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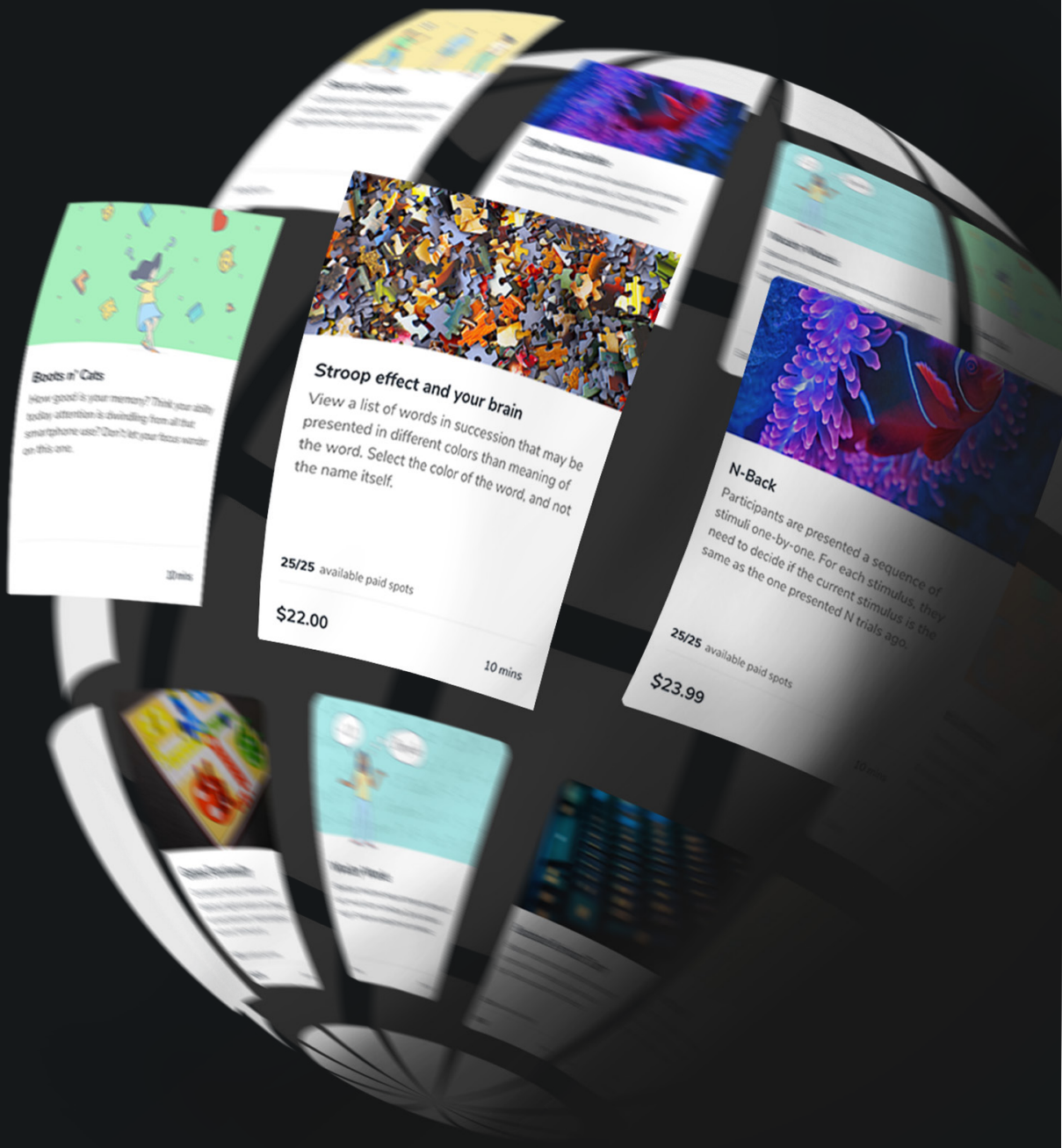
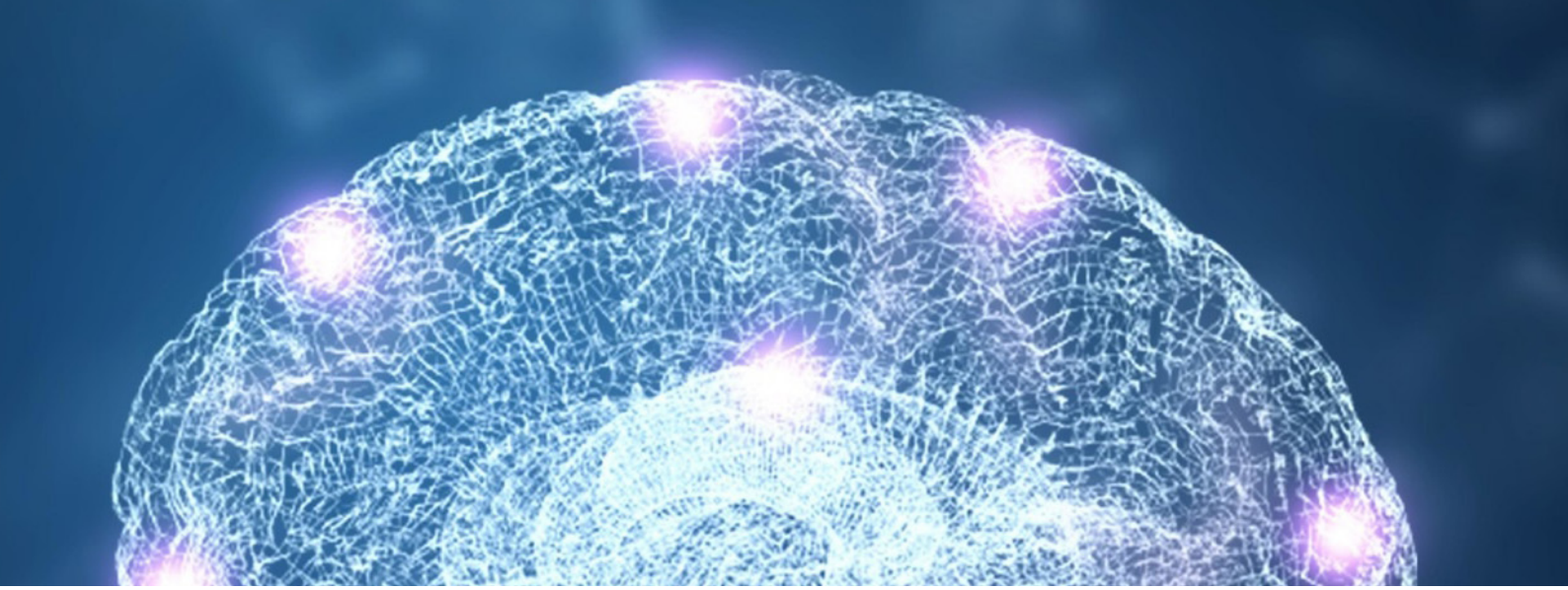


How to conduct faster, smarter, reproducible neuroscience research at scale?

White paper

2021

Contents



Why is neuroscience research important?

The detailed investigation of the human brain will be at the forefront of scientific research in the twenty-first century. It alone has the potential to address two of the most fundamental issues that have arisen in contemporary society: an ageing population, and an increasingly complex technological environment. A deeper understanding of the human brain will provide us with the information we need in order to formulate, monitor & improve treatments for neurodegenerative diseases. It will also allow us to bridge the gap between the human brain and the increasingly complex digital world in which we live. Within this wider context there is a multiplicity of potential applications, ranging from wellness to learning augmentation and beyond. We should also not forget the personal dimension. Neurotechnology offers us the opportunity to gain greater insight into our emotional and intellectual lives, and by doing so will give us greater control in consciously adapting our personal and professional lives in such a way as to maximise our innate capabilities and to enrich our relationships with others.

How do you measure brain activity?

Several modalities exist by which brain activity can be measured: functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and magnetoencephalography (MEG). However, the equipment needed for these modalities is expensive, bulky and immobile, limiting their use predominantly to hospitals and large medical

research facilities. Accordingly, there is an emerging trend towards a preference for Electroencephalography (EEG) as the primary approach for academic research[1]. Neurons within the human brain generally process their information by means of electrical signals. By attaching electrodes to designated areas of the scalp, these signals can be recorded to derive an understanding of the different types of brain activity associated with different areas of the brain and of different types of action and thought. They are basically the language of the brain. We can compare readings from two or more people undertaking the same activity to obtain insights into what type of brain activity is correlated with different levels of performance, for example a game of chess played by a grand master compared to a high school chess coach. By extracting these signals and converting them into digital format, we can also translate this organic language of the brain into the binary language of computers. This can enable someone to control a cursor on screen directly with their mind rather than needing to physically intervene via a mouse.

A major shift has been in the hardware used to record EEG activity, from the use of wet electrodes, which are time-consuming to fit, uncomfortable to wear, and limit mobility, to dry or hybrid electrode wireless headsets, easily fitted, portable, and in addition significantly cheaper to manufacture and operate. These advances in technology are bringing us closer to breakthroughs in neurological research, but we are still not quite there yet.

What is EEG research?

EEG research focuses on gaining a deeper understanding of the human mind by studying the nature of brain activity associated with different activities or in relation to different external environments. An important differentiator of EEG research,

1 E.g., Rashid et al. (2020) p.3, Yang & Deravi (2017) p.2.

now that wireless, portable EEG sets are available, is the ability to examine longitudinal brain activity and in real-world locations rather than being confined to the lab. The applications are almost endless, but include brain function and personal health, for example neuropathologies such as Alzheimer's Disease; brain activity and performance, such as monitoring the brain activity of elite athletes; and the potentially revolutionary field of brain-machine interface (BCIs).[2]

What are the challenges in EEG research & analysis?

Despite the growing number of academic papers, the research environment remains constrained by the small population sets available for neuroscience & neurological research. Laboratory experiments are conducted with limited sample populations, an inevitable consequence of the logistical complexity of academic research. Individual test subjects can only be selected from a restricted geographical area, campus facilities can accommodate only so many individuals, and research budgets are limited in their capacity to remunerate volunteers. Experiments are usually conducted with sample sizes of under 30 individuals, and only rarely with populations of over 100[3]. Small sample sizes are especially problematic for making significant advances in the application of deep learning to the data acquired from EEG experiments.

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What is replication in research and why is it important?

Small sample sizes in particular lead to problems that are at the

2 For a recent overview of EEG-based BCI research see Kawala-Sterniuk et al. (2021).

3 Rashid (2020) pp. 15-20 lists 43 papers, in which only 5 had sample sets of 30 or higher. Belkhiria & Peysakhovich (2020) pp.8-12 list 122 papers, in which only 33 had sample sets of 30 or higher. Yang & Deravi (2017) p.10 note the desideratum of large data sets, and at p.3 refer to a sample set of 108 as 'relatively large'.

core of much scientific endeavour. In contemporary academia, the key considerations are: the issue of statistical significance, the difficulty in drawing meaningful conclusions from an extremely limited dataset, and the associated problem of reproducibility, where the results of experiments cannot be replicated or extended to the general population due to the unique nature of experimental conditions that cannot be compensated for by reference to statistical trends drawn from larger data sets.

Within these constraints, brain research has settled into a pattern common to many scientific fields. Each experiment adds to the last in a process of linear iteration, but the ability to unlock the full potential of all the knowledge thus acquired remains elusive. Each experiment represents one step forward, but we are running out of track – soon we will need to make a leap. The situation was similar with speech recognition back in the 2000s. Decades of research had come more or less to a standstill, when all of a sudden companies like Google combined existing technology with the cumulative input of hundreds of thousands of internet users to refine the product, ultimately leading to the voice companions Google, Alexa and Siri that we have today[4].

Small sample sizes are at the core of current challenges in scientific endeavour: the issue of statistical significance, the difficulty in drawing meaningful conclusions from an extremely limited dataset, and the associated problem of reproducibility.

Building a global neuroscience experiment

EMOTIV is an industry leader in the development of high-performance EEG technology that is inexpensive and easy to use. Our mission is to empower individuals to understand their own brain and to accelerate brain research globally. In response to the logistical constraints currently impeding progress in the field, we have developed a scalable distributed neuroscience research platform: EmotivLABs. This platform has the potential to revolutionize the experimental methodologies of neuroscience & neurological research and to catalyse a transformation in both the range and the granularity of data collected. The results of this research in turn will accelerate the development of those practical applications that today seem always just beyond our grasp.

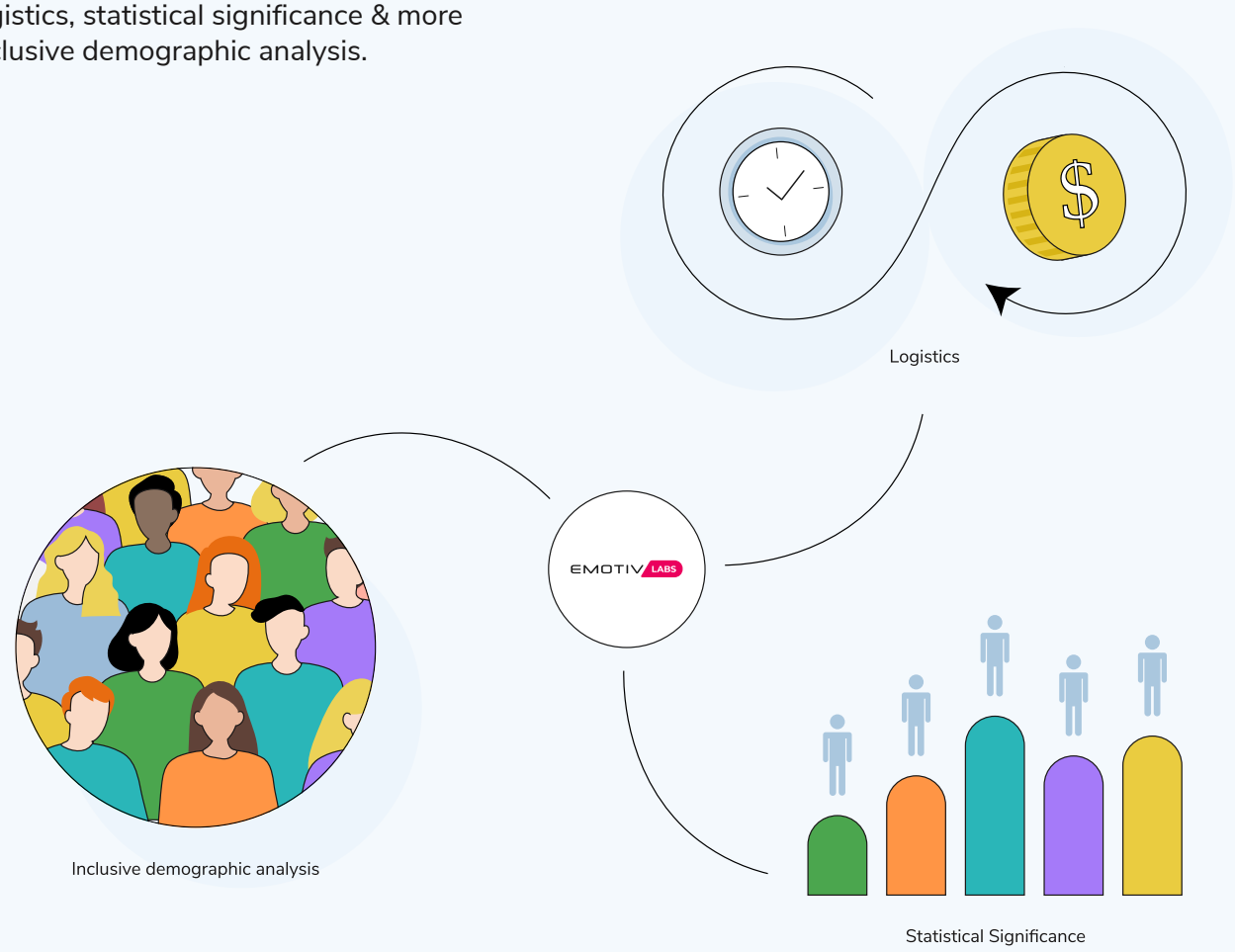
A core feature of the EmotivLABs platform is an online experiment builder and publisher that will act as a gateway between the research community and a global population of research contributors. There are thousands of individuals out there who are curious about how the brain works, who want to know more about themselves, and who want to be part of a

4 Le (2020) 159-60.

story that will change their lives and the lives of those around them. Equipped with Emotiv's wireless and inexpensive headsets, this community will help researchers and developers in three ways: logistics, statistical significance, and more inclusive demographic analysis.

Addressing Neuroscience Challenges

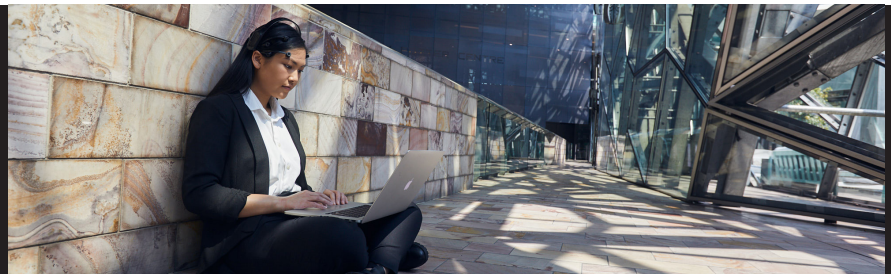
EmotivLABs addresses 3 core challenges currently holding back neuroscience research endeavours: logistics, statistical significance & more inclusive demographic analysis.



Streamlining subject selection, recruitment & compensation

Experimentation and the data it produces is the lynchpin between what we do not know and what we will come to know, between the technology we have today and the technology we will have tomorrow. And yet the engine room of this activity, at the university or the institute, involves a disproportionate amount of time and mental energy. Any experiment in neuroscience requires test subjects. Calls for volunteers have to be arranged, individuals need to be contacted, phone calls and emails proliferate. With an ever-increasing administrative burden in addition to teaching and research, academics are correspondingly time poor. University budgets are strained, a trend exacerbated by the coronavirus pandemic, so that what few resources there are can be decreased unnecessarily by the logistical expense and effort of organising experiments. Participant hesitancy or public health orders can radically affect the ability to collect data in face-to-face laboratory settings.

The EmotivLABs platform frees researchers from these constraints and instead allows them to focus their energy on designing experiments and analyzing the results. Our platform matches the experiment with the most suitable individuals in the subject pool. There is no need to spend time recruiting participants, coordinating & scheduling them, and performing in-lab data collection. All that is required is that the desired demographic be specified in the online platform, and EmotivLABs will make the experiment available to contributors who best conform to the desired parameters. Participants can undertake the experiments in their own homes, using equipment they already own. Their familiarity with the headset removes the need for researchers to provide instruction about its use.



Streamlining collection and automating evaluation of EEG data

A central feature of the new platform is the high quality of the data delivered to researchers. EEG recordings acquired from contributors are subject to a quality assurance process through the use of sophisticated proprietary algorithms. Datasets found to be unsatisfactory are filtered out and no fee is incurred by researchers. The application of machine learning generates a virtuous cycle of improved data quality through the reintegration of information acquired to further enhance the clarity of feature extraction and classification.

Addressing statistical significance in EEG research

The quality of the data provided to researchers dovetails with another feature of the platform that helps to address the very serious problem of statistical significance in neurological research[5]. Statistical significance is one facet of a more generalized problem within the scientific community commonly referred to as the 'replication crisis'. The inability to replicate results diminishes the utility of experimental results, leading to doubts about the validity of inferences drawn from the data and undermining confidence from funding bodies in whether resources are being allocated effectively. The emphasis on this crisis has increased dramatically in recent years, whereas we prefer to view it in terms of a problem inviting solutions that are increasingly available from advances in technology and more extensive meta-research programs[6]. This is the context in which the EmotivLABs platform seeks to make a decisive contribution. By connecting researchers with a global pool of research contributors, the number of subjects in any given experiment can be increased dramatically. This will ensure a more secure basis for statistical analysis and enhance the value of subsequent publications based on that analysis. By decreasing the logistical burden on researchers and by opening up a more extensive

By connecting researchers with a global pool of research contributors, the number of subjects in any given experiment can be increased dramatically. Larger data sets will also facilitate the robust application of machine learning to the analysis of results.

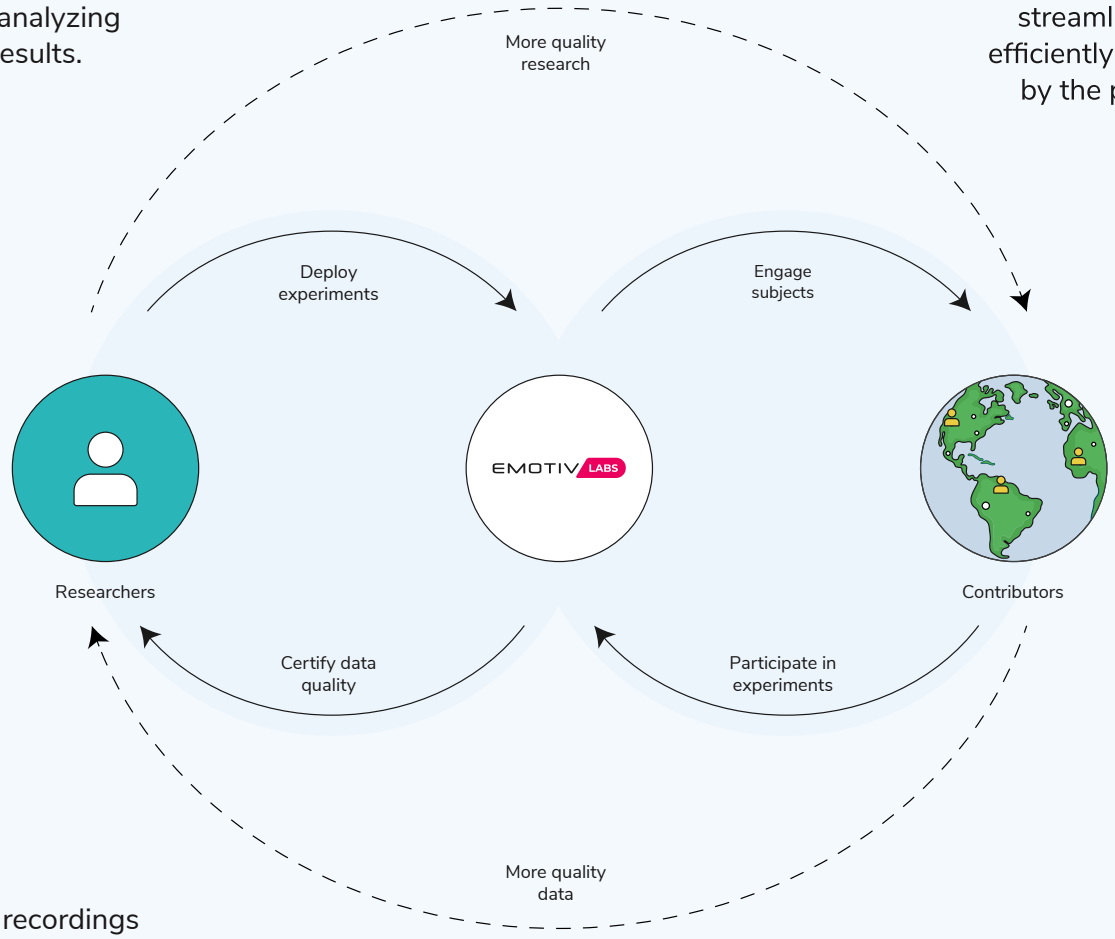
5 Xi-Nian et al. (2019) provide an informative introduction to the problem in relation to neuroscience.
6 Cf. Farinelli (2018) 2630, Porter (2019).

Building a global neuroscience experiment

EMOTIV has developed a scalable distributed neuroscience research platform: EmotivLABs, connecting the research community with a global population of research contributors.

1 The EmotivLABs platform allows researchers to focus their efforts on designing experiments and analyzing the results.

3 The administrative & logistical burden of subject recruitment, coordination and data collection are streamlined and efficiently handled by the platform.



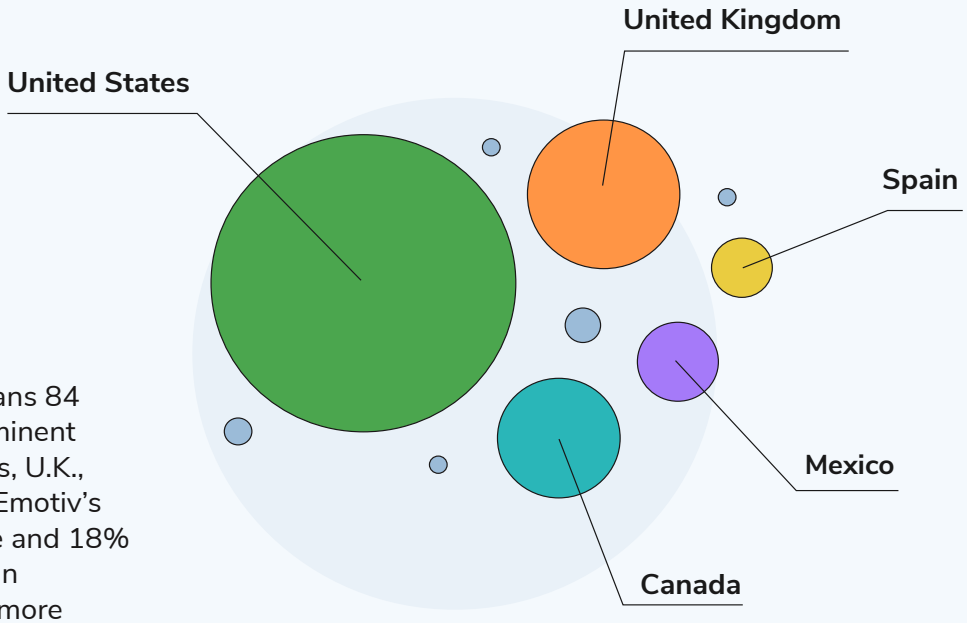
2 EEG recordings are subject to a quality assurance process through the use of sophisticated proprietary algorithms to ensure high quality data is delivered to researchers.

research base, the platform delivers a uniquely efficient and cost-effective way of conducting EEG-based experimentation. Big data is required to overcome the iterative nature of current experimental research in neuroscience, especially at the more complex end of neurodegenerative diseases and brain-computer interfaces (BCIs). Up until now that data has been unavailable. The scalability of the platform will overcome that limitation. Larger data sets will also facilitate the robust application of machine learning to the analysis of results[7].

Are your findings "WEIRD" and overcoming this bias?

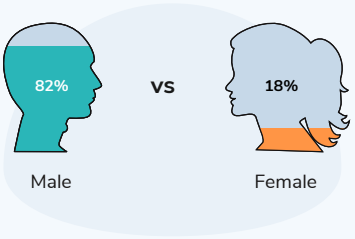
Access to a larger group of research contributors located throughout the world has the further advantage of increasing diversity and adding to the representativeness of any given experiment. The WEIRD problem (white, educated, industrialized, rich and democratic) has gained increasing attention in recent times. An overwhelming majority of scientific research is based upon data from an extremely limited section of the global population. More often than not volunteers in university-based behavioural studies are in fact undergraduates from the very same institution in which the research is being conducted. Up until now it has simply not been possible for researchers to compensate for this due to the difficulty in locating research participants. The EmotivLABs platform introduces researchers to an online global network of research contributors, allowing differences to be identified among various groups as well as commonalities across all contributors. The opportunity to draw upon data from contributors of different ages, different ethnicities and different geographies will produce a sea-change in the level of nuance we bring to the study of the human brain. Freed from the constraint of enlisting volunteers simply to make up the numbers, researchers will be able to target specific populations or sample groups across populations, adding new parameters to experiment design previously unavailable. Research will become truly three-dimensional.

7 On the issue of replicability in the context of EEG and deep learning see Roy et al. (2019) 27.



Contributor pool

Emotiv's contributor pool spans 84 countries with the most prominent presence in the United States, U.K., Canada, Mexico, and Spain. Emotiv's contributor pool is 82% male and 18% female. Of these, 51% play an instrument, 45% speak 2 or more languages, 36% have a Bachelor's Degree, 30% a Master's Degree, and 13% a Doctoral Degree. 83% are right-handed, 13% are left-handed, and 4% are ambidextrous.



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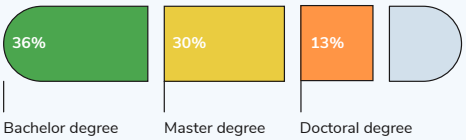

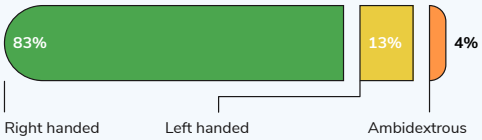

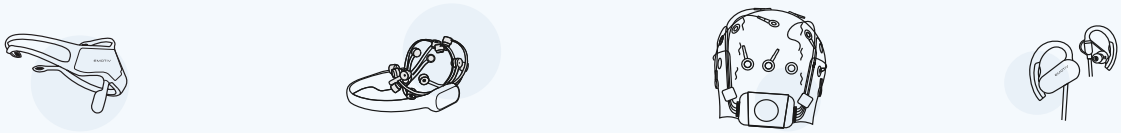

Coda

In 2020 the coronavirus pandemic turned the world upside down. And yet the disruption caused has shown us how receptive we are to new ways of doing things. Above all we have seen the sheer power of the internet and its capacity to promote connectivity as we run multinational organizations from millions of homes around the world. The new scalable research platform, EmotivLABs, can now harness the potential of this global network to transform the state of neuroscience research.

Updates on our efforts will be published at **https://labs.emotiv.com** and we invite your questions, feedback, and participation.

References

Belkhiria, C. & Peysakhovich, V. (2020) 'Electro-Encephalography and Electro-Oculography in Aeronautics: A Review Over the Last Decade (2010–2020)', Frontiers in Neuroergonomics. 1:606719. doi: 10.3389/fnrgo.2020.606719

Farinelli, D. (2018) 'Is science really facing a reproducibility crisis, and do we need it to?' Proceedings of the National Academy of Sciences of the United States of America 115: 2628-31

Kawala-Sterniuk, A. et al. (2021) 'Summary of over Fifty Years with Brain-Computer Interfaces—A Review', Brain Sciences 11.43: 1-41

Le, T. (2020) The NeuroGeneration: the new era in brain enhancement that is revolutionizing the way we think, work, and heal. Dallas TX: BenBella Books.

Rashid, M. et al. (2020) 'Current Status, Challenges, and Possible Solutions of EEG-Based Brain-Computer Interface: A Comprehensive Review', Frontiers in Neurorobotics. 14:25. doi: 10.3389/fnbot.2020.00025

Roy, Y. et al. (2019) 'Deep learning-based electroencephalography analysis: a systematic review', Frontiers in Neuroscience 14: 1-35

Yang, S. & Deravi, F. (2017) 'On the Usability of Electroencephalographic Signals for Biometric Recognition: A Survey', Journal of NeuroEngineering and Rehabilitation 18:15: 1-25

Xi-Nian, Z. et al. (2019) 'Harnessing reliability for neuroscience research', Nature Human Behaviour doi: 10.1038/s41562-019-0655-x.

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