Towards Inclusive Neurotechnology: Addressing Inequity and Adoption Barriers in Brain-computer Interfaces

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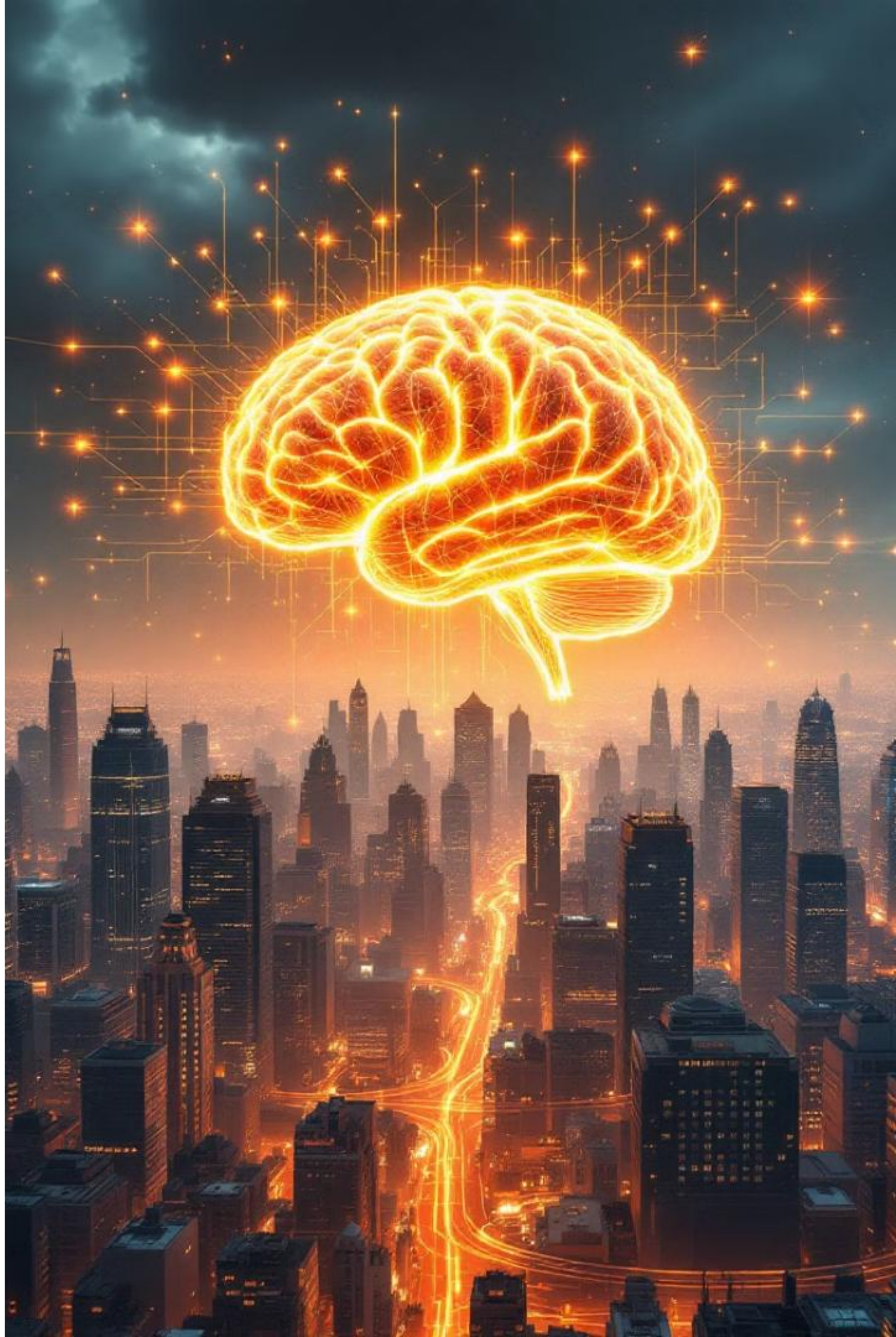
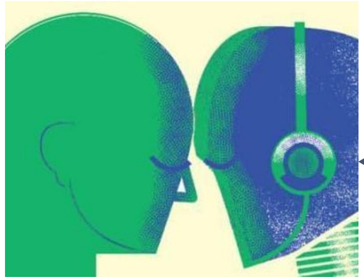


Brain-computer Interface Lab in Sheffield

Research vision: to augment human (physical and cognitive) performance by developing AI-powered, user-centred closed-loop neurotechnologies

Main Research Directions



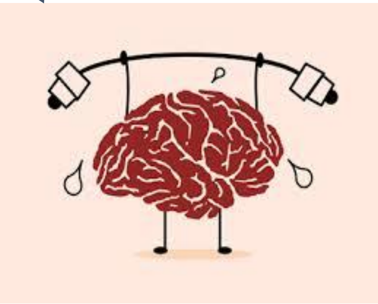
Improving human-machine collaboration

(AI in Wargaming EPSRC £1.2 m, Inclusive Neurotech ARIA £410K)

Monitoring Human States in Real-time (ElectroTools BBSRC £900K, Haleon £400K, Mind4ACCEL EPSRC £50K)

Physical rehabilitation

(TeleRegain funded by MRC IAA, EPSRC IAA & InnovateUK £200K)



Improving cognitive performance & decision making

(SUPER DSTL £410K, Early Dementia MRC DiMEN £200K)

Core of our research: User-centred design, ethical & equitable design

Our Research Spams the Entire Spectrum of TRL 1-6

Inclusivity and Equitability

Definition

Ensures all individuals can access, benefit from, and contribute to neurotechnological advancements, regardless of background.

Some of factors Affecting Inclusivity & Equitability

1. Disparity in Adoption
2. Calibration and Design Biases
3. Disparity in Research Participation

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Factors Affecting Inclusivity and Equitability

1. Disparity in Adoption
2. Calibration and Design Biases
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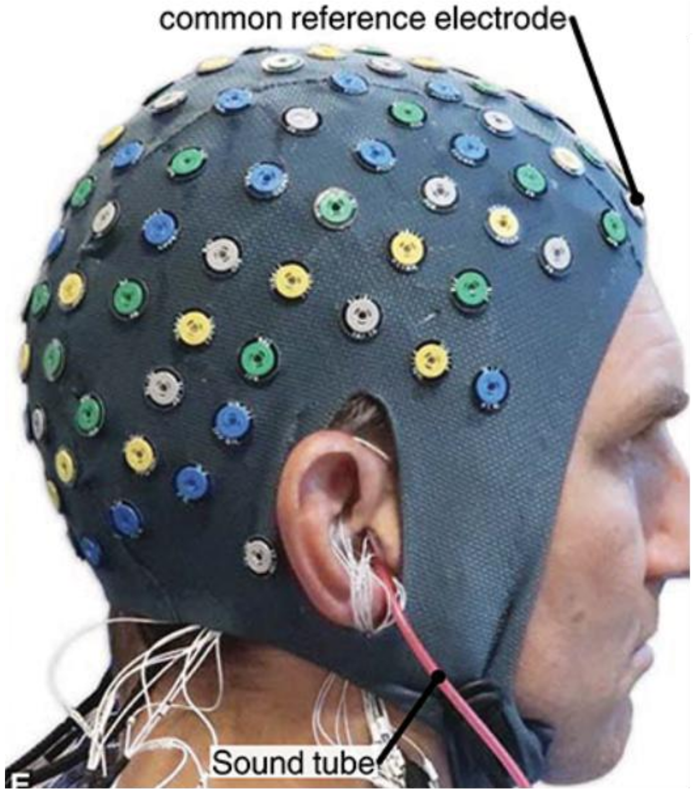
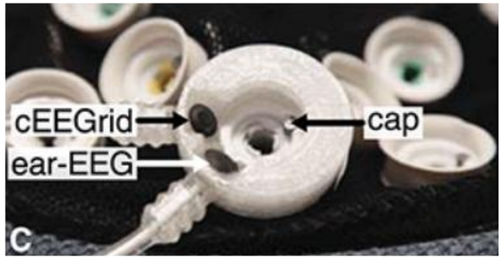
Design biases in EEG



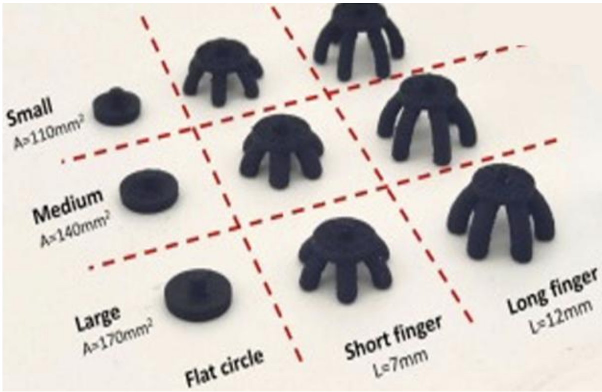


Current standard

Standard EEG device current challenges on thicker, coaserser, curlier hair:

- Limited contact: Electrode to Scalp
- Discomfort & Difficulties with Cap Fitting
- Impedance Threshold > 10kΩ

The above maximises the risk of artefacts which can led to a risk of misdiagnosis; ultimately creating negative experiences for participants & a lack of representation.



New Solutions

Lack of Inclusivity in fNIRS

Light absorption properties differ across skin tones and hair colors.

Reduced Accuracy

Lower sensitivity and accuracy for darker skin tones.

Biased Measurements

Biases in brain activity measurements and hindered adoption in diverse populations.

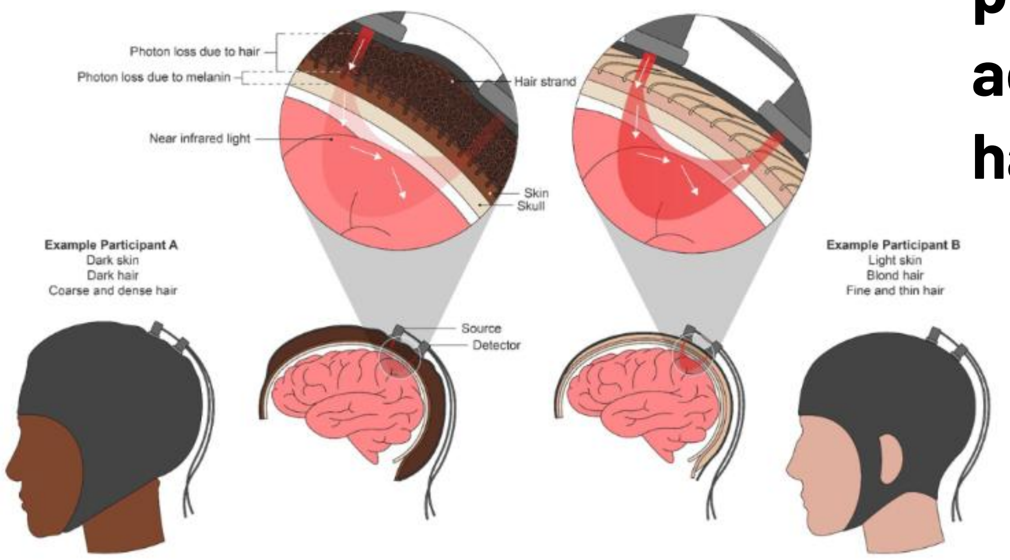
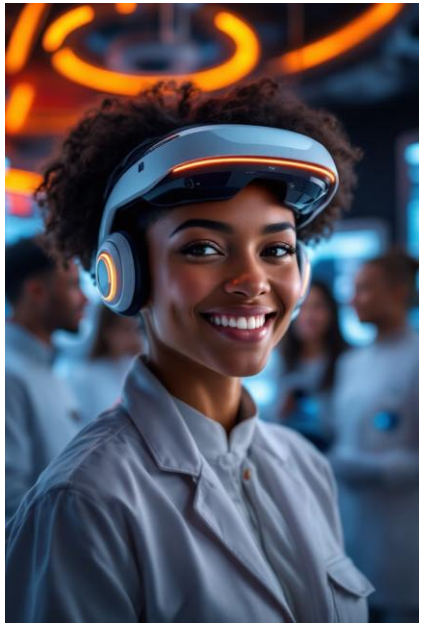
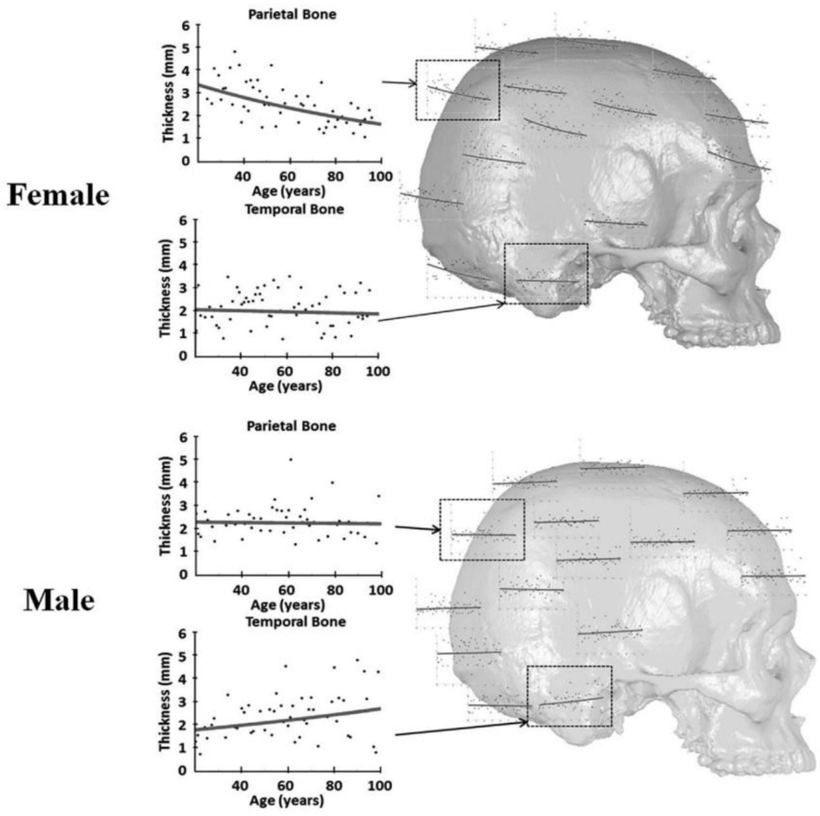


Fig. 1 The image shows two people with different phenotypes. A person with dark skin and curly hair (on the left) and one with light skin and straight blond hair. In the left person, both mechanical blocking due to hair texture and increased light absorption due to melanin weaken the NIR signal, potentially leading to an error in oxygenation estimation. [1]



Calibration and Design Biases in Neurotechnology

Variations in Bone density, skull shape and thickness, skin and hair color, hair type, fat and tissue properties, changes in hormone levels, etc., can impact the outcome of many neurotechnologies across age, gender and races.



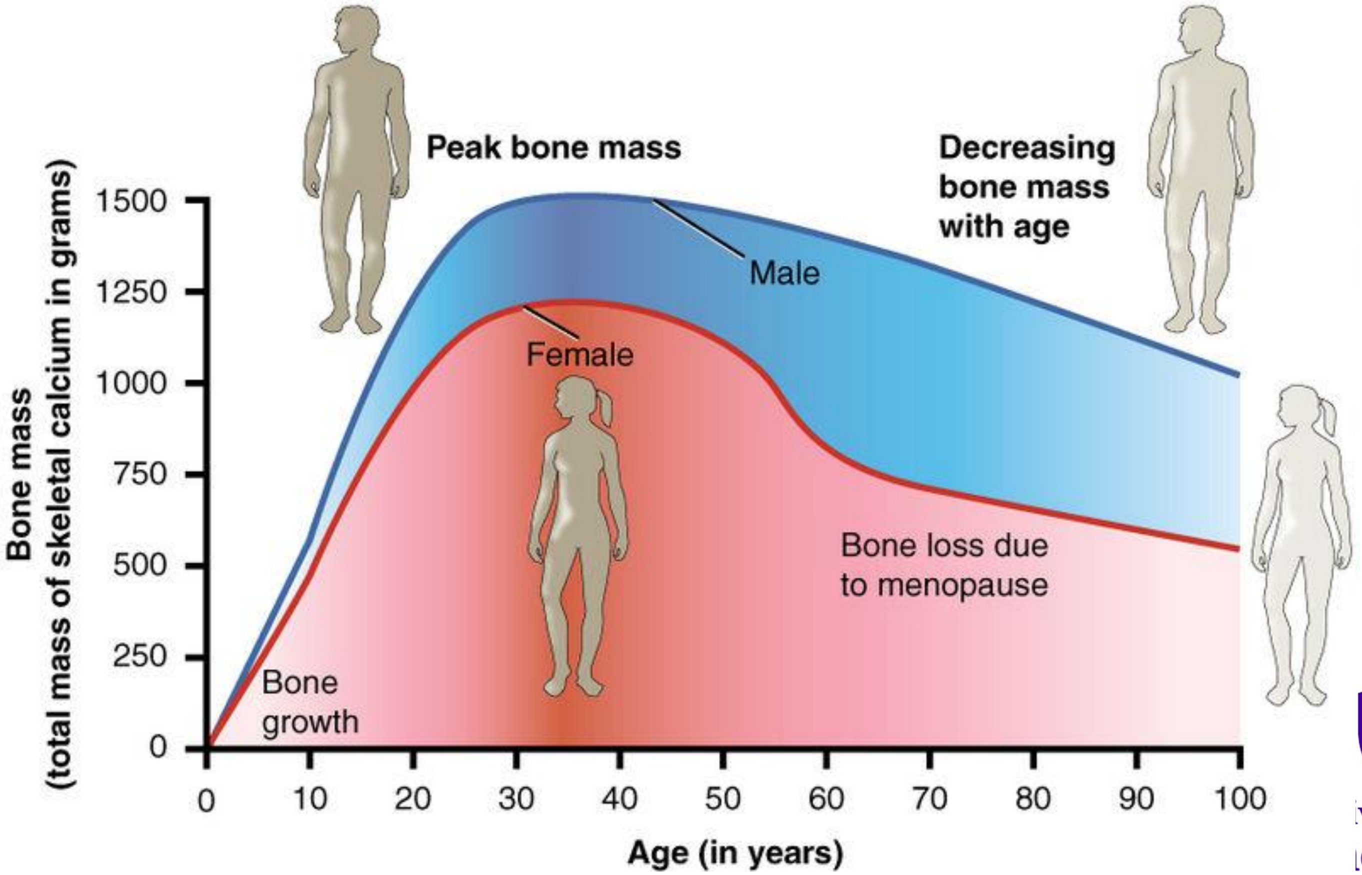


Image sources: LIllie et al, 2016 & Bethlehem et al, 2022

One-size fits all approaches in Neurotechnology

Technologies often calibrated for limited demographic groups, leading to unequal outcomes.

1mA tDCS stimulation

↓

Brain

↓

Behavioral response

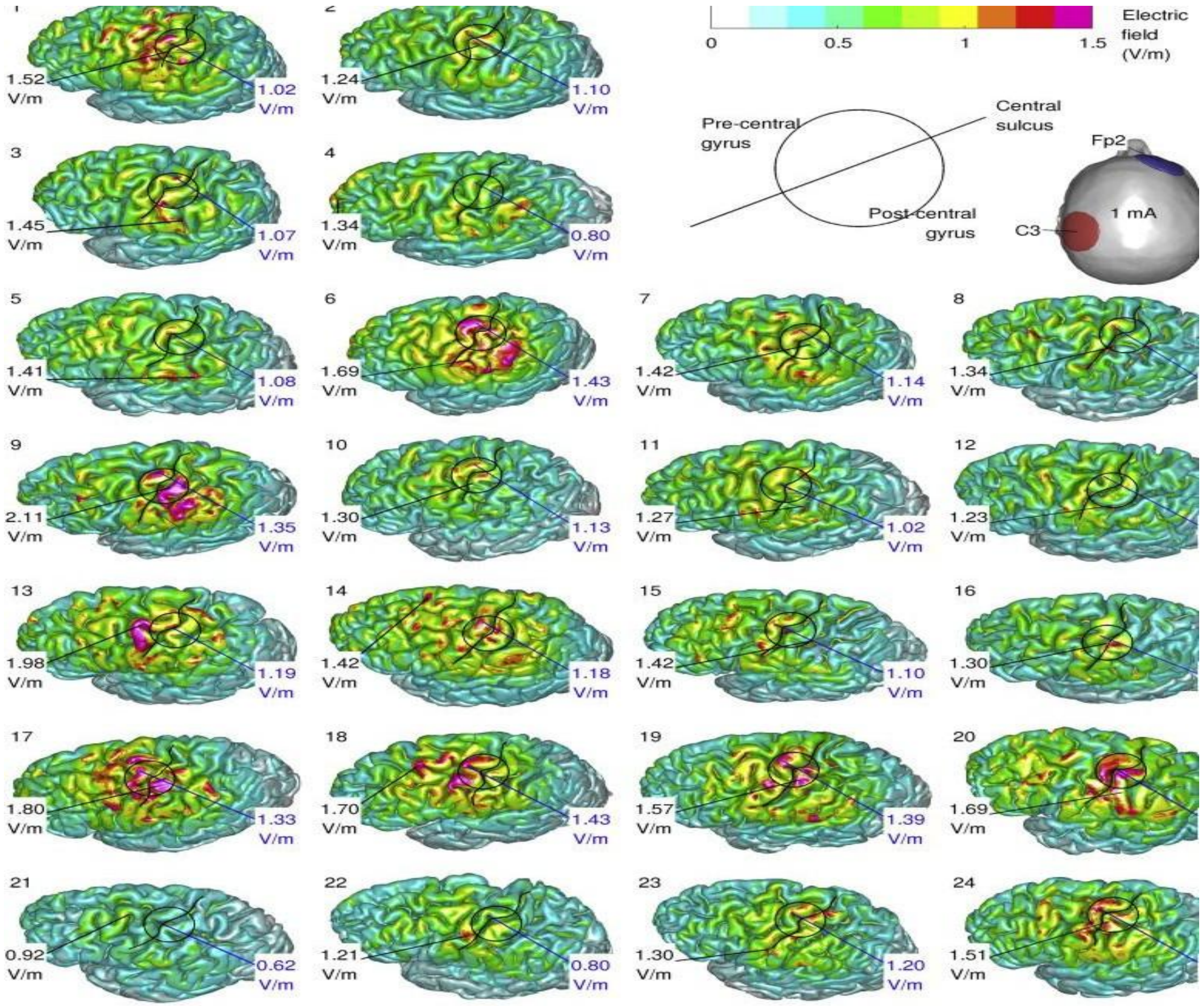


Image source: Laakso et al, 2015

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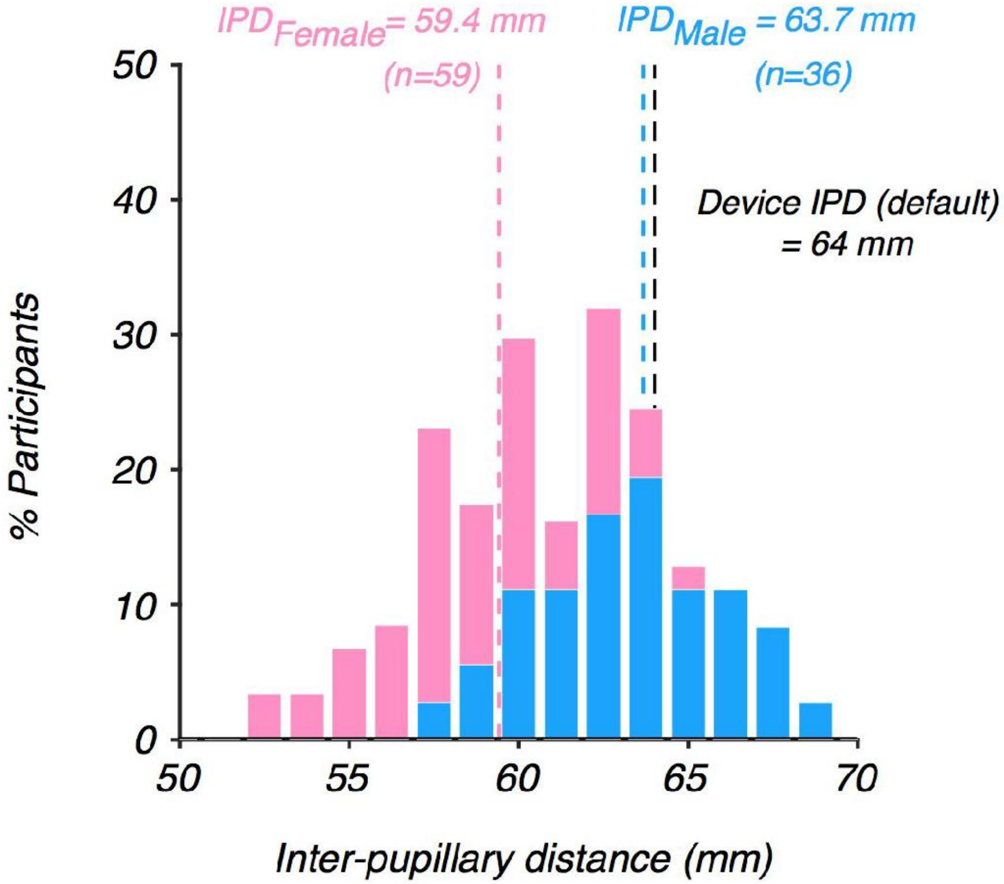
Lack of Inclusivity in VR design

- VR headsets are typically optimised for average measurements, excluding individuals with different facial structures head sizes, causing discomfort, simulatior sickness, headache.



The average male IPD is well-matched to the default IPD of the Oculus DK2, whereas the average female IPD is approximately 5 mm smaller than the default (Fulvio et al. 2018)

Factors Affecting Inclusivity and Equitability

1. Disparity in Adoption
2. Calibration and Design Biases
3. Disparity in Research Participation

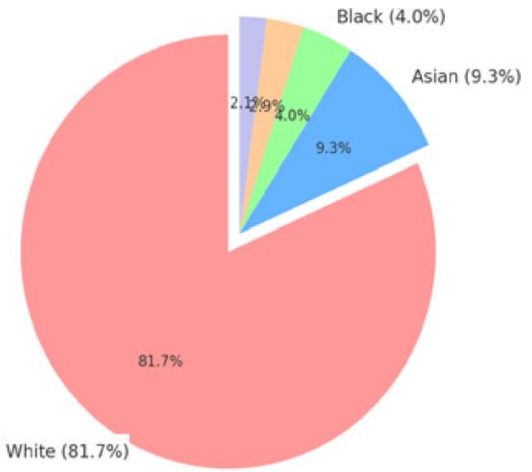
Underrepresentation in Human Brain Research: A Critical Concern

Lack of Diversity

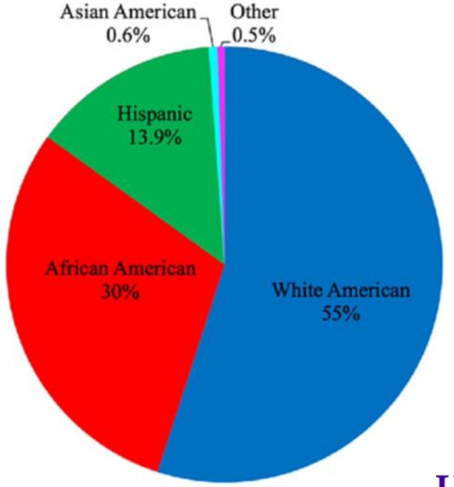
- ✓ Analysis of global neuroscience clinical trials from 2016 to 2021 revealed among 8,015 participants from 47 countries, 85.6% of were White, Black individuals represented only 1.6% (Rutten-Jacobs et al. 2024).

- ✓ 95% of the UK Biobank data, the world's largest collection of neuroimaging data, comes from White participants (Ricard et al. 2023)

Less than 20% of the world population are white!



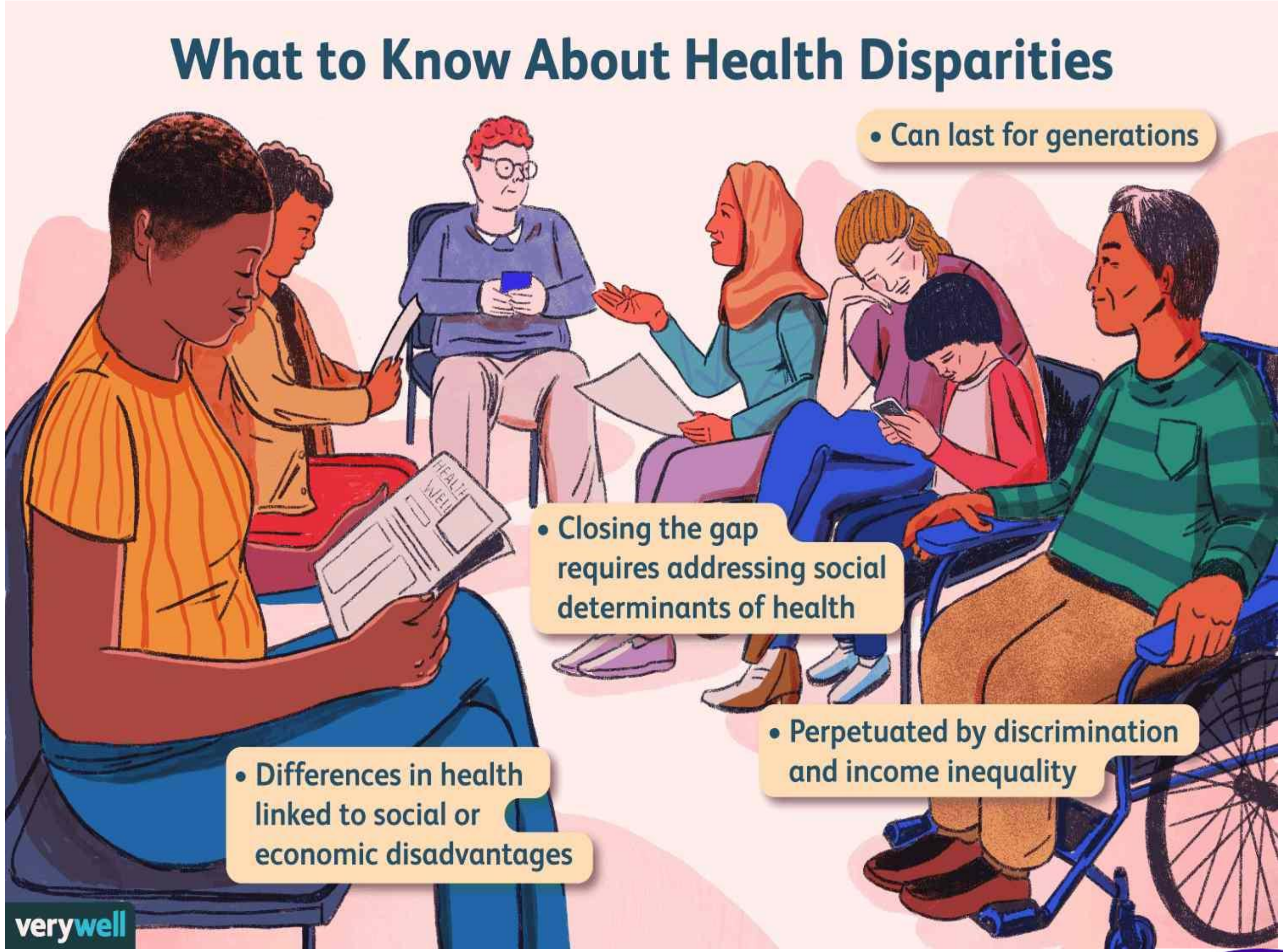
England and Wales (2021)



USA (2022)

Consequences of Underrepresentation in Brain Research

- ➢Limited Generalizability of Results
- ➢Health Disparities
- ➢Bias in Technology Development
- ➢Exclusion from Benefit
- ➢Inability to deliver inclusive and equitable health solutions



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Reasons for Underrepresentation in Brain Research?

- ✓ Lack of awareness of research
- ✓ Inaccessible research venues
- ✓ Inaccessible information and leaflet
- ✓ Language barriers
- ✓ Cultural requirements and needs
- ✓ Stigma in brain research
- ✓ Lack of trust and history of marginalisation
- ✓ Lack of transparency on research goals, funder and privacy
- ✓ Lack of researchers engaging with minority communities

Our Participatory Research with Somalian Community in Sheffield

Research Aims

- Understand social, cultural, and practical barriers to participation in brain research among Black African (Somali) communities.
- Evaluate the acceptability and usability of EEG and fNIRS from participants' perspectives.
- Assess the feasibility of collecting high-quality EEG and fNIRS data for BCI in community-based, non-lab settings.

Methodology

(1) Workshop 1

Neuroimaging
workshop/demonstrations
Group Discussion

(3) Workshop 2

Brain stimulation
workshop / demonstrations
Group Discussion

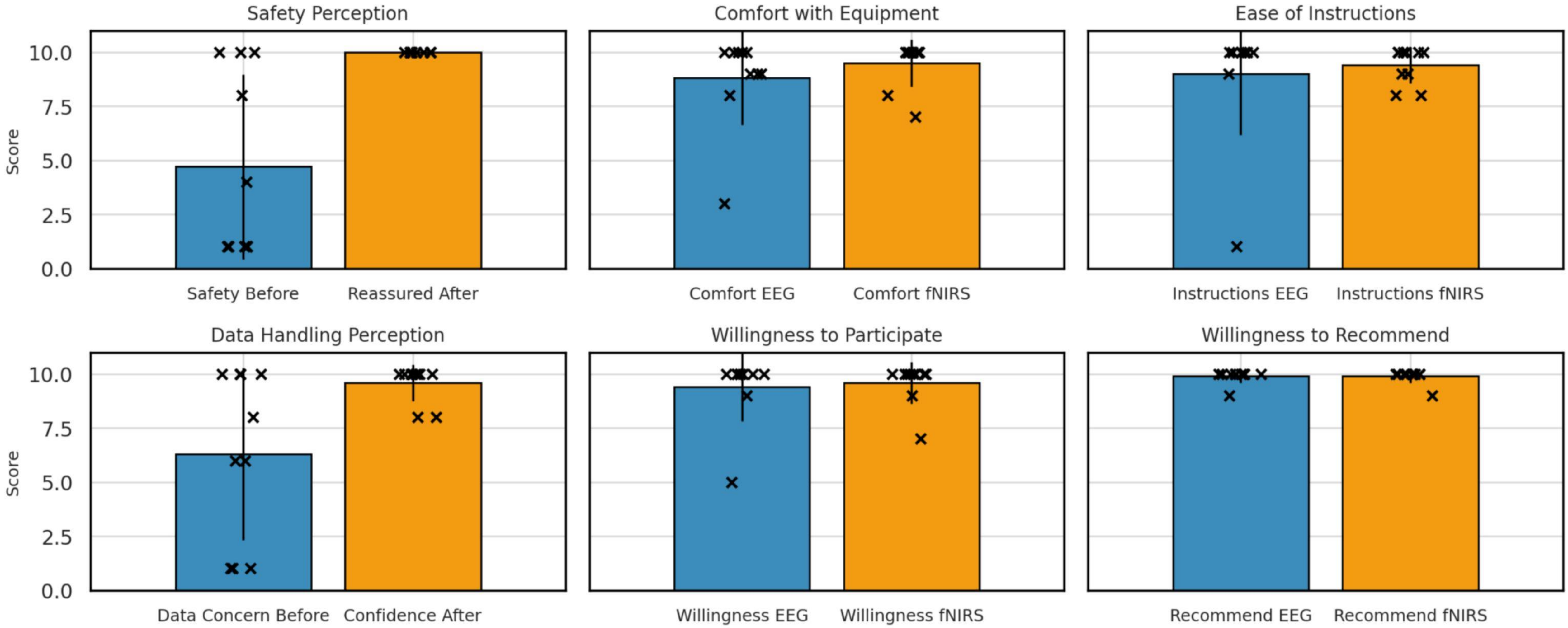
(2) Data Collection

One-on-one sessions
EEG/fNIS / Interviews

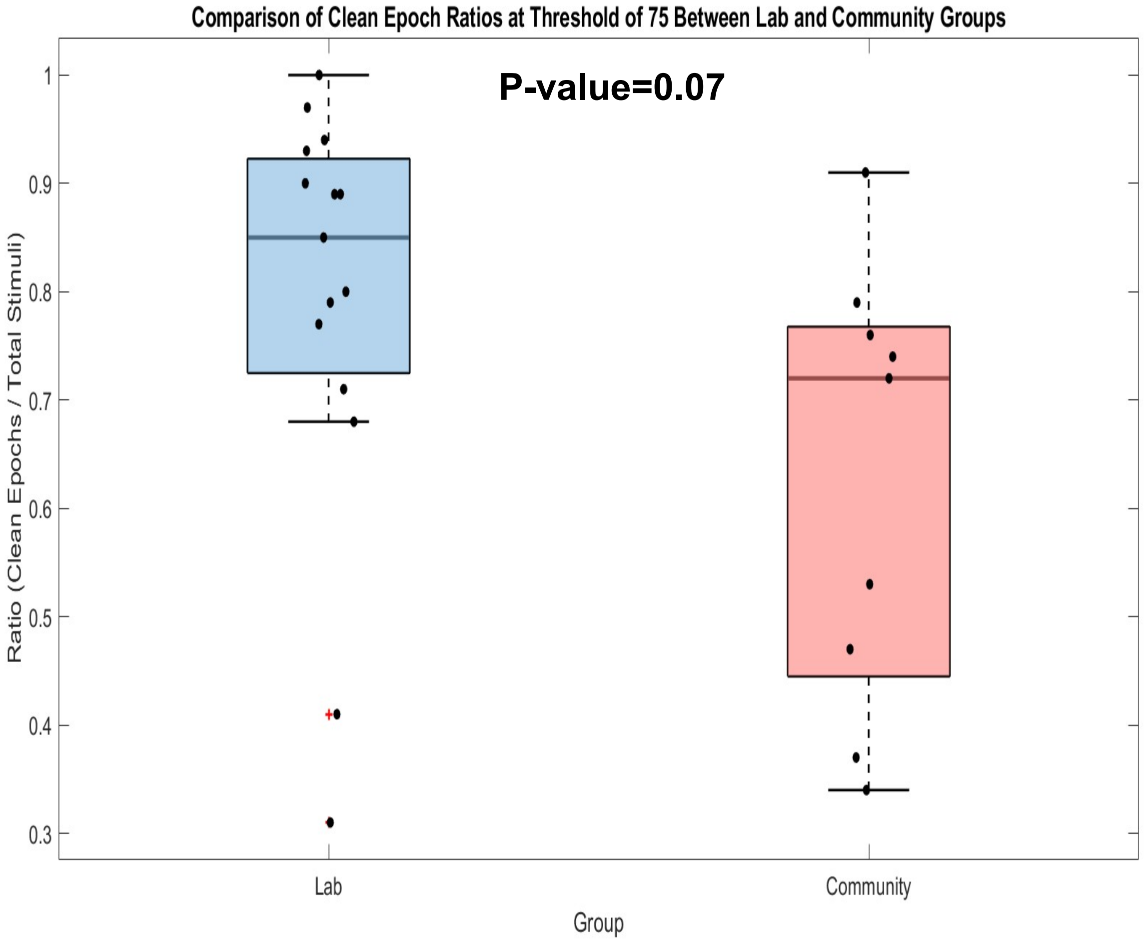
(4) Workshop 3

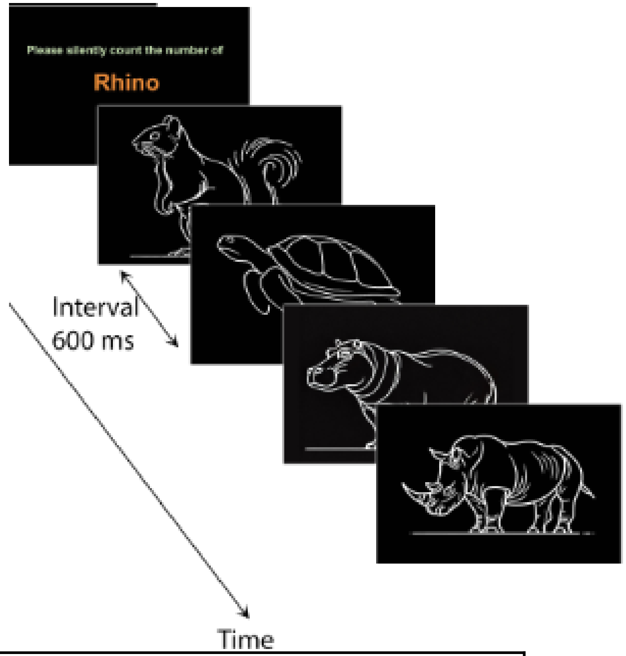
Reflection/Feedback
workshop/demonstrations
Group Discussion

Participants’ Perception of the EEG/fNIRS study



EEG Data Quality: Lab-Based vs Community-Based Collection (n=13 vs n=9)





BCI Accuracy (target vs Non-target)		
	Lab	Community
Number of Participants	13	9
Average Accuracy	70.28 ± 5.82%	74.89 ± 4.91%
Acc. Above Chance	100%	100%

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Parkinson’s disease

- There is no cure for Parkinson’s disease.
- Treatments like medication, and brain stimulation can help manage symptoms.

a progressive neurodegenerative disorder that affects movement and motor control

Cause: loss of dopamine, a neurotransmitter,

Symptoms:

Tremors (shaking), especially in the hands.	Muscle stiffness and slowed movement	Impaired balance and coordination.	depression, anxiety, sleep disturbances, cognitive decline.

Before
Deep Brain Stimulation

After
Deep Brain Stimulation

Disparity in adaption of Deep Brain Stimulation

Gender Disparities

- Women are significantly underrepresented in DBS clinical trials.
- Women are less likely to undergo DBS compared to men.
- Referral and acceptance rates are lower for women despite similar benefits.

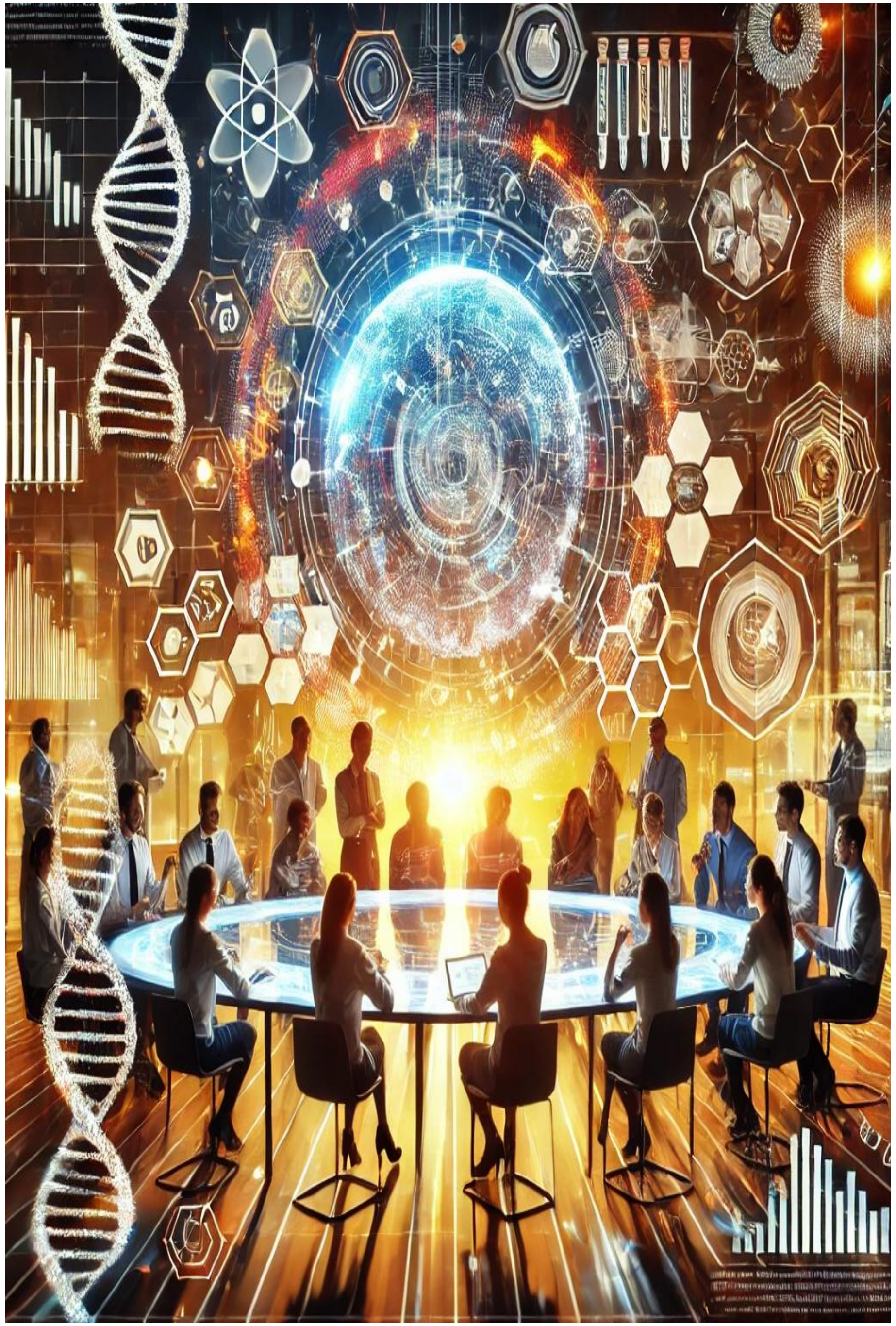
- **Racial Disparities**
  - White Parkinson’s patients are **5x more likely** to receive DBS than Black patients (U.S. data).
  - Lower DBS rates observed for racial and ethnic minorities, even with similar disease severity.

Studies Highlighted

- **Carmen et al. 2022 (U.S.):** Large dataset analysis of Parkinson's patients.
- **Multi-Center Study (Germany & England, 2015–2020,** Kübler et al 2024**):** Gender disparities in DBS referrals and acceptance.

Implantable BCI Clinical Trials: 14% Women Participation Rate

Study (Year)	Age Range	Gender (M/F)	Ethnicity	Country
BrainGate (2004–2021)	24–66 (Median 51)	11 M / 3 F	79% White, 7% Asian, 7% Black, 7% Other	USA
Stentrode "SWITCH" Trial (~2019–2021)	Mean ~61 years	4 M / 0 F	Not reported	Australia
Neuralink "PRIME" Study (2024–ongoing)	22–75 years	At least 1 M (ongoing)	Not reported	USA
Vansteensel et al. (2016)	Adult (exact age not specified)	1 M / 0 F	Not reported	Netherlands
Picostim Epilepsy Trial (2023–2024)	Pediatric	1 M / 0 F	Not reported	UK
UB Synchron COMMAND Trial (2024)	Adult (exact age not specified)	6 M / 0 F	Not reported	USA



Building Inclusive Research and Development

Increase Diversity

Recruiting participants from diverse backgrounds is essential, make protocol more accessible, reach community centres, build trust

Equal Access

Ensuring equitable access to neurotechnologies requires addressing socioeconomic barriers and promoting awareness among underrepresented communities.

Data Collection

Collecting and reporting data on a wider range of demographics, including skin tone, hair type, and skull structure, is crucial for informing calibration and design.

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A Roadmap for Equitable Brain-computer interface

1. **Research**

   Fund and prioritize research that addresses the specific needs and challenges of diverse populations in neurotechnology.

2. **Development**

   Develop neurotechnologies that are calibrated and designed for diverse individuals, taking into account variations in skin tone, hair type, and skull structure.

3. **Accessibility**

   Implement strategies to improve access to neurotechnologies for underrepresented communities, addressing socioeconomic barriers and fostering awareness.

4. **Regulation**

   Develop and implement regulations that promote the ethical use of neurotechnology and ensure its accessibility for all.

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The Ethical Imperative for Inclusive Neurotechnology

1

Justice and Equity

Addressing disparities in neurotechnology is a matter of social justice and equity, ensuring that all individuals benefit from its advancements.

2

Scientific Progress

Inclusive research and development lead to more robust and reliable neurotechnologies, advancing scientific knowledge and innovation.

3

Human Potential

By harnessing the power of neurotechnology for all, we unlock human potential and create a more equitable and thriving society.

Conclusion: Building a Future of Inclusive Neurotechnology

Thank you!

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Engineering and Physical Sciences Research Council

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