GLOBAL MODELS IN TELEAUDIOLOGY

CAPCSD 2021 Annual Conference April 8-10

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TEAM

Herman Myburgh (Co-investigator, SA)
Cas Smits (Co-investigator, Netherlands)
David Moore (Co-investigator, USA)
Claude Laurent (Co-investigator, Sweden)
Hannah Kuper (Co-investigator, UK)
Robert Eikelboom (Co-investigator, Australia)
Stefan Launer (Co-investigator, Switzerland)
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Karina De Sousa (PhD Student)
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Susan Eksteen (PhD student)
Michelle Manus (Master's student)
Nausheen Dawood (Master's student)

FUNDING: NIH, Newton Advanced Fellowship, Hear the World foundation, Google Impact fund, ATIF

hearX

Disclosure: co-founder, scientific advisor

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OUTLINE

1. Telehealth and audiology - concepts
2. Drivers of global hearing innovation in teleaudiology
3. Teleaudiology enabled service-delivery models:
   I. No & low-touch audiology
   II. Community hearing screening for children
   III. Community hearing care for adults

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TELEHEALTH – DEFINITIONS

Providing health care at a distance using information and communication technology

"Delivery of health care services, where patients and providers are separated by distance. Telehealth uses ICT for the exchange of information for the diagnosis and treatment of diseases and injuries, research and evaluation, and for the continuing education of health professionals."

WHO, 2016

Concept as old as telecommunication mediums

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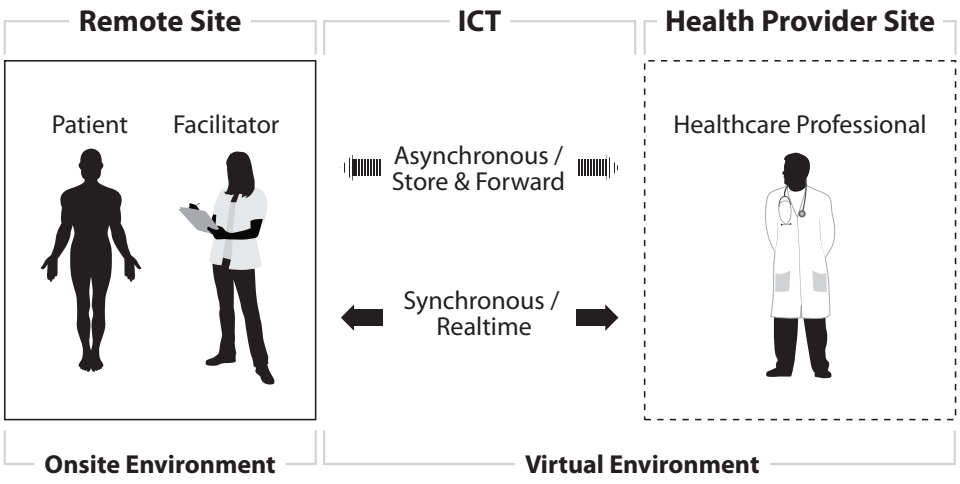
TELEHEALTH – DEFINITIONS



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TELEHEALTH – DEFINITIONS

Terminology

- Telemedicine, telehealth
- eHealth, mHealth
- Remote care, virtual care
- Digital health, connected health
- Face-to-face, in-person
- Remote, virtual, online
- Synchronous, real-time
- Asynchronous, store-and-forward

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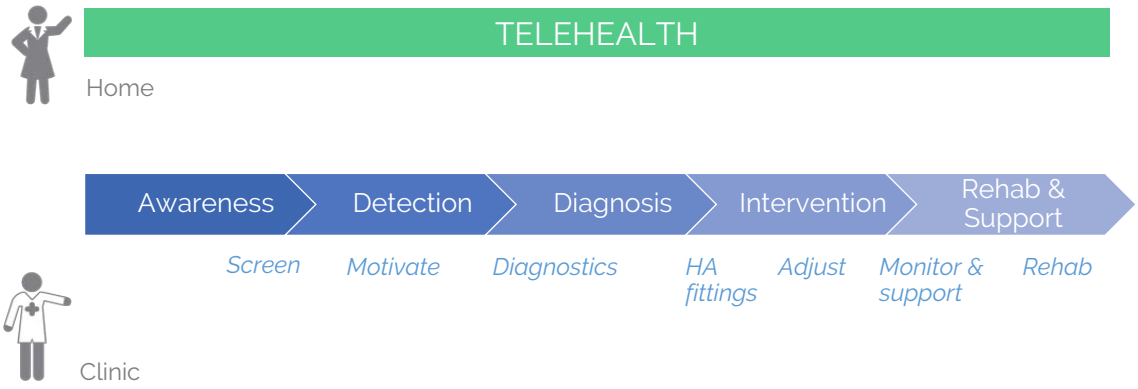
TELEHEALTH - EFFICIENCY & CONVENIENCE



Swanepoel and Hall, 2020:

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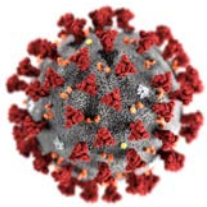
WHAT IS DRIVING INNOVATION IN TELEAUDIOLOGY?



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WORLD REPORT ON HEARING

- Hearing for all, across the life course
- 1 in 5 people live with hearing loss; By 2050 it will be 1 in 4
- 430 million require rehabilitation services (700m by 2050)
- 80% reside in LMICs
- Unaddressed hearing loss impacts many aspects of life
- Costs of unaddressed hearing loss is $980 billion annually

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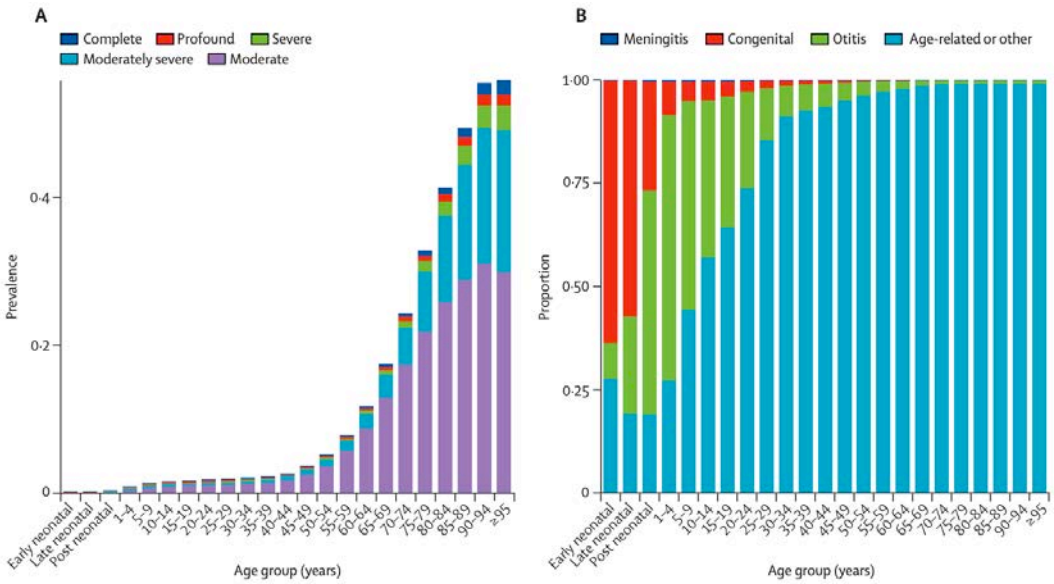

(GBD, 2021. Lancet)

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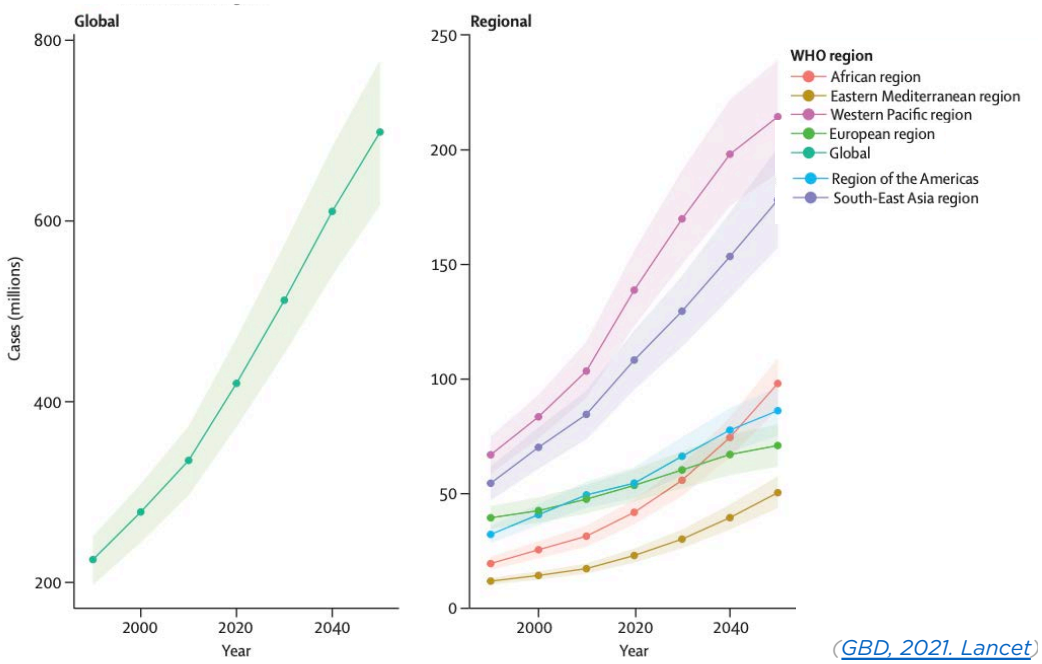
Prevalence of HL 35 dB or greater, 1990–2019, with forecasts to 2050



(GBD, 2021. Lancet)

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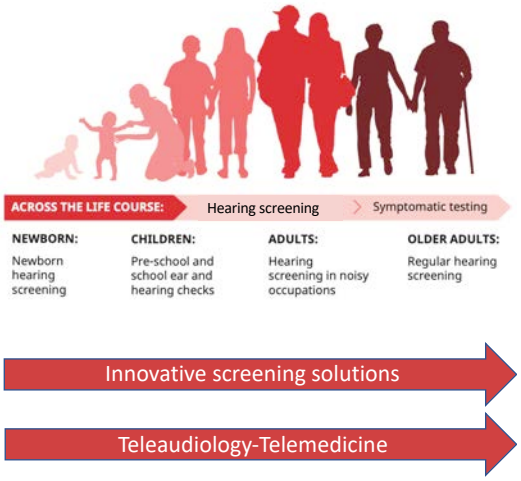
WORLD REPORT ON HEARING

- Most people with HL don't have access to treatments (74-91%)
- Hearing across the life course through; 1) prevention; 2) early identification; 3) appropriate care
- Inadequate human resources - require task-shifting
- Integrated community-based models
- Innovative screening & test technologies required



Innovative screening solutions

Teleaudiology-Telemedicine

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TECHNOLOGY & CONNECTIVITY

99% of people globally have a mobile phone signal (World Bank)

Connected personal supercomputers

	Developed	Developing
Any mobile phone	91%	90%
Smartphone	80%	82%

Global mobile consumer trends: Second edition (2017)

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COVID-19 & INNOVATION

Catapulted digital health transformation (& teleaudiology)

- Traditional test setup high risk
- Typical patient high risk
- Perception changes
  - Consumers *(6/10 predict virtual appointments to be more popular)*
  - Professionals *(87 vs 44% view telehealth important pre- vs during)*
- More enabling telehealth regulation

(Ericsson Mobility Report, 2020; Eikelboom et al. Submitted)

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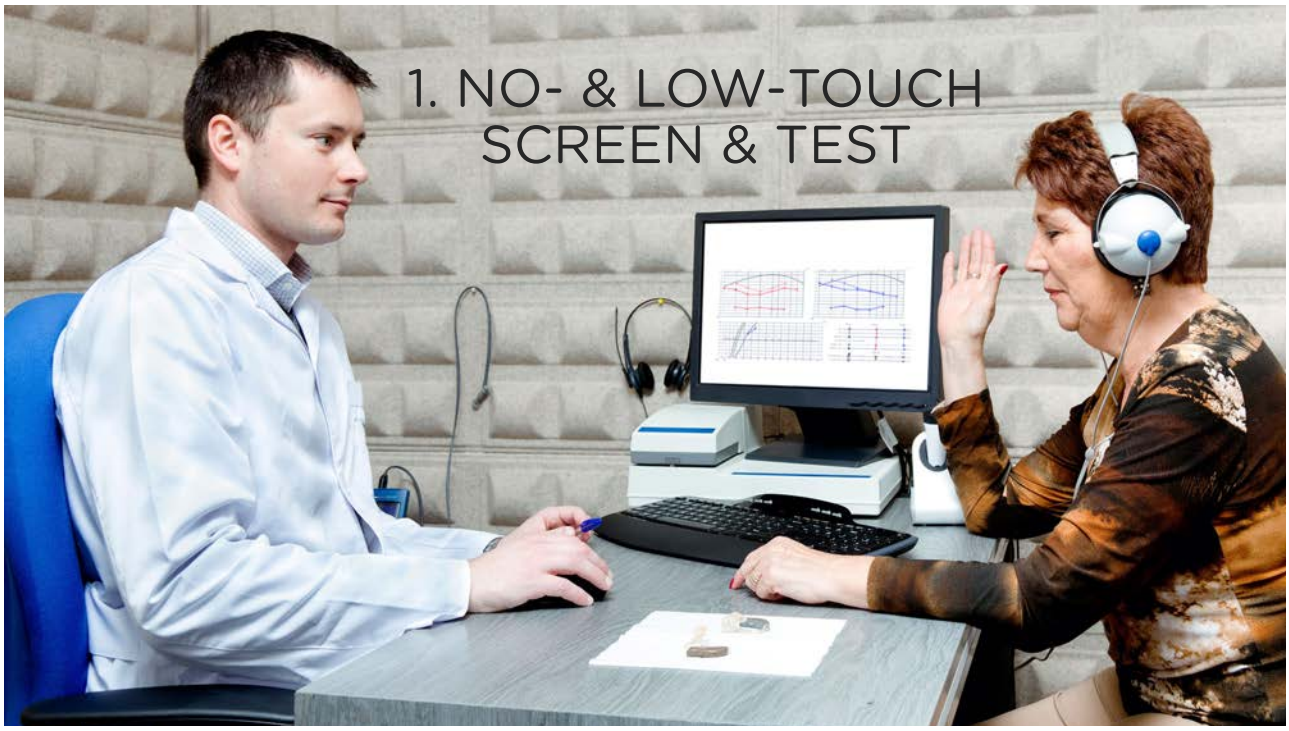

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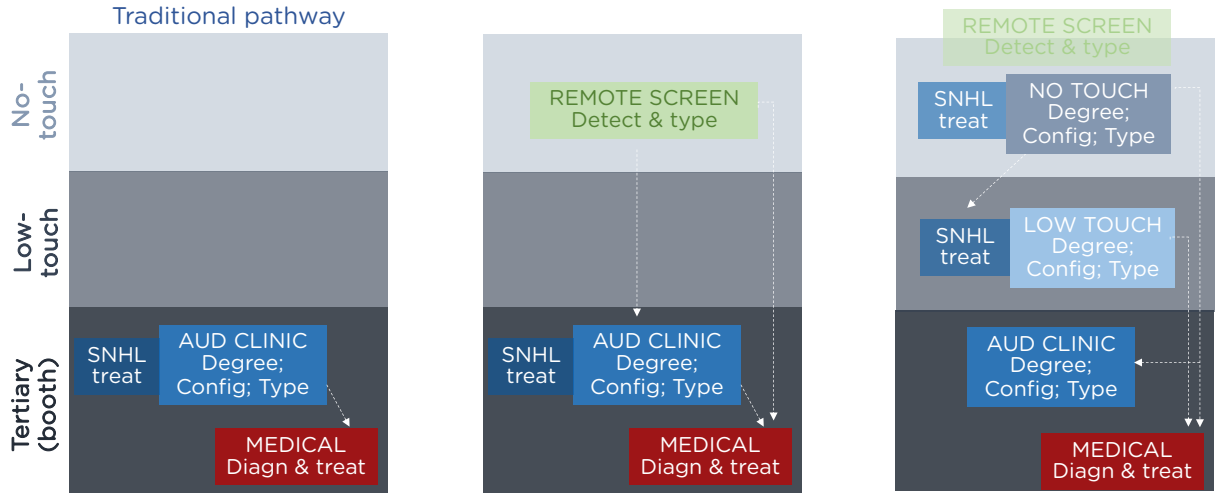
NO- & LOW-TOUCH SCREEN & TEST

Rethinking traditional audiology care pathways



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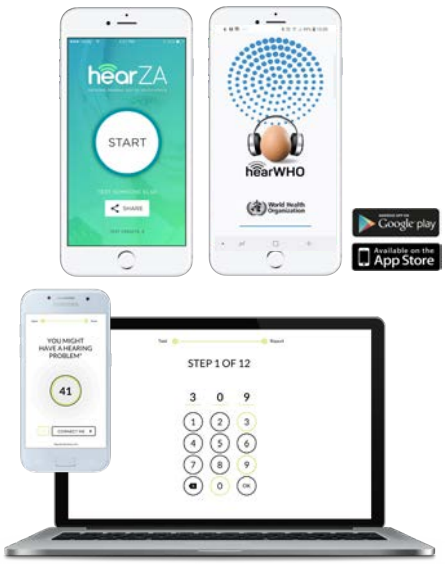
NO-TOUCH SCREEN

- Triage care pathways using remote screening
- Digits-in-noise screening test
  - Binaural triplet test
  - Web-based widgets
  - Smartphone applications



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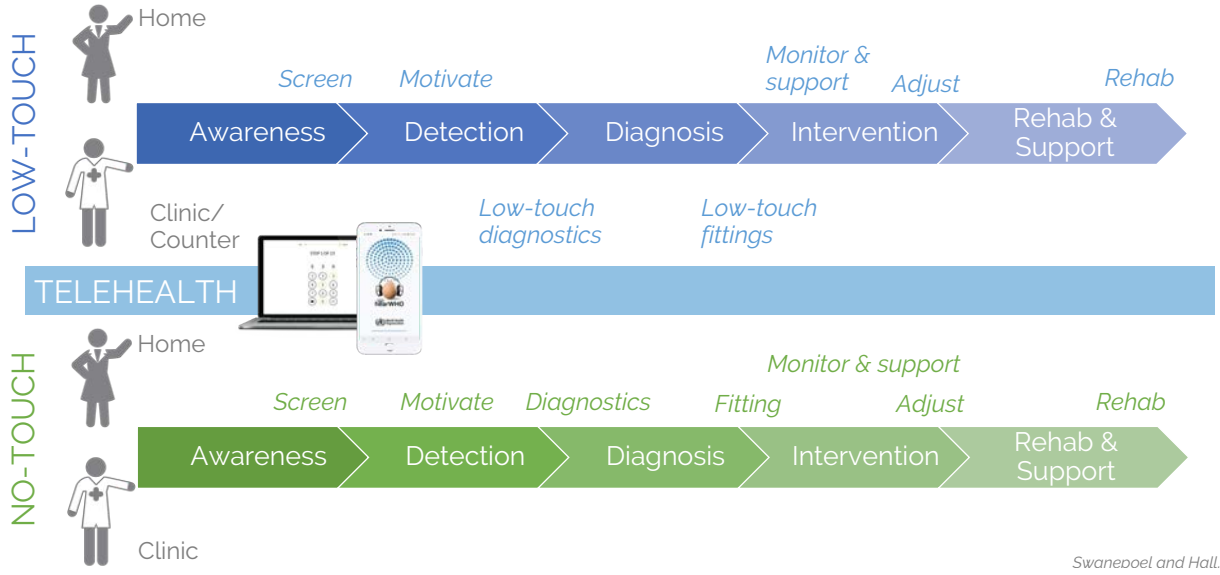
NO-TOUCH SCREEN



Swanepoel and Hall, 2020:

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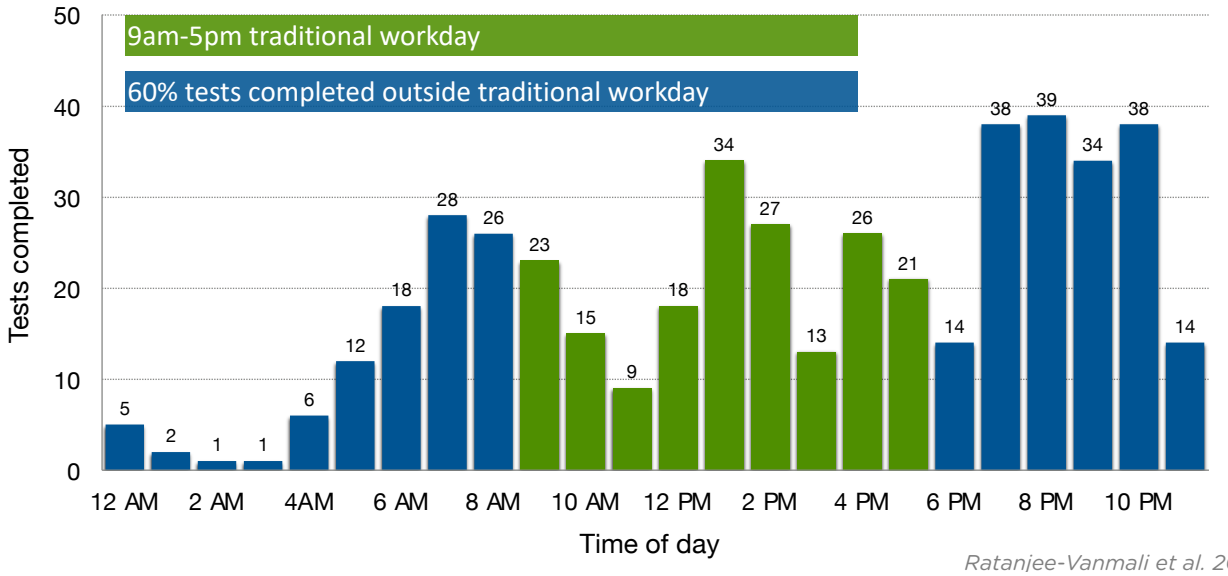
NO-TOUCH SCREEN



Ratanjee-Vanmali et al. 2020

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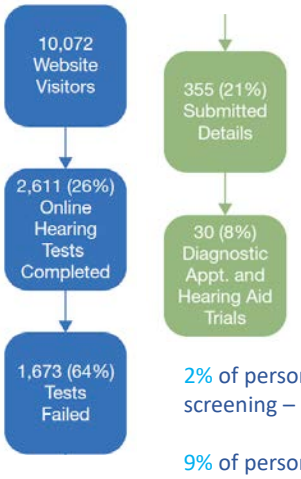
NO-TOUCH SCREEN



2% of persons who fail screening – HA trial

9% of persons who submit details – HA trial

Table 1. Characteristics of Website Visitors and Web Sessions over a 12-month Period

Website visitors (12-month period)	10,072 visitors 88% new visitors
Web sessions	1.25 average sessions 1:30 min per session; 1.97 page views per session
Devices accessing website	83% mobile phones 76% Android; 17% iOS; 7% other 10% tablets 7% computers
Gender	35% female 17% male 48% unknown

Ratanjee-Vanmali et al. 2020

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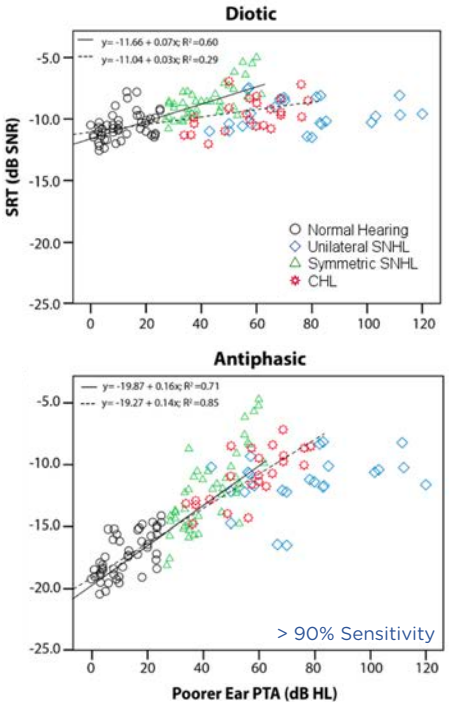
NO-TOUCH SCREEN

Diotic digits-in-noise

- Rapid test of better ear
- Insensitive to conductive HL
- Insensitive to unilateral HL

Antiphasic digits-in-noise

- Rapid test of poorer ear
- Improved sensitivity to detect SNHL
- Sensitive to a/symmetric HL
- Detects conductive HL



De Sousa et al. (2020a). Ear and Hearing

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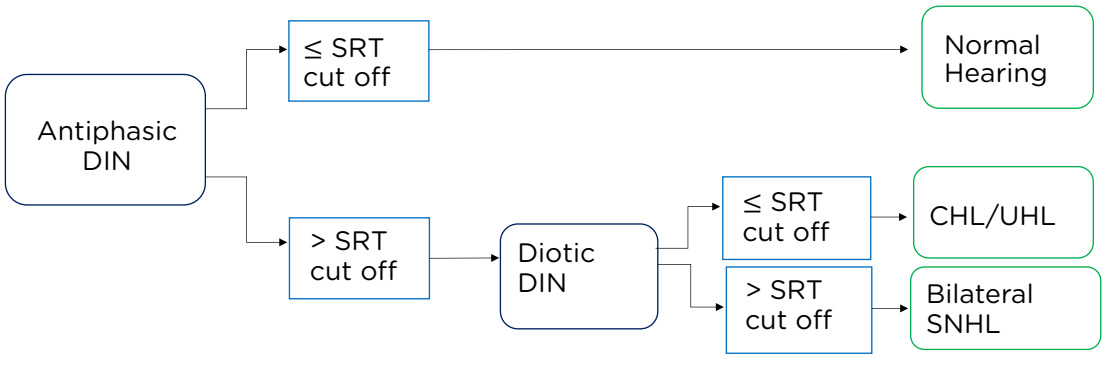
NO-TOUCH SCREEN TRIAGE

2-stage screening approach



De Sousa, Smits, Moore, Myburgh & Swanepoel (Submitted). Diotic and antiphasic digits-in-noise testing as a hearing screening and triage tool to classify type of hearing loss.

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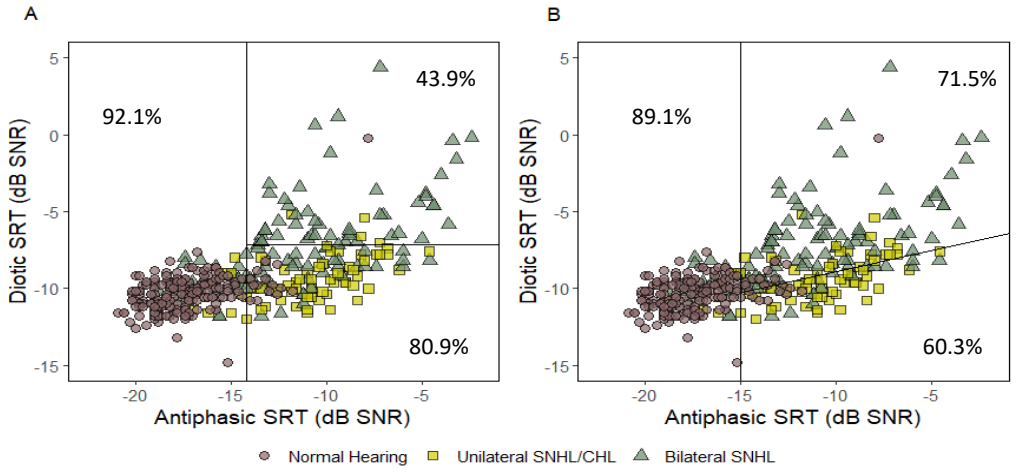
NO-TOUCH SCREEN TRIAGE



De Sousa et al.(Submitted)

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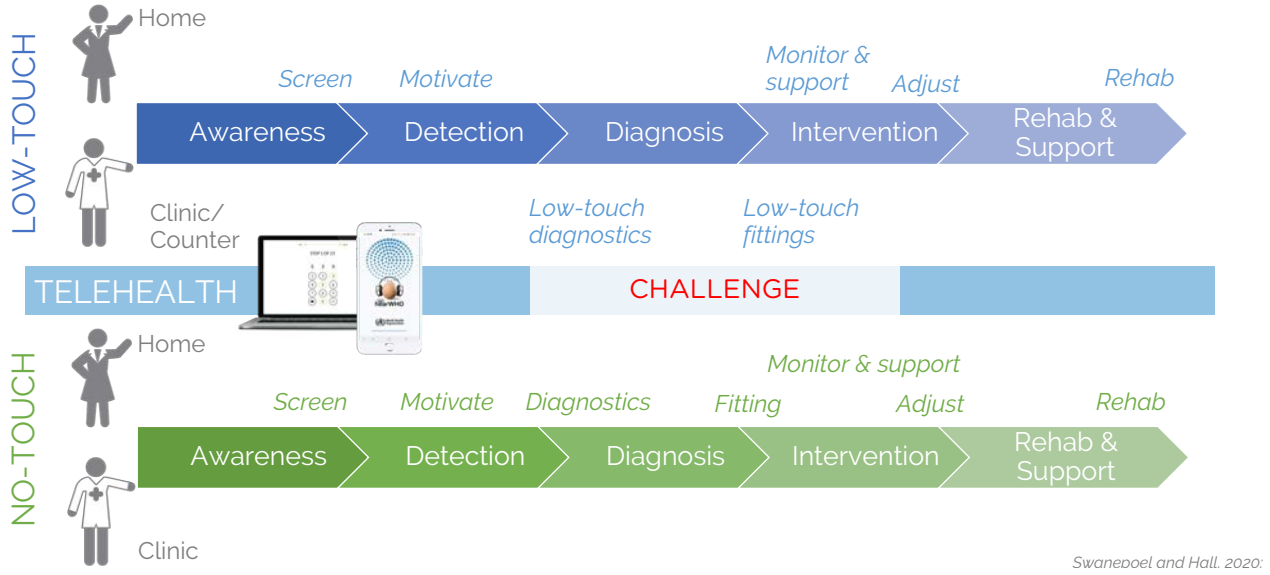
LOW- & NO-TOUCH TEST



Swanepoel and Hall, 2020:

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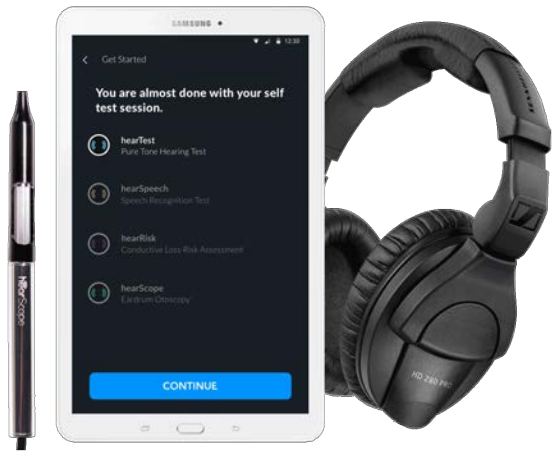
LOW- & NO-TOUCH TEST



hearX SELF TEST KIT

1. Pure tone audiometry – calibrated headphones; rapid automated self-test (5 min)

2. Speech-in-noise – Binaural DIN test (3 min)

3. Risk assessment for ear disease (2 min)
   I. *Conductive loss risk algorithm*

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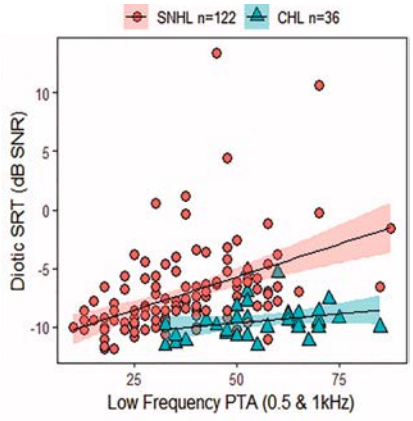
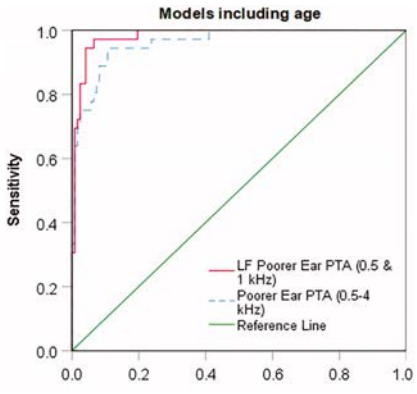
Pure-tone audiometry without bone-conduction thresholds: using the digits-in-noise test to detect conductive hearing loss

Karina C. De Sousa[a], Cas Smits[b], David R. Moore[c,d], Hermanus Carel Myburgh[e] and De Wet Swanepoel[a,f]

INTERNATIONAL JOURNAL OF AUDIOLOGY
2020, VOL. 59, NO. 10, 801–808
https://doi.org/10.1080/14992027.2020.1783585





AUROC
0.98

Sens/Spec
97.2/93.4%

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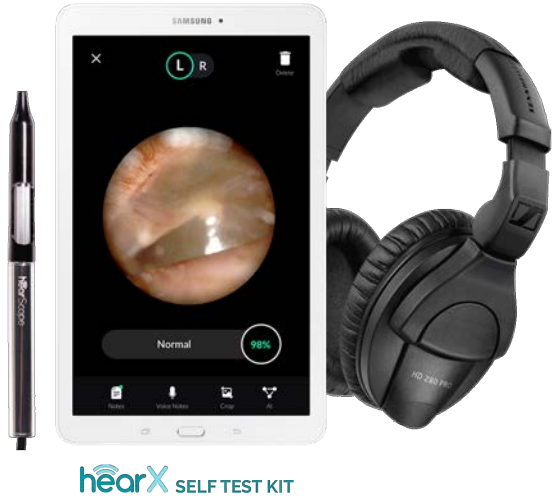
LOW- & NO-TOUCH TEST



hearX SELF TEST KIT

1. Pure tone audiometry – calibrated headphones; rapid automated self-test (5 min)

2. Speech-in-noise – Binaural DIN test (3 min)

3. Risk assessment for ear disease (2 min)
   - I. *Conductive loss risk algorithm*
   - II. *Asymmetric loss screening;*
   - III. *Red flag questions.*
   - IV. *CEDRA questionnaire optional*

4. Digital AI otoscopy – optional (2 min)

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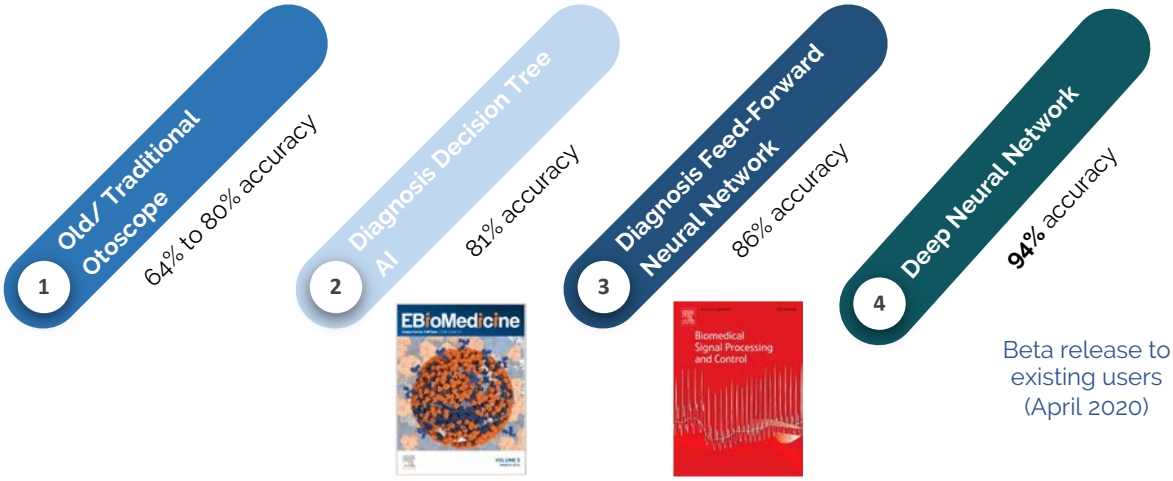
DIGITAL AI OTOSCOPY



Beta release to existing users (April 2020)

Myburgh et al. 2016; 2018

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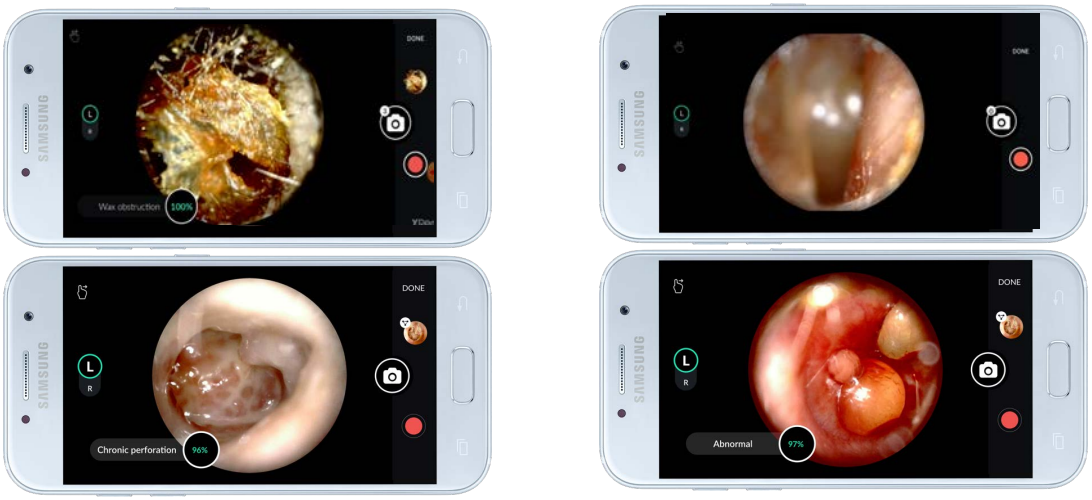
DIGITAL AI OTOSCOPY



Myburgh et al. 2016; 2018

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2. COMMUNITY-BASED HEARING SCREENING FOR CHILDREN

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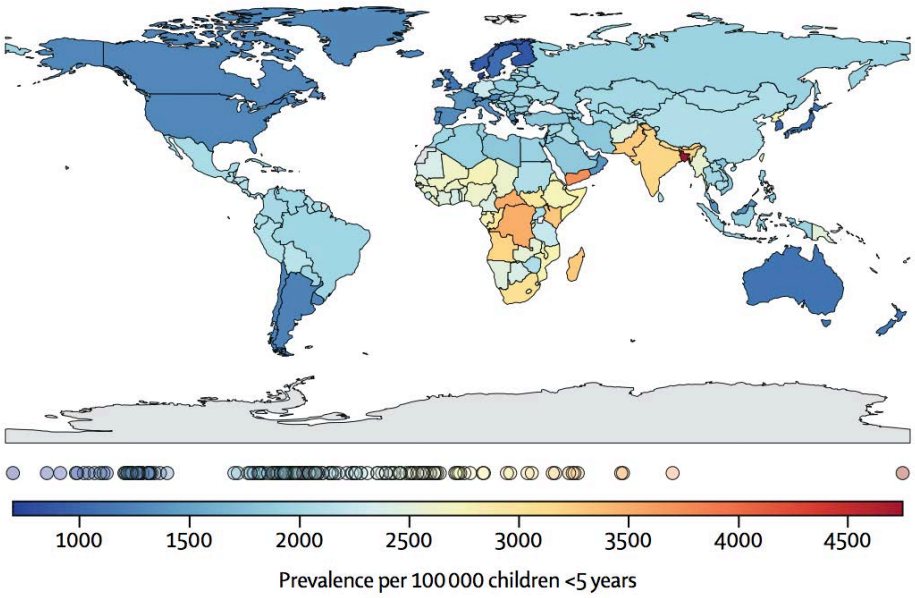
CHILDHOOD HEARING LOSS

60% preventable causes

Hearing care professionals <1 to a million people in Africa



(Lancet Global Health, 2018)

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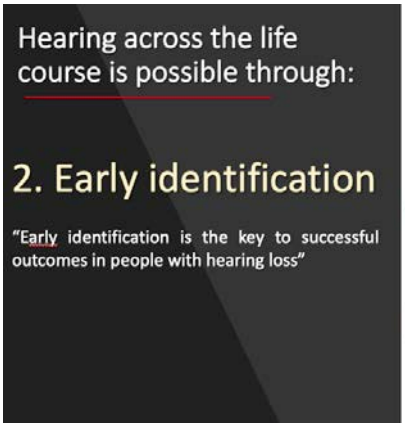
INNOVATION TO ENABLE IDENTIFICATION



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INNOVATION TO ENABLE IDENTIFICATION

BARRIERS	DIGITAL ENABLES
1. Limited professionals	1. Task-shifting, automation, AI
2. Expensive equipment	2. Improved affordability
3. Centralized services	3. Mobile point-of-care
4. Quality control	4. Sensors, algorithms for rigorous QC
5. Data management & surveillance	5. Integrated cloud data and referrals

(Swanepoel, 2020)

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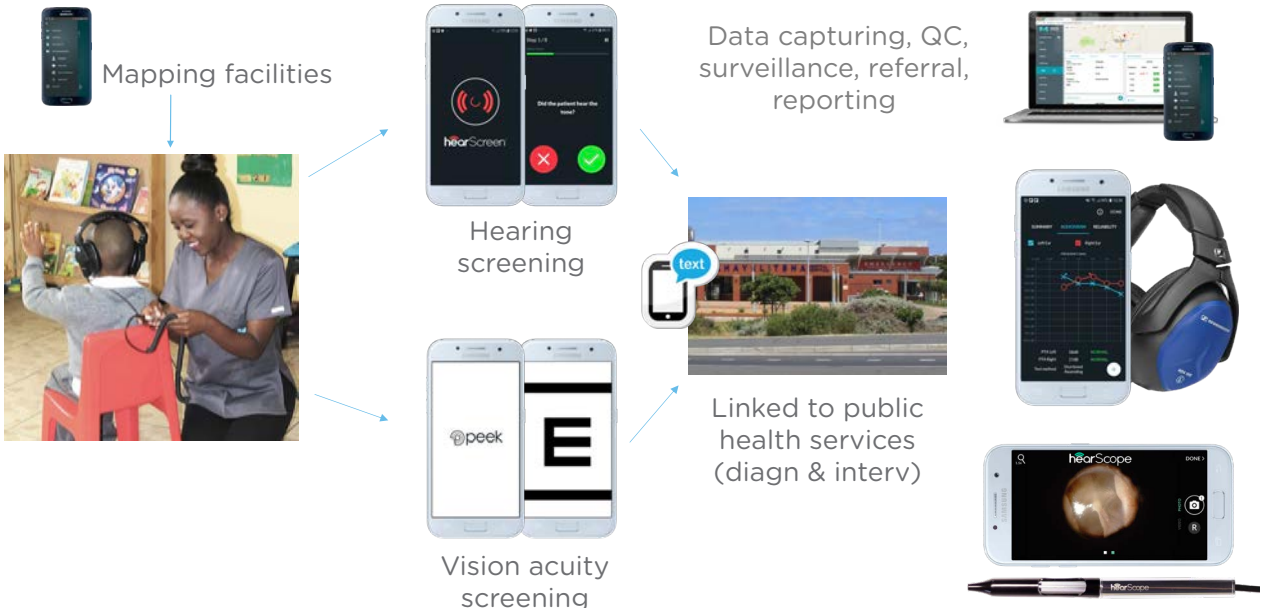
COMMUNITY SCREENING FOR KIDS



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	Community mapping *(i.e. location, kids)*	Screening	Reporting & referral	Diagnostic follow-up	Treatment
Service					
Personnel	Lay community health workers	Lay community health workers	-	Audiologist or trained nurse or health worker	PHC nurse/physician; *Audiologist; Optometrist*
Technology	Smartphone facility mapping & cloud surveillance	Smartphone screen & cloud surveillance	Automated / text message from cloud with geolocated referral	Smartphone PTA & cloud eHealth record	Hearing aids & glasses or medical treatment
Surveillance	Remote review of facilities, numbers for planning	Monitor tests *(Quality control; operator test quality index)*	Text message reports sent and received	Review screen, log diagnostic follow-up. Remote support.	Treatment options captured for review & planning

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COMMUNITY SCREENING FOR KIDS

2016 Yousuf-Hussein et al. Smartphone hearing screening in mHealth assisted community-based primary care

2018 Yousuf-Hussein et al. Community-based hearing screening for young children using an mHealth service-delivery model

2019 van Wyk et al. Supporting hearing health in vulnerable populations through community care workers using mHealth technologies

2019 Eksteen et al. Hearing and vision screening for preschool children using mobile technology, South Africa

2020 Dawood et al. mHealth hearing screening for children by nonspecialist health workers in communities

2020 Manus et al. Community-Based Hearing and Vision Screening in Schools in Low-Income Communities Using Mobile Health Technologies

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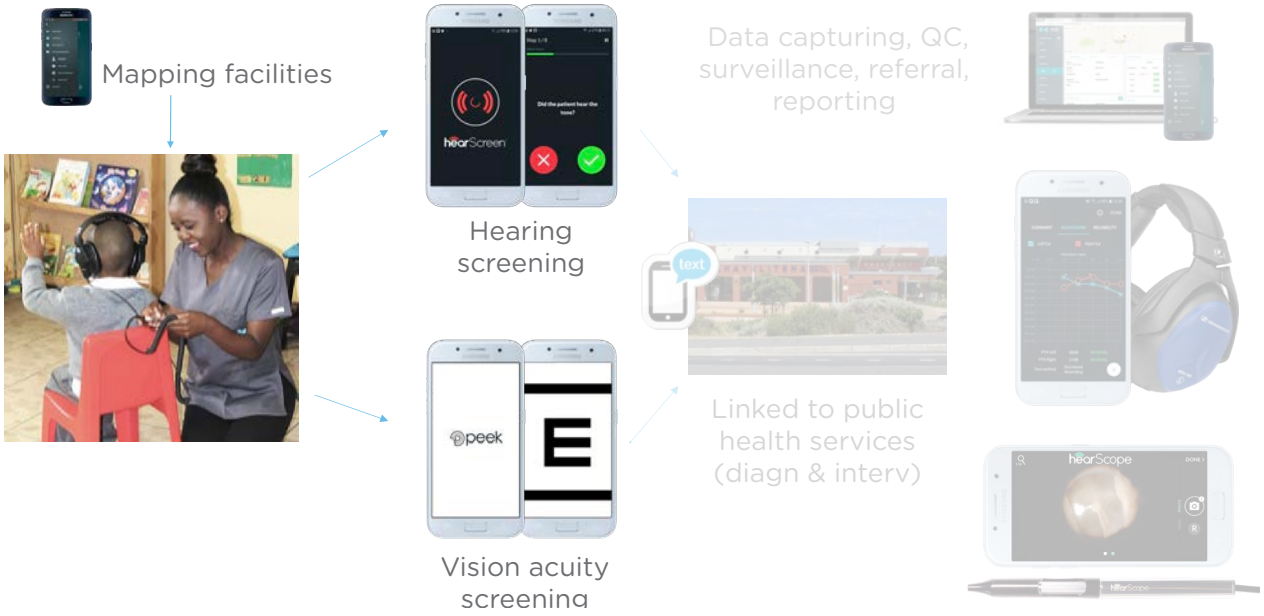
COMMUNITY SCREENING FOR KIDS



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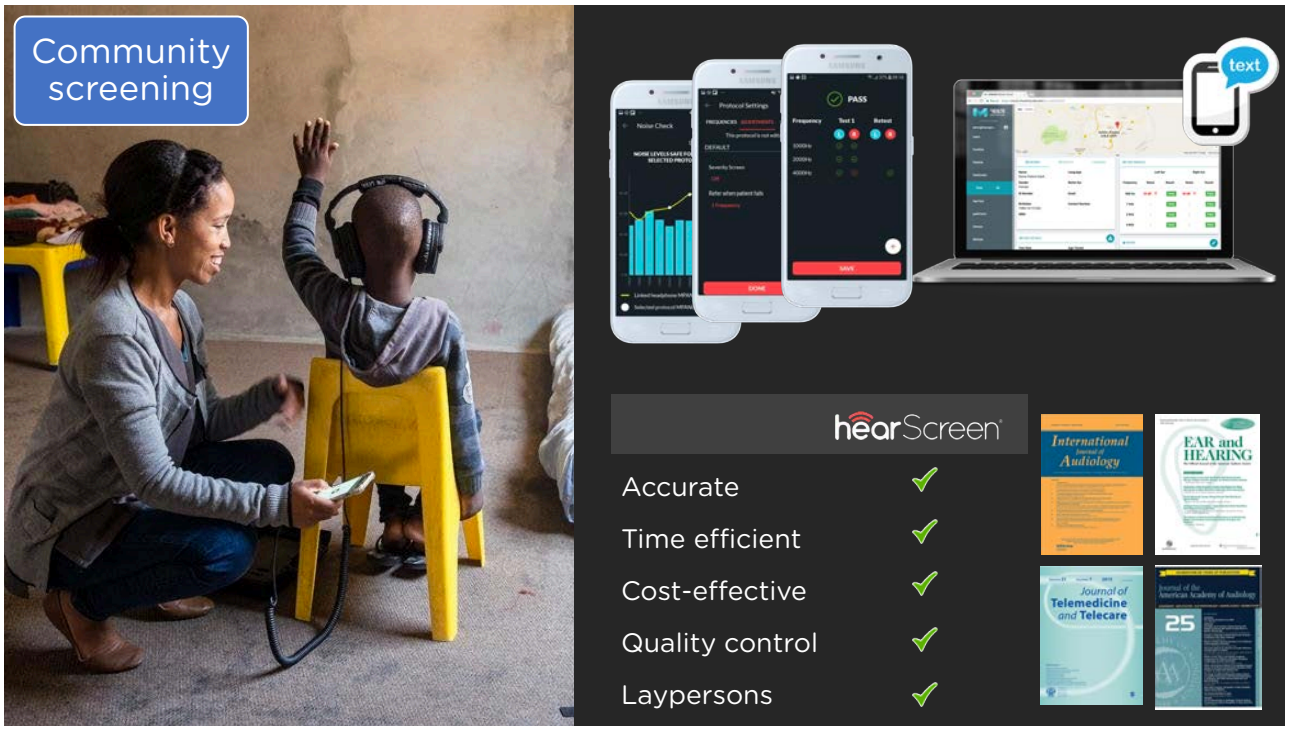

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Community screening

QUALITY CONTROL

1. Noise check
   - Pre-screen environment check
   - Real-time during presentation

(Yousuf-Hussein et al. 2016; Swanepoel et al. 2015)

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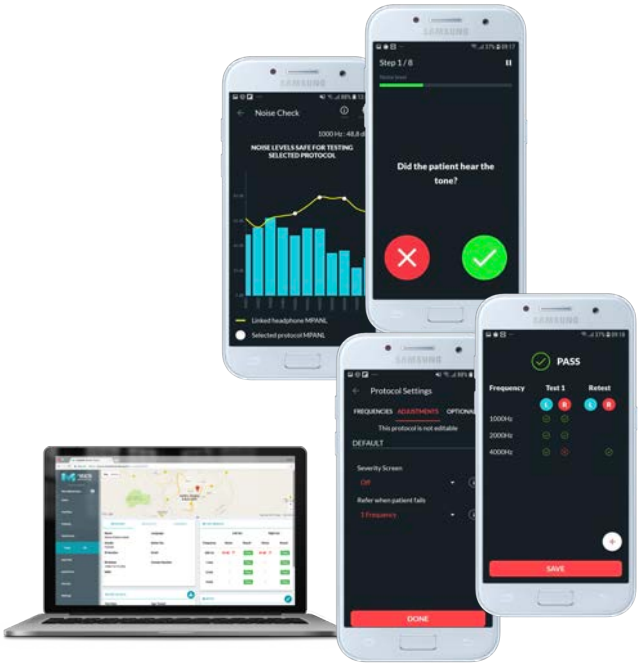
Community screening

QUALITY CONTROL

1. Noise check
   - Pre-screen environment check
   - Real-time during presentation
2. Test operator quality index
   - Randomized false presentation (forced choice response)
   - Track quality index in cloud
3. Immediate rescreen
4. Test time tracking
5. Cloud surveillance



(Yousuf-Hussein et al. 2016; Swanepoel et al. 2015)

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Community screening

LAY HEALTH WORKERS

"hearScreen digital solution demonstrates how people with even basic literacy and digital skills can be participants in community health support through the use of inclusive digital solutions"

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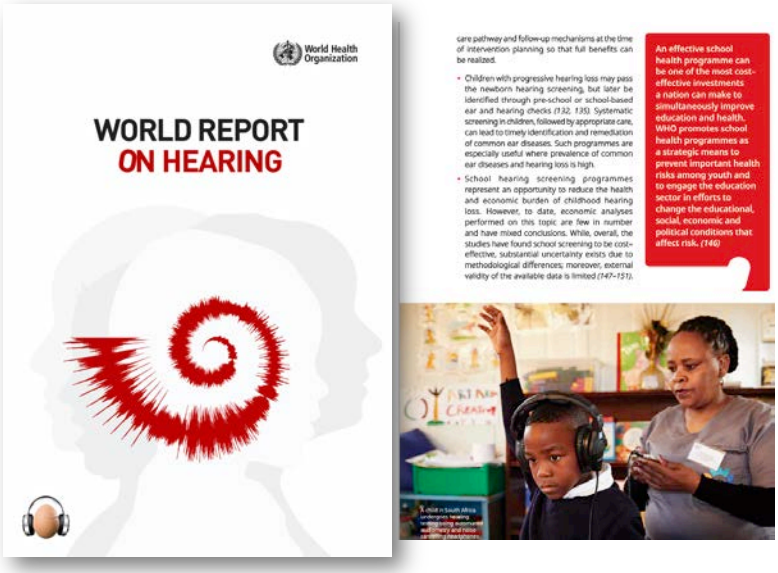
Community screening



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Community screening

CHW responses (%) on usability of smartphone screening and value to community (n=24)

Questions	Strongly Agree	Agree	Neutral
1. Instructions straightforward	88	8	4
2. Administration easy (adults)	75	25	–
3. Administration easy (children)	33	33	17
4. Administration easy (quick)	67	33	–
5. CHW trust results	54	33	13
6. Important for community	38	46	13
7. Community needs hearing health	38	38	25
8. Community positive	46	25	29
9. Community trust results	67	25	8
10. Would continue service	63	38	–

(Yousuf-Hussein et al, 2016; Similar findings by van Wyk et a. 2019)

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Community screening

Dawood et al. 2020 IJA; *mHealth hearing screening by non-specialist health workers in communities*

- 6805 children (Ave 7.6 +/- 1.2; 3 – 10 years)
- 83.6% of tests by school health nurses vs 16.4% by CHWs
- No significant effect of screener type (SHN vs CHW) on screening outcome (p > 0.005; Logistic regression)

Bright et al. 2019; Non-specialists accurately assess hearing using mobile-based audiometry (hearTest)

(Dawood et al, 2021; Bright et al. 2019)

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Community screening

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COMMUNITY SCREENING FOR KIDS

	Hearing	Vision	Both
Total screened (n)	8023/8497	8023/8497	8023/8497
1st Screen fail (25 dB; 1, 2 & 4 kHz)	5.4%[a] (435/8023)	2.1% (170/8023)	
Rescreen referral [a]	1.5%[a] (124/8023)	2.1% (170/8023)	0.7% (58/8023)
Test duration mean (SD)	66.8s (62.3)	91.8s (51.9)	158.6s (85.9)
Diagn follow-up return rate	75.8% (94/124)	73.1% (n=109; 21 await appointments)	

4 to 6 years old's

Eksteen et al. full-cost model $5.63/child
Manus et al. full-cost model $6.67/child

(Eksteen et al. 2019; Manus et al. 2021)

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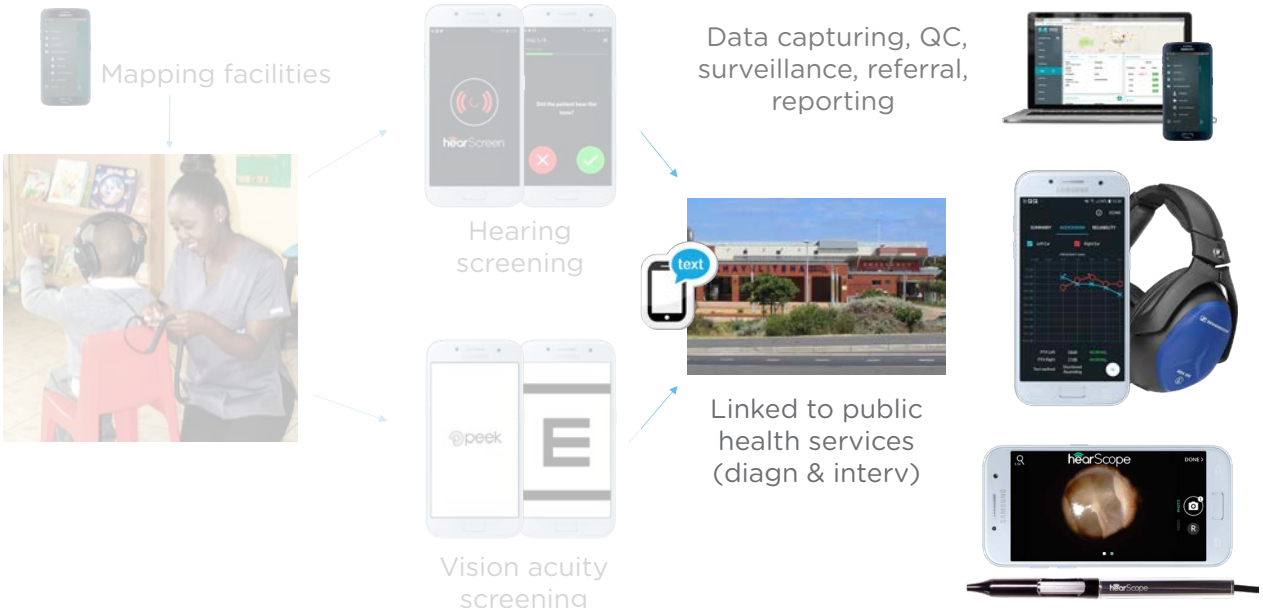
COMMUNITY FOLLOW-UP FOR SCREENING



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COMMUNITY FOLLOW-UP FOR SCREENING

- Initial follow-up by CHWs
- AC PTA (hearTest)
- AI otoscopy (hearScope)
- Hearing follow-up 76%
- 57% had hearing loss
- HL treated for 363 kids
  (>80 appointments outstanding)
- >19 000 kids screened

(Eksteen et al. 2019)

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COMMUNITY SCREENING FOR KIDS

Hearing and vision screening for preschool children using mobile technology, South Africa

Susan Eksteen,[a] Stefan Launer,[b] Hannah Kuper,[c] Robert H Eikelboom,[d] Andrew Bastawrous[c] & De Wet Swanepoel[a]

Bull World Health Organ 2019;97:672–680

mHealth supported hearing & vision screening facilitated by CHWs enable access to care in communities within accepted performance indicators including follow-up return, diagnostic referral and false positive rates at low cost.

1) Minimally trained non-professionals, 2) decentralized service-delivery, 3) reduced costs

FUNDING
Hear the World foundation, Sonova, Newton fellowship

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3. COMMUNITY ADULT HEARING CARE

AIM: Evaluate a method and community model for end-to-end hearing health care in LMICs with mHealth technologies used by CHWs

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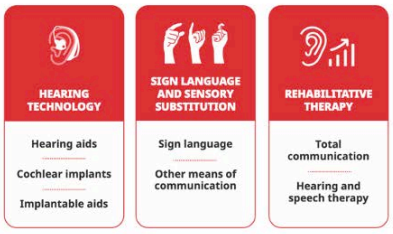
3. COMMUNITY ADULT HEARING CARE

Hearing across the life course is possible through:

3. Appropriate and timely care and rehabilitation

"Hearing loss can be addressed through a holistic approach that considers the person's clinical profile, communication needs, preferences, environment, and fits the resources available."



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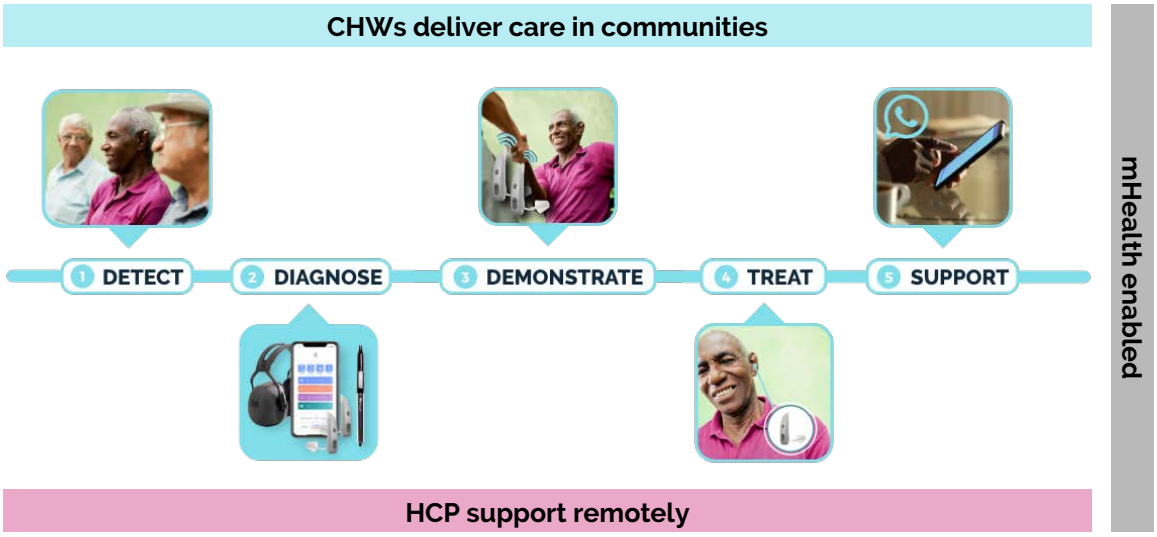
3. COMMUNITY ADULT HEARING CARE



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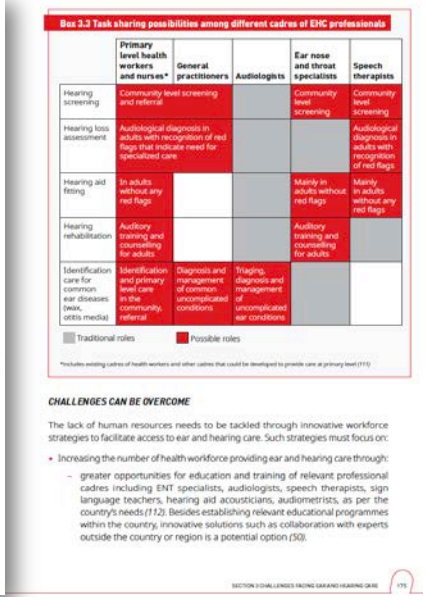
3. COMMUNITY ADULT HEARING CARE



Box 3.3 Task sharing possibilities among different cadres of EHC professionals

	Primary level health workers and nurses*	General practitioners	Audiologists	Ear nose and throat specialists	Speech therapists
Hearing screening	Community level screening and referral			Community level screening	Community level screening
Hearing loss assessment	Audiological diagnosis in adults with recognition of red flags that indicate need for specialized care				Audiological diagnosis in adults with recognition of red flags
Hearing aid fitting	In adults without any red flags			Mainly in adults without red flags	Mainly in adults without any red flags
Hearing rehabilitation	Auditory training and counselling for adults			Auditory training and counselling for adults	
Identification care for common ear diseases (wax, otitis media)	Identification and primary level care in the community, referral	Diagnosis and management of common uncomplicated conditions	Triaging, diagnosis and management of uncomplicated ear conditions		

Traditional roles Possible roles

*Includes existing cadres of health workers and other cadres that could be developed to provide care at primary level (111)

CHALLENGES CAN BE OVERCOME

The lack of human resources needs to be tackled through innovative workforce strategies to facilitate access to ear and hearing care. Such strategies must focus on:

- Increasing the number of health workforce providing ear and hearing care through:
  - greater opportunities for education and training of relevant professional cadres including ENT specialists, audiologists, speech therapists, sign language teachers, hearing aid acousticians, audiometrists, as per the country's needs (112). Besides establishing relevant educational programmes within the country, innovative solutions such as collaboration with experts outside the country or region is a potential option (50).

SECTION 3 CHALLENGES FACING EAR AND HEARING CARE 175

CHW delivered care using mHealth tech

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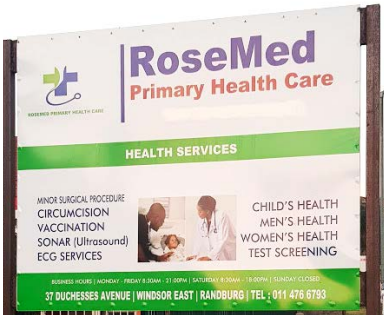
DETECT

Community-based screenings



PHC clinic / pharmacy

Self-report community networks

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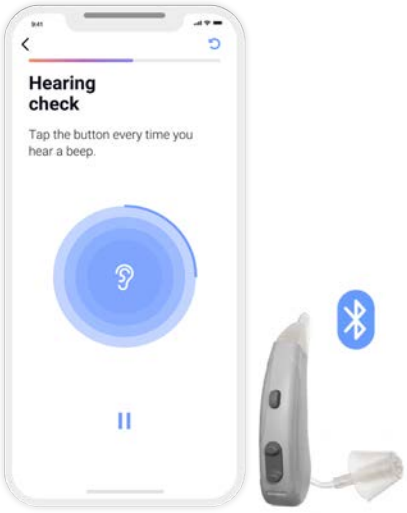
mHEALTH ENABLED



- Low-cost, high-quality hearing aid
  - 16 channel WDRC, Bluetooth, adaptive directionality and noise reduction
  - Mild to severe HL fitting range
- Digitally integrated with mobile platform
- Smartphone-based in situ pure tone audiometry (automated self-test)
- Smartphone HA fitting (NAL-NL2)
- Data-logging

FDA

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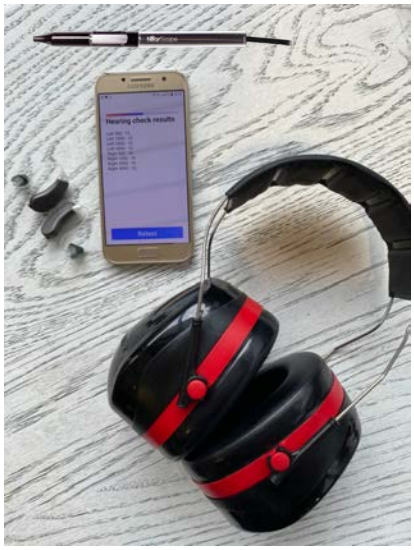
DIAGNOSE

Validated Bluetooth in-situ hearing test

- Hearing aid with Peltor earmuffs to facilitate the hearing test
- Similar to single-walled sound booth
- Audiogram: 0.25, 0.5, 1, 2, 4 and 8 kHz

Innovative triaging test battery

- Determine HL configuration & degree
- Identify conductive HL & ear disease
- Screen for asymmetric HL



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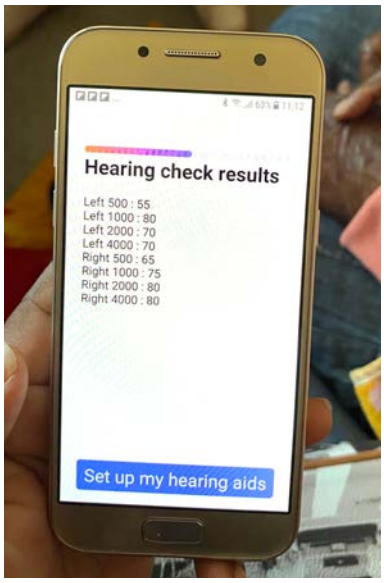
DIAGNOSE



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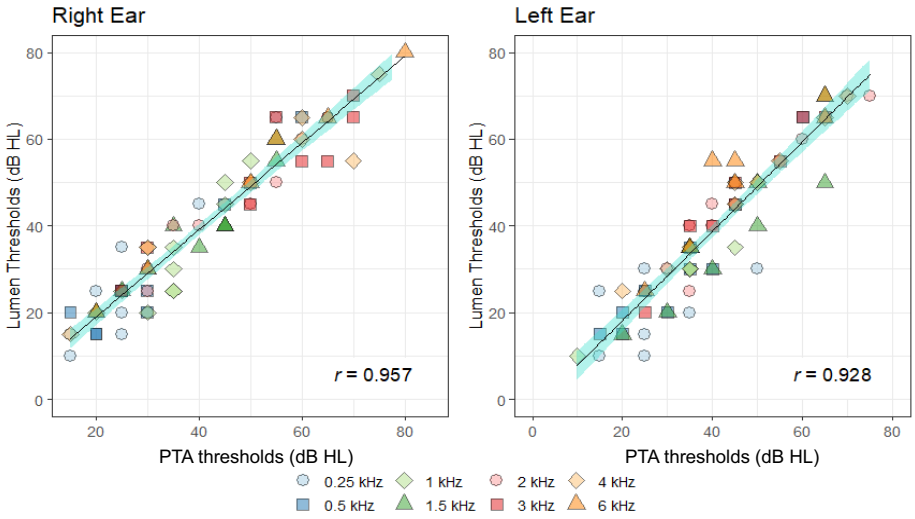
DIAGNOSE

Within subject thresholds using in situ vs reference audiometry

93.2% within 10 dB
78.4% within 5 dB



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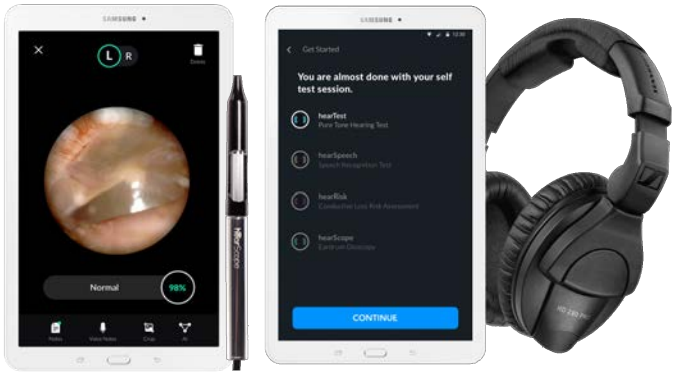
DIAGNOSE



TRIAGE

1. Hearing aids (SNHL)

2. Medical referral (CHL; ear disease; wax)

DEMONSTRATE & TREAT

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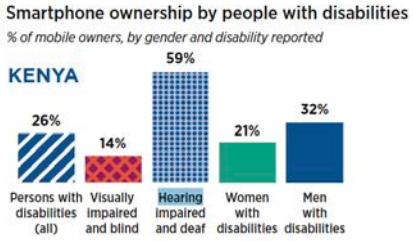
SUPPORT

Community-based support by CHWs including:

- Provision of batteries, disposables
- Troubleshooting, device care, information provision, questions
- CHW connect with audiologist for remote support
- mHealth contact (SMS/Whatsapp)



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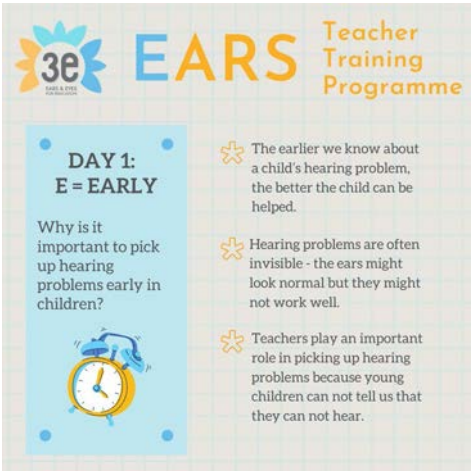
SUPPORT

mHealth HA acclimatization program

- Multi-factorial process - adjustment, handling, maintenance, cleaning, psychosocial factors
- Content - infobytes, voice notes, scheduled
- Social messaging services
- Smartphone penetration >90% in SA
- Whatsapp most widely used platform in Africa

Example ECD teacher training

- Infobyte Whatsapp with voice note
- Significant pre-post effect (n=496 teachers)



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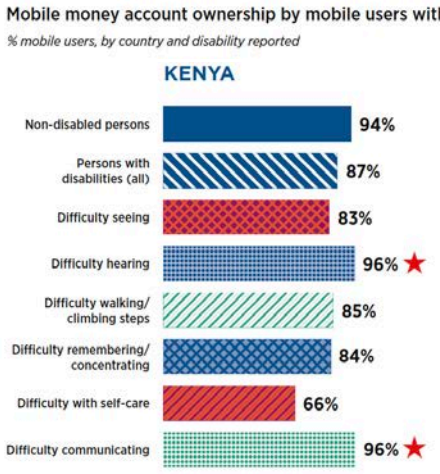
INNOVATION FOR SUSTAINABILITY & SCALABILITY



GSMA, 2019

AT2030

Global Disability Innovation Hub

ASSISTIVE TECH IMPACT FUND

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CONCLUSIONS

- Hearing health transformation driven by 4th industrial revolution, COVID-19 & World Report
- Digital solutions addressing barriers of traditional hearing care & COVID-19 challenges
- Inclusive design, rigorous quality control, automation, AI and cloud-surveillance allow decentralized care
- Innovative (high-tech, soft touch) solutions enable task-shifting to increase access, affordability and scalability
- Global advocacy, digital tech & task-shifting are powerful enablers of change toward hearing for all

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OUTLINE

1. Drivers of global hearing health innovation
2. Digital hearing health enabled service-delivery models
   a) Community-based hearing (and vision) screening for children
   b) Low- & no-touch audiology services
   c) Community-based hearing care for adults

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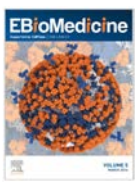
AI OTOSCOPY DIAGNOSIS

1. Old/ Traditional Otoscope — 64% to 80% accuracy
2. Diagnosis Decision Tree AI — 81% accuracy



3. Diagnosis Feed-Forward Neural Network — 86% accuracy

4. Deep Neural Network — **94%** accuracy

Beta release to existing users (April 2020)

Myburgh et al. 2016; 2018

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CHILDHOOD HEARING LOSS

Regions	DHL in children (<15 yoa)	
	Millions	Prevalence %
High-income	0.8	0.5
Sub-Saharan Africa	8.9	1.9
Middle East & North Africa	1.4	0.9
South Asia	12.2	2.4
Asia Pacific	3.6	2.0
Latin America & Caribbean	2.6	1.6
East Asia	3.3	1.3
World	**34.1**	**1.7**

(WHO, 2018)

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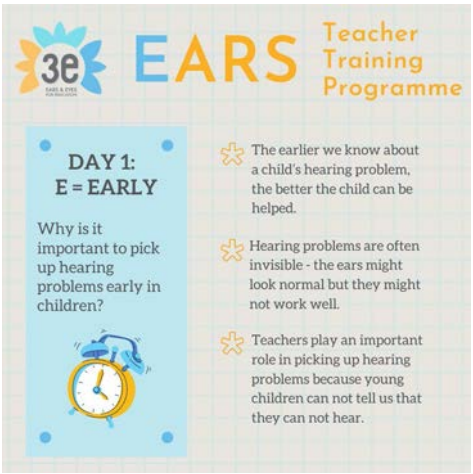
mHEALTH HEARING & VISION TRAINING

mHealth HA acclimatization program

- Multi-factorial process - adjustment, handling, maintenance, cleaning, psychosocial factors
- Content - infobytes, voice notes, scheduled
- Social messaging services
- Smartphone penetration >90% in SA
- Whatsapp most widely used platform in Africa



Example ECD teacher training

- Infobyte Whatsapp with voice note
- Significant pre-post effect (N=496 teachers)

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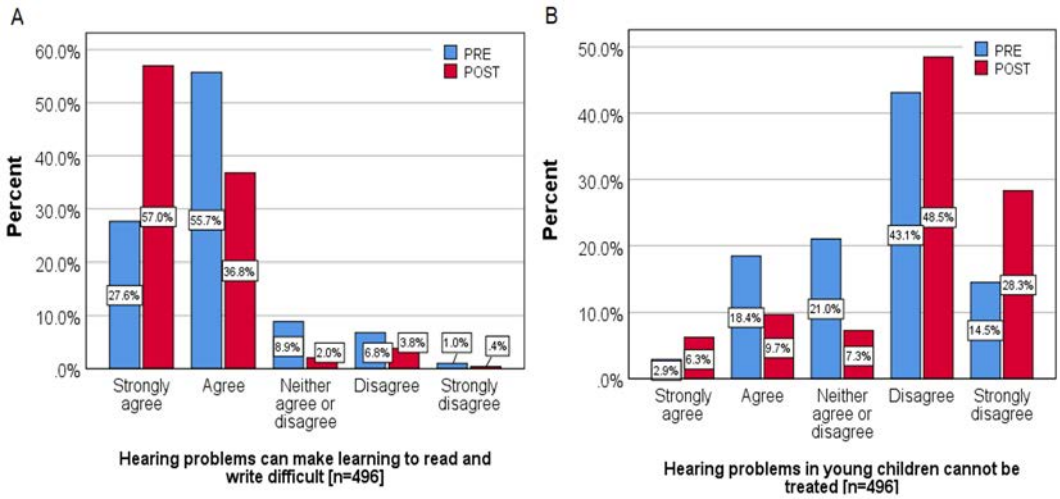

mHealth training via Whatsapp for preschool teachers on early childhood development. Example questions (a,b) showing pre- post improvement in knowledge (n=496)

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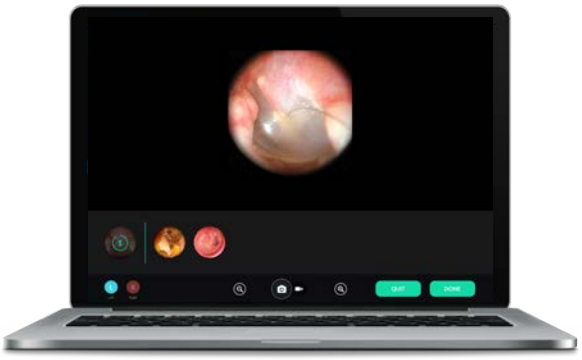
AI SMARTPHONE OTOSCOPY

hearScope

Google Play store

Android devices

mHEALTH
mobile health studio



Compatible with Linux, Windows, Mac

FDA CE

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SMARTPHONE VIDEO-OTOSCOPY

- Ext- & middle-ear related HL
- Chronic OM 65 – 330 million
- 28 000 deaths annually
- Largely preventable
- Early detection reduce long-term morbidity & mortality

(Myburgh et al, 2018; Myburgh et al. 2016)

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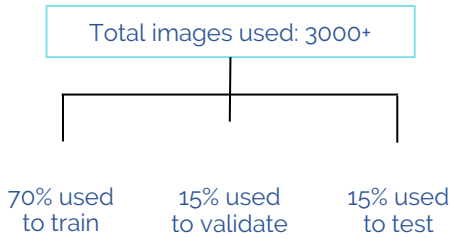
AI MODEL ACCURACY

Images with 2 or more *specialist* consensus diagnoses included for AI model training



AI model accuracy

Overall model accuracy	**94%**
Normal	*98%*
Wax obstruction	*95%*
Chronic perforations	*93%*
Abnormal	*82%*

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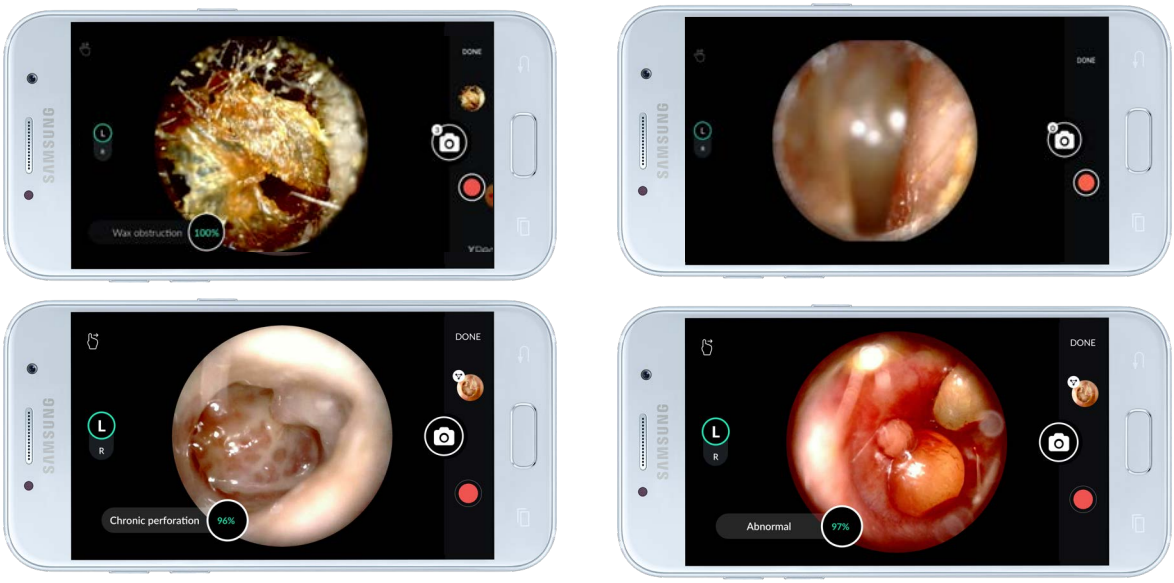
AI IMAGE CLASSIFICATION



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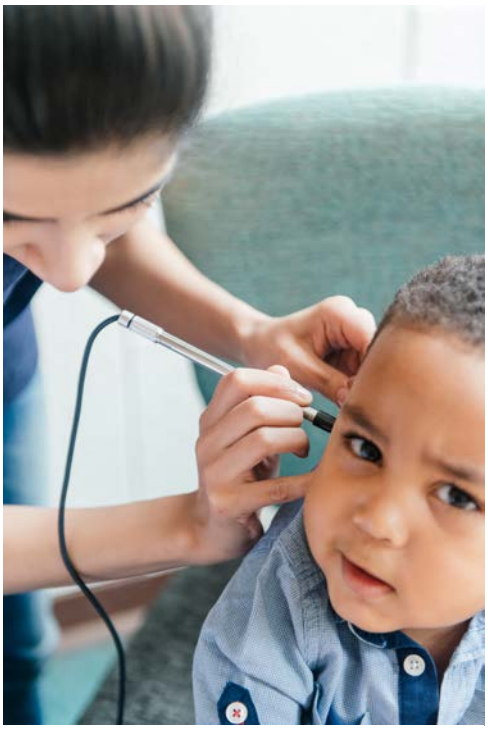
AI SMARTPHONE OTOSCOPY

- Smartphone otoscopy can
  - reduce costs,
  - increases mobility (usability),
  - enable data management

- AI supported diagnosis can
  - be an accurate tool for cross-check,
  - triage and
  - increase access



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Global Health Action

Community-based hearing screening for young children using an mHealth service-delivery model

Shouneez Yousuf Hussein[a], De Wet Swanepoel[b], Faheema Mahomed[b] and Leigh Biagio de Jager[b]

GLOBAL HEALTH ACTION, 2018
VOL. 11, 1467077
https://doi.org/10.1080/16549716.2018.1467077

CONCLUSION:

- Smartphone hearing screening can be used by CHWs to detect children affected by hearing loss
- Asynchronous eHealth program management:

  i) Active noise monitoring, ii) quality indices of test operators and iii) cloud-based data management and iv) referral features

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TECHNOLOGIES FOR HEARING HEALTH ACCESS

De Wet Swanepoel, PhD

1. Dept of Speech-Language Pathology & Audiology, University of Pretoria, South Africa
2. Ear Science Institute Australia, Subiaco, Western Australia

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OUTLINE

- Hearing care access in LMICs
- Exploring new solutions
- 3 technology enabled service-delivery models
  - Community screening for kids
  - Self test kit for COVID-19
  - mHealth supported community hearing care service

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HEARING HEALTH CARE ACCESS

Advocacy & awareness

HR for hearing care

Centralized services

Efficiency challenges

Expensive equipment

Expertise required

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mHEALTH-SUPPORTED HEARING AND VISION CARE FOR YOUNG CHILDREN

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2. WHO Collaborating Centre for the Prevention of Deafness and Hearing Loss
3. Ear Science Institute Australia, Subiaco, Western Australia

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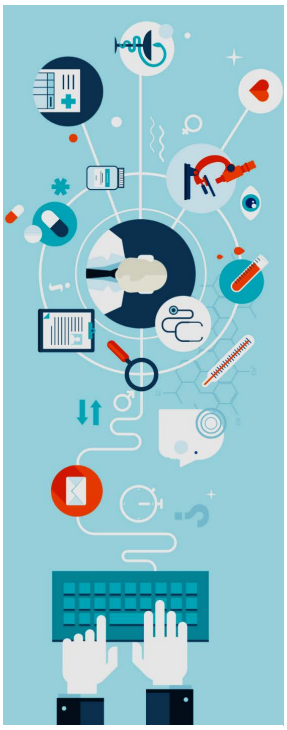
CONCLUSION

- COVID-19 challenges traditional audiological care pathways
- Remote digital screening could support initial triage to direct referrals
- No- and low-touch care can mitigate risk, improve safety & convenience and could work for most adult patients
- Using novel tests to triage for ear disease and CHL risk allows testing outside traditional clinic settings



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