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WHY EEG IS APT FOR BRAIN ACTIVITY MEASUREMENT IN A CASUAL END USER BCI?

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Abstract: Brain computer interface (BCI) is defined as a communication and control system that allows electrophysiological activity alone to control a computer or an external device, bypassing the peripheral nerves and muscles. The prime motive behind developing BCI technology was its ability to act as the only interactive link for disabled people affected by severe neuromuscular disorders like amyotrophic lateral sclerosis (ALS), cerebral palsy, spinal cord injury, stroke, etc. However in last decade, the gradual shift in BCI end-users from patients to casual (healthy) individuals has increased significantly. Because of this shift, BCI community has recognized the need for BCIs to be designed according to the generalized needs of casual end users. Hence, in this work the comparison is first done between different brain activity measurement techniques, which finally results in strengthening the candidature of EEG as the apt brain activity measurement technique for the causal end user BCIs. It also helps in evaluating and ranking all the major brain activity measuring techniques for the context. The comparison is done on the basis of 57 factors derived from "Three Set Criterions"- a comparison standard resulting from the basic rules of designing, attributes of product pleasure and factors essential for non-medical BCIs. This standard covers all the essential considerations for casual end user BCIs and could act as a steer for developing a generalized BCI.

Keywords: Brain computer Interface (BCI), Brain activity measurement technique, EEG, MEG, INR, ECoG, fMRI, PET, NIRS, casual (healthy) user.

I. Introduction

Brain computer interface (BCI) is a device used for communication between brain and a device whose control is independent of the brain's natural output path of peripheral nerves and muscles i.e. it does not require any peripheral muscular activity and enables a user to send instructions to an electronic device only by means of brain signals [1, 2]. The key objective of this system is to function as a unique communication mode for people with severe neuromuscular disorders. But in recent past, it has been observed that BCI could be of much use to the casual (healthy) users [3]. So keeping in mind this change in the user segment from dependent to healthy, we would be focusing on the BCI segment with casual end users only. The general opinion about BCIs with casual end user is it could only allow a user to send some information that one could otherwise convey much more easily and quickly through other interfaces. But this outlook is incorrect and BCIs are useful to casual users in many specific applications/situations like:-

(i). Virtual gaming: - the BCI use has enlarged the associated fun and improved the multitasking skills in virtual gaming world [4]. Moreover, it could also provide a supplementary signal, like an extra key for firing weapon or could change instructions transmitted by primary interface or could even provide a blend of information and features that no other gaming input modality could provide [5].

(ii). State of induced disability: - "Induced disability" is a situation in which casual user is in the similar situation as disabled user. That is under such circumstances casual users couldn't use conventional interfaces effectively. For instance, if verbal communication is not possible due to noise or if user's hands are occupied, in such situations BCI is the best alternative [5].

(iii). It improves ease of use: - Users find BCI hardware easier to use than other interfaces, as BCIs are becoming more wearable and transparent. Hence it is quite possible that they may replace the everyday accessories like watches and mobile phones in near future [5, 6].

(iv). It is more informative: - BCI provides added information those are generally unavailable by the use of other means. For instance real-time error detection and correction [7, 8] or detection of emotion and excitement levels, etc. It helps in modifying the way information is presented to the user and is drawing considerable attention in the field of neuro-marketing [5].

(v). It improves training and performance: - Research result indicates improvement in training and performance, as these training helps to produce specific neural activity patterns, which in turn could help in improving user's performance [5].

(vi). Confidentiality: - A BCI provides the most secure communication medium as compared to conventional interfaces as no one can snoop inside users brain. Hence BCIs could be utilized in situations demanding utter secrecy [5].

(vii). Fast signal detection: - Brain activity required for any action is noticeable several hundred milliseconds before the actual action begins and hence it precedes the awareness of the decision to act [9]. So BCIs could possibly provide early prediction of any action with greater precision and accuracy [5].

(viii). Novelty: - People uses BCIs, simply because it is new, modern, innovative and exciting [5].

Generally BCIs are defined as the amalgamation of few functional segments namely: - Brain activity measurement (signal acquisition), Feature extraction, Feature translation, Control interface, Device controller and Commands execution by the device [10, 11]. Here the objective of this work is to compare and select the best brain activity measurement technique for BCIs with casual end users. Thus, in this paper, **Section II** summarizes different brain activity measurement techniques used for BCIs. **Section III** details the basic rules, attributes and factors collectively named as "Three Sets Criterions". **Section IV** details the implications of "Three Sets Criterions" on the brain activity measuring techniques and forms the "Factor Matrix". **Section V** evaluates all the brain activity measuring techniques and ranks them for use in casual end user BCI. **Section VI** discusses the result.

II. Brain activity measurement techniques used in BCIs

Numerous techniques are available in order to measure brain activities but only few are used for the purpose of BCI [12] such as:

1. **Electroencephalography (EEG):** It is a non-invasive technique that reads scalp electrical activity [13] and is defined as the summation of post-synaptic potentials generated by thousands of neurons having the same radial orientation with respect to scalp. These are composed of different oscillations named "rhythms" and have dissimilar properties [14]. There are 6 such rhythms: Delta (1-4) Hz, Theta (4-7) Hz, Alpha (8-12) Hz, Mu (8-13) Hz, Beta (13-30) Hz and Gamma (above 30) Hz [15]. EEG is commonly recorded by electrodes placed over the scalp based on the 10–20 system and the number of electrodes varies from 1 to 256 [16]. These electrodes are generally attached using an elastic cap and the contact between electrodes and skin is enhanced by the use of a conductive gel but the dry variant of such electrodes are also available [17, 18].

2. **Electrocorticography (ECoG):** It is an invasive method where electrodes are placed directly on the exposed surface of the brain to record electrical activity from the cerebral cortex. Generally ECoG is defined as the synchronized set of postsynaptic potentials accessible mostly in the cortex's pyramidal cells and hence has to traverse through layers of cerebral cortex, cerebrospinal fluid, pia mater, arachnoid mater before being detected by subdural recording electrodes. The most widely used electrode sets for ECoG detection are electrocorticographic ball electrodes, subdural strip and grid electrodes and stereotaxic depth electrodes [19, 20].

3. **Intracortical Neuron Recording (INR):** It is an invasive method for measuring electrical activity within the gray matter of the brain. Here microelectrode arrays are fixed inside the cortex to detect spike signals and local field potentials from neurons. Intracortical neuron recording consists of three components namely i). Single-unit activity (SUA):- achieved by high-pass filtering of single neuron signal ii). Multi-unit activity (MUA):- achieved by high-pass filtering of multiple neuron signal and iii). Local field potentials (LFPs):- achieved by low-pass filtering of the neuron activity in the surrounding region of electrode tip [21, 22].

4. **Magneto Encephalography (MEG):** It is a non-invasive technique that measures the small magnetic fields generated outside the scalp because of the functioning brain, mainly due to post synaptic potentials of synchronously firing neurons at rest during processing [23]. To generate a detectable signal, approximately 50,000 active neurons are needed [24]. MEG is detected by the help of very sensitive magnetometers like superconducting quantum interference devices (SQUID). But liquid helium is an obligation for reducing the temperature of the array of SQUID sensors in MEG helmet and the superconducting lead shell. Each SQUID sensor has a coil of superconducting wire that collects the brain fields and a magnetic coupling of the SQUID and this wire results in a voltage proportional to the magnetic field. This data from SQUID is then transformed into current flow maps with respect to time throughout the brain with the help of computer.

5. **functional Magnetic Resonance Imaging (fMRI):** It is a technique for measuring brain activity which detects the changes in blood oxygenation / flow that occurs in response to neural activity [25,26] When neurons increases their activity with respect to baseline level, modulation of deoxyhemoglobin concentration is induced, generating the blood oxygen level dependent (BOLD) contrast [27]. BOLD fMRI techniques are

designed to assess variation in the inhomogeneity of the magnetic field within tissue. This variation is the result of changes in blood oxygenation. Both deoxy and oxyhemoglobin have different magnetic properties; former is paramagnetic and introduces inhomogeneity into the nearby magnetic field, whereas later one is weakly diamagnetic and has little effect. Hence an increase in the concentration of deoxyhemoglobin would result in an increase in image intensity [28, 29]. Therefore, fMRI is used to produce activation maps exhibiting brain parts involved in a particular mental process.

6. **Near Infra-Red Spectroscopy (NIRS):** It is a brain assessment technique which detects changes in blood hemoglobin concentrations related to a mental activity. It provides information about oxygenation, based on the optical properties of hemoglobin. The oxyhemoglobin and deoxyhemoglobin have distinct absorption properties, the degree of oxygenation in tissue can be determined by projecting light into tissue and measuring the amount of the light that emerges unabsorbed [30]. This method of functional mapping of cortex is called diffuse optical tomography (DOT)/ functional NIRS (fNIR)/ near infrared imaging (NIRI). This utilization of fNIR as a functional imaging technique is based on the principle of neurovascular coupling. At 700-900 nm NIR spectrum, skin, tissue, and bones are mostly transparent to NIR light, while hemoglobin and deoxygenated-hemoglobin absorbs light strongly in this spectrum. Differences in this absorption spectra lead to the measurements of relative changes in hemoglobin concentration.

7. **Positron Emission Tomography (PET)**: It is a nuclear imaging technique which produces a 3D image of functional processes in the body. The system relies on detection of pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer); this tracer is introduced to the body with the help of a biologically active molecule. By the help of computer analysis, 3D images of tracer concentration within the body are constructed. The neuroimaging version of this technique is based on the assumption that brain activities are associated with areas of high radioactivity, which is indirectly the measure of blood flow to different parts of the brain [31].

III. Insight on basic set of rules considered

The framework of a BCI system for a casual end user remains more or less same as that of a normal BCI but there are some additional conditions which could be considered while designing the BCIs for casual end users. Firstly, the BCI with a casual end user has to satisfy the broader definition/rules of interface and hence for the purpose of designing "the eight golden rules of interface design" by Shneiderman's must be considered. The rules are [32]:

Rule 1. Strive for consistency: Consistent series of actions should result in similar situations; the same terms should be used in menus and help screens; and lastly consistent commands should be used all through.

Rule 2. Cater to universal usability: Designs for diverse users, aiding transformation of content. Bridging gaps between ages, expertise levels, disabilities and technology diversities. Added features like pacing, explanations and shortcuts.

Rule 3. Offer informative feedback: For every action feedback should be available. For frequent / minor actions, the reaction can be modest but for infrequent /major actions the response should be substantial.

Rule 4. Design dialog to yield closure: Series of actions should be ordered into beginning, middle and end. The feedback at the successful completion of any particular action awards the user with a sense of respite and accomplishment.

Rule 5. Prevent error: Designing the system in such a way that the user cannot make an error. Still if error takes place then the system should detect the error and offer simple mechanisms for error handling.

Rule 6. Permit easy reversal of actions: This characteristic mitigate the anxiety factor as the user can undo the errors, thus encourages searching of unfamiliar alternatives. The reversibility unit can be a sole action, a complete set of actions or even a data entry .

Rule 7. Support internal locus of control: Expert users desires to be in full control of the system and expects the system to respond to their intents. Unexpected interface actions, monotonous data entries, helplessness or trouble in obtaining information and incapability of producing desired action results in anxiety. So the design should be focused in keeping the users in command.

Rule 8. Reduce short-term memory load: The drawback of our brain's information processing is short-term memory. It demands simple display, multiple page displays to be merged, window-motion frequency to be reduced and ample training time to be allotted for mnemonics, codes and action sequences. Online access to information should also be provided.

Secondly, for the casual end users, BCI is a product and hence the use of this product is satisfying or not will also have a significant impact. So the following set of product attributes which makes it satisfying or dissatisfying to use is also considered. The attributes are [33]:

ATTRIBUTE 1. **Features:** It is an attribute associated with every product i.e. helpful features support the operation whereas unnecessary / insufficient features makes the product displeasurable.

ATTRIBUTE 2. **Usability:** It is a major concern both as a contributor to pleasure and as a factor whose absence cause displeasure.

ATTRIBUTE 3. **Aesthetics:** Appearance robustly contributed to the pleasure which users took in their

products. Lack of aesthetic appeal contributes in making a product displeasurable.

ATTRIBUTE 4. **Performance:** This refers to a product performing its primary task to a particularly high level.

ATTRIBUTE 5. **Reliability:** It is central to user product 'bond'. Study indicated that users become attached to products which had given them years of good service.

ATTRIBUTE 6. **Convenience:** Many products are pleasurable because of their convenience – being particularly fitting for certain contexts.

ATTRIBUTE 7. **Size:** The size of the pleasurable product should be optimal - either in respect of enhancing the product's performance or in terms of suiting the product's context of use.

ATTRIBUTE 8. **Cost**: The level of negative feeling associated with displeasurable products could exacerbate if the product was expensive. Moreover, low cost cannot make a product pleasurable.

ATTRIBUTE 9. **Gimmick:** Products could be regarded as displeasurable because they were seen as being 'gimmicks'.

Last but not the least; we would also like to consider the crucial technical challenges for non medical BCIs (BCIs which are not used for medical reasons), here we focus on the issues that are not necessarily crucial for medical applications but factors which are crucial challenges for development of casual end user BCIs, like [34]:

FACTOR1 **Usability:** This is of major significance as it is the amalgamation of many sub factors which summarizes the needs and demands of the end users like - no support and training, comfort level and ease of use, reduced calibration time, safety and maintenance, speed and privacy.

FACTOR2 **Hardware:** The major hardware improvements required for bringing BCI systems outside laboratories and hospitals are –firstly, sensors have to be dry in order to be comfortable, convenient and easy to mount. Second, sensors must offer good signal quality and minimal numbers of electrodes should be employed and their comfortable placement. Furthermore, an ideal BCI is wearable, light, unobtrusive, comfortable, wireless, cheap and visually appealing.

FACTOR3 **Signal processing:** advancement in signal processing is very important as it is a key factor deciding the performance of a BCI. This factor hails for robustness to noise and changing signal characteristics of brain signals, asynchronous and continuous operation instead of synchronous and discrete, minimal calibration time, and finally an algorithms to classify signals from novel sensors.

FACTOR4 **System integration:** BCIs require quick, easy and seamless integration with existing systems.

The above mentioned considerations are almost covering all the expectations and limitations of a BCI for casual end user. But advancement in the related technologies like electronics, sensor efficiency, biotechnology, signal processing, classification algorithms, etc. in future may lead to inclusion of more conditions in the above list. For the future reference, these set of rules would be referred to as "Three Set Criterions" in this work.

IV. Implications of "Three Set Criterions" in brain activity measuring techniques

The "Three Set Criterions" will have implications on all the segments of a casual end user BCI, but here we would be zeroing on in the first segment only i.e. brain activity measurement techniques / signal acquisition techniques. To designate the best brain activity measurement technique for the BCI with casual end user, we need to evaluate the implications of "Three Set Criterions" on the brain activity measurement techniques. Table 1 summarizes the implications of "Three Set Criterions" on the brain activity measurement techniques and also suggests comparison factors which would decide the superiority of one technique over other in the preset context.

Table1: summarizes the implications of "Three Set Criterions".

Rules / Attribute / factors	Implications of rules/attributes/factors on brain activity measurement techniques	Comparison factors considered	Preferred comparison factor with reason
Rule 1: Strive for consistency	Apt brain activity measurement technique should result in a consistent output.	Consistent results or Inconsistent results	Consistent results – as it would help create standard and generalized segments in the BCI.
	Similar actions in any brain activity measurement should result in consistent outcomes.	High precision or Low precision	High precision – as it increases the repeatability of the output and hence improve the consistency of the BCI
	Apt brain activity measurement technique could be used for diverse users.	Universal or Non universal	Universal –as everybody's brain activity measurement could be done without any modification in the BCI
	Apt brain activity measurement technique should bridge the gap between the beginner and expert	Process is training dependent or Process is training independent	Process is training independent – as training independent means BCI is ready to use hence no gap.

Rule 2: Cater to universal usability	Apt brain activity measurement technique shouldn't get affected by age differences of users.	Age dependent or Age independent	Age independent – as it won't put any constrains on the use of BCI depending on age and improve universal usability.
	Apt brain activity measurement technique shouldn't get affected by disabilities of user.	Disability dependent or Disability independent	Disability independent – as it would increase the universal usability of the BCI
	Apt brain activity measurement technique should bridge the gap between technologies.	Technologically extendable or Non extendable	Technologically extendable – as the technique could be complimented by developments in other technological fields and would improve BCI usability
	Apt brain activity measurement technique should have added features	Additional features available or Not available	Additional features available – as it will increase the percentage of target user population and increase BCI usability
Rule 3: Offer informative feedback	Apt brain activity measurement technique should have provision of feedback mechanism for every action of user.	Feedback available or Feedback not available	Feedback available – as it would guide the user throughout the process and would in turn make the BCI more informative.
Rule 4: Design dialog to yield closure	Apt brain activity measurement technique should have all the actions structured as beginning, middle, and end of the process.	Structured technique or Non structured technique	Structured technique – as it would improve the chances of having a better structured BCI design and improve ease of use.
Rule 5: Prevent error	Apt brain activity measurement technique should have provisions that the user cannot make a error	Availability of error prevention or Non availability of error prevention	Availability of error prevention – as this would lead to reduction of errors and hence improve user's satisfaction.
	If an error occurs then the apt brain measurement technique should be able to detect it.	Availability of error detection or Non availability of error detection	Availability of error detection – as it detects the error committed and hence improves chances of error prevention in the BCI
	If by chance an error occurs then the apt brain measurement technique should be able to correct it.	Availability of error correction or Non availability of error correction	Availability of error correction – as it would correct the error committed and would reduce the chances of error in the BCI.
Rule 6 Permit easy reversal of actions	In apt brain activity measurement technique the user could reverse any fault and hence could undo mistakes.	Action reversal possible or Action reversible impossible	Action reversal possible – as it can undo the done and hence provides comfort to the user as the wrong could be undone and improves user's satisfaction.
Rule 7 Support internal locus of control	In apt brain activity measurement technique the user should be in charge of the process and all the actions are initiated by the user.	User controlled or Process controlled	User Controlled – as it would improve the users satisfaction and control over the BCI.
	No element of surprise should be there in the functionality of an apt brain activity measurement technique.	Assessable process or Non assessable process	Assessable process – as the function at any point of time must be clear and informative to the user which would in turn improve the user's BCI control.
	Apt brain activity measurement technique should be easy to use	Easy to use or Difficult to use	Easy to use – as it would increase the level of users satisfaction and reduce the anxiety factor. In turn improving BCI control by the user.
Rule 8 Reduce short-term memory load	Human information processing demands the apt technique should be simple to understand and implement	Simple technique or Complex technique	Simple technique – as it is easy to apprehend and so reduces the load on BCI user's memory.
	At the start of the process training is required for knowing the process of apt brain activity measurement technique.	Start up training required or start up training not required	Start up training required – as it would provide the user with significant information only, reducing the memory load.
	Online access to information regarding apt brain measurement should be available.	On line support available or No online support available	On line support available – as it would increase the support available to a user and hence would reduce the memory load.
Attribute1: Features	Apt brain activity measurement technique should have useful features	Useful features or Useless features	Useful features – as its availability would increases the versatility of the BCI.
Attribute 2: Usability	Apt brain activity measurement technique should lead to high usability of BCI	Support high usability or Support low usability	Support high usability – as it increases the number of ways in which the BCI could be used
Attribute 3 Aesthetics	Apt brain activity measurement technique should help improve the aesthetic appeal	Improve aesthetic appeal or Reduce aesthetic appeal	Improve aesthetic appeal – as it will improve the visual appeal of the BCI.
Attribute 4	Apt brain activity measurement technique	Efficient or Inefficient	Efficient – as without it the product BCI

Performance	should be efficient.		would be inefficient.
Attribute 5 Reliability	Apt brain activity measurement technique should be reliable.	Reliable or Unreliable	Reliable – as unreliable technique would affect the BCI performance negatively.
Attribute 6 Convenience	Apt brain activity measurement technique should be convenient to use.	Convenient or Inconvenient	Convenient – as inconvenient technique would lead to inconvenient BCI.
Attribute 7 Size	Apt brain activity measurement technique should not lead to increase of BCI size.	Hardware size small or Hardware size large	Hardware size small – as large hardware size will lead to bulky BCI.
Attribute 8 Cost.	Apt brain activity measurement technique should be cheap.	Cheap or Costly	Cheap – as costly measurement techniques would reduce the percentage of target users by increasing the BCI cost.
Attribute 9 Gimmick	Apt brain activity measurement technique should be practical to implement.	Practical or Impractical	Practical – as impractical techniques would never lead to a working BCI.
Factor 1 Usability	Apt brain activity measurement technique should not require external human support.	Requires support or Doesn't require any support	Doesn't require any support – as it would increase the independence of the user and hence the usability of the BCI.
	Apt brain activity measurement technique should be comfortable to use	With pain or Without pain	Without pain – as it would improve the overall comfort level of the BCI use.
	Apt brain activity measurement technique should be stable.	Stable or Unstable	Stable – as stable techniques gives bounded output for bounded input, which improves BCIs usability and performance.
	Apt brain activity measurement technique should be easy to use.	Easy to use or Difficult to use	Easy to use – as it would improve the independence of the user and improve BCI usability.
	Apt brain activity measurement technique should require less calibration time.	Less calibration time or More calibration time	Less calibration time – as it would reduce the preparation time of the BCI, increasing usability.
	Apt brain activity measurement technique should not require regular training, every time one uses the technique.	Requires regular training or Doesn't require regular training	Doesn't require regular training – as it would decrease the complexity and hence the increase the usability of BCI.
	Apt brain activity measurement technique should be safe	Safe or Unsafe	Safe – as safe BCIs would improve usability.
	Apt brain activity measurement technique should have low maintenance	High maintenance or Low maintenance	Low maintenance – as it would reduce the financial burden over the user for using BCI and hence improve usability.
	Apt brain activity measurement technique should be compatible to the user	Invasive or Non invasive	Non Invasive – as it would improve the comfort and safety of the BCI.
	Apt brain activity measurement technique should be portable	Portable or Non portable	Portable – as it would improve the level of convenience for the BCI user
	Apt brain activity measurement technique should be upholding the privacy of the user	Safeguard privacy or Endanger privacy	Safeguard privacy – as it is dealing with user's brain which is storing all the vital information of the user. Hence safeguarding privacy is very essential.
	Apt brain activity measurement technique should have high speed i.e. Information transfer rate (bits/min)	High ITR or Low ITR	High ITR – as it would reduce the overall operational time of the BCI and would increase usability.
	Apt brain activity measurement technique should have high spectral resolution (SR)	High SR or Low SR	High SR – as it would improve the signal processing and hence BCI usability.
	Apt brain activity measurement technique should have high temporal resolution (TR)	High TR or Low TR	High TR – as it would improve the signal processing and hence BCI usability.
	Apt brain activity measurement technique should have real time control	Synchronous or Asynchronous	Asynchronous – as it would improve the controllability and efficiency of the BCI
	Apt brain activity measurement technique should be accurate	High accuracy or Low accuracy	High accuracy – as it would improve the overall performance of the BCI and hence improve usability.
	Apt brain activity measurement technique should have sensing equipment, which are convenient to mount	Convenient mounting or Complicated mounting	Convenient mounting – as it would reduce the preparation time of the BCI.
	Apt brain activity measurement technique should have devices with high sensitivity.	Availability of high sensitive devices or Non availability of high sensitive devices	Availability of high sensitive devices – as it would increase the efficiency of the BCI.
	Apt brain activity measurement technique should have minimal number of sensing equipment.	High number of equipment required or Low number of equipment required	Low number of equipment required – as it would affect the size and wear ability of the BCI.
	Apt brain activity measurement technique	Comfortable placement or	Comfortable placement – as it would

Factor 2 Hardware	should have comfortable placement of sensing devices	Complicated placement	improve the ease of use of the BCI.
	Apt brain activity measurement technique should support wear ability of the BCI.	Support wear ability or Doesn't support wear ability	Support wear ability – as it would improve the BCI user's convenience.
	Apt brain activity measurement technique should help to make the BCI light in weight.	Support lightness or Support heaviness	Support lightness – as it would improve the wear ability of the BCI.
	Apt brain activity measurement technique should support wireless transmission	Wireless or Wired	Wireless – as it would improve the convenience of using the BCI.
	Apt brain activity measurement technique should make the product comfortable.	Improves comfort or Reduces comfort	Improves comfort – as it would improve the overall comfort level of BCI use.
	Apt brain activity measurement technique should be cheap	Cheap or Costly	Cheap – as it reduces the overall cost involved in manufacturing BCI
	Apt brain activity measurement technique should improve the visual appeal of BCI.	Improves Visual appeal or Reduces visual appeal	Improves Visual appeal – as it would improve the looks of the BCI
Factor 3 Signal processing	Apt brain activity measurement technique should be robust to noise	Robust or Weak	Robust – as the immunity to noise would improve the processing performance of BCI.
	Apt brain activity measurement technique should be asynchronous (self-paced).	Synchronous or Asynchronous	Asynchronous – as users can interact with the BCI all the time and issue commands at any time.
	Apt brain activity measurement technique should be measuring the signal in the original form.	Electrophysiological Activity (EPA) or Hemodynamic response (HR).	Electrophysiological Activity (EPA) - as it is a direct method for measuring electrical activity of brain
	Apt brain activity measurement technique could be preprocessed efficiently	Efficient preprocessing or Inefficient preprocessing	Efficient preprocessing – as it would improve the signal processing of the BCI.
	Apt brain activity measurement technique should require minimal calibration time	Less calibration time or More calibration time	Less calibration time – as it would reduce the preparation time of the BCI.
	Apt brain activity measurement technique should have algorithms to classify signals easily.	Classification possible or Classification impossible	Classification possible – as it would reduce the time required for signal processing in BCI.
Factor 4 System integration	Apt brain activity measurement technique should have quick, easy and seamless integration with existing systems.	Easy integration or Difficult integration	Easy integration – as it would increase the probability of better customization and better utilization of various technologies for BCI.

Note: Some of the comparison factors are considered as one because the three sets of criterions have repeated mention of those comparison factors.

The above table is a derivative of "Three Set Criterions" implemented on first segment of BCI, i.e. brain activity measurement techniques and is termed as "Factor Matrix". This table provides the comparison factors which would in turn decide the superiority of a measuring technique on other and hence decide the apt brain activity measurement technique. It should be noted that the "Factor Matrix" will be different for every segments of BCI and has to be deduced for every segment separately.

V. BEST BRAIN ACTIVITY MEASUREMENT TECHNIQUE

To designate the best brain activity measurement technique for the BCI with casual end user, we compare all the brain activity measurement techniques on the basis of "Factor Matrix" deduced form "Three Sets Criterions" mentioned in section IV. We provide weighted value of '+1' to preferred factor and '-1' to the counterpart and get a sum total of weights for each individual measuring technique. The technique with highest weighted value is considered the best brain activity measuring technique for the BCI with casual end user. This technique can be made more precise by allotting fractional weights to comparison factors but for that extensive research and more elaborate information would be required. Hence we use ± 1 as the weighted value for purpose of uniformity and ease of calculation.

Table 2: summarizes the "Factor Matrix" along with their respective weighted value.

Measuring techniques / **Comparison factors considered**	**EEG**	**ECoG**	**INR**	**MEG**	**fMRI**	**NIRS**	**PET**
1. Consistent results or Inconsistent results	Consistent results [35] +1	Consistent results [12] +1	Consistent results [36] +1	Consistent results [37] +1	Consistent results [38] +1	Consistent results [39] +1	Consistent results [40] +1
2. High precision or Low	High precision [41]	High precision [10]	High precision [36]	High precision [38]	High precision [42]	High precision [43]	High precision [44]

	precision	+1	+1	+1	+1	+1	+1	+1
3.	**Universal or Non universal**	Universal [10] +1	Non universal [46] -1	Non universal [46] -1	Universal [47] +1	Non universal [42] -1	Universal [42] +1	Universal [48] +1
4.	**Process is training dependent or Process is training independent**	Process is training dependent [49] -1	Process is training dependent [49] -1	Process is training dependent [36] -1	Process is training dependent [10] -1	Process is training dependent [50] -1	Process is training dependent [39] -1	Process is training independent [44] +1
5.	**Age dependent or Age independent**	Age independent [51] +1	Age dependent [52] -1	Age dependent [53] -1	Age independent [47] +1	Age dependent [42] -1	Age independent [42] +1	Age independent [54] +1
6.	**Disability dependent or Disability independent**	Disability independent [51] +1	Disability independent [55] +1	Disability independent [36] +1	Disability independent [56] +1	Disability dependent [42] -1	Disability independent [57] +1	Disability independent [58] +1
7.	**Technologicall y extendable or Non extendable**	Technologically extendable [42] +1	Technologically extendable [59] +1	Technologically extendable [60] +1	Technologically extendable [61] +1	Technologically extendable [61] +1	Technologicall y extendable [42] +1	Technologically extendable [62] +1
8.	**Additional features available or Not available**	Additional features available [35] +1	Additional features available [63] +1	Additional features available [64] +1	Additional features available [56] +1	Additional features available [65] +1	Additional features available [39] +1	Additional features available [62] +1
9.	**Feedback available or Feedback not available**	Feedback available [51] +1	Feedback available [66] +1	Feedback available [64] +1	Feedback available [37] +1	Feedback available [67] +1	Feedback available [39] +1	Feedback available [68] +1
10.	**Structured technique or Non structured technique**	Structured technique [46] +1	Structured technique [46] +1	Structured technique [46] +1	Structured technique [37] +1	Structured technique [65] +1	Structured technique [39] +1	Structured technique [44] +1
11.	**Availability of error prevention or Non availability of error prevention**	Availability of error prevention [69] +1	Availability of error prevention [70] +1	Availability of error Prevention [71] +1	Availability of error prevention [37] +1	Availability of error prevention [67] +1	Availability of error prevention [10] +1	Availability of error prevention [62] +1
12.	**Availability of error detection or Non availability of error detection**	Availability of error detection [69] +1	Availability of error detection [73] +1	Availability of error detection [71] +1	Availability of error detection [72] +1	Availability of error detection [67] +1	Availability of error detection [39] +1	Availability of error detection [68] +1
13.	**Availability of error correction or Non availability of error correction**	Availability of error correction [69] +1	Availability of error correction [73] +1	Availability of error correction [36] +1	Availability of error correction [37] +1	Availability of error correction [65] +1	Availability of error correction [10] +1	Availability of error correction [44] +1
14.	**Action reversal possible or Action reversible impossible**	Action reversal possible [74] +1	Action reversal possible [73] +1	Action reversal possible [36] +1	Action reversal possible [37] +1	Action reversal possible [65] +1	Action reversal possible [10] +1	Action reversal possible [44] +1
15.	**User controlled or Process controlled**	User controlled [35] +1	User controlled [66] +1	User controlled [36] +1	User controlled [56] +1	User controlled [65] +1	User controlled [39] +1	User controlled [68] +1
16.	**Assessable process or Non assessable process**	Assessable process [42] +1	Non assessable process [75] -1	Assessable process [36] +1	Assessable process [37] +1	Assessable process [65] +1	Assessable process [39] +1	Assessable process [62] +1
17.	**Easy to use or Difficult to use**	Easy to use [45] +1	Difficult to use [75] -1	Difficult to use [46] -1	Easy to use [37] +1	Easy to use [65] +1	Easy to use [39] +1	Easy to use [62] +1
18.	**Simple technique or Complex technique**	Simple technique [45] +1	Complex technique [46] -1	Complex technique [46] -1	Simple technique [37] +1	Complex technique [67] -1	Simple technique [39] +1	Complex technique [44] -1
19.	**Startup training required or Startup**	Startup training required [51]	Startup training required [49]	Startup training required [10]	Startup training required [10]	Startup training required [50]	Startup training required [39]	Startup training required [76]

training not required	+1	+1	+1	+1	+1	+1	+1
20. On line support available or No online support available	On line support available [77] +1	On line support available [77] +1	On line support available [77] +1	On line support available [77] +1	On line support available [78] +1	On line support available [39] +1	Online support available [79] +1
21. Useful features or Useless features	Useful features [35] +1	Useful features [70] +1	Useful features [64] +1	Useful features [56] +1	Useful features [65] +1	Useful features [39] +1	Useful features [62] +1
22. Support high usability or Support low usability	Support high usability [80] +1	Support low usability [46] -1	Support low usability [46] -1	Support high usability [56] +1	Support low usability [65] -1	Support low usability [42] -1	Support high usability [44] +1
23. Improve aesthetic appeal or Reduce aesthetic appeal	Improve aesthetic appeal [81] +1	Reduce aesthetic appeal [66] -1	Reduce aesthetic appeal [64] -1	Reduce aesthetic appeal [10] -1	Reduce aesthetic appeal [67] -1	Improve aesthetic appeal [82] +1	Improve aesthetic appeal [62] +1
24. Efficient or Inefficient	Efficient [83] +1	Efficient [83] +1	Efficient [36] +1	Efficient [37] +1	Efficient [65] +1	Efficient [42] +1	Efficient [62] +1
25. Reliable or Unreliable	Reliable [45] +1	Reliable [37] +1	Unreliable [46] -1	Reliable [37] +1	Reliable [67] +1	Reliable [39] +1	Reliable [62] +1
26. Convenient or Inconvenient	Convenient [35] +1	Inconvenient [75] -1	Inconvenient [46] -1	Inconvenient [84] -1	Inconvenient [42] -1	Convenient [42] +1	Convenient [62] +1
27. Hardware size small or Hardware size large	Hardware size small [46] +1	Hardware size small [55] +1	Hardware size small [46] +1	Hardware size large [10] -1	Hardware size large [49] -1	Hardware size small [42] +1	Hardware size large [85] -1
28. Practical or impractical	Practical [86] +1	Practical [10] +1	Practical [71] +1	Impractical [87] -1	Impractical [87] -1	Practical [39] +1	Impractical [44] -1
29. Requires support or Doesn't require any support	Requires support [46] -1	Requires support [46] -1	Requires support [46] -1	Requires support [84] -1	Requires support [67] -1	Requires support [82] -1	Requires support [44] -1
30. With pain or Without pain	Without pain [51] +1	With pain [75] -1	With pain [46] -1	With pain [88] -1	With pain [42] -1	Without pain [42] +1	Without pain [44] +1
31. Stable or Unstable	Stable [45] +1	Stable [10] +1	Unstable [49] -1	Stable [84] +1	Stable [50] +1	Stable [39] +1	Stable [76] +1
32. Less calibration time or More calibration time	Less calibration time [45] +1	Less Calibration time [89] +1	More calibration Time [36] -1	More calibration time [37] -1	Less calibration time [50] +1	Less calibration time [82] +1	Less Calibration time [76] +1
33. Requires regular training or Doesn't require regular training	Doesn't Require regular training [90] +1	Doesn't require regular training [70] +1	Doesn't require regular training [10] +1	Doesn't require regular Training [37] +1	Doesn't Require regular training [10] +1	Doesn't require regular training [82] +1	Requires regular training [76] -1
34. Safe or Unsafe	Safe [10] +1	Unsafe [10] -1	Unsafe [10] -1	Safe [10] +1	Safe [10] +1	Safe [10] +1	Safe [91] +1
35. High maintenance or Low maintenance	High maintenance [10] -1	High maintenance [70] -1	High maintenance [71] -1	High maintenance [56] -1	High maintenance [91] -1	High maintenance [92] -1	High maintenance [76] -1
36. Invasive or Non invasive	Non Invasive [10] +1	Invasive [10] -1	Invasive [10] -1	Non Invasive [10] +1	Non Invasive [10] +1	Non Invasive [10] +1	Non Invasive [91] +1
37. Portable or Non portable	Portable [10] +1	Portable [10] +1	Portable [10] +1	Non portable [10] -1	Non portable [10] -1	Portable [10] +1	Non portable [91] -1
38. Safeguard privacy or Endanger privacy	Endanger privacy [93] -1	Endanger privacy [66] -1	Endanger privacy [64] -1	Endanger privacy [37] -1	Endanger privacy [65] -1	Endanger privacy [92] -1	Endanger privacy [91] -1
39. High ITR or Low ITR	High ITR [51] +1	High ITR [49] +1	High ITR [36] +1	High ITR [88] +1	Low ITR [10] -1	Low ITR [10] -1	Low ITR [44] -1
40. High SR or Low SR	Low SR [51] -1	High SR [10] +1	High SR [10] +1	High SR [10] +1	High SR [10] +1	Low SR [10] -1	High SR [91] +1

41. High TR or Low TR	High TR [10] +1	High TR [10] +1	High TR [10] +1	High TR [10] +1	Low TR [10] -1	High TR [10] +1	Low TR [91] -1
42. High accuracy or Low accuracy	Low accuracy [49] -1	High accuracy [49] +1	High accuracy [64] +1	High accuracy [94] +1	High accuracy [49] +1	Low accuracy [39] -1	High accuracy [44] +1
43. Convenient mounting or Complicated mounting.	Convenient mounting [46] +1	Complicated mounting [46] -1	Complicated mounting [46] -1	Complicated mounting [37] -1	Complicated mounting [42] -1	Convenient mounting [92] +1	Complicated mounting. [85] -1
44. Availability of high sensitive equipment or Non availability of high sensitive equipment	Availability of high sensitive devices [46] +1	Availability of high sensitive devices [46] +1	Availability of high sensitive devices [10] +1	Availability of high sensitive devices [94] +1	Availability of high sensitive devices [65] +1	Availability of high sensitive devices [39] +1	Availability of high sensitive devices [44] +1
45. High number of sensing equipment required or Low number of sensing equipment required	Low number of equipment required [46] +1	High number of equipment required [46] -1	High number of equipment required [46] -1	High number of equipment required [37] -1	High number of equipment required [78] -1	Low number of equipment required [82] +1	High number of equipment required [44] -1
46. Comfortable placement or Complicated placement	Comfortable placement [49] +1	Complicated placement [46] -1	Complicated placement [46] -1	Complicated placement [37] -1	Complicated placement [42] -1	Comfortable placement [42] +1	Complicated placement [85] -1
47. Support wear ability or Doesn't support wear ability	Supports wear ability [45] +1	Supports wear ability [55] +1	Supports wear ability [71] +1	Doesn't support wear ability [10] -1	Doesn't support wear ability [49] -1	Supports wear ability [42] +1	Doesn't support wear ability [85] -1
48. Support lightness or Support heaviness	Supports lightness [46] +1	Supports lightness [75] +1	Supports lightness [46] +1	Support heaviness [10] -1	Support heaviness [10] -1	Supports lightness [42] +1	Support heaviness [85] -1
49. Wireless or Wired	Wireless [45] +1	Wireless [95] +1	Wireless [71] +1	Wired [56] -1	Wired [67] -1	Wireless [42] +1	Wired [44] -1
50. Improves comfort or Reduces comfort	Improves comfort [49] +1	Reduces Comfort [46] -1	Reduces comfort [46] -1	Reduces comfort [84] -1	Reduces comfort [42] -1	Improves comfort [42] +1	Reduces comfort [44] -1
51. Cheap or Costly	Cheap [45] +1	Costly [46] -1	Costly [46] -1	Costly [94] -1	Costly [10] -1	Cheap [10] +1	Costly [44] -1
52. Improves Visual appeal or Reduces visual appeal	Improve Visual appeal [45] +1	Reduces visual appeal [66] -1	Reduces visual appeal [64] -1	Reduces visual appeal [10] -1	Reduces visual appeal [67] -1	Improve visual appeal [82] +1	Reduces visual appeal [44] -1
53. Robust or Weak	Weak [10] -1	Robust [49] +1	Robust [49] +1	Robust [94] +1	Weak [10] -1	Weak [10] -1	Weak [44] -1
54. Synchronous or Asynchronous	Asynchronous [96] +1	Asynchronous [10] +1	Asynchronous [71] +1	Asynchronous [37] +1	Asynchronous [10] +1	Synchronous [39] -1	Synchronous [44] -1
55. Electrophysiological Activity (EPA) or Hemodynamic response (HR).	EPA [51] +1	EPA [10] +1	EPA [10] +1	EPA [94] +1	HR [10] -1	HR [10] -1	HR [83] -1
56. Efficient preprocessing or Inefficient preprocessing	Efficient preprocessing [77] +1	Efficient preprocessing [77] +1	Efficient preprocessing [77] +1	Efficient preprocessing [77] +1	Efficient preprocessing [67] +1	Efficient preprocessing [92] +1	Inefficient preprocessing [44] -1
57. Classification possible or Classification impossible	Classification possible [35] +1	Classification possible [10] +1	Classification possible [71] +1	Classification possible [84] +1	Classification possible [67] +1	Classification possible [39] +1	Classification possible [62] +1
58. Easy integration or Difficult integration	Easy integration [42] +1	Easy integration [89] +1	Difficult integration [71] -1	Easy integration [61] +1	Easy integration [61] +1	Easy integration [42] +1	Easy integration [62] +1
Total weighted value	**+51**	**+37**	**+34**	**+38**	**+30**	**+47**	**+35**

VI. Discussion and Result

The weighted outcome of the "Factor Matrix" on brain activity measuring technique depicts that EEG is the apt brain activity measurement technique with a sum total weighted value of +51 followed by NIRS with +47 weights. MEG, ECoG, INR follow them closely with weights +38, +37, +34 respectively. Though PET is not yet fully explored for the purpose of BCI, but it exhibits promising future with a weighted value of +35. Lastly, fMRI is exhibiting the least weighted value of +30. According to the outcome of the comparison done on the basis of the "Three Set Criterion", EEG has the maximum preferred factors and is considered to be the apt brain activity measurement technique for a casual end user BCI under current circumstances. This result is considered correct by most of the researchers but prior to this work it was based on few factors like non-invasiveness, cost, etc., but by this comparison the status of all other brain activity measuring techniques also becomes clear.

However there is scope of further improvement in the weighted outcome of "Factor Matrix" as the weighted value assumed is binary, but in a more practical scenario the weights may vary continuously from 0 to 1, for every comparison factors and could minimise the dichotomization errors. However, it would require more information and more research. Moreover these figures and rank may change in coming years because of advancement of new improved techniques but till that point of time EEG brain activity measurement technique is the apt brain activity measurement technique for BCI with casual end user. In future the factor matrices for other segments of BCIs could also be derived and may work as a steer in the direction of having a generalised BCI.

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