THE EFFECTIVENESS OF ELECTROPALATOGRAPHY AS A CLINICAL THERAPY TOOL

A thesis submitted to the faculty of
San Francisco State University
In partial fulfillment of
the requirements for
the Degree

Master of Science

In

Communicative Disorders

by

Timothy M. Kahn

San Francisco, California

May 2015

CERTIFICATION OF APPROVAL

I certify that I have read The Effectiveness of Electropalatograpny as a Clinical Therapy Tool by Timothy M. Kahn, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirement for the degree Master of Science at San Francisco State University.

Laura Epstein, Ph.D. CCC-SLP
Associate Professor
Special Education and Communicative
Disorders Department

Betty Yu Ph.D CCC-SLP
Assistant Professor
Special Education and Communicative
Disorders Department

THE EFFECTIVENESS OF ELECTROPALATOGRAPHY AS A CLINICAL THERAPY TOOL

Timothy M. Kahn
San Francisco, California
2015

Abstract

Articulation therapy, as it is practiced in most clinics, is a decidedly low-tech endeavor. The speech language pathologist relies on mirrors, flash cards, rhymes, and a trove of behavioral and linguistic theory, all in search of an effective means to remediate an /s/, /t/ or the elusive /r/. Often these efforts are met with success. Not always. There are also cases we deem, "intractable." Could we be doing more?" Furthermore, is there a high tech solution? The purpose of this writing is to attempt to address both of those questions by examining the possibility of introducing a bio-feedback technology called electropalatography into clinical practice.

This writing serves to evaluate the efficacy of combining traditional treatments with this budding form of instrumental therapy. While it is limited, existing data appears to suggest that the addition of electropalatography to traditional speech therapy has the potential to greatly improve a Speech Language Pathologist's ability to evaluate and treat clients with speech sound disorders. This potential remains untapped, however, due to a marketplace riddled with obstacles. These too will be explored.

I certify that the abstract is a correct representation of the content of this thesis.

Chair, Thesis Committee

5/22/15
Date

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

The goal of any Speech Language Pathologist should be to provide their clients with accurate models to imitate, practice, and generalize. So how accurate are our models? How much do SLP's really know about tongue placement or manner of production? According to Sharynne McLeod, Ph.D., of Charles Sturt University, Australia, not very much. Dr. McLeod studied 240 Speech Language Pathologists who worked with children with speech sound disorders. She asked them to color grid diagrams of tongue/palate contacts for 24 consonants. She then compared the results to identical grid diagrams produced by a palatograph, a biofeedback device that monitors the contact of the tongue against the hard palate. In most cases the differences were dramatic.

The typical SLP filled in the same four squares at the top of the diagram for the phonemes, /t/ and /n/ and /s/ for example. The palatograph, on the on the other hand, revealed complex and distinct contact patterns. The findings, which McLeod presented at the 2009 American Speech and Hearing Association convention do not necessarily signify something lacking in the auditory perceptual judgments of speech professionals but there can be no doubt that they highlight our limits. The data could be interpreted to suggest that skilled Speech Language Pathologists can improve traditional therapy

practices with the addition of a tool that can support their observations with objective data (McLeod 2009).

(a) Typical SLP's response (b) Typical adult production established with EPG

Figure 1: The description of tongue placement for front consonants among trained speech pathologists compared to the same information instrumentally recorded using electropalatography. From *Speech Language Pathologists' Knowledge of Tongue to Palate Contact for Speech Sound Assessment and Intervention* (McLoed 2009)

With the addition of a dynamic readout of articulatory actions the clinician can identify the specific points of deviation for phonemic productions and compare them to the patterns of a typical speaker. In short, this device helps minimize the guesswork. Recorded objective data can save time and assist the SLP in creating a learning environment that is more concrete and motivating for the client.

Here is how it works. After initial assessments are completed, the client and the clinician are outfitted with customized dental appliances that are formed to adhere to the contours of their palates and upper teeth. This component is called a psuedopalate. It is laden with an array of sensors that are triggered when contacted by the tongue. Each time a contact is made a specific anatomical tracing is recorded and displayed on a computer screen, a virtual footprint in the sand.

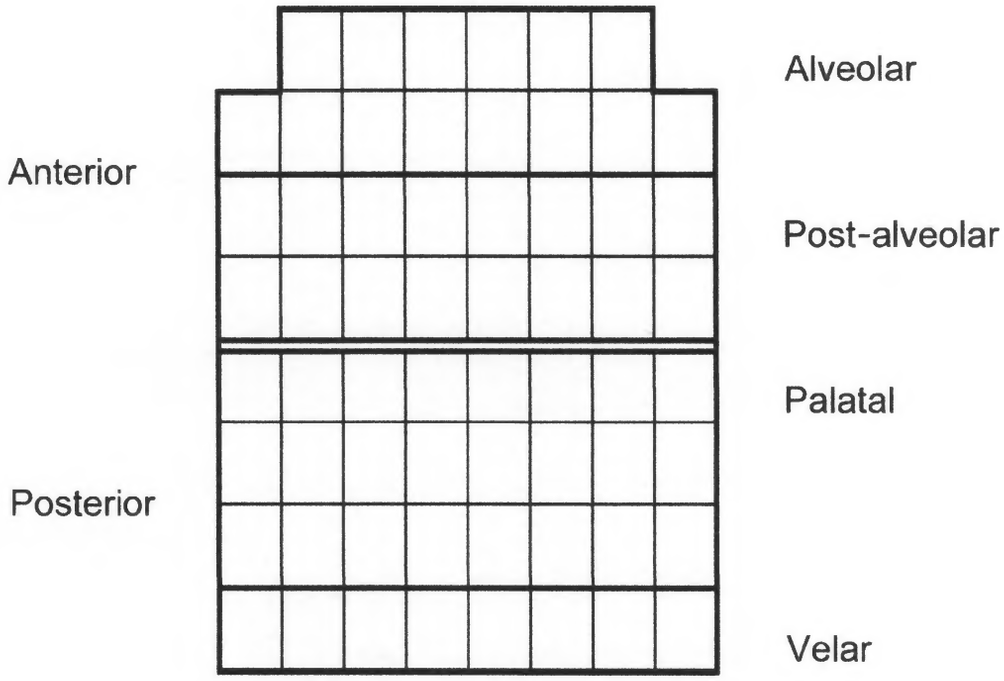

Figure 2: In this grid diagram, each box represents a point of contact for an electronic sensor. When the subject produces a speech sound each point of contact will be darkened. (From Bartle-Meyer et al 2008)

The savvy clinician can use this information in two ways. In therapy palatographs produced by the client can be compared to those of the clinician, allowing the client to attempt to match the modeled targets. For subsequent assessments, client palatographs can be referenced against normative palatography of target phonemes. In at 2007 Master's thesis project, Researcher, Marybeth C. Sanders, of Brigham Young University has, for example, developed a database of, "standardized palatometric articulation files." Access to information like this has the potential to fortify the practicing Speech Language Pathologist with the power to leave simplistic assumptions like those of the professionals in McLeod's study behind.

Operational Definitions

The following definitions are intended to clarify the terminology of this thesis for those who may not be familiar with this course of study:

Affricate: Consonants that begin as stops and end as fricatives

Articulation: the physical act of speech sound production.

Articulatory overshoot: speech sound distortions caused by too much contact of the tongue against the hard palate.

Backing: A speech sound disorder in which sounds that are produced in the back of the oral cavity such as /k/ and /g/ are substituted with consonants produced in the front of the mouth such as /t/ and /d/.

Biofeedback: the application of electrical sensors to physiological systems for the purpose of providing crucial information.

Cognates: Pairs of sounds that share both place and manner but differ by voicing.

Depalatization: a speech sound disorder in which phonemic distortions are the result of reduced contact between the tongue and the hard palate.

Distortions: speech sounds that deviate from the target sound to a degree sufficient to affect intelligibility.

Electropalatography: is a bio-feedback method that measures the dynamic action and the placement of the tongue as it makes contact with the hard palate.

EPG: see electropalatography

Fricatives: Consonants in which the airstream is channeled thus creating friction.

Fronting: An articulation disorder in which consonants produced in the front of the oral cavity such as /t/ and /d/ are substituted with consonants produced in the back of the oral cavity such /k/ and /g/.

Generalizion: The point at which the outcome of therapy has become an integral part of daily functions.

International Phonetic Alphabet: a universal set of symbols by which the speech sounds of all languages may be transcribed.

Lingua-palatal contact: the contact of the tongue against the hard palate.

Manner of Production: refers of how a speech sound is performed physiologically.

Models: These are speech productions performed by a speech therapist with the expectation that a client will imitate them correctly.

Nasalization: inappropriate channeling of airflow to the nasal cavity in the production of consonant sounds.

Omissions: Speech sounds which are unintentionally left absent in the production of connected speech.

Phoneme: speech sounds.

Place of production: refers to the accurate tongue posture required to form an accurate speech sound.

Plosives: See *stops*.

Stops: Consonants in which the airstream is interrupted.

Substitutions: the use of an incorrect speech sound in place of a correct one.

Traditional therapy comprises any evidence based, non-instrumental articulation therapy practice.

Efficacy is a measure of the ability of a therapy approach to achieve the intended result.

Instrumental therapy employs technology that provides real time feedback to clinicians and their clients.

Transcription: a written interpretation of disordered speech sound productions.

1: Electropalatography and Evidence Based Practice

Does articulation therapy work? If you ask speech language pathologists that question they would probably insist that it does. But we practice in an age when declaring our own effectiveness is not sufficient. We must answer to the economic interests of insurers, educational systems, and managed care, institutions who will not be satisfied without definitive proof. Where then do we obtain this proof?

Herein lies the ironic position held by electropalatography in the 21st century. On the one hand it is a technology with the power to yield definitive and objective conclusions on the effectiveness of therapy. On the other, electropalography is itself a method in which the evidence has not exceeded level IV (Gibbon 2011), the rung designated for case-control and cohort studies. Indeed large studies would be financially impractical. One way to untangle this knot could be to adopt the position that electropalatography is a technological solution that allows us to address the problem with such reliability that we can feel comfortable reducing population sizes. This would empower researchers to draw valid conclusions with reduced threats to homogeneity.

Randomized controlled studies, have been the time-tested workhorse of pharmaceutical trials. When comparing the effectiveness of a drug to that of a placebo, the numbers tell all. And so the conventional logic holds that the bigger the trial the more confidence we can have in the results. Testing the efficacy of a behavioral therapy, however, is a much trickier commodity to control for.

If we seek conclusive proof of the effectiveness of speech therapy the large trials are contradictory. Let's examine two such projects. One article entitled, *Randomized Controlled Trial of Community Based Speech and Language Therapy In Preschool Children,* by Margaret Glogowska, Sue Roulstone, Pam Enderby, and Tim J. Peters, published in the *British Medical Journal* (2000) concludes that speech therapy with small children is no more effective than, "watchful waiting." In another randomized trial, published in the *International Journal of Communication Disorders,* entitled, *Is Speech and Langauge Therapy Effective for Children with Primary Speech and Language Impairment,* authors, Jan Broomfied and Barbara Dodd reach the opposite conclusion. In both cases the authors of these studies produce a laundry list of justifications to solidify their conclusions.

One possibility the authors fail to propose, however, is that there can be no definitive evidence for or against speech therapy until clinicians begin to employ more reliable means of measurement. The diametric opposition of these two studies remind us that, although Speech Language Pathologists have developed elaborate means of monitoring and recording the progress of children's articulatory improvement, no method exists that can prove beyond a shadow of a doubt that the therapist is the true arbiter of change. Does therapy cure the client? Or does the client just outgrow the problem?

The two studies mentioned above stemmed from just such a conundrum. Establishing a concrete evidence base for speech therapy became very interesting to the British National Health Service in the 1990's when a trend of early intervention reached a

pinnacle. Now they found themselves spending an estimated 70% percent of their speech therapy budget remediating the articulation errors of preschoolers. To support the short-term efficacy of this practice they had only one empirical study, (Law et al 1998). Long-term efficacy remained undocumented.

In an attempt to confirm or disprove the benefits of preschool speech services the National Health Service contracted Glogowska et al. to embark on a, "pragmatic," randomized control study in which they compared, "routine," speech and language therapy to, "watchful waiting." According to the British Medical Journal, Publisher of *Randomized Controlled Trial of Community Based Speech and Language Therapy In Preschool Children,* a pragmatic randomized control study is one that measures the, "benefit the treatment produces in routine clinical practice." (Roland & Torgerson, 1998) This meant that the trials sampled the caseloads on 16 community clinics across Bristol.

507 preschoolers were assessed at the beginning of the trial. Of these they selected 159 who presented at 1.2 standard deviations below the mean on standardized tests for general language, expressive language, or phonology. The presence of this triumvirate of deficits, (and the myriad of potential conditions that underlie them), was assessed again at six months, and again at the 12 month conclusion of the trial. The children were randomized into the treatment group, who were to receive 6 hours of therapy over the course of a year, or the, "Watchful waiting," group, who received no therapy at all for the same period. Those families for whom the child had been assigned to the latter group, however, were given the option to switch to the treatment group at any

time if they were concerned about their child's progress. This ultimately resulted in 18 parents switching their children to the treatment group before the 6-month assessment.

By the end of the trial some of the children in the treatment group had received 6 hours of therapy over twelve months. Others had received as much as 50% less. Couple this with the vast heterogeneity of the pool and it becomes mysterious that the findings were published. Indeed they were published, however, concluding, "This study provides little evidence for the effectiveness of speech and language therapy compared to watchful waiting over 12 months."

Even if the researchers had maintained a more consistent and reliable design it remains doubtful that 6 hours of therapy over a one-year period is could be considered a measurable amount for comparison. Presumably the decision to provide such limited therapy time was a practical one, allowing the researchers to parse a scant budget across 159 participants and throughout a year. In the *discussion* section the authors boast, "this trial is by far the largest to date, investigating the effectiveness of speech and language therapy in preschool children." This emphasis on quantity over quality mars all aspects of the study.

Further, although 21 speech language pathologists carried out the therapy and assessments, the research team was composed of Enderby, a Professor of Community Rehabilitation, Roulstone, Clinical Research Director, Glogowska, a research assistant, and Peters, a Reader in Medical Statistics. Perhaps it could be argued that such a team

enhanced objectivity. It seems unlikely, however, that researchers with speech and language training could have instituted a study design with such marked disregard for homogeneity.

Perhaps this was what Speech Language Pathologists, Jan Broomfield and Barbara Dodd of City University London thought when, they published their response, a 2011 report, entitled "*Is speech and language therapy effective for children with primary speech and language impairment?*" Unfortunately, their work demonstrates an equal disregard for valid or reliable experimental conditions.

They criticized Glogowska et al. for, assessing abilities that had not been addressed in therapy. They also quote a 2004 critique by T. Pring (also published in the International Journal of Communication Disorders) aptly titled, *Ask a Silly Question: Two Decades of Troublesome Trials*." Pring highlighted the same considerations noted above, that the trial grouped children with, "comprehension difficulties, expressive grammatical difficulties, and phonological difficulties, some children having difficulties with more than one aspect of language." Interestingly the summary of Pring's critique points out that 6 hours of therapy is a, "small amount," but it fails to mention that 10% of the control group switched to the treatment group midstream. Broomfield and Dodd then go on to question the validity of randomized control studies for several reasons. Most notably they argue, "How the outcome is measured determines the findings."

In a strange twist of contradiction Broomfield and Dodd's response was to institute their own randomized control trial; this one even more cumbersome. Their selection criteria, in fact, was far more heterogeneous then the Glogowska et al. study, expanding the demographic to include 27% children aged between 5 and 16 years old. For this reason their own outcome measures are so complex that they obliterate any hope of reliable results.

The Broomfield Dodd sample consisted of 730 participants divided into 3 groups. Group 1 received intervention until month 6, when they were assessed. They were then reassessed after a year. Group 2 received no intervention for 6 months, were subsequently reassessed and then treated for the next 6 months. And group three received intervention for the first 6 months. They were then given a midpoint assessment, after which they were subjected to another 6 months of intervention. Although Broomfield and Dodd can be credited for doubling the amount of treatment, spreading 6 hours of therapy over 6 months, is still hard to fathom how such a miniscule treatment regimen could produce a statistically measurable comparison.

Apparently it did, however. The study concluded that treatment was, "significantly more effective than no treatment." Perhaps this success can be attributed to a design that compares a more balanced set of criteria, one for which the benefits are equally distributed amongst participants. This, at the very least, eliminated the need to allow members of the control group to trickle into treatment. Unfortunately that possibility can only be speculated amid such flawed controls.

Also the results of both studies are confounded by an even more plaguing problem. The measurement of success or failure of therapy remains subjective. And this subjectivity is spread thinly across judges and testing instruments. In the case of the Gloskowa et al. study there were 21 therapists who administered the Bristol Developmental Language Scales, a test dependent on the analysis of speech samples. Broomfield Dodd employed Speech Language Pathologists from across Middlefield (County Durham, UK). Because of the wide variety of ages and presenting conditions among the participants these professionals executed an extensive list of articulation and phonology assessments including the Clinical Evaluation of Language Fundamentals (CELF), the Diagnostic Evaluation of Articulation and Phonology consistency subtest (DEAPC), The Phonological Abilities test (PAT) , the Preschool and Primary Inventory of Phonological Awareness (PPIPA), The Renfrew Action Picture Test (RAPT), The Reynell Developmental Language Scales III (RDLS III), The Receptive Expressive Emergent Language Scales (REELS), and "transcripts." Most importantly, virtually all of these measures depend at least in part on the auditory perceptive judgment of an army of analysts.

In other words, even if one is willing to accept such an unwieldy set of instruments, inter-rater reliability is doubtful. Janet Gooch, Ph.D., Mary, Hardin-Jones, PhD., Kathy Chapman Ph.D., Judith Trost-Cardamone Ph.D and Joan Sussman Ph.D demonstrated the depth of this type of inconsistency in their study, *Reliability of Listener Transcriptions of Compensatory Articulations,* published in the Cleft Palate and

Craniofacial Journal, (2001). Compensatory Articulations comprise a class of maladaptive behaviors that tend to persist in subjects with repaired clefts long after the primary symptoms (eg. velopharyngial insufficiency) have ceased. Because these errors exist in such a small subset of children, Gooch et al. wanted to determine if clinicians who specialized in cleft palate interventions could transcribe these processes more consistently than clinicians for whom such cases were relatively unfamiliar.

They selected 20 certified Speech Language Pathologists, 10 of which were members of a craniofacial team, and 10 of which were, "not specifically involved in the assessment or management of children with cleft palate." Both groups were asked to transcribe a tape containing 130 phrases. 60 of these contained an unspecified combination of conventional errors and correctly produced target words. The remaining 70 contained compensatory articulations. Their transcriptions were then compared to a "gold standard," transcription produced by researcher Judith Trost Cardamone. Although the researchers confirmed that the clinicians with a craniofacial specialty did indeed transcribe the compensatory articulations with roughly twice the proficiency of the inexperienced listeners, they also made some less predictable discoveries. It is these latter revelations that are of particular importance to anyone interested in accurate assessments of articulatory and phonological disorders.

First, percent agreement among transcribers was very low. Even those deemed, "experienced," with compensatory articulations were only able agree on a mean of 53.45% of phrases. Thanks to a supplementary, "Professional Experience

Questionnaire," the researchers also determined that the, "lowest percentage of agreement occurred for the compensatory articulations associated with greatest listener confidence." Place of production proved to a particularly troubling variable, averaging 65% for the experienced group and 44% for the inexperienced group. Across both groups, when the total number of agreements was compared to the so-called, "gold standard," transcription an average of 40% agreement was recorded.

What is perhaps most interesting is that these differences in judgment were not limited to the more difficult errors. In fact they were not limited to errors at all. Even the mean agreement score for correctly produced consonants suffered, averaging 66.25%.

Amidst all this another vexing question surfaces. Can we rely on methodology that compares the auditory acoustic judgments of one of the researchers against that of all the participants? The "gold standard," tape was after all, yet another auditory perceptual transcription. To their credit, the authors concede this contradiction, saying:

"A potential limitation of this study was the reliance on perceptual judgments provided by a single speech language pathologist. It could be argued that this judge may have been incorrect in her transcription and that some or all of the remaining judges may have provided correct responses."

It is the above quandary that underlies the arguments put forth by Ray D. Kent, of University of Wisconsin, Madison in his 1996, American Journal of Speech Language Pathology article, *Hearing is Believing: Some Limits to The Auditory-Perceptual Assessment of Speech and Voice Disorders.* This meta-analytical paper examines

perceptual assessment of voice disorders, stuttering, dysarthria, aphasia, and apraxia of speech, concluding that clinicians must be aware of the "failings and limitations," of auditory-perceptual assessment. He recommends supplementing clinician perceptions with instrumentally derived reports. According to Kent, "Generally, these systems create ordered patterns from data that may appear on superficial examination to be chaotic and disordered."

Kent supports his contentions with an extensive list of possibilities. Most of these boil down to one root concept. As listeners, all of us employ strategies, some innate, some intuitive, and some learned that aid us in understanding the speech of others. These mechanisms, many of which Kent applies clinical labels to, such as "auditory illusions", "phonemic restoration", and "verbal transformations," have tremendous utility in allowing human beings to filter auditory inaccuracies such as imprecise articulations from another speakers message. Yet it is this very gift that hinders even the trained Speech Pathologist from arriving and valid, reliable, objective, and unbiased conclusions.

Kent also makes some very compelling points about inherent contradictions in our methods of transcription. He argues that the International Phonetic Alphabet, the standard notation for speech transcriptions, was designed to record the correct articulations heard in adult speech. The common solution is to expand the transcription of disordered utterances with "narrow," transcription, an enhanced form of notation laden with extra markers known as diacritics. The more narrow and specific the system

becomes, however, the more complex it becomes. And the more complex it becomes the less valid and reliable the result.

To support this logic Kent points to several studies, similar to the Gooch et al. study, that demonstrate the foibles of inter-rater reliability. The most interesting among these was Stockman, Woods and Tishman (1981) in which three transcribers with, "extensive teaching and field experience in phonetics," were asked to transcribe the vocalizations of infants between the ages of 7-21 months. As one would expect, faced with such immature productions, both intra and inter-judge agreement was consistently below 60%

Which instruments he recommends remains undefined. He uses only non-specific terms such as, "acoustic analysis," to describe them. In 1990 sociolinguists, Paul Kerswill of the University of Reading, and Suzan Wright of the University of Cambridge, called on electropalatography to put assumptions similar to Kent's to the test. They argued that:

"it is transcriptions, not actual speech, that form the raw data of much of sociolinguistics. Given its importance, it is surprising that phonetic transcription has seldom been examined by sociolinguists from the point of view of it's validity and its reliability."

Kerswill and Wright conducted an experiment in which they "compared the transcriptions of trained phoneticians with physiological data on the same utterances using electropalatography." Their findings demonstrated inconsistencies between

transcribers and that "there are intervening factors of a psychoacoustic nature that impinge upon a phonetician's transcription." From this they determined auditory acoustic transcription was neither valid nor reliable.

This brings us back to the introductory question: does articulation therapy work? It appears this poser must remain unconfirmed for now. Before we can address the questions of efficacy and effectiveness we must find a reliable means to measure them. First, we must reexamine the utility of large scale randomized controlled studies for which the only variable controlled for is a denial of treatment. We must also modernize our methods of assessment to include more accurate and objective instruments. This is not to suggest that we need to abandon our auditory perceptive observations or scrap our clinical judgment. Our goal after all, is increased intelligibility, an inherently perceptual phenomenon. As Kent points out, "For many purposes in speech language pathology, there is simply nothing better." Amidst cries for evidence-based practice, however, it is imperative that we enhance our professional prowess with more accurate tools. Evidence, after all, is only as irrefutable as the methods used to obtain it.

For the practicing clinician electropalatography has the potential to enhance more than just the effectiveness of treatment. It endows the clinician with accurately measured evidence of that effectiveness. No, speech therapists need not abandon traditional methods. If we are to remain a relevant profession, however, we must embrace modern tools to support our legitimacy.

2: What do we know about electropalatography?

The word electropalatography is not often spoken in clinical practice. It is, in fact, safe to conclude that many, if not most, practicing speech therapists have never heard of such a thing. Even those who could define the term are unlikely to have employed the approach. But this should not lead one to the false conclusion that palatographic biofeedback is novel or untested.

The concept predates speech pathology as we know it. Although data from the top rungs of the research hierarchy such as randomized controlled studies have proven as fruitless as the quest for El Dorado, evidence has been mounting for a very long time. And the moment has arrived to extract this tool from the annals of research labs and use it to facilitate interventions in clinical contexts.

So how old is it really? The technique is, in fact, rooted in a data gathering system that was instrumental in the development of early phonetic theory. Much of traditional articulatory theory, for example, stemmed from the studies of Melville Bell (1867). Bell's wrote about a, "point of constriction," in which the tongue made contact with the hard palate in various postures. To determine exactly where these constriction points were located, Bell used a method then known as direct palatography, in which the palate was coated with a substance that would be removed upon contact with the tongue, allowing the researcher to document its point of contact (Lieberman Blumstein 1991).

And this was not the first time direct palatography was employed. Examples of this type of methodology have been noted as far back as the early 19th century (Fletcher 1998).

Speech scientists would continue these experiments for decades to come. The modern notion of electropalatography, however, was born of a desire to move beyond static representations, to understand the dynamic motions of the articulators. The earliest documented use was in the Ph.D. thesis of Herbert Koepp Baker, a student at the Graduate College of the State of Iowa. Baker created an artificial palate with ten electronic sensors. This device was connected to an amplification system that powered paper tracers. He called the device a "phonokinesagraph," (Articulate Instruments 2013).

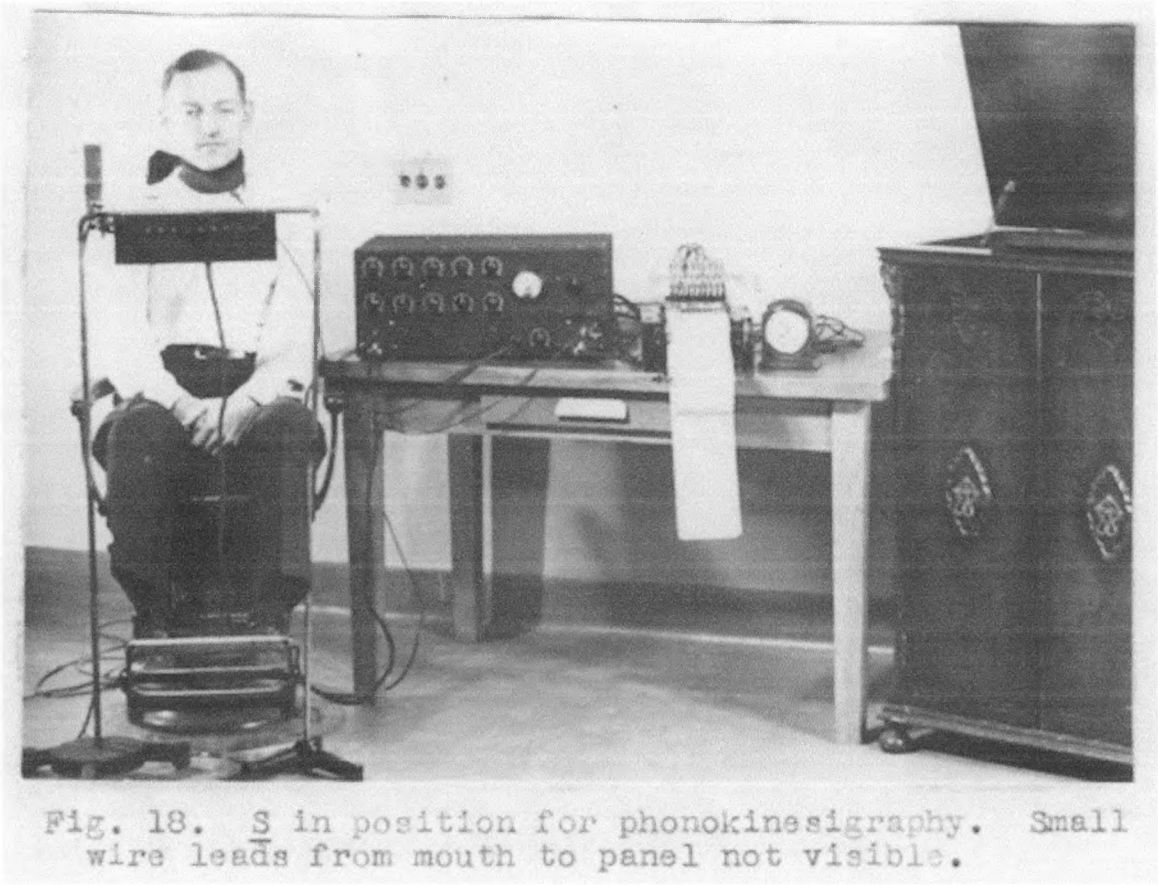

Figure 3: Photograph: Taken from the PhD thesis of Herbert Koepp-Baker 1938 (Courtesy of Iowa State University – Graduate College) Retrieved from Articulate Instruments.com

By the nineteen fifties research into electropalatography was in full swing, flourishing in both the U.S. and the U.K, most notably with the works of Samuel Fletcher of the University of Utah, and William Hardcastle at the University of Edinberg Scottland. Other mid century hallmarks developed in Japanese phonemic studies using a similar device, the Rion DP-01 Electropalatograph System (Gibbon, Hardcastle 2008).

Fiona Gibbon, Ph.D., a student of Hardcastle, has become one of the most influential researchers into electropalatography. She has compiled a bibliography of the electropalatography literature between the years 1957 and 2013. This list is organized by clinical application. And it references over one thousand studies. In pages to come we will highlight some of the more intriguing of these works.

Samuel Fletcher, a professor emeritus at the University of Birmingham Alabama, has written perhaps the most comprehensive tome on the subject. As noted above Dr. Fletcher has been an EPG researcher since the late 1950's and he is among the pioneers in this field. Dr. Fletcher has documented his findings in the book, *Articulation, a Physiological Approach*, (Singular Publishing Group). This text is a comprehensive guide to the theory and application of instrumental therapy. In the preface, Dr. Fletcher describes the electropalatometer as, "simply a tool." He goes on to point out that, "tools are invented to solve problems, but they also shape the way we come to see the problems." There is no doubt that Fletcher has arrived at new ways to view the problem. While he seldom, attempts to defeat existing notions of Speech Pathology, he greatly expands upon them. It is from an expanded view of phonology that Fletcher argues for his approach.

In Fletcher's view, the established theory that articulation is merely the product of accurate voicing, place and manner, is incomplete because no articulatory act can be viewed in isolation. He describes speech as a series of interconnected and coarticulated motor postures. These postures are produced dynamically. In this manner, each phoneme

is shaped by the phoneme that precedes it. Fletcher lays the framework for a motor-based articulation therapy that does not limit treatment to those sounds for which we perceive an acoustic abnormality. He suggests, for example, that the therapist first look to palatographic data to find vowel distortions, pointing out that improving accuracy in vowel production can facilitate smooth motor transitions, thereby accommodating accurate consonant production. In Fletcher's view, electropalatography is the ideal tool for real time assessment and intervention because it can provide a visual feedback to display such dynamic motor postures.

Although Fletcher's findings are built on the wisdom of decades of research that has been largely confined to university speech science labs, it is possible to highlight a history of literature that exposes the tremendous promise of electropalatography. In so doing we can address some of the critical roadblocks that impede the future of the technique.

In truth many such roadblocks are implicit in much, if not all, of the the 20th century research into electropalatography. This research tends to be more descriptive than conclusive. Among the most the most widely cited of this period of electropalotography research, is *Electropalatography in the Treatment of Articulation/ Phonological Disorders,* originally published in The Journal of Communication Disorders (1995), by Paul A. Dagenais of the Department of Speech Pathology and Audiology, University of South Alabama.

Dagenais approaches the subject comprehensively, providing a great deal of meta-analysis on the theory and application of the approach. He concludes that electropalatographic data suggests that the traditional approach to remediation of both modalities needs to be reconsidered. He argues that lingual/palatal contact patterns of different children vary greatly, even if auditory perceptual results yield the same symptoms.

He makes the case for these findings very effectively by displaying pre and post therapy electropalatographic contact patterns. Degenais provides no specific suggestions for how these variations can be addressed in interventions, however, saying only, "the treatment of traditional articulation disorders will have to be evaluated." He later goes on to say, "the system by which systematic articulatory posturing might be addressed still needs to be determined."

Procedural recommendations aside, Dagenais presents an informative picture. He draws most of this information from, case study. Additionally the majority of these cases are derived from secondary sources, chiefly the work of Gibbon and Hardcastle. He does present one original case study, however. And this is perhaps where his most intriguing observations appear.

Dagenais writes of a 6 and half-year old girl who had been referred for assessment at his University of Alabama Speech and Hearing Center. After testing at the 15% percentile with the Goldman Fristoe Test of Articulation she underwent two years of traditional therapy. The results were unsuccessful. The Speech and Hearing center then

began 21 weeks of electropalatographic therapy. Palatographic data revealed that the child produced idiosyncratic lingual postures, (eg. affricates in which the stop portion was not completed before the introduction of the vowel, thus circumventing frication). It is specific and detailed analysis like this that is unlikely to be achieved through auditory perception alone. And it was through these observations that Dagenais was able to create an electropalatographic therapy plan that allowed the child to subsequently score no errors for single words or oral reading passages with the Goldman Fristoe Test of Articulation.

While it is prudent to remain skeptical about tales of remarkable success with one individual, (especially when failed experiments remain absent from the report), there is much to be gleaned from Dagenais' paper. It highlights the possibilities of an instrumentation that can greatly enhance the therapist's tool kit. If nothing else, his article suggests that children who have been unresponsive to therapy are not intractable. Even in the most difficult of cases a clinician can use instrumental data to carefully re-examine the client's unique articulatory postures, potentially exposing the underlying etiology of their distortions.

Where Dagenais focuses the idiosyncratic behaviors of children with speech sound disorders, Fiona Gibbon PhD of the University of Edinburgh Scotland sees the problem from a different perspective. Her works strive to identify similarities. She has observed patterns in electropalatography data of children with persistent speech sound disorders that are worthy of any speech pathologist's attention. In her 1999 article from

the Journal of Speech, Language and Hearing Research entitled, *Undifferentiated Lingual Gestures in Children With Articulation/Phonological Disorders*, she exposes two distinctive characteristics of disordered articulations in children that could have great impact on the remediation of their problems. She defines these two distinctions as, "undifferentiated lingual gestures," and, "covert contrasts."

Let us discuss undifferentiated lingual gestures first. Auditory perceptual transcription data of children's productions reveal such phonological processes as fronting, backing, depalatization and the like. These are mostly described as differences in tongue placement such as an alveolar substitution of /t/ for /d/. Upon the examination of electropalatographic printouts, however, Gibbon suggests that these assumptions are incomplete. She points out that, although the palatographs reveal idiosyncrasies across children's speech, there is also significant uniformity in one key area. It appears that in most articulatory errors, a larger portion of the tongue comes into contact with the palate.

Her most compelling arguments for this notion are those she derives from case studies in which the subject had persistent problems with the backing of alveolar consonants. Perhaps many clinicians would be quick to dismiss such investigations for the practical reason that they are not likely to see such disorders on their caseloads. As Gibbon herself points out (referring to data from Hodson and Paden 1995), "backing occurs in 7 out of 60 children with unintelligible speech." There is, however, sound logic in studying children with this deviation to illustrate the role of the augmented lingual contact in undifferentiated gestures.

The reason for this is that auditory perceptual analysis of backed consonants is likely to sound like a substitution of a velar consonant for an alveolar, leading the therapist to assume that the client's lingua-palatal contact is restricted to the posterior regions of the oral cavity. But electropalatographic data reveals that there is, in truth, significant anterior contact as well. This makes intuitive sense when one considers that the velar contact will physically obstruct any effects that alveolar contact has on the airstream, thereby resulting in what will be perceived to be a /k/ or a /g/. And while alveolar backing is arguably the most illustrative example of undifferentiated gestures, it is no way the only one. Palatographic read-outs reveal undifferentiated gestures appearing throughout the speech patterns of children with speech sound disorders, even amongst sounds that our auditory perception would suggest are correct articulations.

It is here that a discussion of covert contrasts comes into focus. Gibbon's finding is that the lingua-palatal contact patterns of children with disorders of articulation reveal deviations in articulatory posture that occur even when listeners perceive the sound to be accurate. Gibbon contributes powerful evidence to support this hypothesis by displaying electropalatographic data that clearly outlines strong distinctions in the lingual gestures of children with speech sound disorders, differences that perceptual transcriptions will not uncover. She further suggests that by remediating covert contrasts, despite their perceptual clarity, the clinician can improve the overall generalization of the client's speech sound deviations.

One unfortunate weakness in Gibbon's studies is that there is no way to determine the developmental influences that underlie undifferentiated gestures and covert contrasts. The problem is that electropalatography is not a practical tool to assess or remediate speech sounds in pre-school children. The interface is too complex. The pseudo-palates are too delicate. And EPG requires more developed meta-phonological skills than can be expected from toddlers. This renders the notion of cross-sectional study impractical. Still, exposing these unique facets in the speech of older children allows the clinician to examine their baseline productions in much greater detail. Such an expanded view could have a powerful impact on intervention decisions.

One obvious critical flaw of the works of Dagenais, Gibbon and other 20th century electropalatography researchers is that they tout the success of their case studies but make little effort to demonstrate their statistical significance. In most cases the authors make a plea for future randomized control studies that have yet to be realized. This is, of course, because identifying control and treatment groups of acceptable size, and then studying them with adequate longitude is a daunting proposition. Couple this with the cost of instrumentation and it is safe to say that these ambitions are, (at least for the forseable future), an impossible dream.

One study presents a compromise with these limitations. And its results support Gibbon's conclusions about undifferentiated gestures and covert contrasts. Though the authors do not use the same terminology they arrive at similar conclusions about the nature of disordered speech. In *An electropalatographic investigation of lingua-palatal*

contact in participants with acquired apraxia of speech: A quantitative and qualitative analysis, by Carly J. Bartle-Meyer, Bruce I. Murdoch and Justine Goozie, of the School of Health and Rehabilitation Sciences, University of Queensland, Australia, (2009), the researchers introduce more convincing controls to their methods.

In the wake of research, (ie. McNeil, Pratt and Fossett 2004) that has posited the theory that apraxia of speech is characterized by sound distortions as opposed to omissions and substitutions, the authors of this article sought to quantify the, "impact of poor movement control on lingua-palatal contact." They argue that such research is necessary to, "better understand the underlying nature of AOS." In so doing, they have completed the first electropalatography study to surpass the bottom rungs of ASHA's evidence hierarchy. While it was small in scale (N=3 for apraxia group, N=5 for healthy controls) the study was a well designed and controlled, non-randomized experiment. This is in part because they subjected the data to both qualitative and quantitative measures. And they compared perceptual analysis to instrumental results. With this thorough and objective approach they determined that the misdirected articulatory gestures (MAG's) of speakers with apraxia of speech are most often the result of articulatory overshoot, as well as right side dominant contact and increased spatial variability. Like Fiona Gibbon, they observe the pattern of too much contact as opposed to too little. They could find no evidence of true omissions. These results support the notion that the articulatory and prosodic errors associated with apraxia of speech are indeed motoric in nature, not linguistic.

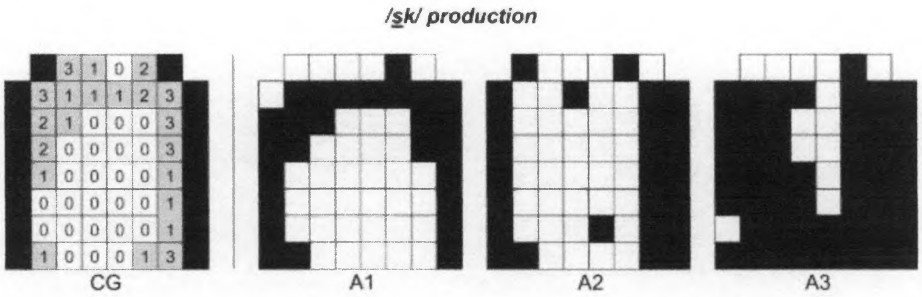

Figure 4: The palatogram on the left is averaged from the productions of 5 Non-apraxic control subjects. The other three have apraxia of speech. (From Bartle-Meyer et al 2009)

In the abstract Bartle Meyer et al state, "the current study is aimed to provide a comprehensive analysis of lingua-palatal contact patterns in participants with acquired apraxia of speech." This seems a bit too ambitious if one considers that a "comprehensive analysis," should examine every vowel, consonant, and consonant cluster in the English language. Recognizing that the expectation that they achieve such a lofty goal is unrealistic, however, they make a good case for the need to objectively examine the productions of speakers with apraxia to identify the true behaviors of their articulators.

In many ways the authors of this study tread on uncharted ground. Electropalatographic studies of apraxia of speech have been limited to qualitative case study reports that extend back to the initial findings of Hardcastle (1985). Naturally these limitations provide the fuel for Bartle-Meyer et al's. justifications. They explore the breadth of existing literature on the subject with an emphasis on its implications, all of which would suggest that a study with careful controls could greatly enhance evidence base for their assumptions. This leads them to argue for their own, "qualitative and

quantitative," analysis techniques. For the sake of clarity, the authors saw fit to break the content down into several categories, such as assessment, analysis of data, selections of participants and controls, etc. The quantitative portion of the study is particularly in-depth, independently examining both groups for their amount, pattern and variability of lingua-palatal contact, as well as aspects of closure, constriction and center of gravity. The authors do not thoroughly explain their choices of target consonants and stimulus phrases, however. Since they obviously had to be judicious in these decisions their rationale for inclusion would be useful to future researchers.

Among the many advantages of instrumental analysis is the reliability of the results. While very often a reviewer can question the objectivity of a study's data, palatographs leave the researcher clear and quantifiable evidence. Like photographs, palatograms do not lie. Barlte Meyer et al (2009) display printouts of the productions of each participant separately for comparison and contrast. They effectively demonstrate that in each case there is no omission, that articulatory overshoot constitutes the majority of the errors of the participants, and there is a tendency toward, "asymmetrical right side contact." This consistently contradicts perceptual analysis that indicates omissions and substitutions among apraxic errors.

The authors argue that their findings provide, "support for a motoric account for articulatory and prosodic deficits in AOS." This is because a phonological disturbance, by definition, would be characterized by an absent mental schema and therefore should be evidenced by complete omission of the target articulatory gesture. The participant's

palatograms display a consistent pattern. In each case the appropriate lingual contacts to form correct productions are all present. They are masked by articulatory overshoot, however, especially in the posterior regions and right lateral margins of the palate.

As is often the case with apraxia studies, Bartle-Meyer et al (2009) concede that their research participants all had some degree of concomitant Broca's aphasia, a potentially confounding variable. They call for future palatographic studies featuring, "pure apraxic," subjects but they offer no advice as to where their successors would find such a population.

Bartle-Meyer et al. (2009) represents an extremely important piece of the apraxia puzzle. In addition to lending credence to the theory that the articulatory and prosodic features of apraxic speech are motoric and not linguistic, the authors reveal insights that can have tremendous impact on treatment decisions. Future clinicians will be able to use this data to shape therapies focused on the reduction of extraneous lingual contact, minimizing time that has been wasted on trying to remediate phonological deficiencies. It is unfortunate, in fact, that this study does not specifically address treatment considerations.

Although studies that institute some form of randomization of small populations such as Bartle Meyer et al (2009) remain the exception not the rule, contemporary electropalatography researchers have made great strides in designing statistically sound single subject experiments. In 2007 Katie L. Martin, Allen Herson, Ros Herman, Jane

Thomas and Tim Pring, of the University of London, published, *The Efficacy of Speech Intervention Using Electropalatography With An 18 Year-Old Deaf Client: A Single Case Study,* in the journal *Advances in Speech Language Pathology.* While it is, indeed, yet another case study, Martin et al (2007) presented a clever compromise by effectively applying design that compares multiple trials for differing traits. In so doing they demonstrate a measurable increase in the efficacy of therapy using electropalatography.

The subject was an 18 year, 4 month old client with, "profound bilateral sensory neural hearing loss and a consistent hearing aid user." Like the subjects of Gibbon, he presented with problems with backing of alveolar consonants. He was referred to the Department of Language and Communication science at London's City University for remediation of persistent deviations of alveolar plosive cognates /t/ and /d/ which he realized as velar consonants /k/ and /g/. He had received speech therapy as part of his educational plan from the time he was six years old. Testing showed that he could discriminate and produce all English consonants with the exception of /t/ and /d/ and the dental fricatives /θ/ and /ð/ (voiced and voiceless /th/ sounds).

Martin et al (2007), started him on a six week, twice weekly (1 hour per session) program of electropalatography therapy to remediate his production of the /t/ while leaving /d/ untreated. They also controlled for /θ/. Besides simply analyzing his palatographic results they played recordings of his productions on single words and connected speech for two panels of 10 listeners, one composed of Speech Language Pathologists and the other composed of untrained listeners. The panelists were asked to

rate the target phonemes on a scale of 1 to 4 for intelligibility, (with words: 1=very poor, 2= poor, 3=good, 4=very good, in sentences 1=understanding nothing, 2=understanding part, 3=understanding most and 4=understanding all). They subjected this data to an analysis of variance and found significant statistical improvement for the treated target sound /t/, some improvement with the untreated /d/ and no improvement for the control sound /θ/. One-month post therapy they found the client had not only maintained the treated and untreated alveolar plosives, he had demonstrated further improvements.

It is intriguing that that unvoiced /t/ generalized to the voiced /d/. The interface of a palatograph allows for explicit teaching of place and manner but leaves voicing unaddressed. If a pattern can be established in future research that suggests a spontaneous remediation of voicing problems when the other distinctive features are treated it could be clinically useful, especially with clients with difficult to treat conditions such as cleft palate or acquired apraxia of speech which are characterized by deficits in voicing (Auzou et al 2000).

And when it comes to patients with hearing loss, voicing errors predominate (Hudgens and Numbers 1942). In fact, electropalatography offers benefits to clinicians with hearing impaired clients that deserve extra attention here. This is because it presents a unique reversal of the logic of traditional approaches.

3: Electropalatography: an alternate learning modality for the hearing impaired.

Hearing loss, especially in the very young, presents unique problems for the Speech Language Pathologist. Congenitally deaf children hone their sounds along a trajectory laden with roadblocks fueled by compromised feedback mechanisms and ill formed phonemic perceptions. This in turn generates an inventory of productions rife with distorted or nasalized vowels, imprecise consonants, and voiced for voiceless sound substitutions (Osberger, McGarr 1982). The magnitude of errors alone is daunting. But perhaps most problematic are the avenues to remediation. Most articulation therapies are, after all, designed to build either motor skills or phonemic schema. These are secondary or even tertiary links in the chain, rendering them fruitless for a first line of attack against deficits rooted in perceptive limitations. In short, one must hear it before one can begin to say it. Electropalatography is a method that affords the client the opportunity to learn with their eyes not with their ears, at least for the duration of a clinical clock hour.

In Fiona Gibbon's bibliography of over a thousand studies enacted since 1957, of these only 27 are directly related to its application with hearing impairment. It is surprising if one considers the potential of this type of instrument to access to the visual system. This is perhaps why the pioneering attempts at the approach were, in actuality, carried out with remediation of deaf speech in mind (Fletcher 1998).

Among the earliest known experiments in "direct palatography," was an 1872 project undertaken by a British Dentist named J. Oakley Coles who worked with patients with palatal clefts, many of whom suffered the comorbid symptoms of conductive

hearing loss brought on by eustachian tube dysfunction. Seeking to better understand the deviations of his patients, Dr. Coles coated his own hard palate in a mixture of flour and gum, he then articulated the 26 letters of the alphabet, observing the areas of the mixture that had been displaced as his tongue and palate made contact. He then used red paint to transcribe his findings onto impressions of his maxilla. Dr. Coles' efforts were not, however, well received academically.

Criticism of Coles', "topographical plates," centered on the fact that Coles included vowels sounds among the presentations. This was seen to invalidate the work because it violated the accepted maxim that vowels do not involve lingua-palatal contact. More than a century later this notion survives despite the fact that palatographic studies have consistently replicated Coles' results (Fletcher 1998).

In a 1992 textbook entitled, An Introduction to Phonology, for example, the author, Francis Katamba, a lecturer at the University of Lancaster writes, "vowels are typically voiced but have no place or manner of production." Pervasive misconceptions about vowels such a Katamba's are in themselves an argument for instrumental biofeedback with the deaf and hard of hearing. A pattern of vowel distortions in which the deaf speakers overgeneralize vowel sounds to resemble the neutral vowels schwa /ə / and carrot /ʌ/ are common (Osberger, McGarr 1982). Electropalatographic readouts demonstrate that these sounds are differentiated from the tense and lax vowels largely by varying degrees of lateral lingual contact with the hard palate (Sanders 2011).

To better understand this direct connection with the vowel productions of the deaf it behooves the clinician to explore the way vowels are perceived first by those with normal hearing and compare that to those of the deaf. Those of us endowed with hearing within normal limits differentiate vowels when we hear the first and second formant frequencies of the sound (Lieberman, Blumstien 1988). The vowel, /i/, for example, has a first formant of 240 Hz and a second formant of 2,400 Hz. Assuming the listener can hear this range of frequencies there should be little question as to the vowel sound when a speaker says the word, "beet," or sweet." But what happens when a listener has hearing that is compromised, especially in the upper ranges, limiting their ability to recognize the second formant?

Monson (1976) suggested that vowel differentiation amongst the deaf is usually limited to the first formant. It should be noted that the production of the first formant is largely moderated by the height of the jaw (Mcgarr McNutt-Cambell 1995). Because the jaw is a visual articulator this would further suggest that deaf speakers learn their vowel sounds with their eyes.

Perhaps this explains why deaf speakers tend to approximate vowels to resemble neutrals. Indeed, in typically developing infants, vocalic sounds are clustered in close proximity to the schwa. As the child matures these sounds appear to migrate outward to their correct frequency ranges (Lieberman, Blumestien 1988). From a clinical perspective, Electropalatography, an approach that enhances the deaf speaker's ability to see and imitate the lateral contact of the tongue and palate is promising.

The same logic applies to consonant production. Among the chief findings of landmark studies on the articulation of deaf speakers a pattern of correct productions seems to favor visual articulators. Nober (1967) ranked correct productions of consonants this way: bilabials 59%, labiodentals 48%, glottals 34%, linguadentals 32%, lingua-alveolars 23%, lingua-palatals 18%, and lingua-velars 12%. In the same study, Nober ranked correct productions as starting with glides, followed by stops, nasals and fricatives. Similarly, Smith (1975) found that deaf speakers had the most success producing bilabial glides and the fricatives /f/ and /v/. In every case the pattern appears to be the same. Those sounds with the most visual salience are produced with the most accuracy. Once again, the visual nature of Electropalatography affords the clinician an alternative mode of teaching where flash cards, mirrors and phonemic models fail.

Place of production is, of course, a natural starting point for therapeutic intervention. The clinician needs simply to model correct production of the sound. A graphic representation of all the electronic sensors that have been contacted will be displayed on the computer screen. The client can then attempt to duplicate number and pattern. Manner requires only slightly more explanation. The clinician can, for example, prompt the client to channel sibilant airflow through the blank space left by sensors for which there are no contacts.

As mentioned above, the question of voicing is somewhat more complicated. Since the place and manner of cognate pairs, (sounds such as /t/ and /d/ that differ only by voice) are identical the clinician cannot depend on palatographic feedback alone to guide

the client to differentiate them. With deaf and hard of hearing clients it is especially important to address this weakness in the system because errors in voice-voiceless distinction are among the most common in their inventories (Hudgens and Numbers 1942). Certainly, the addition of a vibro-tactile cue such as asking the client to touch their throat and feel for the vibration of their vocal folds when distinguishing /t/ from /d/ or /k/ from /g/ could in many cases provide a third modality to supplement the visual approach. Still the subject of voice-voiceless distinction in Electropalatography merits discussion in greater detail.

Although the fact that voicing cannot be directly trained using this instrumentation could prove vexing in clinical practice, the same grey areas provide clues to questions left unanswered by research. It is not uncommon when reading the *discussion* sections of Electropalatography articles to find the author conceding that generalization of therapeutic outcomes remains a mystery. And in the case of studies involving the deaf and hard of hearing the prevailing hypothesis is not simply that one could employ this instrumentation to train motor postures. The additional assumption is that that it could be a source of access to an alternative modality for learning. This opens an even more opaque line of questioning. Can an improvement in production fostered through Electropalatography actually enhance auditory perception of speech sounds? Voice-voiceless distinctions among research subjects suggest that it can.

Martin et al (2007) results suggest that improvements in place and manner carried over to voice perception as well. This argument is strengthened when one considers that

the authors also controlled for the voiceless dental fricative /θ/, a sound the subject also produced in error. In this sound the authors found no change. Although studies of this nature hint at the possibility that speech sound perception could be improved through Electropalatography the question is never directly addressed.

In 1996 Rachael Parsloe, a Speech Language Pathologist at Royal Berkshire, Hospital, Reading UK, attempted to find a more specific answer. She provided a course of Electropalatographic therapy to a profoundly deaf ten-year-old girl. In the pre and post therapy portions of her study, she tested the child using a device called a Speech Pattern Audiometer. This instrument presents the subject synthesized speech sound contrasts that vary by only minor fluctuations in frequency. The subject is expected to identify the sound even if it is only a slight deviation from the ideal. Naturally such a task is difficult for a profoundly deaf person. Although Parsloe's results are not earth shattering, at least one sound contrast demonstrated an improvement in speech sound perception. Parsloe notes, "…the fact that Sophie's initial increase in perception, coincides directly with the onset of production work with EPG suggests that in this case production was leading to perception."

It is perhaps a stretch to assume that the results of a few single subject case studies could lead to the conclusion that improved production through visualization of speech sounds could further enhance speech sound perception. Indeed these assumptions have obvious limits. Speech sound learning through the auditory path, as it exists for children with normal hearing, is a twenty-four hour a day process while

Electropalatography will always be limited to time spent in therapy. This should not, however, deter the clinician from exploring this alternative route. A listener with normal hearing should, after all, be expected to differentiate over 350,000 different sounds (Lieberman, Blumestien 1988). Electropalatography can at least provide some assistance in learning the 44 of those sounds that form the English phonemic table.

4: Electropalatography in Clinical Settings

As electropalatography research advances it is conceivable that a conclusive evidence base for the technology can be established. Naturally there is a lot more research to be done. And although it is easy to be dazzled by the promises of an instrument that provides such in-depth and highly tangible feedback as to the actions of an individual's articulatory mechanism, there are still significant practical concerns.

Chief among these issues is the fact that only a limited number of client's families are able to afford to have pseudo-palates produced and maintained. Although tremendous progress has been made in this area we have a long way to go. This becomes painfully clear when one considers that perhaps the most obvious function of electropalatography is in the area of assessment. What clinician would not want access to purely objective data about an articulation or phonology client's tongue placement? In order to achieve this task, however, the client must first have a dental cast made. Then a custom pseudopalate must be fashioned, a process that takes at least two weeks, and the user

must bare the expense of both procedures. All this seems an unlikely proposition for a client who has not yet been diagnosed with an actual disorder.

Although most existing literature in the field focuses on implementation, there are some exceptions that show researchers are recognizing the need for research and development into a consumer friendly electropalatography. In his article entitled, *Advances in EPG Palate Design*, published in the journal, Advances in Speech Language Pathology, (March 2007), Alan A. Wrench of Queen Margaret University College, Edinburgh Scotland, attempts to address at least some of these problems. He critiques past designs, analyzing such considerations as the number of contacts, the placement of the contacts in reference to a client's anatomy, materials, safety issues, and (most importantly) cost. Finally he proposes a new design that he claims, "minimizes cost while maximizing comfort, safety, convenience, reliability and accuracy." This sounds ideal but the words, "minimizing," and "maximizing," are perhaps a bit exaggerated in comparison to Wrench's results.

The, "Articulate Palate," as it is called, certainly makes advances in the reduction of expense. Although the cost of parts remains comparable to previous versions, the new design presents important features to streamline the manufacturing process. The construction has been simplified to the point where assembly can be completed in 1-4 hours by trained technicians. Earlier models required at least 12 hours to produce.

Unfortunately there are two crucial areas that the Articulate Palate does nothing to address. First, like all the palates that have come before it, this new design comes with

electronic leads that run from the front of the user's mouth to the data link, a significant hindrance to the user's comfort. Wrench concedes that wireless pseudo-palate could be designed by embedding a transmitter but he does not employ this feature because it would be cost prohibitive. Also the Articulate palate uses a thermoformed acrylic housing. This is another cost effective decision, but it results in decreased adjustability. Older palate designs actually allowed for some adjustment to accompany inevitable changes in dentition. This material will not allow for such a luxury.

Wrench concludes, "the ideal of an off the shelf, mass produced, cable free palate is still some way off but work continues to achieve these goals." If work continued as of 2007 it would appear little progress has been made in the last decade. It should be noted, in fact, that in the United States the Articulate Palate, and all other electropalatography hardware and software manufactured by the parent company, Articulate Instruments are not available.

In our country, Electropalatographic instrument manufacture and development is the under the exclusive control of CompleteSpeech LLC, manufacturers of a system called the SmartPalate. They hold the patent. In turn, U.S. clinics are limited to their product. To their credit, CompleteSpeech has made great strides in creating a system that can be a feasible addition to a small clinical practice.

A UCLA linguistics study from the 1990's placed the cost of one pseudo-palate at $1300. (Keating 2011) If this apparatus was damaged, or the dentition of the subject changed, (an unavoidable factor amongst a school age population), it needed to be

replaced. This rendered clinical application (and even extensive research) into the technology impractical.

A couple of decades later, the SmartPalate is a miniaturized palatometer that can be used with any computer. The SmartPalate is coupled with pseudo-palates that can be produced for about $200 per subject. This is accompanied by an insurance policy that allows for easy replacement. CompleteSpeech has also continued to modify their means of delivery to the public, currently offering a subscription-based model that a clinician can access for a small monthly fee.

With a system like this it is conceivable that this technology could be accessible to practicing Speech Language Pathologists and the families they serve. In fact, since researchers have also reported earlier dismissal from therapy when incorporating electropalatography, clients can spend less money out of pocket, making this device more economical than ever before. But, unfortunately, the current climate has yet to yield such and ideal. In 2013 The San Francisco State University research team of Kahn and Shadwick conducted interviews with representatives of CompleteSpeech and with a California, private practice clinic. The results of these discussions highlight practical concerns that cannot be ignored.

The co-owners of this clinic were very forthcoming about their experience with the technology, freely elaborating on the pitfalls. They said that they had been very enthusiastic and excited when they adopted the SmartPalate, but they confessed that since

that time they had only used it with two clients. They reported that they had seen a marked increase in the efficacy of therapy with both children. That was the good news.

They went on to express frustration with the functionality of the equipment, and with the customer support provided by Complete Speech. Chief among their complaints were stories of slow fulfillment of pseudopalate production orders. While CompleteSpeech boasts of a two-week turn around after receiving dental casts, Mazzoni and Lopez reported delays.

They showed us their psuedopalates. Kahn and Shadwick quickly took note of how delicate they appeared. The plastic is a wafer thin material reminiscent of packaging material for common household products. Psuedopalates are designed this way to allow for a relatively unencumbered articulatory system. Samuel Fletcher (1998) said, "Our previous research has indicated that little or no disturbance is found in lingual postures and movements when a psuedopalate is less than 0.5 mm thick and fits to the contours of the teeth and palatal surface closely." The downside to this slender acrylic design was among the problems reported by the Speech Language Pathologists at the clinic.

They said, that at least one of the two clients had broken the palate and it had not been insured, causing an indefinite hold in its replacement. We asked why the family had not insured it one of the clinic owners replied by saying, " They did not want to spend the extra 70 dollars." This situation is indicative of a fundamental problem, incompatibilities between the equipment manufacturers and the end user.

In discussions with representatives of CompleteSpeech, Kahn and Shadwick have suggested the possibility of adjusting the price of the palates to include a warrantee instead of the insurance policy but they gave no indication that they intended to adopt the idea. The therapists at the private clinic did not appear to be open to finding an alternative either. When asked, "Couldn't you bill for the palate as a single package that includes insurance?"

"That is not our business model," one of the owners replied. She offered no explanation as why they should so rigidly adhere to a policy that resulted in a denial of therapy, however. They also told us that the children they had tested the product on were in the 5-6 year old range. When Kahn and Shadwick suggested that perhaps this age group would not be ready for pseudopalates, a concession that is often made by electropatography researchers (eg. Degenais 1995), they strongly disagreed. They offered no alternative explanation for their problems with implementing the system with a small child, however.

Of course, practicing clinicians can only use what has been made available to them. The question of expanding the candidate population is best answered by those responsible for product development, CompleteSpeech. Kahn and Shadwick asked CompleteSpeech General Manager, Dan Smith if the company had considered possible redesigns of the interface that would be more child-friendly. Smith balked at this idea,

saying, "we have not plans to create a whack-a-mole electropalatography system at this time."

Such an offhand rejection seems curious when one considers that the market for articulation tools includes very young customers. Perhaps CompleteSpeech could take a clue from companies like Maico Diagnostics, manufacturers of the Race Car Audiometer Tympanometer. This product, intended for use in audiology clinics, employs cartoon graphics and a child friendly theme to improve the audiometry experience for both the clinician and client (Maico 2015). It has proved popular and it has sacrificed none of the functionality of an ordinary audiometer. CompleteSpeech does not appear to be interested in looking for such creative solutions, however.

When Mazonni and Lopez of TALK Therapy demonstrated their SmartPalate it appeared the two Speech Language Pathologists had some difficulty operating the software. As they struggled with the interface, they complained that training at Complete Speech was not helpful. This may have been the most important information to come out of the meeting. It would appear that the bulk of their complaints could be interpreted as roadblocks along the learning curve and their fading zeal seems indicative of the discovery that this technology requires practice to administer.

Lack of available training in the techniques is a problem that persisted throughout the development of electropalatography. In their article entitled, *Widening Access to Electropalatography for Children With Persistent Speech Sound Disorders*, published in

The American Journal Of Speech Language Pathology (1999), Gibbon, Stewart, Hardastle and Crampin, attempt to address this problem. Gibbon et al proposed a model in which electropalatography would be centralized.

They actually created a network, CLEFTNET, to offer electropalatography services to clinics throughout Scotland. The idea was that clinicians would be outfitted with hand held electropalatography units, called PTU's (Portable Training Units). These units were linked by modem to a central clinic where the data could be analyzed by skilled electropalatography clinicians. The center would then relay their findings back to the clinician who provides the intervention. In this sense the central electropalatography clinic would operate similarly to a medical lab that reports findings of blood or urine samples.

It is not clear whether CLEFTNET still exists. Web searches turn up only references to the *American Journal of Speech Language Pathology* article, some related papers, and a page on the website of Queen Margaret University that is linked to Fiona Gibbon's bibliography of EPG studies. Attempts by Kahn and Shadwick to contact Ms. Gibbon have received no reply.

It would be interesting to know if any aspect of CLEFTNET has survived the test of time. The idea is intriguing. And its functionality extends beyond professional development. Although centralized data analysis is probably not necessary over the

entire span of electropalatographic therapy, it could be a means to provide clinicians with a strong basis for which to build their rationales.

The CLEFTNET idea is, of course, thoroughly rooted in 1990's technological thinking. It leads one to wonder, however, why a company like CompleteSpeech could not advance the availability of electropalatography to practicing clinicians by offering their product on the cloud. At this time, SmartPalate remains a stand-alone software package that costs over a thousand dollars to purchase and is only available for Windows based computers. This is remarkably primitive in the current health care climate. In an age when a patient can use easily downloadable apps to self administer EKG's or check their blood sugar levels, the fact that electropalatography is not being offered in the same way appears archaic and counterproductive.

5: Recommendations for Future Research

If we are to accomplish the goal of incorporating electropalatography into clinical practice it is imperative that research into its effectiveness continues. Since the 1930's, electropalatography researchers have performed experiments, usually concluding that therapy was effective but the results were inconclusive because single case results could not establish statistical significance. This was followed by a plea for larger studies. No such studies have materialized.

When looking over this extended history of small experiments, however, intriguing patterns consistently emerge. In each case the researchers conclusively diagnosed specific physiological deviations that would be pure speculation by auditory perceptual means. This is the instrumental enhancement that allowed early researchers like Fletcher to note lateral lingua-palatal contact of vowels (Fletcher 1998). Similarly Fiona Gibbon found the patterns of covert contrast and undifferentiated gestures (Gibbon 2001) and Bartle Meyer et al. (2009) were able to argue for the presence of anterior lingual contact in apraxia patients who presented with backed consonants. Indeed the entire history of palatographic studies is awash in such revelations.

Current researchers have maximized the statistical significance of their single subject experiments by comparative analysis of the distinctive features of their client's productions. In a 2013 Brigham Young University Master's thesis experiment, for example, graduate student Kristina Lynne Pickett determined that the combination of electropalatographic therapy with traditional therapy was more effective then traditional therapy alone by comparing client productions for /r/ in the initial position, against controlled productions for /r/ in medial and final positions. This type of thinking has bolstered the validity of electropalatography research.

An inherent problem with referencing the results of one phoneme in multiple positions, however, is the potential for carryover effects that could result from training sounds with identical place and manner. It is for this reason that the San Francisco State

Communicative Disorders research team of Kahn and Shadwick have proposed an experiment that compares electropalatographic therapy for /r/ against controls for different phonemic distortions.

The San Francisco State University Department of Human and Animal Protections, as well as San Francisco State University Graduate Studies have approved this project. Although funding was allotted by the San Francisco State Communicative Disorders Department, the research has remained unrealized due to an impasse in negotiations between San Francisco State University Communicative Disorders and CompleteSpeech LLC. It is our intention to complete this project eventually because we believe it could be very valuable to the field. With this data, a Speech Language Pathologist can, in theory, increase efficacy and reduce time spent in therapy.

We have proposed a single subject experimental design for which we will identify 1-3 school age children, each of whom has a documented history of resistance to speech therapy. These will be 11 year olds with persistent /r/ distortions as well as distortions of at least 2 other phonemes. We will begin by assessing each child to provide baselines for /r/. We will also assess the baselines of the other two phonemes in accordance with the child's unique phonological history. Over the course of six weeks, (1, 55 minute session per week), we will treat the /r/ with Electropalatograpy. The second phoneme we will treat with traditional speech therapy. The third we will leave untreated. All three phonemes will be reassessed using electropalatography pre and post treatment condition.

We will then compare this data, focusing our examination on the rate of improvement for the target phoneme /r/ in comparison with the phoneme treated using traditional therapy and the untreated control.

Our proposed study will use the electropalatography pre and post treatment assessments of all both the treated consonants and the controls. This should ensure the highest degree of validity and reliability. Unfortunately, because we will need to conduct the initial assessment before having the client fitted for a pseudo-palate, we will not have this luxury when performing the initial assessment. For this we will have to depend on traditional formal speech assessments such as the Clinical Evaluation of Language Fundamentals (CELF), and The Goldman Fristoe Test of Articulation (GFTA). These tests will only be used to determine candidacy however. Baselines will then be gathered using electropalatography. This way they will not present a threat to the reliability or validity of the experimental results, a comparison between pre and post therapy assessments conducted using the palatograph. To ensure external validity I also recommend that follow up assessments be performed six months post treatment.

The results of this study will be derived from comparisons between pre and post treatment assessments. Our main concern will be the rate of improvement over baseline for the three conditions, the instrumentally treated /r/, the traditionally treated phoneme, and the untreated phoneme. This data will be gathered using the palatograph.

In addition to the instrumental reports, we propose including a second type of analysis. To demonstrate the statistical significance of the subject's articulatory improvement, we will record a language sample. We will play this sample to a group of trained and a group of untrained listeners and ask them to rate it for intelligibility. We will subject the data collected in this test to an analysis of variance. This study will help to determine if electropalatography can be used to increase efficacy in clinical practice.

Still, the potential to reduce time spent in therapy is only one benefit electropalatography has to offer the profession of Speech Language Pathology. It can also be used bolster the credibility of our diagnoses. This is, in effect, one of the key arguments for using instrumental biofeedback in both clinical practice and research. A profound weakness of the traditional method of articulatory assessments stems from our dependence on auditory perceptual transcriptions. Gooch et al (2001) demonstrated only 53% agreement among professional Speech Language Pathologists. Palatagraphic results, on the other hand, will be the same regardless of who administers the test. And while such objective uniformity is the goal of standardized measures, electropalatography is unencumbered by the inherent bias of normative populations. For this reason, future researchers should take a cue from Kerswill and Wright and look past the questions of efficacy and effectiveness, employing electropalatography as an accurate means to confirm the validity and reliability of their findings.

The above recommendation could also be applied in clinical practice because detailed objective data is key to evidenced based practice.

6: Conclusion

In 2006 Nan Bernstein Ratner published an article in the Journal, *Language, Speech and Hearing in the Schools*, in which she explored the barriers to implementing evidence based practice in clinical decision-making. She stated:

"In an ideal world, treatments emerge, are validated through clinical trials, are disseminated to avid consumers of clinical updates, and are applied seamlessly to those whose profiles fit the trial population characteristics. In the "real" world of practicing clinicians, however, frequently employed treatments may actually have little firm validation data, may or may not reach the practicing clinician (who may or may not appear to endorse and use them), and may have unclear relevance to the actual profile of the client one is seeing."

This, "real world," dilemma Ratner describes is probably the best argument for incorporating electropalatography into practice as an adjunct to traditional therapy. It endows the Speech Language Pathologist with a tool that unequivocally reports the outcomes of their interventions to those who fund them, insurers, educational institutions, and, most importantly clients and their families. If speech pathologists are to remain relevant in the 21st century we must reconcile the demand to justify our validity. Electropalatography just may hold the key.

For economic reasons, research into the efficacy of instrumental biofeedback therapies will probably always be limited to single subject designs. A steadfast adherence

to the law of large numbers, however, misses the point. The power of electropalatography lies in the instrumentation's ability shine a light into the invisible microcosm that auditory perceptual means cannot access. But before the working clinician can benefit from the sharpened lens of palatographic data the instrumentation must be within their grasp.

This remains to be resolved. In truth, the practice of electropalatographic therapy is in its infancy. Yet even as it continues to fall short of the goal of integration into the workloads of professionals, it has expert endorsement. The approach, for example, is among the recommended treatments of the ASHA ad hoc committee on Childhood Apraxia of Speech (ASHA 2007). Even in absence of the holy grail that are known as randomized clinical trials, (a medal of honor few therapies can boast of), the allure of reliable, valid and reportable measures conquers the toughest or critics. That said, the dream of the full service electropalatography clinic remains encumbered by roadblocks. These obstacles are not barriers of evidence. They are barriers of commerce.

Tech markets are a moving target. And whether we like it or not, the practice of Speech Pathology is caught in the fray. Like all professions we are faced with a choice of embracing technology for its gifts, or rejecting it at the risk of insuring of our own obsolescence. Recent calls for the field to embrace telepractice should be case in point (ASHA 2015). The question is what will an effective telepractice look like? Will a therapist still be able to hold up a mirror and ask the client to mimic their model? Probably not. Yet a therapy like electropalatography, with its real-time feedback

graphically displayed on the screen would seem the perfect compliment.

It is a high-tech solution for a high-touch field. Unfortunately, as it stands today, electropalatography is only high tech by the standards of earlier decades. Only two companies, CompleteSpeech and Articulate Instruments, each with it's own exclusive geographic domain vie to develop a commercially useful electropalatography system. And to their credit, they have focused their efforts on reducing the cost of a pseudopalate from over a thousand dollars a unit to less than two hundred, warrantee included. Sadly this is where the research and development appears to have dragged to a halt.

A U.S. clinician who choses to invest in electropalatography has only one choice. They must outfit a Windows computer to accommodate a software package, PalateView that costs over a thousand dollars. In an age of tablets, apps, and cloud-based services this model is gravely antiquated. Yet what is particularly puzzling is how easy it is to envision a better plan.

CompleteSpeech has in its palms a commercial app developer's dream product. While most apps enter the market with only the hope of profiting from back-end income such as click through advertising or upsells of enhanced features, CompleteSpeech holds the patent for an essential peripheral. The complete electropalatography set-up will always require the dental appliance and a data-link. This is an avenue to a financially solvent model, even if the software is offered at little or no cost. Such a platform might even provide justification for a raise in price on the palates to allow for the inclusion of

wireless features and heightened durability.

Electropalatography in clinical practice is feasible. Until the manufactures and the end users can forge a common ground, however, it will remain a novel undertaking, relegated to research labs and academic speculation.

Sources Cited

Articulate Instruments Ltd. A history of EPG. (2013) Retrieved January 21, 2015, from http://www.articulateinstruments.com/a-history-of-epg//

(2007) ASHA, Ad Hoc Committee Technical Report on Childhood Apraxia of Speech.. Retrieved January 21, 2015, from http://www.asha.org/policy/TR2007-00278/

(2015) ASHA Telepractice Overview. Retrieved January 21, 2015, from http://www.asha.org/Practice-Portal/Professional-Issues/Telepractice/

Auzou, P., C. Özsancak, R. J. Morris, M. Jan, F. Eustache & D. Hannequin. 2000. Voice onset time in aphasia, apraxia of speech and dysarthria: a review. *Clinical Linguistics and Phonetics*14(2):131–150.

Bartle-Meyer, C. J., Murdoch, B. E., & Goozee, J. V. (2009). An electropalatographic investigation of linguapalatal contact in participants with acquired apraxia of speech*:* A quantitative and qualitative analysis. *Clinical Linguistics & Phonetics*, *23*(9), 688-716. doi:10.1080/02699200903075388

Bell, A. M. (1867) *Visible speech or self –interpreting physiological letters of the writing of all languages in one alphabet.* London: Simpkin and Marshall

Broomfield, J., & Dodd, (2011). Is speech and language therapy effective for children with primary speech and language impairment? report of a randomized control trial. *International Journal of Communication Disorders*, *46*(6), 628-640.

Coles, J.O., (1872) A plan for ascertaining more accurately the physiology of speech. *Transactions of the Odontological Society of Great Britain*, 4, 110-124

CompleteSpeech. (n.d.). Retrieved January 21, 2015, from http://www.completespeech.com/about-us/

Dagenais, P. (1995) Electropalatography in the treatment of articulation/phonological disorders. *Journal of Communication Disorders*,28, 303-329.

Fletcher, Samuel G. (1998). *Articulation A Physiological Approach.* San Diego, California: Singular Publishing Group, Inc.

Gibbon, F. E. (1999) Undifferentiated Lingual Gestures in Children With Articulation/Phonological Disorders. *Journal of Speech, Language, and Hearing Research*,42, 382-397.

Gibbon F, Stewart F, Hardcastle WJ, and Crampin, L.(1999) Widening Access to Electropalatography for Children with Persistent Sound System Disorders. *American Journal of Speech-Language Pathology*, 8, 319-334.

Gibbon, F., & William, H. (2008). Electropalatography and it's clinical applications. In *Instrumental Clinical Phonetics*. Wiley.

Gibbon, F. (2011). *Bibliography of electropalatographic (epg) studies in english (1957-2011)* . (University College , Cork, Ireland).

Glogowska,M., Roulsone,S., Enderby, P. and Peters, T., 2000, Randomized controlled trial of community based speech and language therapy in preschool children. *British Medical Journal,* 231, 923-926

Gooch, J. L., Hardin-Jones, M., Chapman, K. L., Trost-Cardamone, J. E., & Sussman, J. (2001). Reliability of listener transcriptions of compensatory articulations. *Cleft Palate-Craniofacial Journal*, *38*(1), 59-67.

Hudgens, CV., & Numbers FC., (1942) An investigation into the intelligibility of the speech of the deaf, *Genetic Psychology Monographs*, 25 289-392

Katamba, F. (1989). *An introduction to phonology*. London: Longman.

Keating, P. (2011, June). *Ucla phonetics lab, electropalatography*. Retrieved from http://www.linguistics.ucla.edu/faciliti/facilities/physiology/epg.html

Kent, R. D. (1996). Hearing and believing: some limits to the auditory-perceptual assessment of speech and voice disorders. *American Journal of Speech-Language Pathology*, *5*(3), 7-22.

Kerswill, P Wright, S (1990). The validity of phonetic transcription: Limitations of a sociolinguistic research tool. *Language Variation and Change*, 2, pp 255-275.

Law, J., Boyle, J., Harris, F., Harkness, A. and Nye, C., 1998, Screening for speech and language delay: a systematic review of the literature. *Health and Technology Assessment,* 2(9), 1-184

Lieberman, P., & Blumstein, S. (1988). *Speech physiology, speech perception, and acoustic phonetics*. Cambridge [Cambridgeshire: Cambridge University Press.

Maico RaceCar Tympanometer. (n.d.). Retrieved January 21, 2015, from http://www.maico-diagnostics.com/us/products/middle-ear-analyzers/racecar-tympanometer/

Martin, K., Hirson, A., Herman, R., Thomas, J., & Pring, T. (2007). The efficacy of speech intervention using electropalatography with an 18-year-old deaf client. *Advances in Speech-Language Pathology, 9*(1), 46-56.

McGarr N.S, McNutt Campbell, (1995) Ephphatha: opening inroads to articulatory organization in people with hearing impairment, Bell, Berti F. and Rafael L.J. *Producing Speech*: Contemporary Issues for Katherine Stafford Harris: AIP press, New York.

Mcleod, S. (2011). Speech-language pathologists' knowledge of tongue/palate contact for consonants. *Clinical Linguistics & Phonetics, 25*(11-12), 1004-1013. Retrieved from http://0-search.proquest.com.opac.sfsu.edu/docview/925725160?accountid=13802

McNeil, M., Pratt, S. R., & Fossett, T. R. D. (2004). The differential diagnosis of apraxia of speech. In B.Maassen, R. Kent, H. Peters, P. van Lieshout, & W. Hulstijn (Eds.), *Speech motor control in normal and disordered speech* (pp. 389–413). Oxford: Oxford University Press.

Monson R. (1976) Second formant transitions of selected consonant-vowel combinations in the speech of deaf and normal-hearing children. *Journal of Speech and Hearing Research.* b;19:267–278.

Nober, E.H, (1967) Articulation of the Deaf, *Exceptional Children*, 33, 611-621

Osberger, M., & McGarr, N. (1982). Speech production characteristics of the hearing impaired. *Speech and Language, Advances in Basic Research and Practice, 8.*

Parsloe, R. (1997). Notes and Discussion Use of the speech pattern audiometer and the electropalatograph to explore the speech production/perception relationship in a profoundly deaf child. *International Journal of Language & Communication Disorders, 33*(1), 109-121.

Pickett, Kristina Lynne, (2013) The effectiveness of using electropalatography to remediate a developmental speech sound disorder ins a school age child with hearing impairment, *Theses and Dissertations.* Paper 3640

Pring, T., (2004) Ask a silly question: two decades of troublesome trials. *International Journal of Communication Disorders,* 3, 205-302

Ratner, N. (2006) Evidence-Based Practice: An Examination Of Its Ramifications For The Practice Of Speech-Language Pathology. *Language, Speech, and Hearing Services in Schools,* 257-267.

Roland, M., & Torgerson, D. J. (1998). Understanding controlled trials: What are pragmatic trials?. *British Medical Journal*, *316*(285), doi: http://dx.doi.org/10.1136/bmj.316.7127.285

Sanders, M. (2011). Inter and intra subject variability: A palatometric study. *Thesis and Dissertations*.

Smith, C.R. (1975) Residual Hearing and Speech Production in Deaf Children, *Journal of Speech and Hearing Research,* 18. 795-811

Stockman, I. J., Woods, D. R., & Tishman, A. (1981). Listener agreement on phonetic segments in early infant vocalizations. *Journal of Psycholinguistic Research*, *10*, 593–617.

Wrench, A. (2007). Advances in EPG palate design. *Advances in Speech-Language Pathology (Special Edition on EPG)*, 9 (1), 3-12.