricates	−0.1824

Table 10: Correlation Values between the rate of otitis media and various fixed effects

The mixed-effects models did not show any correlation. In general, language data patterned together with only a handful of outliers. (See Appendix for graphs) These outliers are in general the language populations with high rates of otitis media, and they do not show any pattern of behavior. The mixed models end up eliminating the rate of otitis media (rOM) as an effect in the model fairly early on.

Fixed Effects	rOM
Number of Fricatives	0.790 4
Presence of Phonemic Fricatives	0.383 2
Number of Consonants	0.946 1
R-D Distinction	0.117 9
P-F Distinction	0.041 3
K-X Distinction	0.267 7
T-S Distinction	0.236 2
Voicing Contrast	0.966 0
Phonemic Affricates	0.159 4

Table 11: P-Values between the rate of otitis media and various fixed effects

5 Discussion

5.1 What does language comparison tell us?

Is this compelling evidence against a causal relationship between otitis media and a lack of fricatives? Based on the comparisons of world languages with and without fricatives or a high rate of otitis media, the wide variety of linguistic contexts indicates there is little chance for a direct relationship to exist. In addition, the fact that many of the fricative-less languages have established historical sound changes losing fricatives shows that there does not need to be a nonlinguistic *cause* for a paucity of fricatives in a language (Schütz 1994). Even though theoretically it could maybe be possible for the rate of otitis media and resulting impaired hearing to affect fricative development if a high enough percentage of the population was affected, this should be seen in more than just Australian languages.

5.2 Discussion of statistical results

The statistics found using linear and mixed effects models were used as evidence in determining a causal relationship between the rate of otitis media and the presence and number of fricatives in a language population.

Based on the various models, it is clear that the rate of otitis media does not have an association with the number or presence of fricatives in a language. In some of these models, the country the language is spoken in is a better predictor of the number of fricatives than the language family is. In addition, other linguistic factors such as voicing contrast and the number of consonants in a language have a better correspondence to the number of fricatives (and a very low correlation to the rate of otitis media). If the rate of otitis media in a population did affect the general audiological processes, then there should be some broader correlation across languages which these results do not show.

Overall, a larger and more complete dataset with the rates of otitis media in all populations along with the phonemic inventory data would be needed in order to truly have a good idea of the causal relationship between otitis media and fricatives in a language, but as that data does not yet exist and would require extensive epidemiological studies, this is the next best thing. Based on this dataset, there is no causal relationship between the rate of otitis media and the presence or number of fricatives in a language.

5.2.1 A note on reliability

Much of the data collected in this thesis is some shade of unreliable. The rates of otitis media needed for this analysis depend on specific studies of populations which does not happen very often. This means the match between the ethnolinguistic group, the language, and the population sampled by WHO for rate of OM is not exact. In addition, the language data from WALS and PHOIBLE comes from several sources and is not entirely uniform in determining what counts as a phoneme or not (Maddieson 2013; Moran and McCloy 2019). Thus, the conclusions that can be drawn from this data are very broad. However, even broadly the mixed models using this data do not show a correlation between the rate of otitis media and the number of fricatives in a language, and in fact highlights how unique languages can be without taking into account middle ear infections.

5.3 Generalizing limitations of Butcher's hypothesis

Butcher does note in a recent abstract that audiological and phonological processing can be unique in different populations (Butcher 2018). As noted above, the current dataset is somewhat limited and would need to be fleshed out more to continue this research. However, if audiological and phonological processing is different in different populations, then the fact that there are linguistic rarities that appear in only a few languages (such as a lack of bilabials, clicks as phonemes, and lexical tone) is either expected or even linked to some other non-linguistic cause (Maddieson 2013; Blasi et al. 2019).

6 Conclusion

It is clear that overall, Butcher's hypothesis is not supported by strong historical, language comparison, or statistical evidence, which shows that it is possible to have no fricatives without any evidence of high rates of otitis media and high rates of otitis media along with fricatives. This hypothesis cannot be generalized in terms of global language acquisition or development.

If otitis media is used as a proxy for deafness/hearing loss, then there should be other, broader linguistic differences linked to the rate of otitis media, such as an r-d distinction and voicing contrasts, which Australian languages and other world languages do not show. At the very least there should be some correlation, if not causation, which is not seen. In addition, if this hypothesis is only good for Australian languages, there should only be Australian-specific historical evidence...which there is not.

Further investigation into world-wide rates of otitis media would strengthen the pool of data and could maybe show a correlation, but as it is now, there is no correlation between rates of otitis media and the presence and number of fricatives in a language, and there is no concrete, language-specific historical or phonological proof of a causal relationship that fully fits into accepted models of language development.

The assumptions Butcher makes, while superficially intuitive, do not hold up to statistical analysis or further exploration of causal factors. Just because there is an interesting ‘relationship’ between a unique phonemic inventory and a rare medical phenomenon doesn’t mean that the relationship is a causal one. This can also lead to a dismissal of other causes of both high current rates of otitis media and the lack of fricatives in Australian languages which should be investigated to give greater insight into linguistic and cultural change over time.

Appendix

Figure 6: Picture of aural exostosis (Sanna 2018)

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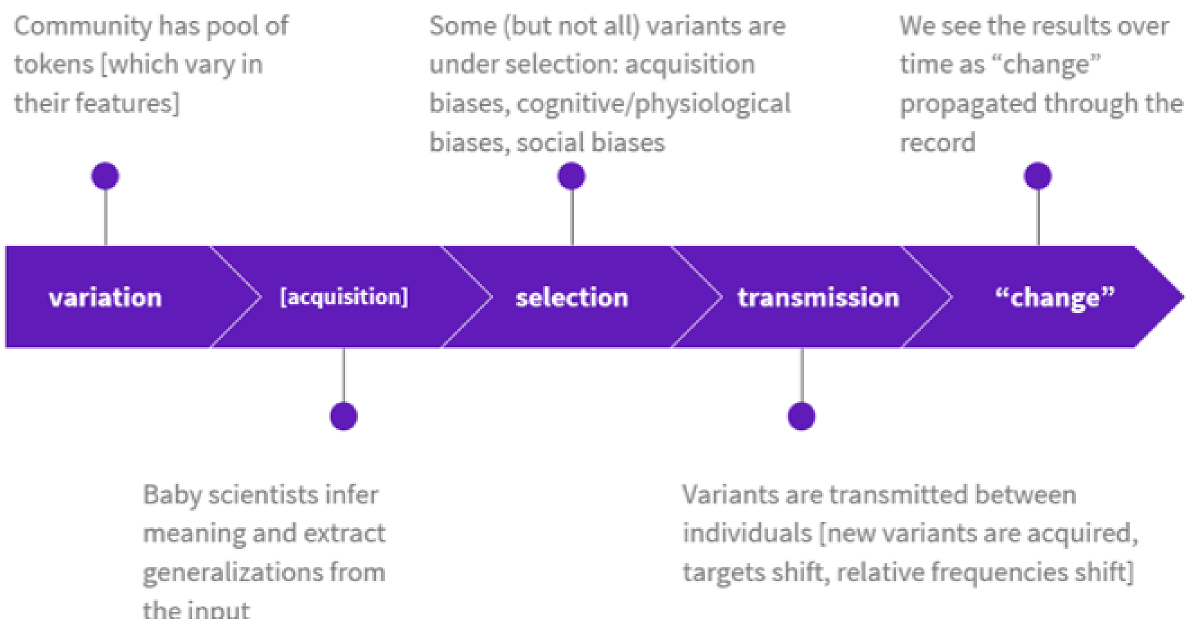

Figure 7: Infographic depicting the general stages of language transmission and development (Bowern 2018)

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Group	Population
Highest (>4%)	Tanzania
	India
	Solomon Islands
	Guam
	Australian Aborigines
	Greenland
High (2-4%)	Nigeria
	Angola
	Mozambique
	Republic of Korea
	Thailand
	Philippines
	Malaysia
	Vietnam
	Micronesia
	China
	Eskimos
Low (1-2%)	Brazil
	Kenya
Lowest (<1%)	Gambia
	Saudi Arabia
	Israel
	Australia
	United Kindgom
	Denmark
	Finland
	American Indians

Table 12: Rate of otitis media by country and population as determined by the World Health Organization (WHO) (Chr 2004).

Group	Population
Highest (%)	Indigenous Populations of:
30-46	Alaska
7-31	Canada
7-12	Greenland
12-33	Australian Aborigines
4-8	Apache, Navajo
High (%)	
4-6	Solomon Islands
4	N.Z. Maori
4	Malaysia
4	Micronesia
6	Sierra Leone
4	Gambia
4	Kenya
4	Nigeria
2-3	Tanzania
Low (%)	
2	Korea
2	India
1.4	Saudi Arabia
Lowest (%)	
<1	US
<1	UK
<1	Denmark
<1	Finland

Table 13: Rate of otitis media by country and population as determined by the International Journal of Pediatric Otohinorlaryngology

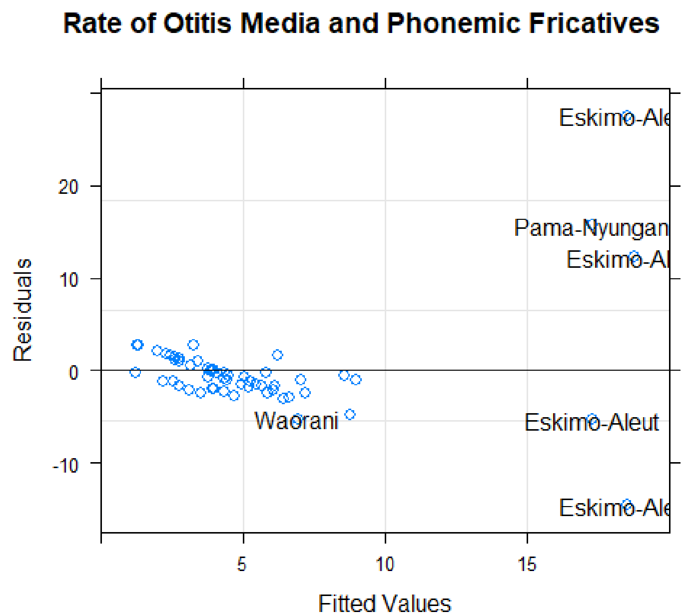

Figure 8: lmer of rate of otitis media and phonemic fricatives with other factors and language family as a random effect (input from R)

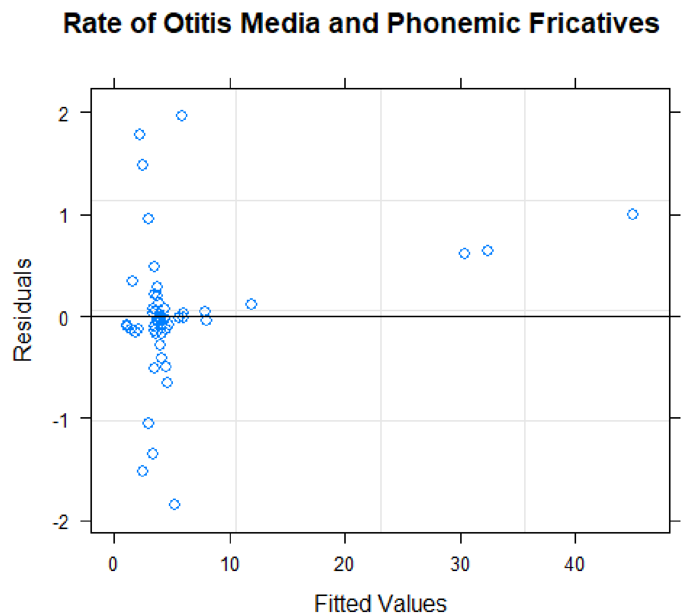

Figure 9: lmer of rate of otitis media and phonemic fricatives with other factors and language family and country as random effects (input from R)

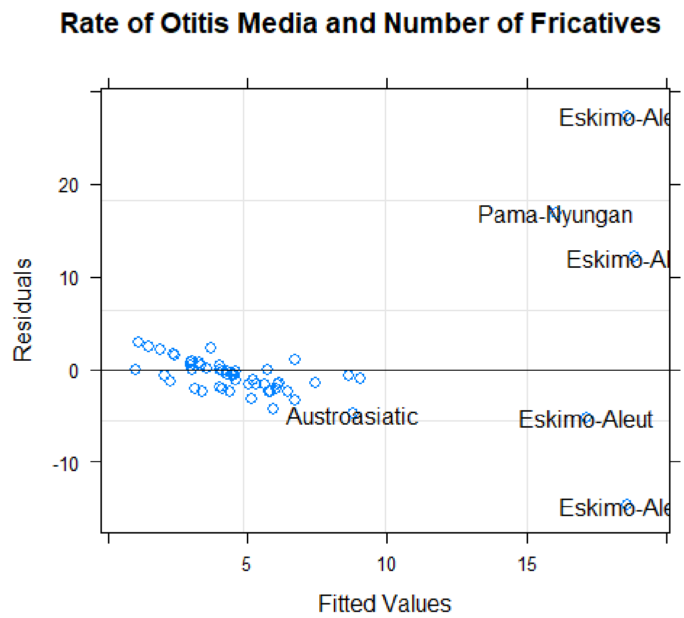

Figure 10: lmer of rate of otitis media and number of fricatives with other factors language family as a random effect (input from R)

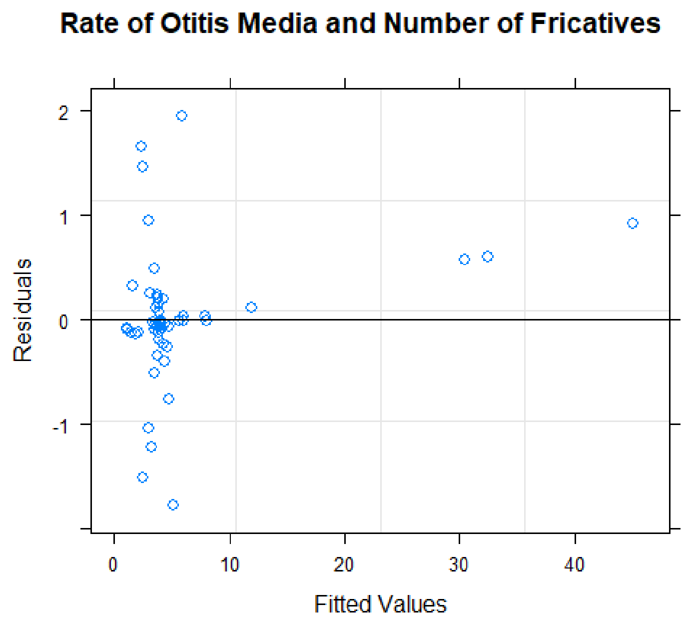

Figure 11: lmer of rate of otitis media and number of fricatives with other factors and language family and country as random effects (input from R)

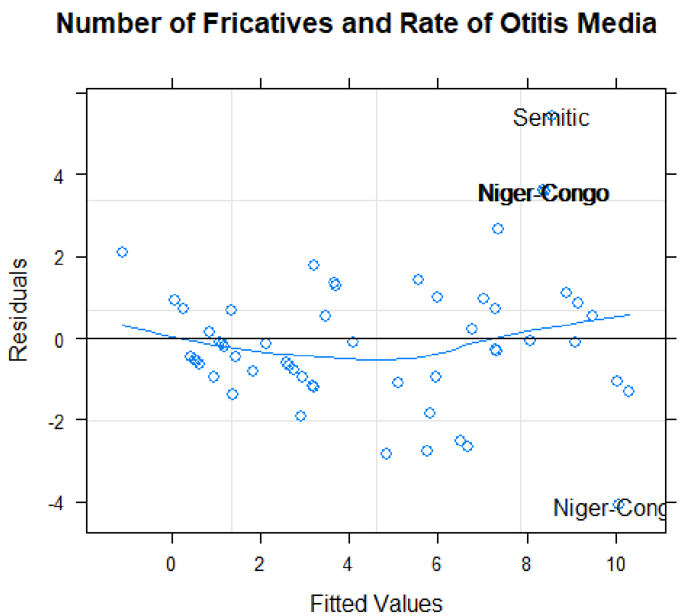

Figure 12: lmer of number of fricatives and rate of otitis media with other factors and language family as a random effect (input from R)

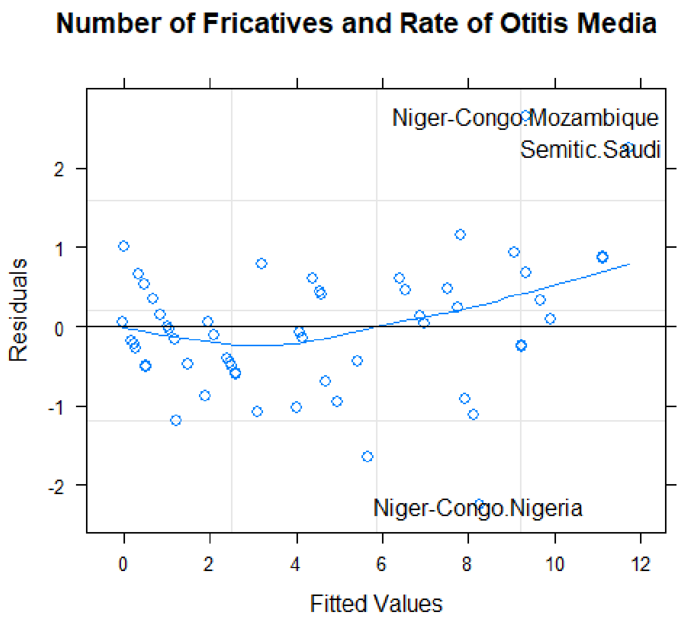

Figure 13: lmer of number of fricatives and rate of otitis media with other factors and language family and country as random effects (input from R)

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