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Brain-Machine Interfaces and Ethics: A Transition from Wearable to Implantable

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I. INTRODUCTION

There is an overwhelming volume of information originating from diverse sources in the current digital era, and it comes with new ideas and content for daily application. People develop new visionary ideas that have helped transform societies. Numerous technologies and societal changes, including brain manipulation, control of computers, genetic modification, death, and others, point towards radical transformations.[1] Technological advancement has led to innovations, lessons, and new processes that define people's daily activities and behaviors. Overall, the technological wave is continuously revolutionizing the way of living across the globe.[2] One such technology is Brain-Machine Interfaces (BMI), also known as Brain-Computer Interfaces (BCI).[3]

BMI represents a communication system in which messages of commands sent by individuals to the external world bypass the normal brain output pathways linked to peripheral muscles and nerves.[4] As predicted theoretically, BMI is supposed to support people's control of many live aspects, but they still lack practical proof.[5] It

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1. Velloso, Gabriel T., *Brain-Computer Interface (BCI): A Methodological Proposal To Assess The Impacts Of Medical Applications In 2022*, 8 ENTERP. AND WORK INNOV. STUD., 57, 58 (2012).

2. Mohammad Bani Younes & Samar Al-Zoubi, *The Impact of Technologies on Society: A Review*, 20 *IOSR* J. OF HUMANITIES & SOC. SCI. 82, 82 (2015).

3. *Brain Machine Interface (BMI)*, ELEC. SIMULATION (Oct. 15, 2018), https://electrical-stimulation.com/2018/10/15/brain-machine-interface-bmi/.

4. Velloso, *supra* note 1, at 57.

5. *Id.* at 58.

is agreeable that there is limited interpretation or comprehension of the consequences and impacts of BMI.[6] Besides, many doubts associated with ethical, moral, philosophical, and religious thinking of how such technology transforms society have been expressed.[7] The development of bioengineering has slowly diminished society's limits, science and engineering, living/non-living, health improvements, nature, technology, and machine/human intelligence.[8] These transformations have made society uncomfortable since they ignore basic concepts of life, describing the world's meaning and what constitutes a human being.[9] Owing to the importance of BMI in the current digital society, it is essential to gain an in-depth understanding of the concept. This article examines BMI in-depth and its associated ethical problems.

II. BMI Control Signal Technology

BMI depends on the control signals for its effective application in determining brain activity.[10] Translation algorithms are used to translate some of the control signals into digital signals, whereas others require more processing to understand.[11] Three kinds of control signals exist, and they include spontaneous, hybrid, and evoked signals.[12] The first control signal is spontaneous signals often produced without external stimulus.[13] Moreover, it is grouped into slow cortical signals, non-motor cognitive signals, and motor and sensorimotor rhythms.[14] Voluntary movements characterize motor rhythms while slow cortical signals arise due to depolarization shifts.[15] Non-motor cognitive signals entail visual counting and musical imagination.[16] Hybrid signals comprise numerous signals generated by the brain and are used when there is no distinct focus on specific areas, and instead, multiple brain aspects are monitored simultaneously.[17] Lastly, evoked signals (P300 and steady-state potentials) result from an involuntary response to external stimuli.[18] Steady-state evoked potentials (SSEP) are produced when a person responds to

6. *Id.*
7. *Id.*
8. *Id.*
9. *Id.* at 59.
10. Rabie A. Ramadan & Athnasios V. Vasilakos, *Brain Computer Interface: Control Signals Review*, 223 NEUROCOMPUTING 26, 32 (2017).
11. *Id.*
12. *Id.*
13. *Id.* at 33.
14. *Id.*
15. *Id.*
16. Ramadan & Athanasios, *supra* note 10, at 33.
17. *Id.*
18. *Id. at 33.*

eternal stimuli such as mild vibrations, moderated sound, and flickering images.[19] Using the sensation process, different brain areas can be examined.[20] Besides, P300 and SSEP signals are witnessed when observing a shocking activity.[21] Looking at the above description, BMI employs control signal technology.

The BMI technology works on the signal acquisition principle, where the signals analysis is required to meet objectives.[22] According to Fazel-Rezai et al., a native BMI interface, the hardware depends on three types of signals, including SSEP, P300, and event-related desynchronization.[23] P300 is vital in event-related desynchronization (ERD), whereby ERD is used in measuring electrophysiological responses to internal or external stimuli.[24] Subjecting individuals to a series of events can generate the P300 signal, where the signal is often linked to the changes in the learning activity of the brain.[25] Memory modification is experienced since individuals are required to learn and remember things by surprise when the brain has already learned the activity.[26] In the current digital era, research has focused more on the P300 signals leading to increased BMI application technology in different areas such as helping disabled people.[27] The P300 software is widely used because it is easier to make the BMI interface non-invasive and measure brain activity.[28] Moreover, the P300 requires less time to train its users and can be applied to most neurological conditions.[29] Besides, it is observed to be a goal-oriented type of control signal to study brain activities. In instances where the need for a continuous signal is not required, P300 is vital for control and spelling applications to learn brain activities.[30] The P300 speller software is the greatest achievement for BMI interfaces because results are produced endogenously.[31]

Studies are underway to make the P300 activity more accurate by including different factors such as repetition blindness, attention blinking, habituation, and target-to-target interval.[32] Such factors have proved to be barriers to the accurate

19. *Id.*

20. *Id.*

21. *Id.*

22. Ramadan & Athanasios, *supra* note 10, at 38.

23. Reza Fazel-Rezai et al., *P300 Brain Computer Interface: Current Challenges and Emerging Trends*, 5 FRONTIERS IN NEUROENGINEERING, 1, 1 (2012).

24. *Id.*

25. *Id.* at 3.

26. *Id.*

27. *Id.* at 2.

28. *Id.*

29. Fazel-Rezai et al., *supra* note 23, at 2.

30. Kaushik Sundararajan, Privacy and Security Issues in Brain Computer Interface, 33 (2017) (Ph.D. dissertation, Auckland University of Technology) (on file with Auckland University of Technology).

31. *Id.*

32. Fazel-Rezai et al., *supra* note 23, at 6.

measurement of P300 signals which has slowed the future development of the P300 software.[33] When studying motion due to stimuli and not flashing stimulus, the P300 can be used to study brain activity if results are stable.[34] The past few decades has seen the development of a range of software and applications to monitor EEG raw data that is important in exploring brain activity.[35] The P300 signal plays a significant role in extracting the raw data of determining brain activity and data quality deeper.[36] The quality of the P300 evoked signal is improved through a series of research projects to ensure numerous neurological conditions are addressed appropriately.[37]

III. BMI Technology Interface

A. BMI2000 System

One of the significant advances in BMI technology interfaces is BCI2000 software.[38] Even though most BMI interfaces have been applied to address people's neurological conditions, the BMI2000 software has moved the technology forward.[39] The software supports communication via documented TCP/IP protocol, which facilitates machines' programming within the network using different languages.[40] The software has improved efficiency, since information passing through the various software components has been designed to minimize dependency and the feedback mechanism is designed so that each component's functioning is monitored regularly.[41]

Every BMI interface requires a quick software response so that the complex brain activity can be understood.[42] Each synapse involves trillions of messages, and the BMI2000 software has the capacity to process those messages as quickly as possible to understand the brain activity.[43] Also, the software ensures minimal pressure on the BMI hardware, thus improving its performance.[44]

33. *Id*. at 4.
34. *Id*. at 6.
35. Sundararajan, *supra* note 30, at 33.
36. Ali Raider & Reza Fazel-Rezai, *Application Of P300 Event-Related Potential In Brain-Computer Interface*, *Event-Related Potentials And Evoked Potentials*, UNIV. OF N.D. ELEC. ENG'G FAC. PUBL'N 19, 23 (2017).
37. Sundararajan, *supra* note 30, at 33.
38. *Id.* at 34.
39. *Id.*
40. *Id.*
41. *Id.*
42. *Id.*
43. Sundararajan, *supra* note 30, at 34.
44. *Id.*

The BMI2000 software comprises four main modules—source, user application, signal processing, and operator modules—that work together to ensure brain activity is understood.[45] Source modules are used in storing and digitizing brain signals and coveys them for further processing and are located in the data acquisition and data storage components.[46] The data acquisition component extracts data from the brain while the data storage component stores extracted brain signals.[47] The user application module is fundamental in bridging the gap between hardware and software by driving established control signals.[48] The user interface offers features such as a virtual keyboard and gyroscope to drive prosthetics signals for disabled people.[49] Another module is the signal processing module in charge of converting brain signals to usable data to be applied to an external device, a process that entails two stages; extraction and translation of features.[50] The extracted brain signals involve specific features such as the evoked response potential's frequency and firing rate.[51] After extraction, an algorithm is used for translating such features into readable signals using external devices.[52] The last one is the operator module used in defining system parameters to enhance software execution.[53] Moreover, it promotes investigator control during experimentation and access to limited application areas.[54]

The four modules define the complete BMI2000 interface and, in most cases, allow users to monitor different brain activities in detail. By using the BMI2000 interface, different applications have been made available to assess and compare various brain signals. Stress resulting machine power use is reduced together with efforts and time invested in testing new devices.[55] BMI2000 interface is driven by the four modules as well as the scalability and independence factors. The BMI2000 interface is advantageous in the current era because its open-system trait[56] gives software developers an opportunity to develop new applications for addressing all voluntary movement disabilities. Moreover, those new applications can support people with cognitive impairments.

45. Gerwin Schalk et al., *BCI2000: A General-Purpose Brain-Computer Interface (BCI) System*, 51 IEEE TRANSACTIONS ON BIOMEDICAL ENG'G 1034, 1035 (2004).

46. *Id.* at 1036.

47. *Id*.

48. Sundararajan, *supra* note 30, at 34.

49. *Id.* at 34–35 (citing Schalk, *supra* note 45, at 1034–1043).

50. Schalk, *supra* note 45, at 1036.

51. *Id.*

52. *Id.*

53. *Id.*

54. *Id.*

55. Sundararajan, *supra* note 30, at 35.

56. Schalk, *supra* note 45, at 1040.

IV. BMI Tools

To make effective use of BMI, applications and tools are required and are intended to drive external devices, as well as support individuals' wellbeing. The operating environment and various tools are explored in this section. The tools included in this section are Pyff, OpenVibe, OpenBCI, BCILAB, BCI++, BF++, Xbci, and TOBI.[57] The Pyff tool is developed using the python language, allowing a successful exchange of experimental information between different research groups and can support the reproduction of already published results.[58] The OpenVibe tool runs on Linux and Windows platforms and constitutes shooting game, spell checker, handball, and motor imagery based on evoked signals.[59] The OpenBCI tool is an open-source platform that is applied in the home environment to support disabled persons.[60] The tool has a multi-flexible server that can accommodate additional components and modules and also runs on both Linux and Windows platforms.[61] Being an open-source tool for doing research, BCILAB has different components, including machine learning, feature extraction, signal processing.[62] This tool also runs on both Linux and Windows platforms.[63] BCI++ runs on Windows platforms only and constitutes two modules, graphical user interface (GUI) and a hardware interface module (HIM).[64] The GUI is mainly applied in the creation and management of computer-driven protocol, whereas, the HIM module is used for obtaining brain signals, storage, and visualization.[65] BF++ toll comprises various components, tools, and libraries for use in BMI interface applications and runs on various platforms including, Windows, Macintosh, and Linux.[66] The Xbci tool is also compatible with Windows, Macintosh, and Linux computers.[67] Moreover, its sophisticated graphical interface allows BMI developers to develop new applications to target specific neurological conditions.[68] Lastly, the TOBI tool runs on Linux and Macintosh operating systems and constitutes three implementation platforms, TiC, TiA, and TiB, that are responsible for signal acquisition.[69] TiC platforms are used in detecting labels and classes within the BMI, the TiA platforms are employed for the

57. Ramadan & Athanasios, *supra* note 10, at 36.
58. *Id*.
59. *Id*. at 34.
60. *Id*. at 38.
61. *Id*. at 36, 38.
62. *Id.* at 34.
63. Ramadan & Athanasios, *supra* note 10, at 36
64. *Id.* at 36–37.
65. *Id.* at 37.
66. *Id.* at 36, 38.
67. *Id.* at 36.
68. *Id.* at 37.
69. Ramadan & Athanasios, *supra* note 10, at 34, 36.

communication of raw brain signals, and the TiB platforms transmit extracted signals.[70] All the tools are important in applying the BMI technology in the study of brain activity but can be applied independently.

V. BMI Companies and Market Share

Several companies have developed varying BMI technologies that can be adopted across different regions. Neuralink, a company by Elon Musk, is one of society's most significant contemporary topics. This is because of the controversies associated with Neuralink products and their contribution to multiple concerns in the real world requiring effective legal solutions to prevent potential adverse effects.[71] Neuralink is a company producing implantable brain-machine interfaces with the hopes of creating a symbiosis between people and artificial intelligence (AI) instead of expecting when AI will replace the human race.[72] Neuralink, as a neurotechnology company, creates microchips that can be implanted behind the ear to reach the brain with thin threads.[73]

A neurosurgical robot ensures high efficiency and accuracy by embedding every individual thread from the microchip to the brain, suggesting robots' capacity to attain desired goals.[74] The technology helps treat various diseases and improve the mental control of paralyzed body parts, contributing to a significant increase in productivity and performance efficiency.[75] Nevertheless, the human brain is a valuable and complex organ, which may encounter unpredictable health outcomes because of interference in its performance. Hence, the results of implementing the idea by Elon Musk could be dangerous and result in colossal health risks to individuals. The risk of the work of Neuralink and the overall BMI technology also extends to society in general. Potential risks may include people losing touch with each other and increased dependence on technology as it remains a cornerstone of everyday life. Other companies apart from Neuralink have been developing BMI technology such as Neuroelectrics, Natus Medical Incorporated, BrainCo, and MindMaze.

70. *Id.* at 34.

71. *See generally* Kulshreshth et al., *Neuralink- An Elon Musk Start-up: Achieve Symbiosis With Artificial Intelligence*, 2019 INTER. CONF. ON COMP., COMM., AND INTEL. SYST. (ICCCIS) 1, 4–5 (2019) (drawing attention to the ethical concerns associated with technologies such as one Neurolink proposes).

72. Emmanuelle Robin, *The Neuralink Project: Explanation And Human Benefits Of Brain*-Machine *Interfaces*, MEDIUM (Sept. 10, 2019), https://medium.com/1-one-infinity/the-neuralink-project-explanation-and-human-benefits-of-brain-machine-interfaces-500cb30ccff.

73. *Id.*

74. Elon Musk, *An Integrated Brain-Machine Interface Platform With Thousands Of Channels*, 21 J. MED. INTERNET RSCH. 1, 6 (2019).

75. Robin, *supra* note 72.

For instance, in the US market, the key players include EMOTIV, Neurosky Inc., and Natus Medical Incorporated.[76] In terms of regional development of the BMI technology, the United States currently dominates the market with Asia Pacific projected to show the highest growth rate between 2020 and 2027.[77] That is, there is a high rate of adoption of BMI within healthcare in these regions where such diseases as Alzheimer, and Parkinson has steadily increased in recent decades and are projected to rise in coming years.[78] Other parts of the world witnessing a moderate adoption of BMI technology are in nations such as Saudi Arabia in the Middle East and South Africa in the African Countries.[79] Other countries adopting this technology, include those from South America including Brazil and Mexico.[80]

VI. Challenges Associated with BMI Technology

Despite BMI being an important technology in the current digital era, it presents numerous challenges. Non-invasive EEG lacks a robust sensor for measuring brain signals efficiently and at high fidelity.[81] The signal acquisition hardware requires a continuous upgrade for non-mobile applications and the BMI interfaces have poor reliability when applied in studying brain activity.[82] Furthermore, the BMI is required to offer a real-time execution of brain assessment, where an effective use of the BMI technology necessitates training for users and facilitators.[83] In particular, the Non-invasive EEG requires adequate training on how to use and monitor it regularly to ensure quality results are obtained.[84] Such training is time-consuming as the user must be taken through the procedures and recorded sessions thoroughly.[85] Information transfer rate (ITR) can be measured using time, the number of classes, and accuracy.[86] Signal to noise ratio is one of the barriers to achieving high ITR since it can lead to inaccurate detection of targeted signals as the ITR increases the number of class upsurges, making it complex to manage class distribution.[87] Many P300

76. Brain Computer Interface Market Size, Share & Trends Analysis Report By Product (Invasive, Partially Invasive, Non-invasive), By Application (Healthcare, Communication & Control), By End-use, And Segment Forecasts, 2020 – 2027, GRAND VIEW RSCH. (Feb. 2020), https://www.grandviewresearch.com/induindu-analysis/brain-computer-interfaces-market [hereinafter BCI Report]; IDEO: Epoc Headset for Emotiv, Emotiv, https://www.emotiv.com/news/ideo-epoc-headset-for-emotiv/ (last visited Mar. 3, 2021).

77. *BCI Report*, *supra* note 76.

78. *Id*.

79. *Id.*

80. *Id*.

81. Sundararajan, *supra* note 30, at 41.

82. *Id.* at 42.

83. *Id.*

84. *Id.* at 41.

85. *Id.* at 42.

86. *Id.*

87. Ramadan & Athanasios, *supra* note 10, at 40.

BMIs are likely to be ineffective among persons unable to control their gaze, and this is a hindrance in its application among users with a severe disability.[88] For the effective performance of the BMI interfaces, the above challenges ought to be addressed appropriately.

VII. Ethical Facets of Incorporating Brain-Machine Interfaces (BMI)

The incorporation of BMI presents challenges particularly due to the threats and risks the invention poses to societies and individuals. The human body is complex enough to make the outcomes of implanting microchips hardly predictable. It is difficult to guarantee that physical and mental health will not change dramatically after microchips become implanted under the skin.[89] Also, as long as microchips have a program that computer engineers design to support various functions, it is obvious that the program might change. Furthermore, the influence of BMI on personality development is outstanding, which means that mental integrity, personhood, and mind-reading could change in any direction because of microchips' insertion.[90] Microchips are most likely to expose personal information, including memories, emotions, feelings, and thoughts, leaving the unprotected to hackers, employers and governments among other parties who might use such data for malicious activities.[91] The ethical impact of integrating BMI also extends to the overall society. The implantation of microchips in people may result in increased dependence on technology, as the case in today's technology, where people no exhibit extensive desire to communicate with each other directly.

An example of technology dependence is illustrated by the rise of the internet and smartphones.[92] BMI may worsen this situation because it will allow people to merely establish a connection with the minds of others and begin to communicate with others, thus limiting real life and face-to-face communication. At the same time, the loss of productivity and its effects on society due to the increased dependence and addiction to technology also indicates another issue associated with BMI.

VIII. Legal Solutions

Currently, the legal background of protecting humans from the potentially adverse effects of BMI is weak.[93] In Canada and the United States, the safeguarding of

88. Fazel-Rezai et al., *supra* note 23, at 12.

89. Sasha Burwell et al., *Ethical Aspects Of Brain Computer Interfaces: A Scoping Review*, 18 BMC MED. ETHICS 1, 4 (2017).

90. *Id.* at 5, 8.

91. *Id*. at 8.

92. Debra S. Dwyer et al., *Technology Use: Too Much of a Good Thing?* 48 ATL. ECON. J. 475, 476 (2020).

93. Anastasia Greenberg, *Inside The Mind's Eye: An International Perspective on Data Privacy Law In The Age Of Brain-Machine Interfaces*, SOC. SCI. RSCH. NETWORK 1, 2, 25–27 (2018).

people's privacy has significant gaps because of the lack of constitutional protection of health-related data.[94] In contrast, the European Union protects more precisely with the people's right to not be subjected to analysis of crucial information, the right to an explanation, and the right to be forgotten.[95] In this way, the improvement of legal solutions to the potentially harmful effects of microchips is necessary. Robotics and AI demand liability of owners who utilize ground-breaking technologies. As such, Neuralink among other corporations that create AI products, must be legally liable for the consequences of integrating microchips into the human brain. The human rights law that the United Nations regulates should be improved by adding an act that would protect people from AI's negative influence.[96] Finally, it is necessary to expand the data privacy law, which should forbid collecting and using personal information, including brain data.

IX. Analysis of BMI using Technology Assessment

The analysis of BMI is done using the technology assessment tool.[97] Technology assessment has been adopted in evaluating emerging technologies,[98] in this case, the BMI technology. Technology assessment is a communicative, scientific, and interactive process aimed at contributing to knowledge about the political and public opinion of societal aspects associated with technology.[99] In the early years of technology assessment studies, the concept was regarded as a kind of policy research examining long and short-term ethical, legal, or economic effects that can be linked to a given technology.[100] For instance, technology assessment was introduced as a way to inform policy makers on policy alternatives regarding emerging technologies to protect societies.[101] The process embraces different policy analysis techniques to analyze the application of new technology.[102] The overall goal of technology assessment is to offer policymakers alternatives to guide the application of new technologies.[103] In the 1960s, technology assessment was used to give parliamentarians a prediction of the negative effects of technologies.[104] Now,

94. *Id.* at 19.

95. *Id*.

96. U.N. Secretary-General, *Promotion and Protection of the Right to Freedom of Opinion and Expression*, ¶ 20, U.N. Doc. A/73/348 (Aug. 29, 2018).

97. Velloso, *supra* note 1, at 60.

98. *Id.*

99. *Id*.

100. *Id.*

101. *Id.*

102. Arie Rip, FUTURES OF SCIENCE AND TECHNOLOGY IN SOCIETY: CONSTRUCTIVE TECHNOLOGY ASSESSMENT 99 (2018).

103. Velloso, *supra* note 1, at 60.

104. *Id*.

technology assessment helps in understanding the response to problems existing between society and technology. The consequences and conditions for implementing technology are systematically evaluated using technology assessment. Furthermore, technology assessment becomes fundamental when seeking the integration of available knowledge to the decision making used to implement and adopt technologies.[105] Also, technology analysis helps in understanding the benefits and impacts of such technologies and the need to emphasize strategies to address anticipated risks.[106] Finally, technology assessment is important since it highlights the need to solve societal conflicts linked to technology and its associated problems.

BMI was assessed to determine uncertainty that is likely to permeate any debate presently and in the future using the constructive technological assessment.[107] Emerging technologies such as BMI have been described as those that arise due to the innovative application of existing information leading to the rapid growth of new capabilities, opportunities for solving societal issues, and the capability to disrupt existing industries.[108] Technology assessment was applied in this study since BMI is in its earlier stages of development to predict any uncertainties now and in the future that are likely to affect its adoption and implementation in different fields. BMI is likely to experience many challenges in the future as an emerging technology. Constructive Technology Assessment (CTA) is a recently introduced technology assessment method focused on improving evaluation, understanding, and use of technology development.[109] CTA is the best approach for analyzing the current perspectives and potential BMI effects. The method was selected because it can help system developers to bypass the Collingridge dilemma.[110] The Collingrige dilemma suggests that controlling technological development direction is hard due to many opportunities at the inception of new technology.[111] The CTA helps develop and test scenarios that are likely to affect different aspects of new technologies. The main aim of conducting CTAs is to establish responsible innovation. The new technology should address the most pressing individual and societal issues while preventing potential implications and unprecedented consequences. Responsible innovation also factors in ethical considerations associated with new technology. In this regard, technology assessment is applied in understanding the benefits and ethical issues surrounding BMI technology. The tool is applied in understanding the current

105. Lukasz Nazarko, *Future-Oriented Technology Assessment*, 182 PROCEDIA ENG'G 504, 506 (2017).

106. *Id*. at 505.

107. Velloso, *supra* note 1, at 62–3.

108. *Id*. at 62.

109. *Id*. at 63.

110. Audley Genus & Andy Stirling, *Collingridge and the dilemma of control: Towards responsible and accountable innovation*, 47 RESEARCH POLICY 61, 65 (2018).

111. *Id*.

perspectives on BMI, followed by potential benefits and risks of the new technology and BMI technology's legal framework.

X. Current Perspectives on BMI

BMI is also known as Brain-Computer Interface (BCI), a communication technology between users and systems.[112] It is one of the alternative methods of communication and control of the human brain.[113] Further, BMI has been described as a form of divulgation between the human brain and the digital computer.[114] BMI is also defined as a type of software and hardware communication system that enables people to interrelate with their environs without the use of muscles and peripheral nerves.[115] Instead, BMI facilitates this communication through interactions by control signals generated from electroencephalographic activity.[116] Another significant definition of BMI is Elon Musk's Neuralink, which is a type of interface through which people can connect themselves to any machine capable of reading the inputs from the brain.[117] BMI works by observing the state of the user or enabling the user to deliver the ideas.[118] The BMI system then records the brain waves sending them to a computer system to complete the intended task, enabling the expression of an object's ideas or control.[119] There are two main methods involved in the BMI tech, invasive and non-invasive.[120]

Its historical analysis provides a further understanding of BMI. The concept of this technology began with the work of Hans Berger, who discovered the connection between electrical activity within the human brain and the development of electroencephalography (EEG).[121] Early examples of a developed BMI technology includes a piece of music for solo performance by Lucier, an American composer,[122]

112. Sarah Abdulkader et al., *Brain Computer Interfacing: Applications and Challenges*, 16 EGYPTIAN INFORMATIES J. 213, 214 (2015).

113. Poonam Chaudhary & Rashmi Agrawal, *Emerging Threats to Security and Privacy in Brain Computer Interface*, INT'L J. OF ADVANCED STUD. OF SCI. RSCH 3 (12), 340 (2018).

114. Naila Naz et al., *Ethical Issues of Brain-Computer Interface*, 18 INT'L J. OF COMPUT. SCI. AND NETWORK SEC. 21, (2018).

115. Luis Fernando Nicolas-Alonso & Jamie Gomez-Gil, *Brain Computer Interface: A Review*, 12 SENSORS 1211, (2012).

116. *Id.*

117. Kulshreshth, *supra* note 71, at 2.

118. *Id.*

119. Abdulkader et al., *supra* note 112.

120. *Id.* at 219.

121. Geeta Sharma et al., *A Detailed Study of EEG Based Brain Computer Interface*, Proceedings of the First International Conference on Information Technology and Knowledge Management pp. 137–143, 2017.

122. Anton Nijholt, BRAIN ART: BRAIN-COMPUTER INTERFACES FOR ARTISTIC EXPRESSION 85, 86 (2019).

and an initial peer-review publication regarding the topic was by Professor Jacques Vidal.[123]

XI. Current Applications of BMI

Major applications of BMI have been explored in the existing literature. The focus of such applications has been directed to the medical field.[124] The medical field has several applications that can benefit from knowledge on brain signals in several phases, such as prevention, detection, diagnosis, and restoration. Therefore, BMI has the potential to provide help to many people with a variety of clinical disorders.[125] First, prevention BMI is beneficial because it can enable assessment of conditions revealing how they can be prevented. For instance, there has been an increased investigation into the effects of smoking and consuming alcohol and how BMI can prevent the possibility of losing function.[126] The study of concentration levels is also a field of research facilitated by BMI to help prevent accidents. The use of BMI in detection and diagnosis through mental state monitoring functions of the technology is also used for forecasting and detecting of health issues such as seizure-related disorders (epilepsy), brain structured conditions (brain tumor), and brain swelling conditions (encephalitis).[127] Brain tumors that come about from uncontrolled self-dividing cells can be discovered through Electroencephalography (EEG) as well as sleep disorders that can also be detected using BMI.[128] For instance, EEG signals can be employed to identify idiopathic rapid-eye-movement (REM), sleep behavior disorder (iRBD), which is also identified as an early sign for Parkinson's disease (PD).[129]

The application of BMI in rehabilitation and restoration entails various cases. For instance, BMI can enable mobility rehabilitation, a form of physical rehabilitation that allows patients with mobility problems to recover their lost functions, thereby regaining their previous mobility levels.[130] This can also include at least helping these patients to adapt to their disability. This is commonly utilized for patients who have had a stroke when the brain cells die because of lack of oxygen, causing them to lose the ability to speak and have memory problems.[131] BMI technology is also used in the development of robots such as mobile robots that can provide locked-in persons

123. *Id*. at 66.
124. Chaudhary & Agrawal, *supra* note 113, at 342.
125. Musk, *supra* note 74, at 1.
126. Abdulkader et al., *supra* note 112, at 215.
127. *Id.*
128. *Id*.
129. Sharma et al., *supra* note 121, at 137.
130. Abdulkader et al., *supra* note 112, at 216.
131. *Id*.

to conduct their daily activities as in the case of stroke patients who cannot recover their previous abilities.[132]

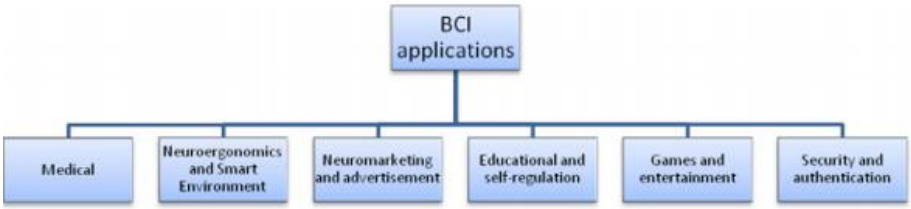

Figure 1: BCI application fields
Source (Abdulkader, Atia and Mostafa 2015)

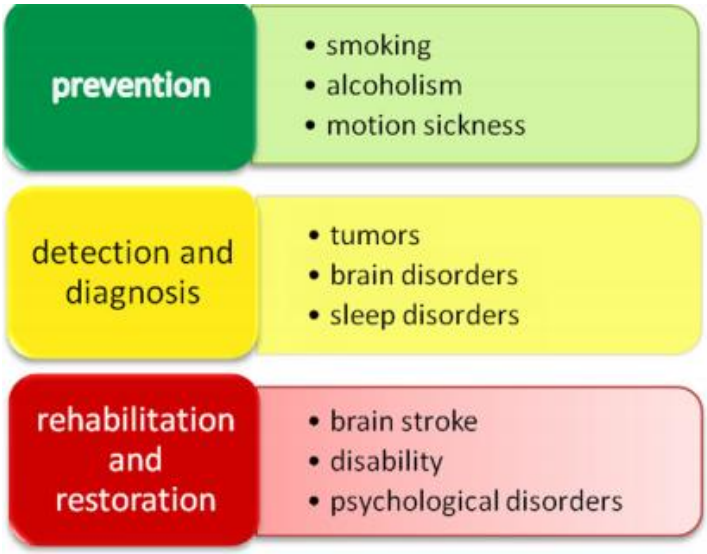

Figure 2: Usage of BCI in medical field phases
Source: (Abdulkader, Atia and Mostafa 2015)

At the same time, BMI technology has non-medical applications. Neuroergonomics and the smart environment is an example of a non-medical area in which BMI is used.[133] Some of the samples of this are illustrated by the smart environment applications such as transportation, work environment, and workhouses

132. *Id.*

133. Abdulkader et al., *supra* note 112, at 216.

that use BMI to provide efficiency, safety, and physiological control to daily life. BMI usage in the workplace includes improving work conditions by analyzing mental fatigue and task time.[134] BMI is used to assess drivers' behavior, given that fatigue and distraction are major causes of accidents within the transport sector.[135] For instance, EEG signals can detect fatigue and alcoholic drivers.[136]

Games and entertainment also represent another non-medical area that has benefited significantly from BMI technology.[137] This is possible by combining features of existing games and brain controlling capabilities to provide multi-brain entertainment.[138] EEG based BMI interfaces have been adopted widely in helping disabled people to interact with machines. Moreover, such technologies are being utilized in the gaming industry as controllers.[139] Games using the BMI technology involve neurofeedback in which EEG signals are conveyed to the users in real-time. Many games involving neurofeedback have shown potential effects in healing people affected by attention deficit hyperactivity condition. The games follow two stages, signal processing and implementation. Most EEG-based games software work on three principles, ready games, roll your own, and point and click principles.[140] EEG-based games serve the purpose of improving the mental thinking capacity of people. Cortical firing is often employed among non-mobile users to translate the output device.[141] Suggested new gaming technology, kinetic, is a form of computer gaming only for non-disabled individuals. Limb movement activity patterns and EEG data are divided using the kinetic sensor.[142] The Arena game was recently launched which entails shooting fireballs using the mind and necessitates user training with specific actions to ensure they can play.[143] The Arena game has different variations that have been developed by other companies.[144] In this game, players can score goals by imagining hand movements.[145]

The development of EEG headsets has significantly transformed the gaming environment. Thoughts are involved without touching or using a mouse of the

134. Lotte et al., *Brain-Computer Interfaces: Beyond Medical Applications*, 45 COMPUTER 26, 28 (2012).

135. *Id*.

136. Abdulkader et al., *supra* note 112, at 217.

137. *Id*.

138. *Id.*

139. Qiang Wang et al., *EEG-based "Serious Games" Design for Medical Applications*, INT'L CONF. ON CYBERWORLDS 270, 270 (2010).

140. *Id*.

141. Scherer, Reinhold, et al., On the use of games for noninvasive EEG-based functional brain mapping, 5*IEEE Transac. on Comput. Intel. and AI in Games,* 155, 156 (2013).

142. Sundararajan, *supra* note 30, at 37

143. *Id*.

144. *Id*. at 37–38.

145. Shiv Kumar Mudgal et al., *Brain computer interface advancement in neurosciences: Applications and Issues*, INTERDISCIPLINARY NEUROSURGERY, June 2020, at 1, 6.

keyboard. The gaming environment offers a relaxed experience to the players, where users play brain-ball games and brain activity is measured in real-time, and playing opportunities are given except when players are in a relaxed state.[146] Such games have found major applications in helping relieve stress and support the control between relaxation and stressful states.[147] Research into BMI in the gaming industry has also focused on epileptic teenagers in which the Space Invaders game was developed.[148] The BMI interfaces employs motor imagery to enhance the game playing experience when playing games such as Ms. Pac-Man, Pong, and Tetris.[149] EEG-based game users are required to push, arrange, and rotate stones to form a recreated structure.[150] Such games are significantly transforming the lives of populations with neurological strains.

	Body of research	Societal relevance	Economic viability	Price sensitivityof consumers/customers	Time to market
Control of devices	+/-	-	-	-	5-10 yrs
User state monitoring	-	+	+	+/-	3-5 yrs
Evaluation	-	-	+/-	+/-	1-3 yrs
Training and Education	-	+	+	+/-	3-5 yrs
Gaming and entertainment	+/-	-	+	+	now
Cognitive improvement	-	+/-	+	+	3-5 yrs
Safety & Security	-	+/-	-	+/-	5-10 yrs

Figure 3: Overview of non-medical BCI applications and their ratings (- denotes low, +/- denoted moderate, + denotes high).

Source: (Lotte and Tangermann 2012)

XII. BMI's Potential Benefits and Dangerous Effects

Some of the most significant benefits and potential risks associated with the BMI technology. This section will first explore the potential benefits,[151] followed by the dangerous effects or risks of BMI technology.[152]

146. Sundararajan, *supra* note 30, at 38.

147. *Id*.

148. *Id*.

149. Anton Nijholt et al., *Turning Shortcomings into Challenges: Brain Computer Interfaces for Games*, 1 ENT. COMPUTING 85, 88 (2009).

150. *Id*.

151. *See* discussion *infra* Section XI.A.

152. *See* discussion *infra* Section XI. B.

A. Potential Benefits

BMI is in the developmental stage and is expected to offer numerous benefits to different users across a wide spectrum of fields. The most significant BMI benefits include its ability to offer smart technology, promote telepresence, and capacity to minimize accidents.[153] Since BMI has transformed passive devices into active and smart devices, it is deemed advanced technology. One such smart and active device is prosthetics used to replace, correct, or support different body parts.[154] For instance, dentures can be used to replace teeth to enhance chewing. Also, using BCI-controlled communication devices, deaf and mute individuals can communicate with each other. Another key benefit of BMI technology is its ability to allow people to express themselves widely using telerobotics. For example, BMI can be employed in military settings to enable staff to monitor any suspicious activity within the military borders and combat such activity before affecting military productivity and performance.[155] The last important benefit associated with BMI technology is its ability to prevent accidents. Car-related accidents are the cause of many deaths across the world. With the use of BMI-enabled cars, the driver's thoughts are examined in a matter of seconds to prevent any form of accident from occurring.[156] Nissan, the automobile manufacturing company, is engaging in continuous research and development linked to BMI-enabled cars to develop a system that is likely to slow cars or turn the steering faster than the driver after sensing danger.[157] Regardless of these benefits, BMI technology has numerous associated risks as discussed below.

B. Dangerous Effects

Technological improvements and innovations penetrate the modern world, but the outcomes of new digital solutions are not always beneficial. While BMI results in several benefits,[158] there are also several risks to its application that cannot be disregarded on individuals and society. Failure to properly connect the BMI technology directly to the human brain may negatively affect the users.[159] Some of the fundamental risks include the inaccuracy of outcomes, uncomfortable user experience, health risks, and insecurity.[160] For many years, it has been difficult to understand the human brain and what transpires to make certain moves. This is a

153. Naveen Joshi, *Exploring The Benefits And Risks Of Brain Computer Interface*, ALLERIN (Sept. 1, 2019), https://www.allerin.com/blog/exploring-the-benefits-and-risks-of-brain-computer-interface.

154. *Id.*

155. *Id*.

156. *Id*.

157. *Id*.

158. Joshi, *supra* note 153.

159. *Id.*

160. *Id*.

possible occurrence due to the complex nature of the brain.[161] Using BMI technology will not be any different from this situation because it is unlikely to interpret brain signals effectively, thus misinterpreting users' intentions. For example, if the BCI fails to identify intentions of raising the index finger, a disabled person may raise the middle finger when using a prosthetic.[162] In this regard, inaccurate outcomes are the greatest risk of using BMI technology to make life difficult. When using BMI technology, numerous connections are involved, and this makes users have an uncomfortable experience. In particular, the bulkiness of the BMI technology due to numerous wires connecting the user to the computers puts more pressure on the user.

Health risks are also associated with BMI technology. The application of BMI can encompass the implantation of electrocorticography (ECoG) to decode motor cortical signals.[163] While these electrodes are preferred for use in this manner, they pose a risk to those who are implanted with them. Particularly, Electrocorticography (ECoG) poses the risk of hemorrhage and infection.[164] The risk of BMI is further illustrated in the case whereby microelectrode arrays bring about the issue of biocompatibility between the implanted objects and the surrounding tissues. That is, there is the possibility that the electrodes may result in a change of this tissue despite its neutral nature. Such changes may be salutary even more if they result in the necessity for neuroplasticity and the generation of new neuronal connections. A further explanation of how bleeding may come about is through the application of invasive methods of BMI that can cause damage to tissues within the brain, resulting in the formation of the Glial scar.[165] This is a method through which the body is attempting to repair its tissue, which can prove fatal in situations, where the brain is involved by causing further brain damage.[166]

Finally, security is an essential element when applying technology to shape life activities. The lack of security and privacy is yet another risk of BMI. Data security may not be guaranteed when using BMI technology, as will be analyzed later.[167] The computerized nature of BMI places users at risk of their minds becoming easily decoded, resulting in privacy invasion.[168] Moreover, by using this technology, any

161. Naz, *supra* note 114, at 21.

162. Joshi, *supra* note 153.

163. Sharma, *supra* note 121, at 139.

164. Nicolas-Alonso et al., *supra* note 114, at 1214. *See also* Winston Chiong, et al., *Neurosurgical Patients as Human Research Subjects: Ethical Considerations in Intracranial Electrophysiology Research*, NEUROSURGERY, Jul. 2018, at 1, 8–9.

165. Kulshreshth, *supra* note 71, at 2. *See also* Cristina Marin & Eduardo Fernandez, *Biocompatibility of Intracortical Microelectrodes: Current Status and Future Prospects*, FRONT NEUROENGINEERING, May 28, 2010, at 1, 3.

166. Joseph W. Salatino et al., *Glial Responses to Implanted Electrodes in the Brain*, NATURE BIOMEDICAL ENG'G., Nov. 2017, at 862, 865.

167. Naz, *supra* note 114, at 23. *See also* Chaudhary & Agrawal, *supra* note 112, at 342.

168. *Id.*

person can understand what another person is thinking without their consent. For instance, by reading the mind of military personnel, a hacker can uncover confidential information.[169] Given that researchers indicate that attackers can rewrite the memories in the minds of people in the coming years, this is a major anticipated risk for the future.[170] Such possibilities demonstrate the sensitivity of the matter and grave risk the field presents, emphasizing the need to ensure effective security within the exploitation of BMI.[171] Increasing awareness of this risk could help adopters of BMI technology use such technologies to achieve their desired objectives.

The issue of privacy is further illustrated in the United Nations (UN) Special Rapporteur analysis of AI's impact on human rights of 2018.[172] One of the key problems noted in the document is the loss of human supervision.[173] Currently, AI is governed by humans. However, there is fear that future development may result in humans losing control of this technology and instead become governed by it, causing a risk to transparency and accountability.[174] Furthermore, there is the possibility that AI may have an impact on freedom of expression and opinion.[175] AI may be used to incentivize promotion and recommendations of various forms of inflammatory content to sustain user engagement online.[176] Social media companies and other online-based companies that depend on user engagement for advertising and sales can abuse this function.[177]

BMI, as in the case of emerging technology, also presents several risks to society. Unfortunately, most literature on the risk of this technology has placed most focus on the risks to individuals with almost no mention of BMI's risk to society. However, these risks can be assessed from the viewpoint of the risk of technology in society. One of these risks is connected to the likelihood of BMI emerging as a basis for human life. Thus, this technology may become an integral aspect of human interaction and communication, destabilizing community relations. Therefore, social relations are prone to be impacted by BMI, as illustrated by the rise of new inventions such as social media.[178] This is even more likely if researchers find a way of linking BMI to the internet.

169. Joshi, *supra* note 153.

170. *Id.*

171. Chaudhary & Agrawal, *supra* note 113, at 342–343.

172. United Nations, *Promotion And Protection Of The Right To Freedom Of Opinion And Expression* (2018) 1–21, *at* https://freedex.org/wp-content/blogs.dir/2015/files/2018/10/AI-and-FOE-GA.pdf.

173. *See id.*at ¶ 8. One of the key problems noted in the document is the loss of human supervision.

174. *Id.* (arguing that the lack of clear-cut policies regarding AI technologies worsens the problem).

175. *Id.* at ¶ 27–32.

176. *Id*. at ¶ 12.

177. *See generally* United Nations *infra* note 171 (believing corporations such as social media can exploit the BMI tech for their marketing advantage).

178. *See* Younes, *supra* note 2, at 82.

The risk of advanced BMI and its connection to the internet can also increase time wastage among people and spread unauthenticated information that will impact communities.[179] This can result in society becoming affected by such information's negative effects, including increased hate amongst people.[180] The possibility of a rise in conflict amongst people is a social risk that can come about from BMI advancement.

XIII. The Current Legal Framework of BMI

A. General Legal Framework in the US and Canada

The U.S. and Canada are amongst global nations that have yet to establish an effective legal framework for BMI.[181] First, the US regulation on BMI use has mainly been made through the Food and Drug Administration (FDA). This is mainly because of the major use of BMI technology in the medical field.[182] The FDA is an organization that regulates the type of medical devices that are used. In particular, such devices must show valid scientific evidence that it is equivalent to a legally marketed device.[183] To add, the device's gains must outweigh the risks.[184] Some laws currently touch on aspects of BMI and neurotechnology data protection. One of these laws is the 2019 John S. McCain National Defense Authorization Act for Fiscal Year 2019 which requires more action regarding AI.[185] Individual states have also adopted several regulations to protect against the negative effects of poor data protection relating to AI. For instance, the State of Nevada developed the first legislation regarding the testing of autonomous vehicles.[186] This generalization of available policies on AI demonstrates inefficiency, whereby, they do not present any implications on the protection of brain data.

The regulation of BMI technology in Canada is clearly indicated under regulations for AI. The Canadian tech sector is vast, which contributes considerably to its development, and for this, the country greatly depends on it for its development,

179. *See id.*

180. *See id.*

181. Greenberg, *supra* note 93, at 80.

182. *See* Nijholt et al., *supra* note 149, at 85.

183. *Learn if a Medical Device Has Been Cleared by FDA for Marketing*, FDA, https://www.fda.gov/medical-devices/consumers-medical-devices/learn-if-medical-device-has-been-cleared-fda-marketing (last updated Dec. 29, 2017).

184. *Id.*

185. Law Libr., *Regulation of A.I.: The Ams. and the Caribbean*, LIBR. OF CONG., https://www.loc.gov/law/help/artificial-intelligence/americas.php (last updated Dec. 30, 2020). *See also* Joel Rose, *Canada Wins, U.S. Loses in Global Fight for High-Tech Workers*, npr, (Jan. 27, 2020, 5:00 AM), https://www.npr.org/2020/01/27/799402801/canada-wins-u-s-loses-in-global-fight-for-high-tech-workers.

186. *Id.*

including its economic growth.[187] Thus, the Canadian government has invested heavily in this sector although little focus is directed towards AI regulation and only intermediate level of personal data protection is provided.[188] Nonetheless, some considerable efforts have been directed towards issues of privacy and transparency concerning electronics as per the implemented Personal Information Protection and Electronic Documents Act (PIPEDA).[189] Consent is an essential element of the PIPEDA, indicating organizations must obtain consent before collecting data.[190] While the PIPEDA is an essential law towards protecting people's privacy, it is yet to touch on brain-related data like BMI and other forms of neurotechnology.[191] This indicates the essence of undertaking additional studies on the legality of this data and makes improvements to PIPEDA.

Accordingly, the US and Canada need to increase their efforts to enhance their legal framework of BMI and facilitate brain data protection. Their current laws are not sufficiently explicit regarding issues of BMI and other forms of neurotechnologies. This general nature of the laws, including the overall focus on AI, is a serious threat to users' wellbeing. Nonetheless, these technologies also present substantial benefits to the human population, not only those with clinical needs but also the advancement of the specie.

B. Countries with the Most Advanced Laws and Regulations on BMI

Europe has strived to implement an effective legal framework of BMI. This is illustrated by the enactment of the EU GDPR that came into effect in May 2018.[192] This policy regulates the field of robotics and AI.[193] The EU GDPR was developed in a way that created a specific legal status for robots, and could, in the long run, regulate the AI world in the event the establishment of the most sophisticated robots occurs.[194] The EU GPDR policy includes those which may have the same status as that of electronic person protection of people's information must remain significant.[195] The continuity nature of this law is quite significant because it

187. Law Libr., *Regulation of A.I.: The Ams. and the Caribbean*, LIBR. OF CONG., https://www.loc.gov/law/help/artificial-intelligence/americas.php (last updated Dec. 30, 2020). *See also* Joel Rose, *Canada Wins, U.S. Loses in Global Fight for High-Tech Workers*, npr, (Jan. 27, 2020, 5:00 AM), https://www.npr.org/2020/01/27/799402801/canada-wins-u-s-loses-in-global-fight-for-high-tech-workers.

188. *Id.*

189. Greenberg, *supra* note 93, at 103.

190. *Id*. at 105.

191. *Id*. at 107.

192. Gauthier Chassang, *The Impact of the EU General Data Protection Regulation on Scientific Research*, ECANCERMEDICALSCIENCE, Mar. 1, 2017, at 1, 1.

193. *See generally id.*

194. *Id*. *See also* Robert van den Hoven van Genderen, *Privacy and Data Protection in the Age of Pervasive Technologies in AI and Robotics*, 3 EUR. DATA PROT. L. REV. 338, 346 (2017).

195. *See* Chassang, *supra* note 193; s*ee also* van den Hoven van Genderen; *supra* note 195.

demonstrates the degree of commitment to the protection of people's data despite the advancement in technology as per the case of BMI.

C. Countries with No Laws and Regulations on BMI

Asia is a region whose general legal framework regarding the management of data is weak.[196] Therefore, this is a region in which BMI and brain data protection is an issue that is yet to be addressed in any significant legal framework among nations from the region. An assessment of the laws in China demonstrates this gap. Like many nations of the world, China has established several laws relating to the management of AI as per its long-term AI development plan.[197] While there has been all this focus on AI development, China has considerably neglected the area of protection of data that emanates from this, including brain data. In fact, there is little recognition of BMI and neurotechnology, including their potential negative effects relating to data protection and privacy. India is another example of an Asian nation with no laws and regulations on BMI technology and data protection. In fact, India has no current laws or any government-issued guidelines on applying AI in the country.

African nations are also yet to establish any considerable legal BMI framework.[198] This state can be blamed on the reality that the matter is yet to be recognized as an issue within these nations, given their slow technological advancement. However, borrowing from the tech growth happening in other parts of the globe and the inevitable possibility of BMI application by people from these nations, a BMI legal framework remains a critical issue.

For these countries with no legal framework to protect against BMI's negative effects, the solution for this can entail their respective legal institutions to bring about change. Accordingly, there are several legal aspects that they will need to consider to effect this change. One of these aspects is the need to ensure the protection of human dignity. This is a legal concept that must be adhered to towards developing laws to facilitate BMI ethics adherence. Particularly, this is essential for preventing people from becoming controlled biological devices. The right to privacy is another legal aspect that the legal institutions in these countries will need to consider.[199] Thus, the laws that will be developed should define the best way of safeguarding this particular right.

196. Sarah Pearce & Paul Hastings, *Data Privacy in Asia Pacific: A Fragmented Landscape*, REGUL. ASIA (Dec. 10, 2019), https://www.regulationasia.com/data-privacy-in-asia-pacific-a-fragmented-landscape/.

197. *See generally* Karman Lucero, *Artificial Intelligence Regulation and China's Future*, 33 COLUM. J. ASIAN L. 94 (2019).

198. Clayton Besaw & John Filitz, *AI & Global Governance: AI in Africa is a Double-Edged Sword*, UNITED NATIONS UNIV. (Jan. 16, 2019), https://cpr.unu.edu/publications/articles/ai-in-africa-is-a-double-edged-sword.html.

199. *Id.* at 204–05.

D. International Legislation on Legal Framework of BMI

International legislation can be employed to tackle the gap in laws and regulations on BMI. For instance, the OECD council has adopted nine principles to ensure responsible innovation within neurotechnology which serves as the first standard international law within this given field.[200] Specifically, these principles target and serve as a direction for governments and innovators in addressing the key ethical, social, and legal problems that come about following the exploitation of neurotechnology. This is to take place while also promoting innovation within this field of technology. The main areas that these principles touch on include safety, responsible innovation, dealing with unintended misuse, and facilitating oversight and advisory bodies.[201] Another essential area is fostering inclusivity, allowing for scientific collaboration, promoting culture, and enabling scientific collaboration.[202]

1. Neurorights

Neurorights represent a new set of human rights meant to address the challenges posed by AI systems such as BMI and their application.[203] Particularly, these rights are meant to guide for what and when it should be unlawful to access or meddle with one's individual neural operations or another person's.[204] These rights are furthermore significant since currently there are insufficient ways of addressing the various legal and ethical problems related to the advancement of BMI.

2. The Right to Cognitive Liberty

The above right is meant to provide people with the fundamental freedom to reach liberal and proficient judgments concerning BMI and other types of neurotechnologies. Accordingly, any competent adult reserves the right to use BMI for clinical reasons.

However, this should occur provided these persons are not infringing on other persons' liberties. Further, this is a right that protects people from any possible coercive applications, including the coercive ones. This right's significance is to

200. *Recommendation of the Council on Responsible Innovation in Neurotechnology*, OECD (last visited Mar. 31, 2020), https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0457. *See also* Greenberg, *supra* note 93, at 19.

201. *Id.*

202. OECD, *supra* note 202.

203. Rafael Yuste et al., *Four Ethical Priorities for Neurotechnologies and AI*, 551 NATURE 159, 162 (2017). – "and colleagues" on p.1 of source as well as link identifies more authors.

204. *See generally* Marcello Ienca & Roberto Andorno, *Towards New Human Rights in the Age of Neuroscience and Neurotechnology*, 13 LIFE SCI., SOC'Y. AND POL'Y. 1 (2017).

prevent future scenarios involving people becoming in danger of having their mental state manipulated by the state, malevolent actors, and large corporations.[205]

3. The Right to Mental Privacy

This is a right that will allow persons to seclude neural information, therefore protecting it from potential uncensored manipulation. Thus, as a consequence of these rights, users of BMI will be able to maintain control of their behavior without the worry of the potential rupture of their identity.[206] This is quite a significant right to guarantee users of BMI, given that they are at a higher risk of experiencing breaches in mental privacy in comparison to other forms of information privacy. The reason for this lies in the limited extent of voluntary control of the signals of the brain.[207]

4. The Right to Mental Integrity

The mental integrity right is expected to be enforced in instances involving uncensored manipulation of the neural performance leading to physical and mental injury to BMI users. This right has become universally adopted by the international law. This is illustrated by Article 3 of the European Union's Charter of Fundamental Rights.[208] Nonetheless, there is some insufficiency about this because it is expressed as an overall right towards access to psychological welfare services. This means it lacks any specific provisions concerning the misuse of neurotechnology such as BMI leaving users vulnerable. Thus, it is imperative to have a reconceptualization of these rights so that their goals become more than merely protecting people from mental illness, and demarcating the domain of any manipulation of individuals in the neural process.

5. The Right to Psychological Continuity

The right to mental continuity is recommended to guide towards dependable incorporation of BMI control, therefore, ensuring the preservation of sense of agency of populations and individual identity, usually assumed to be the continuity of one's mental life from any possible uncensored manipulation.[209] This is significant because it will allow BMI users to retain power over their behavior and thus not experience any feelings of control loss, including any potential rupture of their personal identity.[210] It is also essential to point out that this right will protect BMI users from

205. Yuste, *supra* note 205, at 162. – "and colleagues" on p.1 of source as well as link identifies more authors.

206. *Id.*

207. *See id.*; Ienca & Andorno, *supra* note 206, at 14.

208. Ienca & Andorno, *supra* note 206, at 18.

209. *Id.* at 20–23.

210. *Id.*

uncensored interventions conducted by third parties.[211] This is a concept that has been taken into consideration within matters of military studies and national security. However, there remains much to be tackled concerning individuals.

6. The IPR over Inventions created by machines

The intellectual property rights over inventions created by machines are currently under development. There are no laws yet that provide machines rights to patent inventions created by them. For instance, a historic ruling was made in the EU regarding naming an AI system as an inventor.[212] The applicant Dr. Stephen Thaler had filed a patent application (EP 18 275 163) in which he sought for DABUS, a system of AI, to be recognized as the inventor as per the information he presented in form 1002.[213] The argument of Dr. Thaler was DABUS was the inventor because the AI system had identified the novelty of its own idea way before a natural person did this.[214]

The application was denied since it failed to meet the requirements that required a natural person to be indicated as the inventor.[215] Therefore, DABUS could not be recognized as the inventor because the AI system was not a natural person.[216]

In both the U.S. and EU, patents are legal rights that can only be conferred on persons. There are no rights set for machines yet, given that the legal definition of a person does not include machines.[217] Thus, this indicates the need for additional legislation within this sector. This is significant because, with technological advancement, there will be more inventions by AI systems. Therefore, this raises an interesting question on whether AI systems should be protected and the need for a fifth neuro right within this capacity. That is, what will happen to the inventions that will be created by these AI systems? In this case, can these inventions be used by anyone for purposes of commercialization and other reasons while the AI systems that invented them not have a right in the matter? This further brings to the fore the possibility of these systems developing to the point of gaining human status and thus rights.

211. *Id.*

212. Eur. Patent No. *EP3564144* (filed Oct. 17, 2018).

213. Rudolf Teschemacher, *European Patent Applications Naming An Artificial Intelligence (AI) System As An Inventor Refused*, EUR. PAT. LAW'S. ASS'N (Jan. 29, 2020), http://eplaw.org/epo-european-patent-applications-naming-an-artificial-intelligence-ai-system-as-inventor-refused/.

214. *Summary of the Relevant Facts and Submissions* EUR. PAT. OFF. (Jan. 27, 2020), https://register.epo.org/application?documentId=E4B63SD62191498&number=EP18275163&lng=en&npl=false.; *see EPO Publishes Grounds For Its Decision to Refuse Two Patent Applications Naming A Machine As Inventor*, EUR. PAT. OFF. (Jan. 28, 2020), https://www.epo.org/news-issues/news/2020/20200128.html.

215. *Id.*

216. *Summary of Relevant Facts*, *supra* note 216, at 5.

217. *Id.*; FlashPoint IP Ltd, 2019 Dec. Comm'r Pat. 1.

7. Brain Data as the Ultimate Refuge of Privacy

Brain data as the ultimate refuge of privacy focuses on how this type of data can be the decisive factor in the safety of people's privacy. That is, how to ensure the safety of people's privacy from the brain data collected through neurotechnology such as BMI.[218] There are several privacy-related consequences of using BMI technology. These consequences have resulted in fear of the issue of literal hacking of the brain.

One of the privacy-related consequences of using BMI is the potential attack of information of users which can occur through passive eavesdropping.[219] For instance, the information derived from the brain and transmitted to smart devices may be hacked.[220] This occurrence is possible because BMI can facilitate contact between the brain and the peripheral device.[221] An example of a scenario where this can occur is through a prosthetic limb's neuro medical application.[222] An attacker can intercept the transfer of information between a physician and patient following the complete raw EEG establishment despite any applied encryption. Thus, it is possible for the attack to illicit commands resulting in the malfunction of a device.

Authentication is yet another privacy-related consequence that emanates from the use of BMI. Brain signals are a component of BMI that can be used for authentication, and thus they can pose a privacy risk to users. This is because attackers can try executing an attack by developing a model such as one that can decipher the thought process of a subject. This attack can result in an eventual breakdown of the authentication, therefore, exposing the thoughts of a BMI user.

There are several methods of information extraction that can be used to bring about the above privacy-related consequences. One of these models is the oddball paradigm, which is a technique that results in a user being asked to react to a given targeted stimulus.[223] However, this stimulus usually contains a hidden occurrence of a non-target stimulus. Another method used is the guilty non-knowledge test (GKT). These methods work on the hypothesis that it contains information that can evoke varying responses to a similar stimulus. Thus, these techniques can lead to neural signals that manipulate people, forcing them to do things against their wishes or approval.

Some laws have been established to ensure the safety of the confidentiality of brain data. For example, the EU nations through the European General Data

218. *See generally* Ienca & Andorno, *supra* note 206.

219. *Id.* at 7.

220. *Id.* at 17.

221. *Id.*

222. *Id.*

223. *See generally* Fali Li et al., *Different Contexts in the Oddball Paradigm Induce Distinct Brain Networks in Generating the P300*, 12 FRONTIERS HUM. NEUROSCIENCE (Jan. 7, 2019), at 1.

Protection Regulation (GDPR) law.[224] This is a law that has had a considerable impact on confidentiality and data security in the region. For instance, construction companies are responsible for factoring this law in designing buildings with digital technology such as BMI. This includes passing these models on the management of assets.

The EU GDPR is a law that has been quite specific in tackling privacy problems as it entails BMI technology.[225] This is the only international law that limits the treatment and sale of mental information such as personal data and ensures privacy protection. The role of the EU GDPR towards the protection of brain data is further illustrated in its provision that perceives people as data subjects. Thus, this law affirms that each data subject has the right to all and any personal data they are identified with.

However, there is a notable degree of focus on health data receiving higher requirements for protection. For this reason, any brain data that is gained from medical devices will receive more protections. For the protection of brain data, this type of data should be classified as medical and thus treated. Thus, recording such data and its additional usage should only be after acquiring consent from the data subject.

This limitation is highly theoretical in nature. It suggests the need to do more towards the protection of brain data. To add, the EU GDPR does not provide optimal protection because the data subjects can easily consent to their data being used in return for something they perceive as valuable, as in the case of smartphones.[226] In this case, these data subjects will receive payment as an exchange for accessing their brain data. Therefore, it is possible that this a business model that could be developed for brain data whereby people accept payment from companies and other interested parties to access their brain data.

XIV. BMI and Ethics

The critics of the use of BMI point to the various ethical issues involved. The use of BMI presents an emerging threat to the security and privacy of users. The collection of an individual's information into a single area causes vulnerability to their privacy and security.

Such sensitive data can be exploited to cause interference to the memory of these people impacting their emotions and both unconscious and conscious interests. There are numerous ways in which such incidences can happen in the mind of users of BMI. One of these ways is through the exploitation of the features of extraction and

224. *See generally* Chassang, *supra* note 193.

225. Chassang, *supra* note 193, at 3.

226. Chassang, *supra* note 193, at 10–11.

classification algorithms.[227] At the time, the ethical criticism in relation to BMI technology is illustrated by the one field whereby it is heavily utilized, medicine. The absence of a caretaker presents an ethical issue. For example, if a person is completely shut down as a consequence of paralysis, it is vital for an ethical contract to be developed to allow a physician to use BMI towards their treatment. This becomes a difficult issue when a person is alone and requires treatment.[228] The physician involved faces an ethical issue implanting the BMI technology so as to save patient's life while they still are unable to do so without consent. This brings about the ethical issue of informed consent. Healthcare professionals have the responsibility of obtaining consent from patients before using BMI for their treatment.[229] This also includes those who cannot speak.[230]

The experiments conducted by Facebook and Elon Musk through his Neuralink company have been a source of ethical contention, given the possibility of developing neurotechnology that can read the brain.[231] To begin with Facebook, CEO and Chairman Mark Zuckerberg have been investing heavily in research on BMI that will enable thoughts to be picked directly from people's neurons and be translated into words.[232] There has been a major development in this as the researchers have confirmed that they have already developed an algorithm that can decode words from the brain's activity. A company such as Neurosky is deemed as the market leader in the manufacture of BMI technologies for consumer product use. For instance, this company has developed headsets that are based on BMI technology. Their headsets are rather simple compared to those of EMOTIVE, which are highly complex.[233] As for Neurolutions, this is a company that is seeking to develop some form of revolutionary platform devices that can be used by disabled patients following neurological injury.[234]

As for Elon Musk's Neuralink, the company has announced its creation of flexible threads implanted within the brain.[235] The company's goal focuses on developing a

227. Chaudhary & Agrawal, *supra* note 113, at 342–43.

228. Naz, *supra* note 114, at 24.

229. *Id.*

230. *See generally id.* at 4.

231. Yuste, *supra* note 205, at 160–61.

232. Josh Constine, *Facebook Is Building Brain-Computer Interfaces for Typing and Skin-Hearing*, TECHCRUNCH (Apr. 19, 2017, 1:55 PM), https://techcrunch.com/2017/04/19/facebook-brain-interface/.

233. *IDEO: Epoc Headset for Emotiv*, EMOTIV, https://www.emotiv.com/news/ideo-epoc-headset-for-emotiv/ (last visited Mar. 8, 2021); Neal Pollack, *Mind Control: How A £200 Headset Is Redefining Brain-Computing Interaction*, WIRED (Nov. 23, 2010), http://www.wired.co.uk/magazine/archive/2010/12/features/mind-control?page=all. *Enabling Technologies for Next-generation mHealth Solutions*, NEUROSKY, http://neurosky.com/about-neurosky/ (last visited Mar. 31, 2021).

234. NEUROLUTIONS, https://www.neurolutions.com/ (last visited Mar. 13, 2021).

235. Musk, *supra* note 71, at 2–3.

link between the neurons within the brain, and a machine such as a smartphone is for. This technology would enable users someday to control computers and smart devices through their thoughts someday.[236] The development of this neurotechnology is so far impressive. However, this development also questions the possibility of misuse and as such, emphasized the need to reinforce the law to include the jurisprudence of the mind to ensure protection.[237] There is the possibility that this technology results in the interference of even the most basic manner in which human beings think. Failure to control this may result in difficulty to determine where humanity ends, and the machine begins. The current laws are poorly equipped in this regard, and so are the ethical practices.

XV. Merits of BMI and Ethics

Those who argue for the ethical nature of BMI use several examples to back these arguments, therefore demonstrating its merit. One of the arguments put forth regarding the ethics of BMI is that involving the issue of privacy. For instance, BMI can be applied to advance lie detection and polygraph. This supposition is best demonstrated by the example of terrorists who are usually concerned with hiding information on whom they are or involved in the following capture. However, the BMI tech makes it possible to determine the suspects' intention, an element that adds to the positive impacts of such technologies. For a long time, authorities have attempted to determine these intentions using the polygraph test based on the autonomic nervous system. The modern ECG BMI provides an opportunity for an improved system of lie detection. Particularly, a system created using this technology that uses a P300 probe can facilitate a P300-based concealed information test.[238] This can be used to achieve an improved extraction of information through pattern recognition. The above situation demonstrates the merit of disregard of ethics in brain data. While it is quite helpful that a situation involving a terrorist will result in positive outcomes such as putting to an end the destructive plans of the terrorist, the truth remains that the information used was obtained without consent. Rather, the collected data happened through the brain hacking of the terrorist's brain.

The above situation brings about the ethical issue of being held accountable if brain data is accessed even for the greater good. The issue of distributed moral responsibility (DMR) comes into play in this regard. There is minimal focus on classic ethics concerning DMR.[239] One of the components of this concept is that which is evil will always be evil despite the potential that it may lead to that which

236. Abhinav Kulshreshth et al., *Neuralink*: *An Elon Musk Start-Up: Achieve Symbiosis with Artificial Intelligence*, INT'L CONF. ON COMPUTING & INTELLIGENT SYS. 1 (2019).

237. Ienca & Andorno, *supra* note 206, at 5–7.

238. Fazel-Rezai et al., *supra* note 23, at 6–7.

239. Luciano Floridi, *Faultless Responsibility: On The Nature And Allocation Of Moral Responsibility For Distributed Moral Actions*, 374 PHIL. TRANSACTIONS ROYAL SOC'Y 1, 3 (2016).

is deemed as morally good.[240] In this case, hacking the brain of the terrorist remains a wrong thing to do despite the fact that it results in the discovery of the plans of the terrorist and the saving of lives that had been endangered by these plans.

XVI. CONCLUSION

This paper has considerably covered neurotechnology BMI. This is a technology that has brought about a substantial amount of change in how people can communicate. Therefore, it has proven revolutionary, as evidenced by the various benefits, especially within the medical field. At the same time, BMI has resulted in many risks to users that can cause them harm and undermine their wellbeing.[241] The risks include possible brain damage through internal bleeding likely to occur because of BMI technology's invasive methods.[242] Other risks of BMI technology use are inaccurate results and lack of privacy. The lack of privacy is the main risk of a preoccupation of discussion on ethics involving BMI and other forms of neurotechnology.[243] Accordingly, ethics in the use of BMI has emerged as a serious issue.

Neurorights are useful recommendations set forth regarding the rights protection of persons who exploit neurotechnology. These rights are among the key strategies that ensure ethics are upheld during the application of BMI technology. The different BMI stakeholders, including impact analysis experts, neurotechnology researchers, and neuroscientists, need to determine the most suitable way to improve these rights and their usage. While this is the case, there remain many questions that require answers, including determining whether euro rights should be perceived as renewed legal requirements or evolutionary understanding of the current human rights.

Further, there remain various grey areas concerning the legal and ethical provisions needing additional exploration—for instance, the rights as to whether the parents or children should neuroenhancers the children. Thus, several ethical dilemmas arise concerning BMI and other neurotechnologies. Effective solutions can be obtained if there is a public debate that involves more than the scientific community and includes ethicists and the general public.

Simultaneously, researchers and developers such as Elon Musk and Mark Zuckerberg must consider that addressing issues of ethics and legality of BMI and other forms of neurotechnology need to be more than an afterthought. That is, these are issues that need to remain an active part of the research process. For instance, there should be daily conversations concerning each component of development taking place in the technology. The focus of these conversations should be on how

240. *Id.*

241. Burwell, *supra* note 89, at 4–5.

242. Salatino, *supra* note 166, at 13.

243. Yuste, *supra* note 205, at 161–62.

the new development of neurotechnology will impact users and society as a whole. Accordingly, this makes it possible to identify potential negative effects and identifying ways of addressing them. This is even more so due to the need to ensure protection becomes a form of neurological integrity for humans. To add, this will be essential in guaranteeing an equal society among the people living in it and thus provide control in its evolution for the better.

Therefore, the advantages that neurotechnology provides us are impressive, but it is important not to ignore the visible need for more efforts concerning the risks posed to individuals and societies at large. The current legal frameworks remain quite insufficient in their address of ethical issues relating to neurotechnology. This is evidenced by the limited international legal framework of BMI. As per the analysis conducted in this work, only the EU shows some advanced legal approach towards tackling the ethical concerns connected to the application of neurotechnology. Other countries continue to show disregard for this issue, as evidenced by the lack of a proper legal framework. This is quite unfortunate, especially for a nation such as the US, which is a main propagator of neurotechnology as per Facebook and Neuralink.

Finally, unless ethical questions are adequately addressed early on, the future presents the choice of BMI, creating more problems than that which it is meant to address. The advantage at the moment is, there is still time for companies such as Neuralink to develop effective strategies to deal with ethical challenges while at the same time pursuing innovation.