



The Future of Cognitive Neuroscience

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Abstract

Cognitive neuroscience is an interdisciplinary area focusing on the application of neuroscience knowledge in areas such as neuroimaging studies, computer science, psychology, marketing, business, general and special education, social sciences, engineering, biology, learning science, health, etcetra. It is a new emerging field that may help Malaysia in the move towards 2050 for the development of economic, improve levels of knowledge and education, intensify healthcare, enhance people’s well-being and expand network collaboration. Academicians, scientists, industry and educators must concentrate on the application cognitive neuroscience in their field of studies. There is a lack of neuroscientists in these fields, and concentrated efforts must come from the top down as well as the bottom up. We need to bring brain and mind sciences and neuroscience to a reputable level that will improve physical and mental health and increase creativity and innovation in Malaysia: A national institute to amalgamate the creative and innovative mind, behaviour, and brain sciences and neuroscience must be established.

Keywords: Cognitive Neuroscience, Neuroscience, Neurotechnology, Cognition, Mind, Malaysia

1. Introduction

Cognitive neuroscience is an interdisciplinary area focusing on the application of neuroscience knowledge in the diverse areas such as neuroimaging studies, computer science, psychology, marketing, business, general and special education, speech and language sciences, social sciences, engineering, biology, learning science, health, etcetra.

Cognitive neuroscience, emerges as one of the sustainable development goals (SDGs) towards 2030 [1-30] and a critical component in the science, technology and innovation (STI) agenda towards 2050 (see Figure 1) [2]. This is reported by the United Nations and the Academy of Sciences Malaysia ([2]; This field is therefore an important agenda within the field of science, technology and innovation (STI),

It was indicated that Malaysia will require a minimum of 10 cognitive neuroscience experts per 100,000 labour force workers by 2050, [2] . However, at present, Malaysia only has 150 experts in the field (including postgraduates) [2] which is not sufficient compared to the rapid progress of neurotechnology and opportunities in the related field of cognitive neuroscience such neuromarketing, neuroeducation, neurolinguistics, business and industry 4.0, artificial intelligence, computational neuroscience required not only in Malaysia but other parts of the world.

Cognitive neuroscience represents a way for developing Malaysia to foster economic development, improve levels of knowledge and education, intensify healthcare, enhance people’s well-being and expand network collaboration [2]. Figure 1 demonstrate the Jobs’ prospects related to the field of Cognitive neuroscience that will

be created in Malaysia from 2015–2050, mainly in the private sector.

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| <ul style="list-style-type: none"> ▪ Neuroscientists with expertise in informatics/statistics/big data ▪ Neurobiologists with expertise in genetic manipulations (e.g. Clustered Regularly Interspaced Short Palindromic Repeats, or CRISPR) ▪ Cell biologists with expertise in neuroscience and neurodevelopment ▪ Cell biologists with expertise in stem cells ▪ Neurophysiologists with system modeling expertise ▪ Clinicians with expertise in neuroscience and neurodevelopment ▪ Neurodevelopment processes specialist ▪ Neurophysiologists/neuropsychologists ▪ High-quality clinical studies coordinator ▪ Novel pharmacology and repositioning tools ▪ Genetics and patients segmentation specialist | <ul style="list-style-type: none"> ▪ Objective end-points and biomarkers researcher ▪ High-quality diagnostics and patient segmentation specialist ▪ Response biomarkers neurotechnicians ▪ Clinical neurophysiologists and clinical psychologists ▪ Functional imaging specialist ▪ Novel treatment strategies pharmacists ▪ Patient segmentation specialists ▪ Behavioral analysis, animal models specialized in neuroscience and data-capture and data analysis specialist |
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Fig.1: Cognitive Neuroscience related Jobs (adapted from Forum on Neuroscience and Nervous System Disorders; Board on Health Sciences Policy; Institute of Medicine, 2015a)

2. The Emergence of Neurotechnology towards 2050

Rapid advances in neurotechnology have shown great potential in developing cognitive neuroscience ([30]). The growth of cognitive neuroscience can open up opportunities and expansion in many sectors ([30]). Apart from the need for a sufficient number of experts in the field, foresight and strategic planning are required to implement the SDGs and STI agenda successfully. Therefore, the emphasis of recent foresight planning has been on neurotechnology and cognitive neuroscience, including clinical neuroscience (e.g. treatment of neurological disorders), brain fingerprinting, computational neuroscience, neuromarketing and others.

2.1. Neurological Healthcare

The rise in neurological diseases and mental health resulted in the increasing need for neurological healthcare in Malaysia. Corresponding improvement and innovation with emphasis on management, diagnosis and treatment are essential. The multidisciplinary expert collaboration from clinical neuroscience, cognitive neuroscience, neuroimaging, pharmaceutical science and other fields would be beneficial improve understanding of human brain function, diagnosis and treatment of brain-related diseases, monitoring of the progression of brain-related disease and development of novel diagnostic and treatment methods. Inevitably, the development of algorithm for the analysis of big data from healthcare database is critical. This will definitely require a collaborative effort from experts in neuroinformatics and engineering with cognitive neuroscience experts in the development of protocol, data acquisition from qEEG (quantitative electroencephalogram) recording and interpretation or in management of treatment and rehabilitation care.

In Malaysia, The Academy of Sciences Malaysia and the Malaysia Industry-Government group work together to ensure the patient data management system follows the standards (Health Informatics Center Planning Division, 2013). The Malaysian health data warehouse (MyHDW) (Health Informatics Center Planning Division, 2013, 2017) is a project that has been implemented in Malaysia, and the Malaysian Brain Mapping Project [28].

2.2 Advance in Neuroimaging Modalities

Progress in neuroimaging modalities (e.g. electroencephalography (EEG) and magnetic resonance imaging (MRI)) also promotes the next generation of technology for identifying individual information, called *brain fingerprinting*. Neuroimaging modalities offer a powerful tool for measuring human cognitive brainwaves and brain response. Growing interest in brain fingerprinting is also promoting a new level of security identification and verification systems. Each individual's brainwaves are unique ; every single word, phrase or picture is featured in specific brainwaves. Therefore, we can use brainwaves as a password for ATMs [14]), door locks, safe boxes, etc.

Brainwaves can be used to prove the identity of a person [14]). The development of brain fingerprinting also opens a new wave of police interrogation methods (Kraft & Giordano, 2017). It is not easy to prove whether a suspect is guilty or innocent. In the criminal justice system, careful and precise investigations are essential. All the information about crimes and violent activities (e.g. relevant words and/or images) is stored in the brain [9]. Previous studies of brainwave analysis using EEG indicate that the P300 and P300-MERMER responses detect true information that has been concealed or misreported [11]). Furthermore, the results of brain fingerprinting tests provided scientific evidence in the Terry Harrington case [10]. The evidence showed that Mr Harrington was innocent, and the court released him after 24 years in prison [10]. Robin Palmer, a professor of law at the University of Canterbury stated that brain fingerprinting or forensic brainwave analysis has potential as evidence or as a crime-solving tool in New Zealand

[24]. The process of brain fingerprinting can also be applied by the authorities in Malaysia to solve criminal and terrorist cases. A special unit called 'Forensic Brainwave Analysis Unit' could be set up to reinforce the

3. Brain Based Education

Although cognitive neuroscience is a new discipline, recent findings promote its development and show its potential to transform educational practices in Malaysia by 2050. The application of knowledge in neuroscience and technology related to the educational theories and practices will advance the understanding of the cognitive processes, mind and academic performances of normal students and special needs children. Educators have to be creative and flexible [8] in their effort to apply instructional strategies relevant to the students' needs in learning.

Neuroimaging technology and rehabilitation is not meant for those in healthcare or radiologists, neurologists and neuroscientists anymore. Educators can apply neuroimaging modalities to optimise the learning process[3]. The use of neurofeedback training for example may help the normal children for peak performance in Mathematic. A previous study on a simple mathematical calculation (involving addition and subtraction) with different background conditions showed a significant change in brain activation and connectivity when the subject performed the calculation in a noisy background compared to a quiet background[1, 31] . The brain activation and connectivity changes involved the auditory (i.e. Heschel's gyrus and superior temporal gyrus), attention (i.e. middle cingulate cortex) and working memory (i.e. inferior, superior and middle frontal gyrus) areas [1] of the brain. Research on a reading test with dyslexic adolescents and young adults using fMRI showed reduced connectivity in the cognitive control area (left inferior frontal gyrus) and the controlled grapho-phonological word processing areas (posterior temporal areas) in the dyslexic readers compared to the non-impaired readers[26].

4. New Wave of Marketing

The number of entrepreneurs is increasing every year in Malaysia [25]. This growth shows an increase in local services and products output. However, it is difficult to increase or maintain product sales when the products or services offered are similar to global brands. Effective marketing strategies are essential to compete with global brands in local and foreign markets and to improve sales performance. The combination of classical marketing and the cognitive neuroscience called *neuromarketing* shows the potential to optimise marketing management.

Neuromarketing is a new branch of marketing that explores the mysteries of consumer purchase behaviours, preferences, emotional influences and decision-making processes [4-17]. Neuro-marketing helps the marketing analyst understand the process taking place in the consumers' brain during the buying process, that is, the consumer reaction to packaging forms, colours, sizes, designs, product information and advertisements [17]. Globally, there are dozens of companies (e.g. Brain Intelligence, Buyology, FKF Applied Research, Forebrain, Innerscope Research, Institute of Sensory Analysis, Keystone Network, Merchant Mechanics, Mindlab International, MSW Research (MSW/Lab), Neurensics, Neuro-Insight, NeuroFocus, Neurosence, NeuroSpire and One-to-One Insight) using brain technology to explore consumers' behaviours, emotions, memory and decision-making processes [17].

The growth of the neuromarketing field in Europe and the United States is opening a new wave in marketing analysis and strategies in Malaysia. Neuromarketing has the potential to lift marketing analysis and strategy in Malaysia to the next level.

5. Big Data from Mind, Behaviour, Brain and Neurosciences

It is estimated that data from animal, human and many other sources will be open access and standardised to allow researchers worldwide to find ways to prevent, control or cure diseases of the mind, behaviour, brain and neuroscience. Table 2 shows the current and future needs of big data.

These data will require them to collect, stored and analysed ethically, using standardised software and shared between researchers in formats that will need to withstand the ever-changing format of computer software and hardware (see Figure 3) up to the year 2050 and beyond.

Table 2 . Current and projected volume of big data from neuroscience

Source	Description
Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Working Group Report to the Advisory Committee to the Director NIH, (2014) Forum on Neuroscience and Nervous System Disorders; Board on Health Sciences Policy; Institute of Medicine. (2015)	China's connectomic projects are estimated to generate 1 terabyte (Tb) of data per day (or 365 Tb/year/lab), with a 1-cc brain tissue sample containing roughly 2,000 Tb of data.
Human Connectome Project, (2013) Singer, (2013)	The Human Connectome Project, which plans to collect diffusion tensor imaging and resting state functional magnetic resonance imaging from 1,200 human subjects, is expected to generate more than 30 Tb of data.
Human Connectome Project, (2013) Brown, (2013) Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Working Group Report to the Advisory Committee to the Director NIH, (2014)	Imaging studies in animal brains will generate more than 1 gigabit of data per second; Steve Allen's anatomical datasets will grow to the more than 10 petabyte scale

Data Analysis Skills Relevant to Neuroscientists	Disciplines with Which to Collaborate on Data Analysis
<ul style="list-style-type: none"> ▪ Matlab ▪ R ▪ Python ▪ Apache ▪ Hadoop ▪ Visualization software ▪ Multivariate statistical analysis ▪ Competence in cloud computing (storage, retrieval, and distributed processing) ▪ Versioning of computer code script files ▪ Digital signal processing (aliasing, Nyquist, analog to digital trans-forms, filtering) ▪ Feature extraction (time, frequency, wavelet, chaotic) ▪ Data classifiers (supervised and unsupervised) ▪ Regression ▪ K-nearest neighbor algorithm ▪ Support vector machines ▪ Data clustering ▪ Data basics (storage, databasing, integration, search, provenance) 	<ul style="list-style-type: none"> ▪ Computer science ▪ Machine Learning ▪ Engineering ▪ Signal processing ▪ Materials science ▪ Nanotechnology

Fig 3: Relevant skills for behaviour, and brain-and-mind scientists to expand interdisciplinary and translational research in Malaysia (adapted from Forum on Neuroscience and Nervous System Disorders; Board on Health Sciences Policy; Institute of Medicine, 2015)

6. Conclusion

The emergence of neurotechnology is bringing cognitive neuroscience to a new level towards 2050. More experts in the field are required to face the challenges of the 21st century and to implement the STI agenda by 2050. Cognitive neuroscience subfields such as computational neuroscience, neuroinformatics, brain imaging, brain fingerprinting, neuroeducation and neuromarketing can help address various issues associated with the brain, improving social well-being and lifestyle and transforming the socio-economic face of Malaysia.

Brain awareness program derived from knowledge transfer program were carried out in different states in Malaysia with the goal

to encourage high school students into brain science and gradually into scientific research careers, including neuroscience research. These are the activities selected based on their ease of implementation

One intervention the authors developed is the use of Massive open online classes introducing students to basic contemporary neuroscience module. In a convenience sample of 124 students, the authors found that almost all students use the internet for information about careers, in addition to consulting family members and teachers. Students' career selections are influenced most by family members, teachers, and people already in the field. The most important factors students look for in their future career are money, fun, and a good match between current interests and future careers

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