Professor William Hardcastle FBA, Professor of Speech Sciences and Director of the Speech Science Research Centre presented the Lord Lloyd of Kilgerran Award Lecture in the Kohn Centre of The Royal Society on 5th December, 2006

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[The slides are at the end of this text]

The subject for tonight's talk is Electorpalatography or EPG, a technique for recording and analysing on important aspect of tongue movement during speech, namely the precise location and timing fo tongue contact with the roof of the mouth.

I've been working with this technique and using it for phonetic research and for clinical purposes for over 35 years now. It's a journey which started in what was the Phonetics Department at Edinburgh University in the early 1970s when I was doing my PhD under Professor John Laver and the work continued at the University of Reading, the Institute of Phonetics at the University of Kiel in Germany and for the past 15 years in the Speech Science Research Centre at Queen Margaret University College in Edinburgh.

We originally developed the technique as a tool for phonetic science research but the potential applications of the device for speech and language therapy in the assessment, diagnosis and treatment of speech disorders soon became apparent and with the help of funding from a number of sources such as the MRC, ESRC CSO in Scotland and various major charities we were able to develop this aspect of the work further. Along the way we set up a spin-out at QMUC called Articulate Instruments which sells and promotes the device and I'm pleased to say it's used in over 50 research and clinic centres worldwide and there are at least 750 research papers in international journals describing work with the technique.

It's been a fascinating journey because the technique has opened whole new areas of investigation into speech processing for me and my team at the SSRC at Queen Margaret and have encouraged us to view thorny issues such as the nature of complex speech disorder in a new light. We've seen real improvements in the speech of people with a wide range of communication problems after EPG therapy and we'd like to think our work has influenced policy decisions in the profession and the way clinicians approach therapy for certain types of speech disorders.

I'll be describing the technique, illustrating the sorts of data you can obtain with it and how you can use it in treating speech disorder, and finish up with some reflections on the research so far and the challenges which face us in the way forward.

Firstly I'd like to set the scene for the application of EPG in helping people with communication problems. Communication problems are a serious issue for our society. They can impact on a person's quality of life and have a very serious effect on educational and employment opportunities and general social interaction. You may be surprised at the size of the problem and the range of conditions linked to communication problems.

SLIDE:
We are not including here people whose native language is not English but of course they can suffer from the same negative effects because of this.

The slide shows a wide range of conditions. Some are related to structural or sensory abnormalities such as cleft lip and palate and deafness. Others are related to neurological disorders such as stroke (e.g. Aphasia) or diseases such as Parkinson's. In other cases such as many of the childhood speech and language problems there is no obvious etiology if we look at prevalence of the conditions and percentages that result in communication problems.

SLIDE:
Conservative estimates only. Add up to about 2.7% of the population of the UK which is about 1.6m people. That is, 1.6m people who have a moderate communication disorder where speech and language is noticeably disordered. This is a lot of people and their impairment can occur on a number of different levels.

SLIDE:
From the linguistic point of view the impairment may be mainly to do with how their speech sounds and sound systems they're using (the phonetic/phonological levels) or the impairment may occur mainly at the syntactic level (how words are put together into larger units) the semantic level, to with the meanings of words, pragmatics to do with how words are used in social interactions and so on. We'll be talking mainly about the speech output and we'll be referring to problems of articulation which may be linked to a whole host of potential problems whether they are sensory, structural, motor, developmental, cognitive or language related.

What can we do about articulation problems? Well at the chalk face is the speech and language therapist who plays an absolutely key role, who aims first to diagnose and assess the nature of the disability as a precursor to planning a therapy programme. This usually involves a process of trying to represent the speech sounds in some sort of phonetic transcription (usually the IPA) a technical skill which is part of the curriculum for all student SLTs. The transcription is a valuable tool for the therapist but it is auditorily based and by it's nature quite subjective, therefore somewhat unreliable. There are also some fundamental difficulties that tend to be associated with a representation of the speech signal based on a transcription, a sequence of discrete symbols representing speech sounds arranged spacially from left to right on the page.

Some of these limitations are listed in the next slide
SLIDE:
Segment based: using symbols to represent sound segments. Many of these are technical difficulties such as the representation of speech as a succession of discrete sound segments. Speech doesn't actually work like that; there is constant overlapping of all the organs involved in speech production such that one segment effectively merges into another. Transcription= end result of a whole complex of interacting processes involving many different speech organs. Also the transcription gives us no precise information on individual speech organs although this is necessary for a more accurate and reliable evidence base for identifying the nature of articulation disabilities and planning appropriate therapy. Ideally we need to supplement our auditory judgements with objective, instrumentally based methods.

SLIDE:
Advantages of instrumental methods
One particularly important organ that we need precise information on is the tongue, in view of its central role in the production of speech. However, although we know the tongue is important, we know surprisingly little about how it works and there are many problems associated with gaining solid objective data on tongue function during speech.

SLIDE:
Challenges for recording and analysing tongue movements during speech.
However, over the years there have been a number of techniques developed for studying different aspects of tongue activity. But as we'll see, problems are associated with all of them.

SLIDE:
Techniques
First of these is Video X-ray system. MIT is the classic technique for looking at the dynamics of speech production. Outlines shape of tongue, lower jaw, teeth, soft palate. Good for looking at movements of different speech organs in relation to each other. Sagittal view so not 3D. Limitations: Potential damage to soft tissues from radiation, so look for safer alternatives.

SLIDE:
MRI offers new opportunities and its starting to be used increasingly for speech research purposes. But speakers are in a supine position inside a chamber so may experience claustrophobia. The equipment is very expensive, particularly for clinical and speech research purposes. Relatively slow sampling rate.

SLIDE:
Alan with ultrasound

Ultrasound offers a safe alternative and is relatively non-invasive. Another technique borrowed from medicine. Hold the probe under the chin. Can get both sagittal and coronal views depending on orientation of the probe.

SLIDE:
Real-time ultrasound imaging. Tongue tip at right.

SLIDE:
Very useful for showing effects of context on speech sounds /t/in/versus /a/context. This is difficult to interpret, doesn't represent tongue tip well and is expensive for average SLT clinic.

SLIDE:
EMA technique plots movement of coils placed on the surface of speech organs through an electromagnetic field generated by a number of electromagnets within the helmet. Very good for looking at coordination between different speech organs such as lips, jaw and tongue and the kinematics of movements such as amplitude, velocity and acceleration. Promising new developments all the time but still very expensive. It requires quite elaborate setting-up so clinic use limited, also difficulties with calibration and how it responds to skewing of the tongue. So although many advantages with these techniques there are also problems.

This brings us to EPG

SLIDE:
EPG palate
Each speaker wears a customized artificial palate made from a plaster impression of the upper palate and teeth.

SLIDE:
Artificial palate in plaster impression
Similar to a removable brace. Very small current (less than 5micro Amps) passes through the body and when contact occurs between tongue and palate as you speak, a circuit is completed and the contact is recorded by the computer.

SLIDE:
Shows relationship between arrangement of electrodes and computer display. Front four rows are closer together than back four rows.

SLIDE:
EPG idealized quasi-static patterns. Use as the basis for description. Aim to achieve groove at for /s/. Full closure at back for /k/ etc. Obviously for detailed analysis there needs to be a permanent record of contact patterns. We can get various types of record; also synchronized with ac. Signal which we can display along with the contact pattern.

SLIDE:

Shows articulatory landmarks that occur during production of the word ‘tactics’. Reads like a cine-film from left to right 10ms intervals.

SLIDE:
‘Fred can go’
These printouts are very useful for finding out interesting facts about speech that are very difficult to hear. Two ways of producing the sentence ‘Fred can go’, upper trace fairly deliberately with contact in the front region (top) for the /n/ followed by short period when both front and back the back contact is released and air comes out for the /g/ in go. Contrast with lower trace where no evidence of /n/ in ‘can’. It’s been assimilated into the /g/ in ‘go’ so there’s only contact at the back. Not necessarily detected but its subtle features such as this that are important for precise diagnosis of a disorder. For example let’s look at production of the word ‘deer’ spoken by a normal speaker and a speaker with apraxia of speech. This is a problem with planning or motor programming of speech events that in this case occurred following a stroke.

SLIDE:
‘Deer’
Normal with normal horseshoe-shaped configuration for the /d/
Contrast with
SLIDE:
‘Deer’
Spoken by the speaker with apraxia of speech. This is heard as ‘deer’ but not normal in terms of tongue contact. They seem to begin by selecting the wrong target, a pattern more appropriate for a /g/. Then detects the error and corrects it to the right pattern for a /d/ but keeping the back pattern. Finally releases it as a /d/. This is heard as a /d/ but clearly is not a normal /d/. Another example, this time from another person following a stroke with a condition known as conduction aphasia which may also present with problems in speech motor programming.

SLIDE:
‘Key’
Starts off with a correct /k/ target then halfway through comes an abnormal intrusive /t/ pattern which is heard as ‘a tee’. If you were simply listening to this you would probably conclude this was a straight substitution of a /t/ for a /k/ but there’s clearly more to it than that and its this sort of fine-grained information that is very useful to the SLT in trying to understand what the underlying nature of the speech deficit is – whether it’s a problem of simply selecting the wrong phoneme /t/ for /k/, or is it the case here that the correct choice seems to be interacting with an intrusive /t/-like gesture. Another case where EPG can provide additional insight into the nature of a disorder, which would remain undetected by auditory judgement alone.

Another example is from our cleft palate group
SLIDE:
This is a printout of ‘a pig’ spoken by a child with a repaired cleft lip and palate. What we see here is something we frequently observe in these children. Contact at the rear of

the palate accompanying more anterior closures such as the lip closure for the /p/. Clear in EPG but not heard in isolated words; back contact marked by lip closure. This information is important for the SLT. Connected speech difficult to understand and we believe this retracted placement as seen in the isolated word occurs also simultaneously with other sounds such as /f/ /v/ may be contributing to this.

Therapy
EPG therapy is particularly useful in those cases where there is an intractable speech problem. Where conventional therapy has been carried out for a long period and the child has reached a plateau in performance. In many of these cases the SLT knows the child is using abnormal lingual patterns; it’s very difficult to change these patterns because it is very difficult to detect where your tongue is in your mouth. EPG can then provide a different dimension: using the visual real-time display, children can begin to control their tongue position more precisely and begin to incorporate these new correct patterns into their speech. Carry over of the newly learned patterns into everyday speech has in most cases been very good. A recent survey by my colleagues at QM identified 148 studies in the literature describing therapy with EPG.

SLIDE:
EPG therapy covering a wide range of different disorders all linked to articulation problems: most functional articulation disorder, and cleft palate.

SLIDE:
Most studies have been single case studies, all of which report improvement. Typical of some of the children we have studied over the years are these three children;
SLIDE:
Rebecca
SLIDE:
David
SLIDE:
Emma
Because these children had intractable speech problems these breakthroughs with EPG have been very cost effective in cutting substantially the number of therapy hours. Thus EPG can minimize valuable therapy time so could potentially save the NHS considerable sums.

I would now like to show some very early results from a new project we are running looking at speech problems associated with Down’s syndrome

SLIDE:
Rationale for the project is that the majority of children with DS have communication problems that can have a significant impact on their education and social interaction. Previous research has shown that they respond very well to visual stimuli so we believe EPG may be particularly effective in treating their speech abnormalities.

SLIDE:

Controlled Study
Looking at the data from one of the children on the project, she has particular problems with /s/ production;
SLIDE:
I can say sun again. Pre
SLIDE:
Frame freeze
SLIDE:
A sun

The first couple of therapy sessions concentrated on /s/

SLIDE:
I can say sun again. Post
SLIDE:
A sun
Very early days but great progress so far

To finish Dr Goodman has asked me if I would like to reflect on some of the issues that have arisen from the story of EPG as a case study. One of the interesting things for me is an appreciation of how broad any discipline of speech science is. Unlike many more traditional disciplines the study of speech knows no boundaries, it bridges the gap between the sciences and humanities and it is archetypically interdisciplinary. This has had many advantages. I've had the benefit of working closely with speech and language therapists, engineers and computer scientists as well as my fellow linguists and phoneticians over many years and I'd like to think that this relationship has been a mutually beneficial one. My clinical colleagues and I share a common interest in understanding the complex nature of the process of speech production and perception, although we are coming at it from slightly different standpoints. Coming from a phonetics background I've seen great insights into normal processing from studying what happens when speech breaks down. My speech and language therapy colleagues have been able to apply many of the advances in instrumental phonetics such as EPG to improving assessment, diagnosis and treatment of disorders. This has been a productive interdisciplinary relationship over many years. I'm sure this interdisciplinary approach has helped us in winning major research council funding. However, we are never really sure who to apply to. We've had funding from MRC, EPSRC, ESRC and the Scottish CSO as well as some major charities and even industry.

There's no doubt the evidence base for speech and language therapy needs to be strengthened and I believe it is accessible instrumental techniques such as EPG that will help this. The CLEFTNET project could be a useful model. This is a project run by us involving EPG as an assessment and therapy tool and which links all the cleft palate centres in the UK. We'd like to see this widened to all people with speech disorder so that anyone with an articulation problem who could possibly benefit from EPG would be able to access it on the NHS. Our challenge now is to obtain the necessary infrastructure funds so that we can set up a network of NHS centres across the UK that could offer EPG in this way.

I would finally like to thank the various sponsors of our research over the years and also thank all those who have been involved in EPG research and development.

Visualising the tongue:

Assessment and treatment of speech disorders with Electropalatography (EPG)

Bill Hardcastle
Director, Speech Science Research Centre
Queen Margaret University College, Edinburgh

Conditions linked to communication problems

- Aphasia following stroke
- Autism spectrum disorder
- Asperger's syndrome
- Alzheimer's disease
- Cerebral palsy
- Cleft lip and palate
- Developmental language delay and disorder
- Dyslexia
- Dementia
- Friedreich's ataxia
- Head injury
- Hearing impairment and deafness
- Huntingdon's chorea
- Learning disability
- Mental health problems
- Motor neurone disease
- Multiple Sclerosis
- Muscular Dystrophy
- Neurological diseases eg Parkinson's disease
- Stammering
- Visual impairment
- Voice disorder

About 2.7% of the population = 1.6m people have a moderate communication problem

Levels of impairment

- phonetics/phonology
- syntax
- semantics
- pragmatics
- prosody
- non-verbal communication
- voice

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Auditory judgments

Limitations:

- unreliable
- segment-based, therefore:
  - relatively abstract representation
  - encourages categorical judgments
- attempts to represent what listener hears, so:
  - no precise information on individual speech organs

Objective instrumentally-based methods

- providing precise information on articulatory, laryngeal and respiratory activities
- increase diagnostic precision
- objective and reliable data
- represent continuous nature of speech events
- important for development of evidence-based therapies
- some can be used as biofeedback techniques in therapy

Recording and analysing tongue movements during speech

Challenges:

- largely hidden from view
- particularly sensitive organ
- rapid movements during speech
- unique anatomy and physiology: muscular hydrostat

Range of techniques for measuring tongue movements directly

- X-ray
- Magnetic Resonance Imaging (MRI)
- Ultrasonics
- Electromagnetic Articulography (EMA)

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MRI images during speech (source: S. Narayanan et al JASA 2004 from the USC-SPAN group)

Ultrasound set-up showing stabilising helmet and probe

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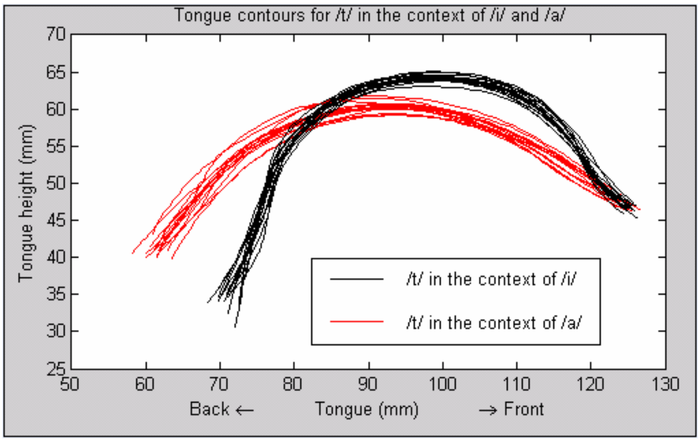
Ultrasound traces showing contextual effects on /t/



(source: Zharkova & Hewlett 2006)

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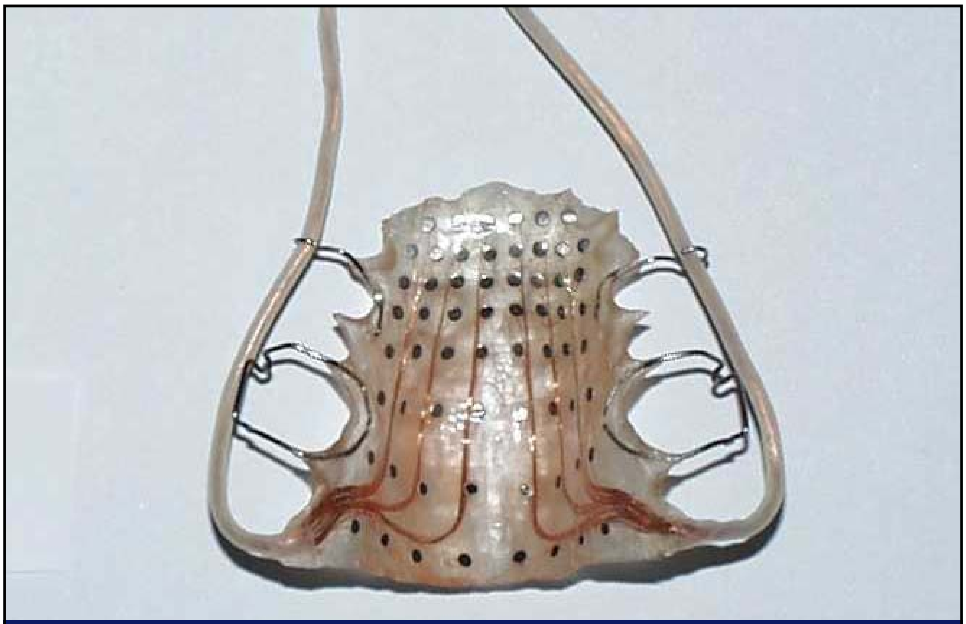
Electromagnetic Articulography (EMA)



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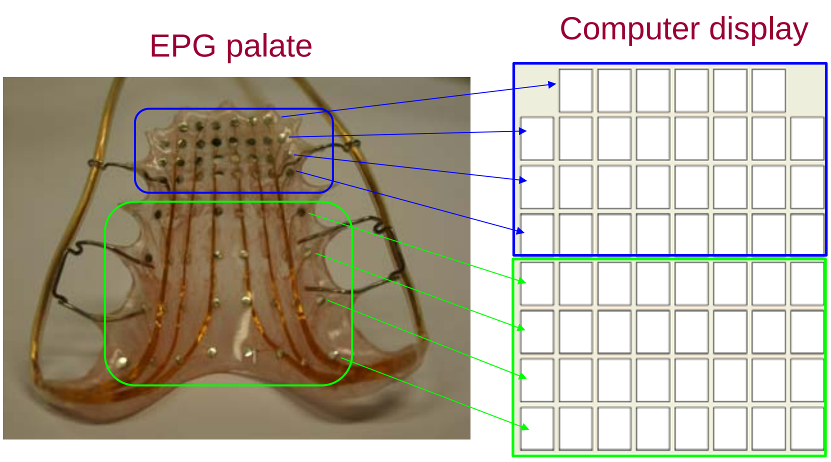

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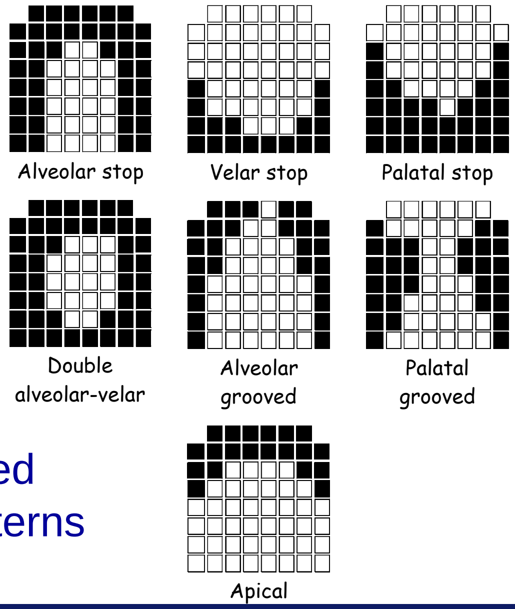
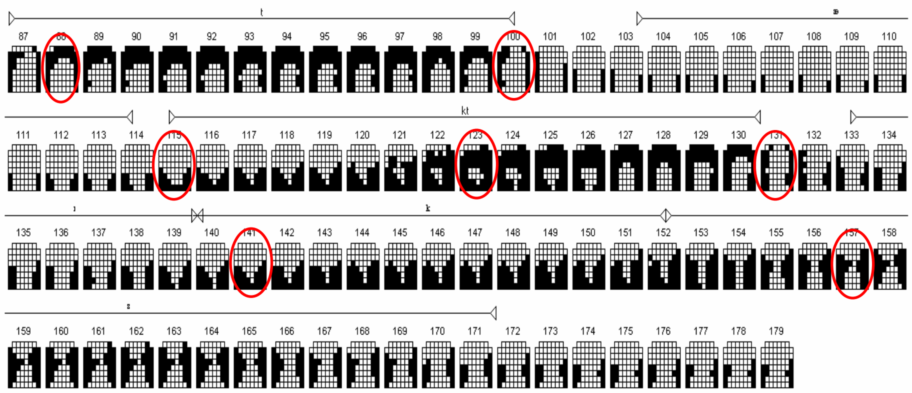
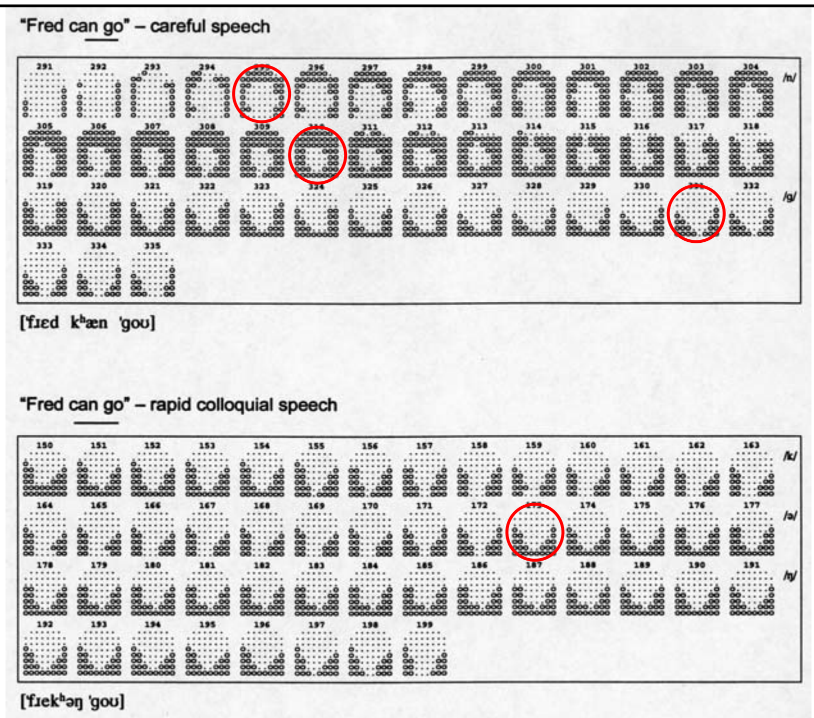


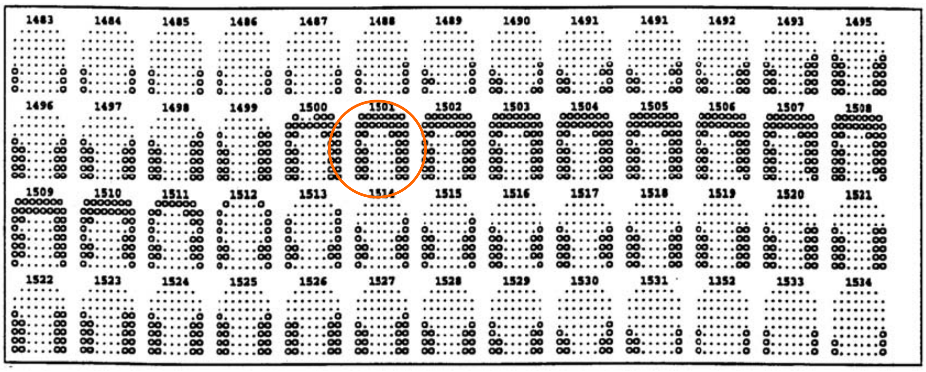
EPG idealised ‘quasi-static’ patterns

Printout of “tactics” (frame interval 10ms)

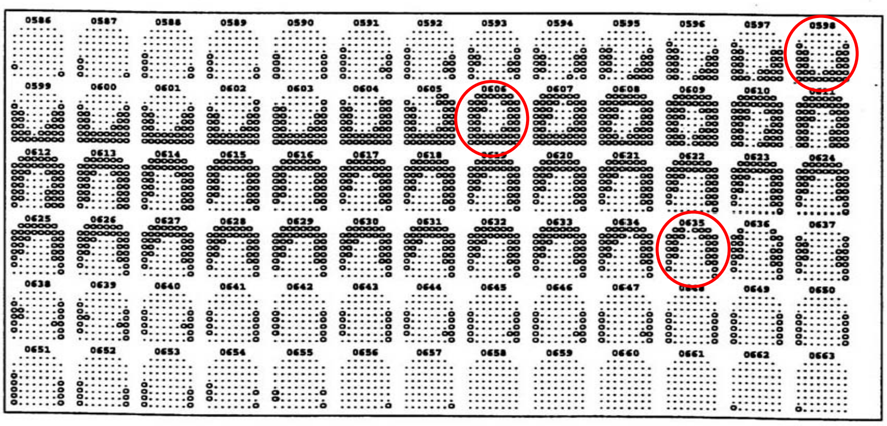




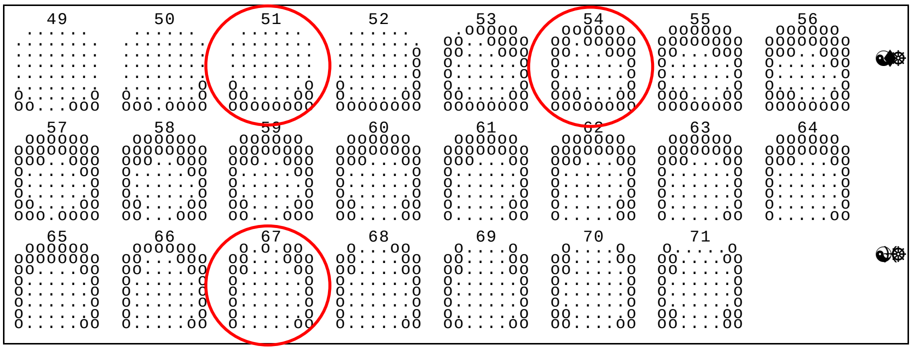
Normal speaker - target 'deer'



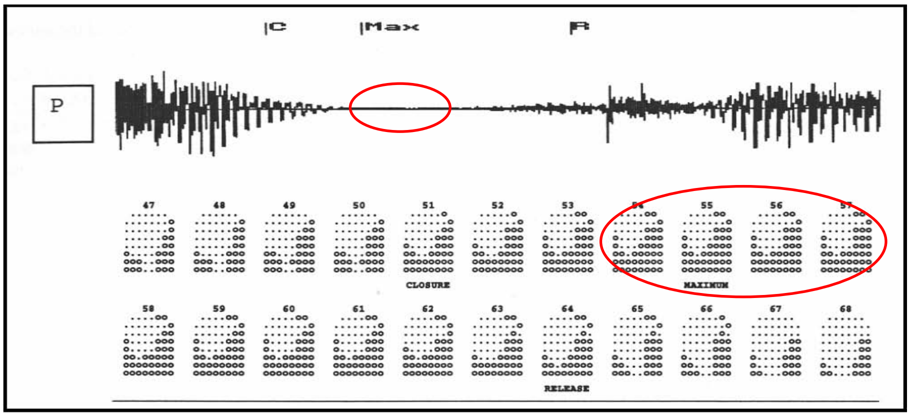
Apraxia of speech - target ‘deer’



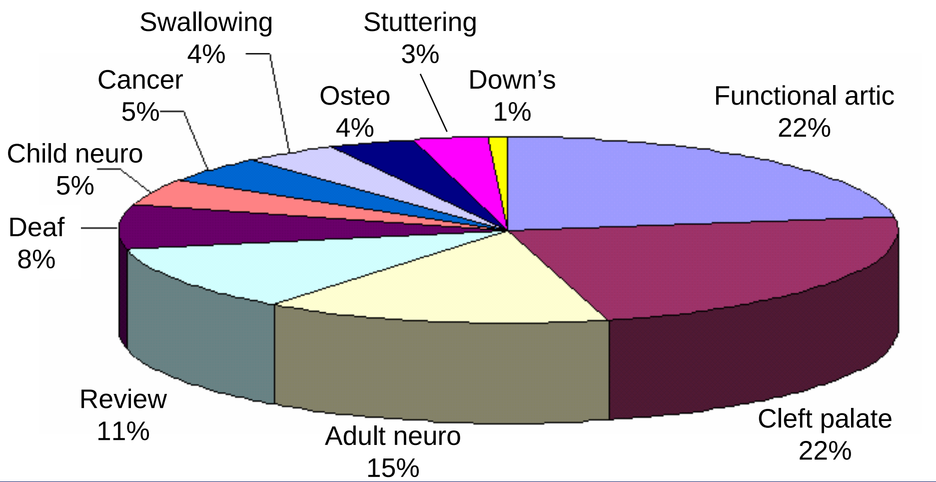
Conduction aphasic - target ‘a key’



Child with cleft palate - target ‘pig’



Clinical studies using EPG (N=148)



Efficacy of EPG therapy

- 148 clinical studies on a range of speech pathologies
- functional articulation disorders and cleft palate most commonly studied
- most study school-aged children
- most report small groups of <5 speakers
- single case studies **ALL** report positive change
- small groups of 2-3 report positive change in some but not all cases
- study of 12 children with cleft palate: improvement in 66% cases

[Source Gibbon,2003 and EPG bibliography http://qmuc.ac.uk/ssrc]

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Rebecca (female, 12;3 years, Dent et al. 1995)

- functional articulation disorder (lateral lisp)
- a saw

before therapy

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 ......
ooooo...
oooooooo
oooooooo
oo....oo
oo....oo
oo.....o
o.......
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after therapy

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 ......
oo...ooo
oo...ooo
oo....oo
o......o
o......o
o......o
o......o
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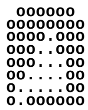
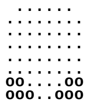
David (male, 9, Gibbon and Wood, 2003)

- functional articulation disorder (velar fronting)
- a cap

before therapy



after therapy



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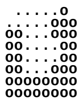
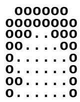
Emma (female, 9 years, Gibbon et al. 1993)

- functional articulation disorder (alveolar backing)
- a tar

before therapy



after therapy



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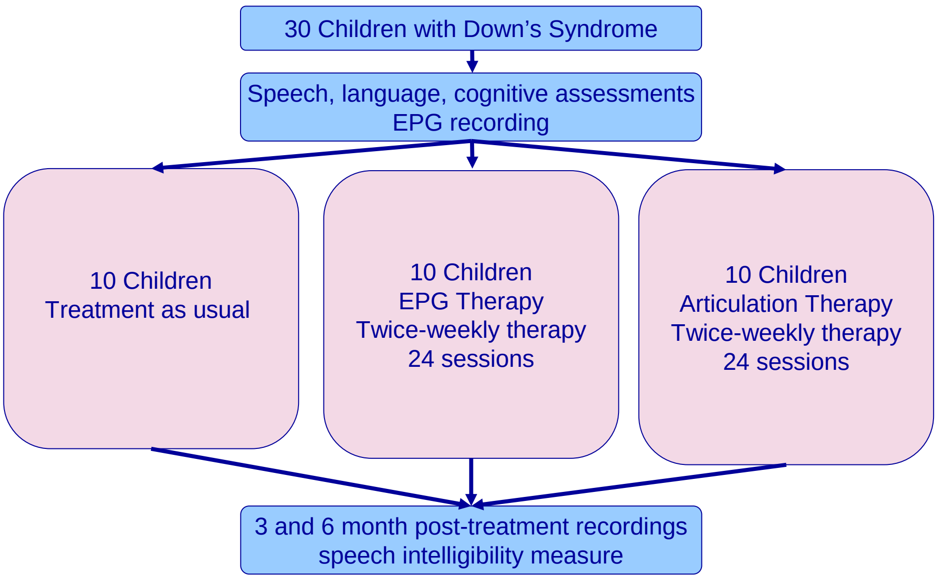
Current Down's Syndrome project

- Assessment and treatment of speech motor control in children with Down's Syndrome
- collaborative project between QMUC and Edinburgh University
- funded by the Medical Research Council for 3 years
- additional funding and support from Down's Syndrome Association



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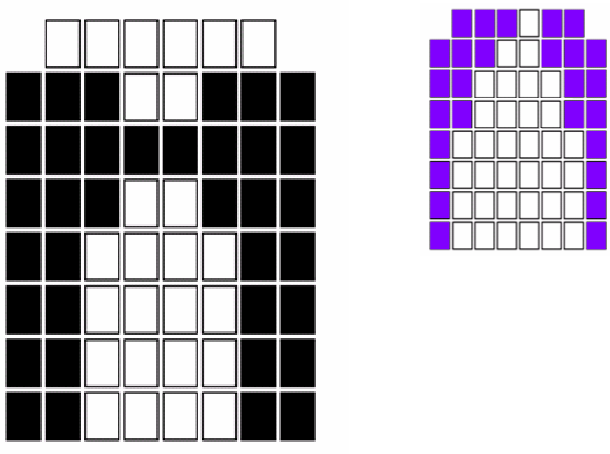

“I can say sun again”

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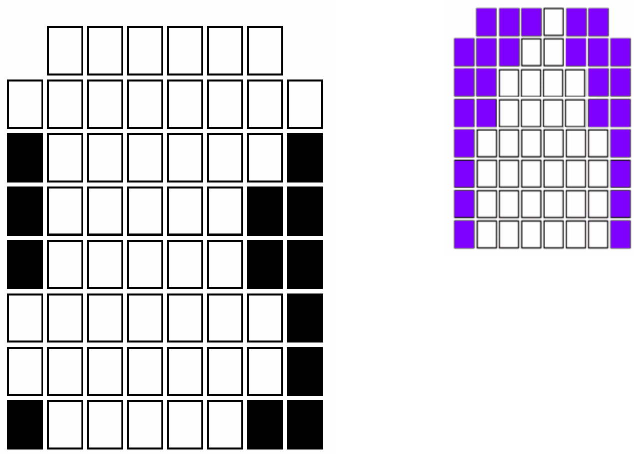

“a sun”

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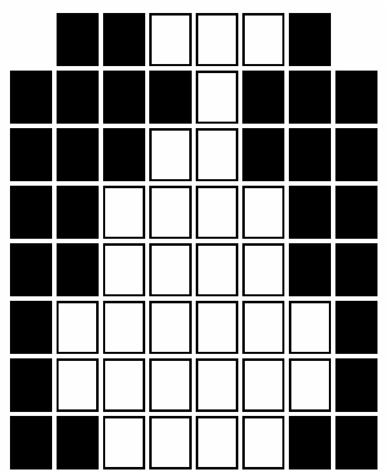

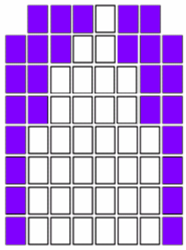

I can say "sun" again

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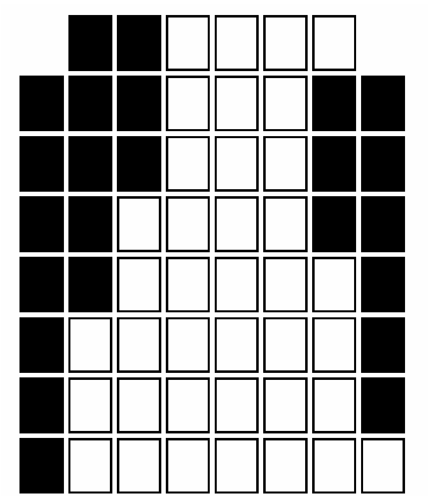

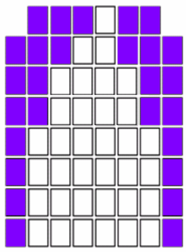

a "sun"

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Thanks to the sponsors of our research

- MRC
- ESRC
- EPSRC
- Chief Scientist's Office, Scotland
- IBM
- Down's Syndrome Association
- BBC Children in Need
- Down's Syndrome Scotland
- Lloyds TSB Foundation Scotland
- McRobert's Trust
- Gannochy Trust
- London Law
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- Daiwa Foundation

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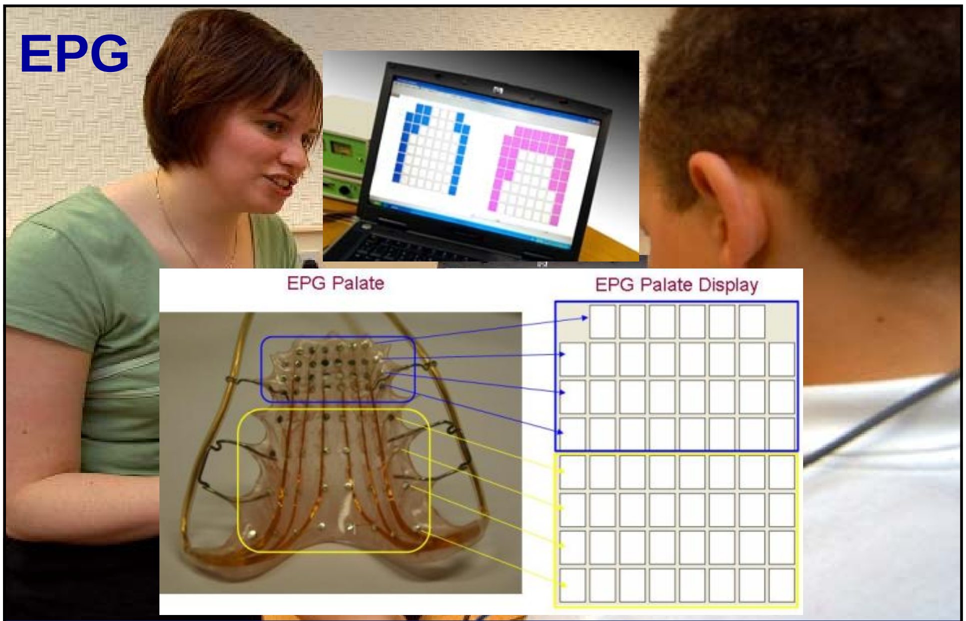
Daniel Recasens
Peter Roach
James Scobbie
Noriko Suzuki
Claire Timmins
Sara Wood
Alan Wrench

EPG



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  - The children who are taking part in the project
  - The children's families, teachers and SLTs
  - The Medical Research Council for funding the research
  - Down's Syndrome Scotland for supporting the research
  - The Down's Syndrome Association for funding the linked PhD studentship on voice in DS

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Visit our website
http://www.qmuc.ac.uk/ssrc/DownSyndrome/home.htm

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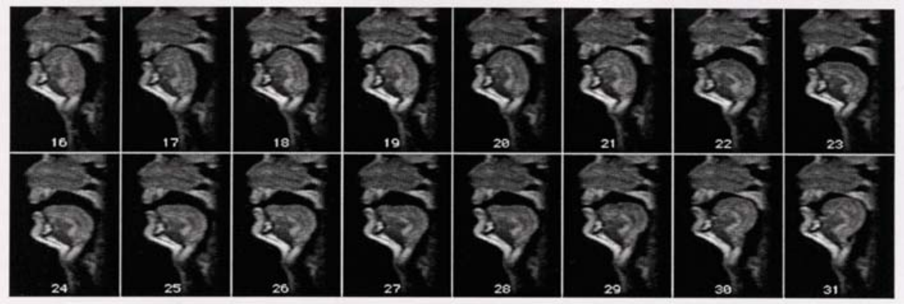
Joanne McCann or Claire Timmins: 0131 317 3681

Tongue as one of the most important speech organs

- placed in various parts of the mouth to create momentary obstruction to air flow
- placed in close proximity to other structures to produce turbulent air and fricative noise
- moved about in mouth region to change resonating characteristics in the formation of vowel sounds

MRI frames



The sequence /ieaou/ pronounced by a male speaker.
Frame rate approximately 5 Hz.

(source: Didier Demolin)

MRI in speech research

Advantages:

- safe
- non-invasive
- clear images of vocal tract anatomy (including different types of tissue) in different planes
- no obscuration

Drawbacks:

- costly
- subject in supine position
- subjects may experience claustrophobia
- relatively long image time
- poor sampling rate for dynamic imaging

Ultrasound in speech research

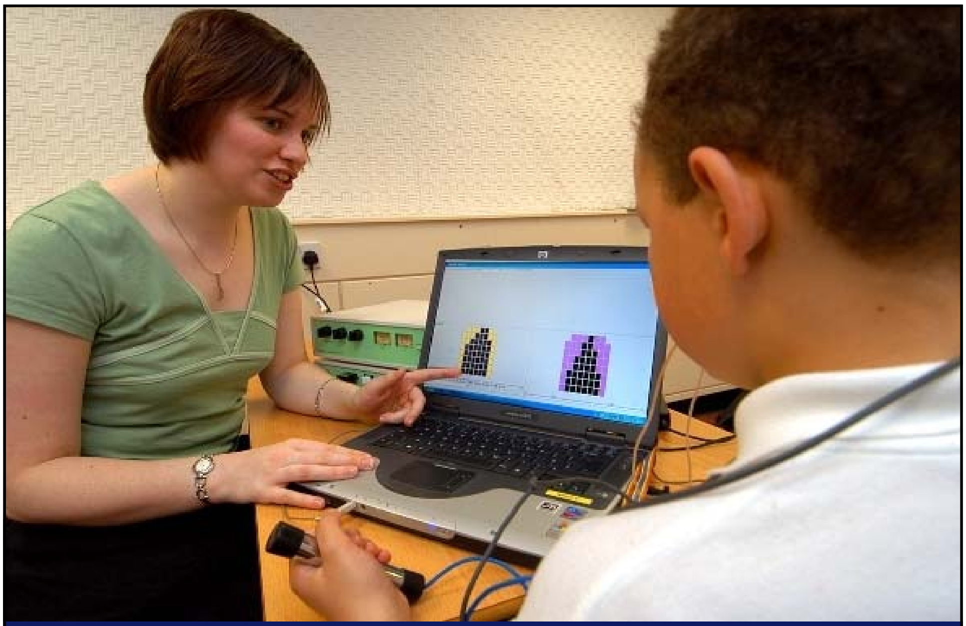
Advantages:
- safe
- non-invasive
- no interference with speech naturalness
- coronal and sagittal views
- good soft tissue definition
- real-time

Drawbacks:
- costly
- air gaps prevent transmission (1 cm of tongue tip normally not imaged)
- soft tissue only, no palate or pharyngeal wall
- relatively slow sampling rate (depends on video)

EMA in speech research

Advantages:
- relatively safe
- fast tracking rate
- able to track multiple articulators simultaneously
- provides quantitative kinematic data

Drawbacks:
- costly
- needs careful calibration
- subject to errors from tilt and displacement from midline
- elaborate preparation necessary
- tracks points only
- may interfere with normal speech
- absolute tongue co-ordinates in space difficult



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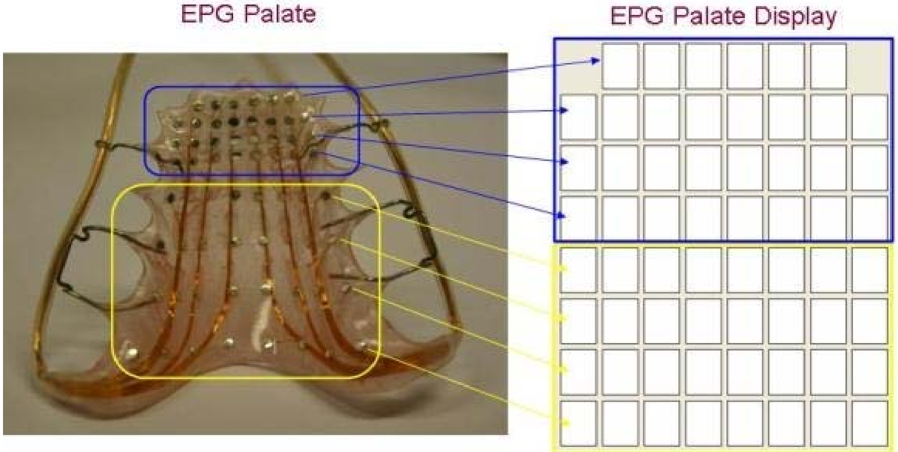
Electrode configuration



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Prevalence of speech and language disorders

	% per head	% with disorder
Developmental language delay and disorder	3.0	100
Mental health problems	2.5	55
Stammering	1.07	100
CVA	0.5	30
Deafness	0.2	60
Cerebral palsy (based on new-born population)	0.17	60
Cleft lip and palate (based on new-born population)	0.14	40
Parkinson's Disease	0.12	55
MS	0.06	55

(Percentages based on Enderby & Philipp, 1983 & ASHA)

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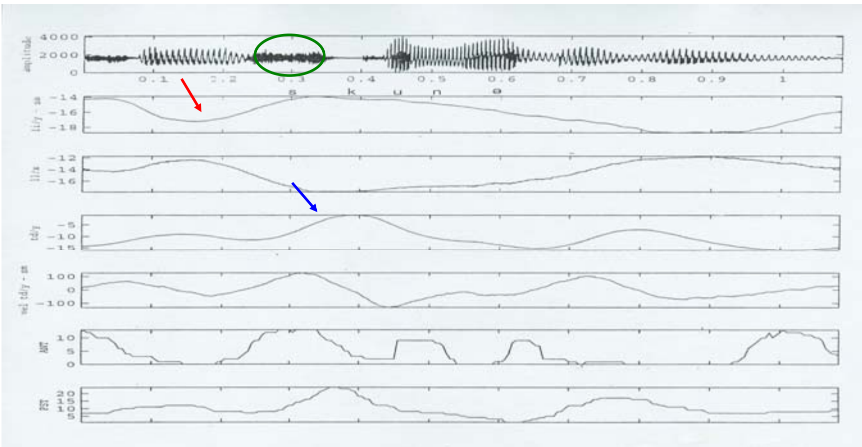
EMA record of sentence "say schooner again" spoken by Scottish English speaker



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