Institution: Queen Margaret University, Edinburgh

Unit of Assessment: UoA 26 Modern Languages and Linguistics

Title of case study: Children with persistent speech disorders benefit from our basic and clinically-applied research into the articulation of speech

Period when the underpinning research was undertaken: 2006-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof James M Scobbie	Research Fellow, Professor	1993 – present
Dr Joanne Cleland	Clinical Research Fellow & Speech & Language Therapist	2002 – 2015
Zoe Roxburgh	Clinical Research Assistant & Speech & Language Therapist	May 2015 – Oct 2016
Cornelia Heyde	Research Assistant	May 2015 – Oct 2016
Prof Alan A Wrench	Self-employed (Articulate Instruments) Professor	2006 – 2020 (Category C) 2013 – 2014 (Category A)

Period when the claimed impact occurred: Aug 2013 - 31 Dec 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The main impact was the clinically significant resolution of persistent and apparently intractable speech sound disorders in children. Speech therapy exploited our instrumentation, analysis measures, and clinical protocols, making children's speech more like that of their peers, and more intelligible.

Our stabilised, spatio-temporally detailed and acoustically-synchronized ultrasound images convey the shape, location and movement of a child's tongue accurately. Our speech therapy treatment protocols facilitate accurate clinical assessment and effective intervention. Meaningful feedback (in real time and using previous in-therapy recordings) supports clinicians (and their families) to help children to suppress incorrect speech gestures, and introduce correct ones.

2. Underpinning research

Our interdisciplinary approach involved engineering, linguistic and clinical research. Results from each area informed the others. Furthermore, clinical intervention was conceived within a cyclic, causal model of research/impact: so our clinical intervention generated the bulk of the impact in this case study, but also fed "back" into our research (see environment). Our research achieved:

- Audio-synchronised, stabilised, high-speed Ultrasound Tongue Imaging (UTI), making ultrasound more effective and accessible as a tool for articulatory phonetics [1-3]
- Experimental studies (clinical and non-clinical) of child (and adult) speech e.g. [3-4]
- Adaption of motor therapy principles, producing protocols for the assessment and remediation of persistent and intractable speech sound disorders using UTI [4-5]
- Theoretical models of clinical speech sound gesture acquisition and mastery involving gradient and categorical changes at the phonetics/phonology interface e.g. [6]

Ultrasound scanners are safe and non-invasive, and so can advance articulatory phonetic research by imaging the shape and location of the tongue during speech. Even off-the-shelf medical scanners can provide reasonable feedback that might be clinically useful, a potential area of impact that was an initial motivation for this research. Our early underpinning research [1] solved technical problems arising because off-the-shelf scanners (a) sampled the moving tongue at low rates, causing artefacts, (b) had no integrated capacity to record audio (speech sounds) and (c) produced low quality video output that was unacceptably variable when aligning ultrasound and acoustic signals post-hoc. Between 2006 and 2016, QMU and spin-out company Articulate Instruments Ltd (as Category C research collaborator) invented and developed reliable, (ultra) high-speed audio-visual systems for speech capture and analysis [2]. QMU also commissioned and tested the Articulate Instruments' aluminium headset, which provides stabilisation without forcing speakers to restrict natural head movements. These new instruments were implemented and improved in QMU's unique multi-channel articulatory laboratory [2] along with methods for ergonomic data-collection. We developed methods suitable for within and between speaker comparisons of children's speech through developmental and clinical research that recorded over 100 child speakers (including 58 typically developing children within the EPSRC-funded "ULTRAX" project [4]). Carnegie Trust funding let us use parallel MRI and UTI studies of 12 phoneticians producing canonical samples of speech sounds to enhance our understanding, improve analyses, and to record two expert model talkers Janet Beck (QMU) and John Esling (Victoria, Canada) comprehensively exemplifying the International Phonetic Alphabet [3].

Most importantly, our applied clinical research included real-world interventions for a range of persistent speech sound disorders. Clinical researcher and SLT Cleland (with support from Roxburgh as a PhD student) undertook over 100 clinical sessions during ULTRAX (2011-2014) with 8 children [4]. Building on this research, clinical researcher Roxburgh (in collaboration with Cleland, who had taken up a permanent post at Strathclyde University) recruited 20 children (mean age 8.9 years) for the CSO-funded Ultraphonix (2015-2016) of whom 15 underwent, in total, over 200 sessions (45 for baseline assessment, 157 for treatment and 12 for maintenance probes) [5]. Clinical use of real-time visual biofeedback of articulation was not entirely new, but elements of this clinical research directly led to impact by using our own underpinning:

- **technical advances** providing stabilised high quality data [1-2]
- **understanding** of typical child speech development and adult speech production in relation to (a) ultrasound images [2-4] and to (b) (clinical) models of real-time, delayed and therapist-mediated biofeedback in relation to motor learning, [4-5]
- **articulatory norms** for measuring degrees of overt and covert phonological contrast [4-6].

Moreover, for the clinical research, our research created a detailed, practicable and effective intervention protocol using motor-learning therapeutic techniques [4-5] tailored for our ultrasound system's capabilities [2]. Audio-ultrasound recordings of previous sessions (and typical child productions [4]) let client and clinician reflect on the client's improvement, or enabled comparisons to the age-matched typically-developing children collected for this specific purpose during ULTRAX [4].

3. References to the research

[1] Wrench AA. and **Scobbie** JM (2006) Spatio-temporal inaccuracies of video-based ultrasound images of the tongue. *Proceedings of the 7th International Seminar on Speech Production*, pp. 451-458.

[2] Wrench AA. and **Scobbie** JM (2016) *Queen Margaret University ultrasound, audio and video multichannel recording facility (2008-2016).* CASL Working Papers, Queen Margaret University, WP-24.

[3] **Cleland** J, Wrench AA, **Scobbie** JM and Semple S (2011) Comparing articulatory images: An MRI / Ultrasound Tongue Image database. *Proceedings of the 9th ISSP*, pp. 163-170.

[4] **Cleland** J, **Scobbie** JM and Wrench AA (2015) Using ultrasound visual biofeedback to treat persistent primary speech sound disorders. *Clinical Linguistics & Phonetics, 29(8-10), pp. 575-597*.

[5] Cleland J, Scobbie JM, Heyde C, Roxburgh Z and Wrench AA (2019) Enabling new articulatory gestures in children with persistent speech sound disorders using ultrasound visual biofeedback. Journal of Speech, Language, and Hearing Research, 62(2), pp. 229-24.
[6] Cleland J and **Scobbie** JM (2019) Acquisition of new speech motor plans via articulatory visual biofeedback. In Fuchs, Cleland and Rochet-Cappelan (eds.) *Speech Production and Perception: Learning and Memory.* Berlin: Peter Lang. 139-159.

Evidence of 2 quality: some outputs were peer reviewed, for journals [4-5] or proceedings [1, 3]. Outputs submitted in REF2 are [4] & [5]. The research in [3] was competitively funded by the Carnegie Trust. Two research-council-level projects (CSO & EPSRC) funded the clinical research generating [4-6]. Note, some impact arising (2014-2020) from our underpinning research is therefore reported within (hence is corroborated by) underpinning research outputs (Section 4.1). Authors in **bold** were QMU members of staff at the time of publication.*

4. Details of the impact

4.1 Planned, Causal, Internal Clinical Impact

In our research/impact model, we recruited 28 child clients aged 6-14 to two clinical research projects, treated in 1 hour therapy sessions in a 10-12 week block. Most of the clinical impact arising during the census period occurred within the Ultraphonix project (2015-2016), and is corroborated by our underpinning research output [5], so we focus here on that Case Series.

15 children recruited for Ultraphonix were suitable for and completed our protocol of motor-based therapy with ultrasound visual biofeedback [5]. Overall, they improved speech intelligibility (rated holistically by their parents, see below). Intelligibility improved because our research interventions identified, targeted and successfully resolved errors in key consonants or vowels that had been persistent and unresolved, to a clinically significant degree for 10 of these children, as quantified by effect-size analysis [5].

Audible improvements in speech sounds above stable baseline (BL) can be shown as "percent treated targets correct (% TTC)". Figure 1 charts the mean improvement of all the 15 children. Accuracy increased from below 5% TTC at baseline to 60% TTC in maintenance assessments (3 months post-intervention), as measured in clinic using probes, which, because they comprised words that had not been used in treatment, show both generalisation and retention [5-6].

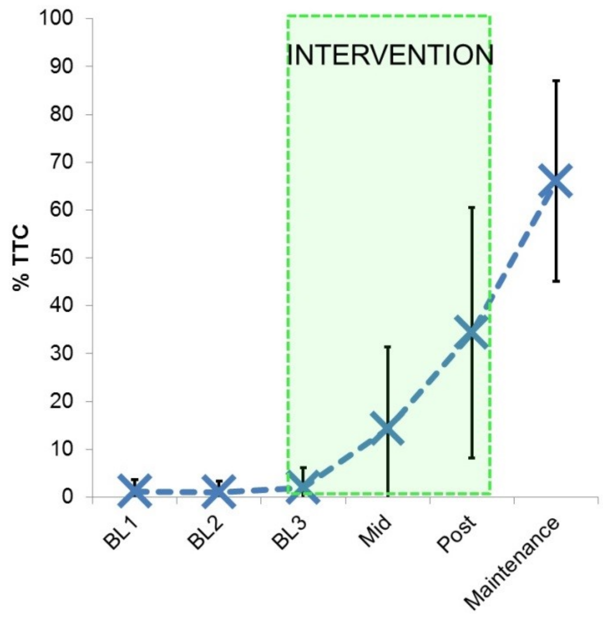

Figure 1.
Mean increase in Treated Targets Correct in Ultraphonix Project (+/- 1 s.d.)

Generally [5], our intervention protocol (a) was successful, (b) in a wide variety of targeted speech sounds, (c) was relatively rapid, and (d) speech continued to improve after treatment ended (Figure 1). Wide individual differences in rates and levels of improvement were found, suggesting children with comorbidities might benefit from higher dosage [5].

As noted, holistic improvements to the children's intelligibility were reported by parents, post-intervention. These were quantified via the "Intelligibility in Context Scale" (ICS) [5]. Children improved from being "sometimes understood" to "usually understood" [5] outwith clinic. This improved intelligibility is permanent, and improves the quality of life of the children **[s1]**.

ULTRAX (2011-2014) and Ultraphonix (2015-2016) plus other treatment by our PhD students and clinical research staff were the first using UTI in Europe. In a systematic review of all 29 published intervention-based research studies worldwide 1985-2017 **[s2]**, ULTRAX [6] was one of 19 studies with positive outputs for all its participants. Like Ultraphonix, but unlike most previous studies [6, 8], **[s8]**, ULTRAX targeted a diverse range of speech sounds (vs. the focus on consonant /r/ in North American research). ULTRAX had 8 child participants, the second highest enrolment to 2017. However, only three ULTRAX children were treated during the impact census period, so we do not highlight the project as a whole here, beyond noting aspects that apply to all the participants. Moreover, Ultraphonix had more participants, some with comorbidities, and a more diverse set of targets. Also, we noted above that materials from both projects fed back, cyclically, into our underpinning (and other) research [6], and that research then generated more impact (see below).

Longer term, increased accuracy and intelligibility can bring long-lasting and deep social, personal and educational benefits, augmenting the evidence of %TTC and ICS in [4, 5]. For example, client A (treated in ULTRAX before Aug 2013) sent an unsolicited email in 2018 illustrating the long-lasting nature of the impact (i.e. after August 2013):
"*the … speech therapy at Queen Margaret University helped me more than nine years of normal speech therapy through the schools and the doctors. Having this experience helped because it made me understand the movements of my tongue through looking at the scans. This experience gave me so much more confidence and really helped me get from bottom of almost all of my classes in primary school and really struggling. It helped me moved up in my classes and not feel so shy.*"(sic) **[s1]**

4.2 Early Stage External Clinical Impact

[s3]: A paediatric NHS Speech and Language Therapy service piloted a specialist clinical provision 2015-2016, adapting our clinical protocols [4, 5] for 12 children with varied disorders. Beneficial impacts were (and see also **[s10]**):

1. *Confirming diagnosis of articulatory difficulty in terms of tongue placement*
2. *Supporting children and young people to understand what they needed to change in terms of their tongue placement*
3. *Helping families to understand their children's articulatory difficulties and treatment*
4. *Being a useful motivator for some children*

[s4] An external EPSRC research project (ULTRAX-2020) has been extending our underpinning research. It incorporated clinical intervention which we cite as impact. It shows "*that by using ultrasound to provide visual feedback of the tongue in real-time, children can learn to produce speech sounds which have previously been impossible for them*". Due to COVID, planned collaborations with clinicians were cancelled or severely curtailed in 2020.

[s5] ULTRAX-2020 adopted clinical protocols and norms from [4-5], disseminating an open access *Clinicians' Resource Manual* in 2018. This free-to-use 87 page clinical manual from SLTs and clinical researchers on the ULTRAX-2020 project presents our underpinning research in a format tailored for practical clinical use, including our wordlists and protocols. **[s6]** notes for those clients "whose errors persist despite treatment", our protocols succeed, and do so for a wider variety of targets than other clinical research groups have addressed.

4.3 Engineering, Educational and Open Science Resources

[s7] Our ULTRAX and Ultraphonix data (annotated and labelled) was adopted as the initial content for "UltraSuite" (2018), an open curated repository for machine learning engineers. Our contribution comprised over 13 hours of speech from 76 children, of which the clinical speech component (from before and during treatment) is the largest articulatory corpus worldwide.

Our underpinning research [3] was used for a website **[s8]** that is used for phonetic courses, self-learning, and continuing professional development for SLTs **[s9]**. For example, **[s10]** notes that **[s8]** is used by clinicians to “develop the child’s and parents’ knowledge of how particular sounds are made”, enhancing therapeutic intervention and providing motivation. **[s8]** is itself the subject of an impact case study from the University of Glasgow, which notes that 10% of over 250,000 users worldwide are SLTs (along with students, the public, second language learning community), and that 99% of users rate it useful.

5. Sources to corroborate the impact

[s1] Client A (mid-teens) – Unpublished, unsolicited private email to QMU (2018). [document]

[s2] Sugden E, Lloyd S, Lam J, Cleland J (2019) Systematic Review of Ultrasound Visual Biofeedback in Intervention for Speech Sound Disorders. *International Journal of Language & Communication Disorders* 54(5): 705-728. [behind paywall, so submitted as document]

[s3] Hawkes C et al (2017). *A pilot of the use of Ultrasound Tongue Imaging in the assessment and therapy of children with Speech Sound Disorders within NHS Settings*. Unpublished private report. NHS Lothian Children and Young People’s Speech and Language Therapy Service. [document]

[s4] *ULTRAX-2020*. EPSRC project. (Aug 2017-May 2021) and Ultrax2020: Ultrasound Technology for Optimising the Treatment of Speech Disorders.

[s5] Cleland J, Wrench A, Lloyd S, Sugden E (2018) *ULTRAX2020 : Ultrasound Technology for Optimising the Treatment of Speech Disorders: Clinicians' Resource Manual*. Open Access manuscript

[s6] Javier Jasso (March 2019) Ultrasound visual biofeedback: a new tool for treating SSD. [website] *The Informed SLP.* [content behind paywall so text presented as document]

[s7] *UltraSuite: a repository of ultrasound and acoustic data from child speech therapy sessions* [website repository and 2018 paper]

[s8] *Seeing Speech: an articulatory web resource for the study of Phonetics*. [website] in particular the pages on Comparing MRI and UTI pages and Recording UTI and Lips

[s9] Testimonial by member of Royal College of Speech and Language Therapists Speech Sound Disorder Clinical Excellence Network [personal contact details]

[s10] Hobden C, Cowen S, Hawkes C (2018). *From Research to Everyday Ultrasound – A Community Clinician’s Perspective*. Unpublished private report. NHS Lothian Children and Young People’s Speech and Language Therapy Service [document]