Philosophy & Technology (2022) 35:101
https://doi.org/10.1007/s13347-022-00597-1

RESEARCH ARTICLE

# The Unique and Practical Advantages of Applying A Capability Approach to Brain Computer Interface

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Received: 26 May 2022 / Accepted: 1 November 2022 / Published online: 23 November 2022


## Abstract

Intelligent neurotechnology is an emerging field that combines neurotechnologies like brain-computer interface (BCI) with artificial intelligence. This paper introduces a capability framework to assess the responsible use of intelligent BCI systems and provide practical ethical guidance. It proposes two tests, the threshold and flourishing tests, that BCI applications must meet, and illustrates them in a series of cases. After a brief introduction (Section 1), Section 2 sets forth the capability view and the two tests. It illustrates the threshold test using examples from clinical medicine of BCI applications that enable patients with profound disabilities to function at a threshold level through computer mediation. Section 3 illustrates the flourishing test by exploring possible future applications of BCI involving neuroenhancements for healthy people, using examples adapted from research currently underway in the US military. Section 3 applies a capability lens to a complex case involving dual effects, both therapeutic and non-therapeutic, showing how the threshold and flourishing tests resolve the case. Section 4 replies to three objections: neurorights are the best tool for assessing BCI; the two tests are moving targets; and the analysis utilizes a capability view to do work it is not designed for. The paper concludes that a capability view offers unique advantages and gives practical guidance for evaluating the responsible use of present and future BCI applications. Extrapolating from our analysis may help guide other emerging technologies, such as germline gene editing, expected to impact central human capabilities.

**Keywords** Artificial intelligence · Brain computer interface · Ethics · Neurotechnology · Neuroethics

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## 1 Introduction

Intelligent neurotechnology is an emerging field that combines neurotechnologies like brain-computer interface (BCI), neuroprostheses, and neuromodulation with artificial intelligence (AI). With the help of AI, important features of neurotechnology can be enhanced. For example, BCI equipped with AI-enhanced extraction and processing of brain signals could predict user intentions and preferences with a degree of probability that enables it to function with reduced user input, or without user input. One could also equip BCI-driven exoskeletons or wheelchairs with environment-sensing, obstacle-avoidance, and path-finding capabilities. Bidirectional BCI, which not only extracts and processes brain signals but delivers feedback, such as somatosensory signals, can create a potentially more natural experience for users. These possibilities prompt the question of whether a neurotechnology originally designed to enhance the functioning of people with diminished capabilities could be used in ways that reduce human functioning and capabilities by substituting machines.

To focus this question, we examine one type of neurotechnology, BCI, and discuss its responsible use in current and possible future applications. Unlike neural prosthetic devices, such as cochlear and retinal implants, which are designed to provide a substitution for a particular function, BCI is more general purpose, and provides an alternate mode of passing information from the brain to the outside world. BCI's primary application has been to assist people with severe neuromuscular disorders recover functions such as communication, mobility, and environmental control by extracting brain signals corresponding with users' thoughts and intentions, decoding them, and relaying them to a connected device, such as a computer screen for communication, wheelchair for mobility, or robotic arm or other assistive device for environmental control.

BCI uses three common approaches to extracting brain signals. First, EEG (electroencephalography) measures the brain's electrical activity from the scalp, accruing information from relatively large volumes of brain on the order of centimeters (Abiri et al., 2019). Second, electrocorticography (ECoG) involves surgically implanting electrodes under the dura (the external lining of the brain), directly on the surface of the brain. ECoG gathers electrical data from populations of about a million cells at a time (Miller et al., 2020). Third, intracortical devices involve surgically implanting electrodes within the cortex of the brain, measuring the activity of single to small groups of cells (Milekovic et al., 2018). With increasing invasiveness, one generally obtains measurements with greater spatial and functional resolution (Abecassis & Ko, 2018). Ultimately, the goal of BCI is to enable direct communication between the brain and computers in order to control the external environment in a manner commensurate with the user's intentions. BCI accomplishes this by utilizing a user's thoughts (represented as recorded brain activity) to trigger a series of events.

A paradigm example involving EEG-based BCI is repurposing motor control brain signals to carry out motor tasks. The user is prompted to imagine movement, which activates a relatively large region of the brain involved in real movement. In EEG-based BCI systems, this manifests as a drop in signal power within characteristic frequency ranges over the sensorimotor cortex, referred to as "event-related desynchronization" (ERD) (Abiri et al., 2019). Training both the user and signal-processing algorithms for a one-dimensional task, such as moving a cursor up or down based on these signals, is often possible within minutes, but more complex tasks can take months (Abiri et al., 2019). Other EEG-based BCI paradigms (such as imagined body kinematics (IBK)) seek to characterize patterns of brain activity evoked during natural movements. Changes in EEG recordings signifying the intention to move can be decoded and represent a popular paradigm for rehabilitation. Less commonly, paradigms leveraging EEG signals are linked to attention and eye movement, external sound stimuli, and even olfactory cues used to drive BCI devices (Abiri et al., 2019). External noise, artifacts from muscle contractions, and inconsistent location of electrodes across recording sessions remain challenges in decoder accuracy for such systems.

With ECoG BCI systems, an analogous ERD can be seen, as well as a more spatially specific increase in power at higher frequencies, representing an increase in activity in a population of cells numbering in the millions (Miller et al., 2020). These BCI systems are invasive, requiring implantation of electrodes on the surface of the brain; such electrodes allow better signal fidelity and greater spatial resolution compared to EEG, but detect signals from limited regions of the brain. Currently, implantable systems allow anywhere from 1 to 64 channels of data and have been used to translate mental imagery into 1-, 2-, and 3-dimensional control signals (Miller et al., 2020). The nature of these brain-derived control signals is generally stable over years (Fraczek et al., 2021b), and long-term feasibility of BCI implants with small numbers of electrodes has been reported in multiple series. Importantly, these implantable devices often provide the ability to deliver electrical stimulation, which can be used as a form of sensory feedback (Caldwell et al., 2019) or as a therapeutic stimulation to treat tremor on the basis of physiological needs (Fraczek et al., 2021a). Such bi-directional BCI applications are in clinical trials to treat essential tremor and Parkinson's disease and to aid in stroke rehabilitation.

In contrast to EEG and EcoG BCI systems, intracortically implanted BCI systems use action potentials from individual or small groups of cells as control signals. Neuronal firing, or "spikes," exhibit detectable patterns reflecting intended activities such as imagined movement. This provides a potentially richer feature set for control of a computer but requires tracking of the statistics of neural activity over time and periodic recalibration of the decoder because these neural signals are not stationary (Jarosiewicz et al., 2015). Such systems cover the smallest area of the brain and must be directly implanted into regions involved in whatever brain function is being mapped to computer activity. Over time, gliosis, or scarring, can cause signal loss and further complicate maintenance of BCI decoder accuracy, although approaches have been described that can maintain consistent BCI operation for months without intervention from technicians or caregivers (Milekovic et al., 2018).

Current challenges to applying BCI outside clinical settings include slow speeds, high error rates, and the complexities of operating BCI systems. However, on the assumption that these challenges can be overcome, researchers are exploring using BCI for recreational purposes, such as gaming; virtual reality and creative expression; attention monitoring, such as measuring alertness in safety–critical tasks like air traffic control; and cognitive diagnostics, such as coma detection and meditation training (Blankertz et al., 2012; Moody & Mappus, 2010). Spectacular demonstrations of BCI have promoted the prospect of wider application, including using BCI to enable a multi-person orchestra to control virtual instruments and perform before a live audience (Multimodal Brain Orchestra, 2009); to provide an adult paraplegic the opportunity to kick the first football of the season at the World Cup using a BCI-controlled exoskeleton (Martins & Rincon, 2014); and to allow a paralyzed man to fist-bump former US President Obama with a BCI-controlled robotic hand while experiencing the tactile sensation of bumping through sensory cortex stimulation (White House, 2016).

In a 2017 scoping review of the ethics literature addressing BCI, Burwell et al. (2017) noted that most literature furnishes little in the way of recommendations for handling concrete ethical issues and urged closer linkage between ethical reasoning and BCI decision-making in particular contexts. This paper fills the gap. It does this by introducing a capability framework and operationalizing it for application to BCI by means of two tests that any BCI application must pass: the threshold and flourishing tests. Section 1 introduces the capability framework and the two tests. It illustrates the threshold test using examples from clinical medicine of BCI applications that enable patients with profound disabilities to function at a threshold level through computer mediation. Section 2 illustrates the flourishing test by exploring possible future applications of BCI involving neuroenhancements for healthy people, using examples adapted from research currently underway in the US military. Section 3 applies a capability lens to a complex case involving dual effects, both therapeutic and non-therapeutic, showing how the threshold and flourishing tests resolve the case. Section 4 replies to three objections: neurorights, not capabilities, are the best tool for assessing BCI; the two tests represent moving targets; and the analysis utilizes a capability view to do work it was not designed to do. The paper concludes that a capability view offers unique advantages and gives practical guidance for evaluating the responsible use of present and future BCI applications. Extrapolating from our analysis may help guide other emerging technologies, such as germline gene editing, expected to significantly impact central human capabilities.

## 2 A Capability Approach to Current Clinical Applications of BCI

To illustrate how a capability approach can give practical guidance to current BCI applications, we first introduce the view, and then show its application to two cases where BCI is currently used to support a patient with amyotrophic lateral sclerosis (ALS) (a progressive neurodegenerative disease that causes muscle weakening and inability to move) and a patient post-stroke with weakness in all four limbs (quadriparesis).

**The Capability View** The capability approach is a normative framework first developed by Sen (1992) and Nussbaum (2011) to evaluate human welfare using the metric of what people are able to do and be. Whereas Sen emphasizes capabilities broadly, as the real opportunities that people have reason to value, inviting public reasoning to specify them more fully, Nussbaum proposes a list of ten capabilities that are required for a human life to be "not so impoverished that it is not worthy of the dignity of a human being" (Nussbaum, 2000, p. 72). For Nussbaum, these central capabilities are moral and political entitlements, because they make it possible for people to lead nonhumiliating human lives. Both accounts draw a distinction between "functionings," which refer to achieved well-being, and "capability," which refers to the freedom to pursue well-being (Robeyns & Byskov, 2021). Unlike other approaches, such as those that evaluate human welfare using metrics such as subjective well-being, preference satisfaction, or resources, the crux of a capability approach is that what people can do and be is the best metric for most kinds of interpersonal comparison.

The following list, adapted from Nussbaum (2011) and defended at greater length elsewhere (Jecker, 2020, Ch. 3), is one plausible way of specifying the central capabilities:

1) *Life*: having an unfinished narrative;
2) *Health*: being able to have all or a cluster of the central capabilities at a threshold level;
3) *Bodily integrity*: being able to use one's body to realize one's goals;
4) *Senses, imagination and thought*: being able to imagine, think, and use the senses;
5) *Emotions*: being able to feel and express a range of human emotions;
6) *Practical reason*: being able to reflect on and choose a plan of life;
7) *Affiliation*: being able to live for and in relation to others;
8) *Nature*: being able to live in relation to nature and other species;
9) *Play*: being able to laugh, play, and recreate; and
10) *Environment*: being able to regulate the immediate physical environment.

We take this capability list to be plausible, while acknowledging that there may be other plausible lists. Like any capability list, ours is put forth provisionally and might change if the conditions under which humans live change in major ways. Since capabilities point to a shared understanding of central human capabilities, rather than an essentialist view of human beings, our list can also change if new information or arguments come to light (Jecker, 2022). Although provisional, certain capabilities, such as the capability to think or to affiliate with others, might reflect more-or-less fixed ideas about humanity, and might be considered more central than others, such as the ability to play or experience nature. Generally speaking, "The more crucial a capability seems, the stronger the burden of proof is for those who would propose removing it from a capability list" (Jecker, 2020, pp. 50–51). Ultimately, a capability list is arrived at by agreement, reflecting a shared understanding of a human form of life (Nussbaum, 1992).

As an approach to justice, capabilities are often paired with a *principle of sufficiency*, which requires affording people a minimal threshold of each central human capability. Some proponents of capability approaches render sufficiency as a requirement to respect human dignity (Roebyns and Byskov, 2021). According to this rendering, when people experience disabilities that cause their capabilities to dip below a threshold level, this hinders their ability to live a full and dignified human life, and society should make reasonable efforts to bring people to a capability minimum. Various capability metrics have been developed to assess capability thresholds, most prominently the United Nations Human Development Index, which assesses the human development of countries (Roebyns, 2006). In domains of health and social care, a standard of achieving "basic capabilities" or "a minimum level of capability attainment" has also been incorporated into capability metrics (Mitchell et al., 2017).

As a general approach to ethics, capabilities are also paired with a *principle of human flourishing*, which stresses enabling people to realize central capabilities more fully and aspire to human excellence (Nussbaum, 2011, pp. 125–131). Human flourishing can be understood as "a life well-lived" or "a kind of living that is active, inclusive of all that has intrinsic value, and complete, lacking nothing that would make it richer or better" (Nussbaum, 2004, p. 61).When a person flourishes in this sense, they thrive in all aspects of their life. Metrics for measuring flourishing have been developed and applied to assess impacts of clinical or social interventions across multiple domains (VanderWeele, 2017; VanderWeele et al., 2019).

Principles of sufficiency and flourishing emphasize what people require to survive and thrive as human beings. So understood, a capability approach can be drawn on to illuminate the significance of different BCI applications by identifying their impact on the central things people can do and be. Applied to BCI, a capability view provides an analytic tool that allows us to evaluate proposed BCI uses by asking what effects they are likely to have on a person's central human capabilities. Since a capability view regards capabilities as ultimate ends, they cannot simply be traded-off to maximize aggregate capability. More precisely, a capability view defines a minimal floor that capabilities should not fall below. Once this minimal bar is cleared, a capability account asks if benefits gained through sacrifices people make accrue to them, helping them to thrive and flourish, or accrue solely to others. This ensures that individuals are not used solely as a means to achieve someone else's ends. For the purpose at hand, it is helpful to formulate these ethical concerns in terms of two tests:

> *Threshold Test:* Does enhancing reasonably protect people's minimum capabilities?
> *Flourishing Test:* Does enhancing increase people's capabilities and enable them to lead better lives?

Taken together, the two tests operationalize the capability approach by establishing what is required to justify a particular BCI application. Passing the threshold test is necessary for respecting human dignity understood as reasonable efforts to support capability minimums. Passing the flourishing test respects dignity in a different sense; it ensures that an individual is not enhanced as a mere means to realizing someone else's ends. The two tests link a general capability framework with practical decision-making about cases and policies. They do this by introducing a moral vocabulary, centered around capabilities, for specifying morally salient features of a situation. The tests lend themselves to weighing and balancing multiple competing goods in a manner that is scalar, rather than binary. In this way, the capability view facilitates thoughtful application and legislation.

In the analysis that follows, we confine ourselves to showing how the capability view we propose generates practical normative guidance for BCI in specific contexts. Although we respond to objections (in Section 4), our principal aim is not to defend the capability view as such, but to show how it fills a critical gap in the literature. Specifically, we argue that the threshold and flourishing tests do a better job than other normative frameworks in giving practical guidance for the responsible use of BCI, succeeding where others fail. We consider two alternative frameworks: utilitarian ethics and neurorights. Utilitarian ethics is a general normative view that prescribes maximizing utility for everyone affected by a decision. While variously interpreted, "utility" is generally understood in terms of happiness or well-being. Neurorights is a deontological view that assigns priority to certain ethical claims, even when this does not produce the best consequences overall (Goering et al., 2021; Ienca, 2021; Strickland, 2021; Yuste, 2017; Yuste et al., 2021). These claims concern the domain of mental life, and include, for example, rights to cognitive liberty, mental privacy, mental integrity, and psychological continuity (Ienca & Andorno, 2017).

**Current Medical Applications of BCI** To demonstrate how the threshold test applies to existing BCI applications, consider two medical cases where BCI restores threshold functioning through computer mediation in patients with profoundly diminished capacities.

> *Case 1: Patient with ALS and locked-in syndrome* (Vansteensel et al., 2016).
> A 58-year-old patient with locked-in syndrome (complete paralysis and inability to speak) from late-stage ALS was able to communicate using eye movements and blinks denoting "yes" and "no" but was otherwise completely paralyzed. Subdural electrode strips were placed over the patient's sensorimotor region, and the patient was trained to activate their motor cortex ("brain click") by trying to move their right hand to move a cursor to hit a target. Eventually, the patient was able to activate the motor cortex to select letters, words, and phrases highlighted on a computer screen. The patient was provided with a home use system run on a Microsoft surface tablet and at day 197 used the system independently, without assistance from investigators, with a mean accuracy rating of 87% for brain click tasks at 7–9 months post-surgery.
> *Case 2: Patient with Stroke and Quadriparesis* (Moses et al., 2022).
> A 36-year-old patient who had an extensive brain stem stroke at age 20 experienced weakness in all four limbs (quadriparesis) and inability to articulate intelligible speech (anarthria). Cognitive functioning was intact and eye movement was unaffected. A subdural multielectrode array was placed over the sensorimotor cortex area of the brain that detects speech. In a 2-phase trial, the patient was first, presented with 1 of 50 words and 2 seconds later, prompted to say the word aloud. Neural data gathered during these attempts was used during phase 2. In phase 2, researchers combined words from the first phase into 50 sentences, presented the patient with

**Table 1** Examples of BCI-enabled capabilities in cases 1 and 2

| Examples | BCI-enabled capabilities |
|---|---|
| "I want to save for my son's college" | Life narrative |
| "I want treatment for an infection" | Life narrative; Practical reason; Bodily integrity; Health |
| "Foot hurts" | Health; Bodily integrity |
| "I want to talk" | Mental and emotional health; Affiliating |
| "I am thirsty" | Health; Bodily integrity |
| "Move my head to face the door" | Bodily integrity; Senses, imagination, and thought |
| "Play music" | Senses, imagination and thought; Play |
| "I love my cool son" | Emotions; Affiliation |
| "I want to live at home" | Practical reason; Life narrative; Bodily integrity |
| "Go outside" | Nature; Senses, imagination, and thought |
| "Pawn to E4" | Play; Practical reason |
| "Open the window" | Environment; Nature |

the sentences, and prompted them to reproduce the sentences with the aid of natural language modeling that generated next-word probabilities. Computer-decoded words and sentences were displayed in real time for the patient to check for decoding errors. At 81 weeks, the median sentence error rate for each word was 25.6%.

While these BCI applications are not ethically contested, they serve to illustrate how the threshold and flourishing tests apply in current medical contexts. The therapeutic BCI applications in cases 1 and 2 pass both the threshold and flourishing tests, because they support BCI users' minimum capabilities and help them lead better lives. Dignity, the ethical value underpinning the capability view, explains the importance of these therapeutic BCI uses and justifies prioritizing BCI for patients with profoundly diminished capacities. In cases 1 and 2, even though BCI does not restore patient's capabilities directly, it offers computer-mediated substitutes that bring patients closer to threshold capabilities in a range of ways. Table 1 illustrates how communicating with an output device using BCI gives users in cases 1 and 2 a range of associated capabilities.

Although BCI enhances patients' functioning, the current state of the art limits the support BCI can offer. For example, in Case 2, there was a 50-word limit and 25.6% error rate per word. As BCI technologies advance, it is expected that greater improvement of patients' capabilities will be possible. The threshold test gives ethical backing to further developing BCI to afford patients like those in cases 1 and 2 better opportunities to function at a threshold level.

## 3 A Capability Approach to Future Non-clinical Applications of BCI

While medical applications of BCI aim to support the threshold capabilities of patients with debilitating disease or injury, researchers are exploring future applications outside the medical setting, which seek to extend baseline capabilities in healthy people. Experts forecast that the current trajectory is leading to a future where we can "decode people's mental processes and directly manipulate the brain mechanisms underlying their intentions, emotions and decisions," "communicate with others simply by thinking," and have "powerful computational systems linked directly to people's brains" (Yuste & Goering, 2017). This section discusses possible future BCI applications and shows how the threshold and flourishing tests resolve ethical disputes in a reasoned way.

While some scholars discussing possible future BCI applications have focused on applications that are further in the future, such as improving moral character (DeGrazia, 2014; Douglas, 2008, 2015; Earp et al., 2018; Persson & Savulescu, 2008, 2012), or ushering in a new stage of human evolution (Bostrom, 2003; Harris, 2007), we consider military BCI applications, because there are multiple well-funded research projects currently underway designed to produce near term results. In the USA, the military has not only been a leading funder of BCI research and development since the 1970s; it is currently embarked on research forecast to result in near-term military applications. In 2018, the Defense Advanced Research Projects Agency (DARPA) launched a program to design next-generational nonsurgical neurotechnology (N3) with the aim of developing "a safe, portable neural interface system capable of reading from and writing to multiple points in the brain at once" (DARPA, 2018). DARPA funded six teams under this program to produce high-performance nonsurgical brain-machine interfaces for able-bodied service members with national security applications by the year 2050. The teams are exploring diverse nonsurgical modalities, including ultrasound, magnetic fields, light, electrical fields, and optical tomography, to improve warfighting ability (Ganzer, 2020).

Unlike BCI applications in cases 1 and 2, which are not ethically contested, neuroenhancement stirs significant controversy. Some scholars hold that cognitively enhancing is morally imperative to save the planet (Douglas 2008, 2015; Persson & Savulescu, 2008, 2012); others maintain it is allowable in certain instances if people elect it (DeGrazia, 2014). Still others endorse humans improving themselves in a thoroughgoing way (Bostrom, 2003; Harris, 2007). On the opposite side of this debate are those who oppose most forms of enhancing on the ground that it is dehumanizing (Mehlman, 2012); compromises authenticity (Sandel, 2007); diminishes solidarity (Sparrow, 2014); or creates unjust inequalities between enhanced and unenhanced people (Buchanan et al., 2000). Evidence from a 2020 Pew Research Center Report shows that US public trust in hypothetical neuroenhancements, like implanting brain chips to increase concentration and information processing, is low (69% report being "very/somewhat worried") (Funk, 2020). Despite ethical concerns, the US Department of Defense anticipates that public trust will increase in the future, as the healthcare field "acclimatizes the population" to the use of neuroenhancers, creating an opening for other areas, including defense (Emanuel et al., 2019).

Battelle, one of the groups DARPA has funded as part of its N3 program, moved to phase 2 research in 2020 to develop an interface called BrainSTORMS (Brain System to Transmit Or Receive Magnetoelectric Signals), which involves injecting tiny magnetoelectric nanotransducers (MEnT) into the circulatory system and then guiding them with a magnet to targeted regions of the brain, with the aim of subsequent bi-directional interfacing. Eventually, MEnT is guided out of the brain and into the bloodstream to be processed out of the body (Battelle Media Relations, 2019). The team reportedly already achieved "precise reading and writing to neurons," with phase 2 focused on maturing this capability (Businesswire, 2020). Case 3 describes a hypothetical future scenario using a version of Battelle's bidirectional BCI interface to enhance a soldier's warfighting capabilities.

> *Case 3: 2-way BCI to deploy remote smart weapons* (adapted from Battelle Media Relations, 2019).
> A 27-year-old soldier was injected with Battelle's MEnT and trained to control weaponry using thoughts based on signals from a command-and-control center. The soldier achieved 92% mean accuracy over a 6-month period and was placed in a classified Special Operation strike cell. During missions, the soldier worked in an office thousands of miles from the combat zone deploying smart weaponry.
> The soldier was subsequently ordered to engage in a mission demanding rapid reaction time in response to anticipated terrorist threats. To achieve this, BCI was automated: the computer occasionally selected goals by predicting with a high level of confidence what the BCI user's goals would be in the situation and determined optimal steps to realize these goals.

In Case 3, a primary ethical justification for BCI is utilitarian: BCI enhancements increase warfighting capabilities, such as maintaining military readiness as technologies advance and protecting military assets by keeping soldiers remote. A utilitarian argument gains added force if one thinks that BCI enhancements will be endorsed by militaries around the world and that developing them will be necessary to maintain military readiness. Military applications might be considered a higher priority than non-medical applications like entertainment, because the benefits that accrue are vital to national security. It could also be argued that military uses would be safer for users, because soldiers could be more closely monitored for adverse effects than individuals using BCI for entertainment in private settings. These lines of thinking suggest that military BCI enhancement creates the greatest good.

From a capability standpoint, the utilitarian assessment of Case 3 glosses over BCI's potentially adverse impact on the soldier's threshold capabilities. Such concerns are already emerging in interviews with soldiers waging remote warfare without BCI. According to a *New York Times* report, soldiers who operate drone weaponry remotely to launch airstrikes show higher levels of emotional distress, post-traumatic stress disorder (PTSD), suicidal ideation, and broken marriages compared to conventional soldiers (Philipps, 2022). Unlike regular combat soldiers, they are not recognized as being deployed, do not earn additional time-off for combat service, and can face added stigma if they seek mental health services, because they are classified as office workers. While "drones were billed as a better way to wage war –a tool that could kill with precision from thousands of miles away, keep American service members safe and often get them home in time for dinner," they eventually created "an unseen toll on the other end of those remote-controlled strikes" (Philipps, 2022). Case 3 highlights that changing a single capability can have spillover effects on other capabilities and other aspects of a person's life, complicating the ethical analysis. Notwithstanding these concerns, the use of remote weapon systems and unmanned vehicles is increasing on the modern battlefield (Emanuel et al., 2019).

Imagine a second hypothetical future scenario, depicted in Case 4, in which BCI allows seamless interactions between individuals and machines to deploy drones, weapons, and other remote systems with a 3-way BCI interface enabling communication between users, commanders, and soldiers.

> *Case 4: 3-way BCI for communications and deploying remote weapon systems* (Emanuel et al., 2019).
> A 32-year-old special operations soldier was injected with Battelle's MEnT and trained to use thoughts for 3-way communication with the unit commander and other members of the special operations force. MEnt also made it possible for the solider to control remote weapons systems using thoughts alone. This enhanced warfighting capabilities by enabling greater situational awareness and more rapid response to threats.

A capability analysis of cases 3 and 4 identifies several capabilities that are at-risk of falling below a capability minimum; Table 2 illustrates, giving specific examples of threats to threshold capabilities in cases 3 and 4.

In contrast to the medical applications of BCI (in cases 1 and 2), which helped patients by compensating for capability losses, military applications (in cases 3 and 4) help the military realize its objectives. In the process, iatrogenic effects on soldiers potentially produce capability shortfalls that interfere with soldiers' threshold abilities to be the author of their lives, be healthy, have bodily integrity, trust their senses, and identify mental states and emotions as their own. Although soldiers routinely sacrifice to benefit others, it is not the case that "anything goes"—there are ways we can treat soldiers that fall below the minimum required to respect their dignity.

Still, it might be argued that an individual's life plan might feature a military career, and, in this sense, BCI enhancements might fulfill their career aspirations. Yet, even if BCI enhancements advance soldiers' military careers, a capability view would reject them. Fundamental dignities are ultimate ends and cannot be ethically traded-off in this manner, nor can an assault on dignity be made right by benefits later on. Analogously, when performance-enhancing drugs, such as anabolic steroids, improve a cyclist's ability to win races, the price is too high, because the same drugs pose serious risks to health and life—they are linked to significantly greater risk of death and a variety of cardiovascular, psychiatric, metabolic, endocrine, neurologic, infectious, hepatic, renal, and musculoskeletal disorders (Pope et al., 2014).

In contrast to the clinical BCI applications in cases 1 and 2, which pass both the threshold and flourishing tests, non-clinical BCI applications in cases 3 and 4 fail the threshold test, because they imperil threshold capabilities. They fail the flourishing test if they are solely or primarily used to promote the military's goals.

However, in response to our analysis, it might be argued that the existing analytic framework, known as neurorights, adequately protects threshold capacities for the soldiers in cases 3 and 4. Rather than introducing a new framework, why not say

**Table 2** Potential threats to threshold capabilities from future BCI devices in cases 3 and 4

| Central capabilities | Threats to threshold capabilities |
|---|---|
| Life narrative | Reduced authorship over life narratives when AI is used to predict intentions and goals; uncertainty about the source of thoughts/feelings |
| Health | Reduced mental health associated with remote killing; increased substance use disorder, depression, divorce; disassociation from thoughts/feelings |
| Bodily integrity | Reduced bodily integrity when computers perform actions in lieu of the body; uncertainty about who/what instigates action |
| Senses, imagination, thought | Loss of direct sensory experiences when input is computer mediated; reduced trust in the senses |
| Emotions | Reduced emotional well-being due to moral distress, detachment, emotional numbness |
| Practical reason | Reduced sense of agency and accountability due to uncertain ownership of thoughts/feelings |
| Affiliation | Reduced affiliation, physical contact, and in-person interaction |
| Nature | --- |
| Play | --- |
| Environment | Reduced control over the environment when computers substitute for one's own action |

that the soldiers in these cases have a neuroright to *cognitive liberty*, understood as a right not to have one's mental states unreasonably interfered with, and/or a neuroright to *mental privacy*, understood as a right to have a protected private mental space (Ienca & Andorno, 2017).

In reply, although a neurorights framework recognizes some central capabilities, it downplays or omits others. For example, in Case 3, a neurorights approach does not protect the soldier's threshold capacities to author a life narrative; be physically and mentally healthy; feel and express a range of human emotions; have bodily integrity; affiliate with other people and nature; play and recreate; and regulate the environment. While the threshold test safeguards all of these capabilities, a neurorights framework is narrower, centering capabilities to think freely and deliberate without interference. While human capacities for thought and practical reasoning are certainly important, they hardly exhaust the central capacities pertinent to Case 3, which is principally concerned with BCI's impact on the soldier's capacities for emotion, affiliation, and mental health.

It might be countered that a more expansive version of neurorights can remedy this by simply adding neurorights for each central capability. However, the language of neurorights works better for some capabilities than others. For example, Ienca and Andorno's neurorights framework recognizes not only cognitive liberty and mental privacy, but also *mental integrity*, which is the right to have mental states protected against potential harms and *psychological continuity*, which is the right to have mental states critical to personality and personal identity protected (Ienca & Andorno, 2017). These additional neurorights could be rendered narratively (although Ienca and Andorno do not interpret them this way) and incorporate the capacity to author a story of one's life. Yet, rendering some of the other capabilities in terms of neurorights is difficult. The language of neurorights seems particularly ill-suited to capabilities like health, bodily integrity, affiliating, emotions, relating to nature, and play, which involve more than mental states. If we want to protect the full range of central things human beings can do and be, neurorights do not suffice. Some defenders of neurorights agree, holding that neurorights "will not ensure the protection of all ethical values adversely implicated by AI, given that human rights norms do not comprehensively cover all values of societal concern"; hence, "more work needs to be done to develop techniques and methodologies that are robust" (Yeung et al., 2020, p. 76).

Taken together, the analyses of cases 1 through 4 demonstrate that BCI not only holds promise for supporting threshold capabilities in people with severe disease and injury, but also poses threats to threshold capabilities and dignity. The two tests promote responsible use of BCI by ensuring respect for persons and human dignity.

## 4 A Capability View and Dual-Use BCI

The threshold and flourishing tests seem to offer an initially plausible way to guide the responsible use of BCI and limit adverse impacts on BCI users. For example, these standards provide ethical backing for enacting laws to protect threshold capabilities, which seems feasible and has already occurred in one nation.[1] However, it would be hasty to conclude that ethical concerns BCI raises have been adequately dealt with. Consider a further case, adapted from clinical research currently underway testing a closed-loop deep brain stimulator (DBS) called the NeuroPace Responsive Neurostimulation (RNS) system (Krystal, 2019).[2] This device can sense brain activity associated with deleterious mood states and responds with electrical stimulation to treat major depressive disorder (Scangos et al., 2021).

*Case 5: Closed-Loop DBS for Dual Use.*
A soldier's individual anatomy was tested to locate brain regions where stimulation generated a preferred response. The soldier was then fitted with RNS+, a closed-loop DBS system to inhibit potentially problematic responses to violence, fear, and anxiety. In contrast to *open loop* DBS, which sets brain simulation

[1] In 2021, Chile became the first nation to enact a constitutional requirement that technological developments protect people's physical and mental integrity; it specifically protects brain activity and information related to it (McCay, 2022). While it remains to be seen how the new law will be interpreted, one reasonable interpretation is that it would forbid automation of the sort used in case 3, regarding it as too disruptive of end users' mental and physical integrity. The law might conceivably ban the BCI application envisioned in case 4, if it does not sufficiently protect brain data from being manipulated during wartime, e.g., preventing enemy combatants from seeking to gain a military advantage by sending disruptive brain signals to confuse and incapacitate soldiers, commit information theft, manipulate soldiers' emotional states, or erase their memory. These uses clearly harm BCI users and fail the threshold test.

[2] Trial start date was July 2019, with estimated completion June 2035 (Krystal, 2019).

parameters at a constant level, *closed loop* DBS automatically adjusts based on the brain's real-time response, enabling a more effective outcome.

RNS+ had twin objectives: (i) enhancing military performance by reducing psychological resistance to warfare and (ii) preventing PTSD, a mental health condition that can occur after exposure to shocking, frightening, or hazardous events, and produce symptoms such as flashbacks, nightmares, intrusive thoughts, anxiety, avoidance, and changes to mood and thought that can interfere with relationships and work and become chronic (National Institutes of Mental Health, 2022). The intervention also produced unanticipated blunting of soldiers' threshold capacities, causing unproblematic emotional response to fall below a threshold considered minimal.

Case 5 seems to challenge the capability view, yielding contradictory results. On the one hand, the capability view directs us to use RNS + to prevent PTSD, because PTSD would place the soldier's future threshold capabilities at risk. On the other hand, the view directs us not to use RNS +, because it directly undermines the soldier's generalized capability for emotions. The case illustrates what is sometimes termed, "dual use." The term refers to interventions with applications in more than one domain; for example, a neurotechnology originally developed for clinical applications and later used for political, security, or intelligence applications (Ethics & Society Committee, Human Brain Project, 2018). Typically, dual use involves outcomes that are permissible in one domain but either impermissible or morally problematic in the other. Case 5 exemplifies a special case of dual use: both outcomes occur with a single intervention applied to a single user. Hence, avoiding the undesirable effect (generalized reduction of emotional response) also prevents the sought-after effect (enhanced warfighting and PTSD prevention).

The Ethics & Society Committee of the Human Brain Project defines *responsible* dual use as the promotion of responsible research and innovation practices, where "responsibility" refers "not to fixed norms," but to processes and practices within research and development systems, and the extent to which they encourage or constrain the capacity of all those involved in the management and operation of research to reflect upon, anticipate and consider the potential social and ethical implications of their research, to encourage open discussion of these, with a view to ensuring that their research and development does indeed contribute to the health and well-being of citizens, and to peace and security (Ethics & Society Committee, Human Brain Project, 2018).

The capability approach we are developing provides both a process and a modest norm. The process involves a way of deliberating about neurotechnology applications that considers their effects on central human capabilities; the norm prescribes respecting these capabilities at a threshold level. By relying on modest premises, the capability view can gain wide acceptance in public discussions and assist with establishing guidelines for responsible use of BCI (Jecker, 2022).

In Case 5, an automated DBS system that effectively eliminated brain signals associated with emotional response to warfare would not be justified. However, a system that inhibited brain signals to a lesser extent, leaving intact a threshold level of emotions like terror and fear, might be justified, provided it could be switched off outside military contexts to prevent iatrogenic effects, such as disinhibiting violence in a family setting. Importantly, a capability framework is agnostic with respect to method. For example, if psychopharmaceuticals, such as propranolol, were used to block soldiers' emotional reactions to war or torture, they would not be justified on a capability framework. What matters from a capability standpoint is whether an intervention protects threshold capabilities, leaving them intact, not the type of intervention used.

The analysis of Case 5 brings to light that training and preparation of soldiers for warfare occurs along a continuum. At one end is basic training, discipline, and indoctrination designed to prepare recruits for combat by making them more comfortable with warfare; today, this includes advanced computer simulations like virtual reality as well as video gaming (Mead, 2013). At the other end are leading edge neurotechnologies, like the futuristic RNS +, which delivers direct personalized automated brain stimulation in response to brain signals indicating emotional states that could diminish military performance. All along this continuum, soldiers are being primed to kill and to regulate and inhibit their ordinary psychological reactions to killing. In this respect, all forms of military training potentially inflict moral damage. Dobos characterizes soldiers who are "able to kill and maim people without feeling anything" as lacking the *virtue of proper affect*, which is "the disposition to be emotionally moved in a way that is fitting to the moral gravity of what one does and encounters" (Dobos, 2020). Even when a soldier is not *doing* anything wrong; e.g., they are fighting a just (defensive) war, there is a sense in which their *disposition* to feel nothing is morally flawed, because emotional anguish about killing is fitting. For this reason, Dobos characterizes military conditioning as "corrosive of virtue" (Dobos, 2020). According to Marlantes, a Vietnam veteran, healing requires coming to terms with emotions wrought by killing: "healthy grief about taking a life … is part of the sorrow of war" (Marlantes, 2011, p. 46); others describe healthy grieving as "remembering the past, recalling difficult memories and confronting the ugly truths of what the soldier has seen, done or failed to do in war" (Sites, 2013, Kindle location 117). These points underscore the importance of mitigating the moral hazards associated with military training. At the same time, in the military, as in other fields (such as medicine), training to regulate native responses to witnessing pain and suffering might be necessary to effectively do the next, right thing.

Finally, it could be argued that in Case 5, diminishing soldiers' emotional response to violence below a minimal level would not truly enhance soldiers' warfighting abilities. The reason is that the so-called "fight-or-flight response," which triggers increased heart rate (tachycardia), anxiety, increased perspiration, tremor, and increased blood glucose concentrations, not only instills terror, but helps soldiers survive, mobilizing them to act quickly in response to dangerous and life-threatening situations. Arguably, protecting this survival response at a floor-level both achieves military objectives and respects persons. If this is correct, then a preferred resolution involves locating a "sweet spot," which balances multiple considerations: allowing threshold emotional responses but blunting these responses enough to enhance warfighting capability and reduce PTSD incidence.

## 5 Replies to Objections

We turn finally to objections to the capability analysis and our replies.

**Neurorights are Adequate** Defenders of neurorights might remain unconvinced. For example, Ienca and Andorno maintain that neurorights represent the best analytic approach for assessing the ethical use of neurotechnologies (Ienca & Andorno, 2017). They defend four neurorights (cognitive liberty, mental privacy, mental integrity, and psychological continuity), which they claim comprise a complete analytic framework well-suited to evaluating BCI.

In reply, although neurorights sharpen normative analyses of BCI in helpful ways, obstacles arise when attempting to translate abstract neurorights to practical guidance and decision-making. First, neurorights are binary, making it difficult to weigh and balance them against one another and determine which takes precedence in a particular case. By contrast, a capability view lends itself to such weighing and balancing, because capabilities are scalar, ranging from a minimal threshold associated with dignity to a high level associated with flourishing. Threshold and flourishing tests give normative guidance by locating points along a continuum for each capability, which serve as reference points for determining allowable capability losses and gains.

Second, neurorights generally require only negative duties of non-interference. By contrast, a capability approach provides a strong basis for positive action to afford people with diminished capacities real opportunities to do and be what they have reason to value. For example, although rights to cognitive liberty, mental privacy, mental integrity, and psychological continuity justify non-interreference in cases like 3 and 4, they do not justify prioritizing positive actions in cases like 1 and 2.

Third, as noted already, capabilities are broader in scope than neurorights. A capability view protects threshold capacities such as emotions, bodily integrity, affiliation, and play.

Despite such differences, the two approaches—rights and capabilities—go well together. Capabilities show why rights matter, directing us to the central things that people can do and be, which neurorights protect. For example, the four neurorights Ienca and Andorno propose relate directly to the capabilities discussed in Sections. 1 and 2, showing how infringements of them impacts central things people can do and be. Table 3 illustrates this linkage.

In Table 3, the right to cognitive liberty matters because it protects people's capability to reason about their plans and goals, author a life narrative, and regulate their environment. Mental privacy matters because it protects against brain monitoring without consent and information theft. The right to mental integrity matters because it safeguards people's ability to be mentally healthy; exercise and trust their senses, imagination, and thought; and have and express a range of emotions. Psychological continuity carries significance for people because it underlies mental and emotional health, sustains relationships over time, and imparts meaning to life's events by fitting them into a coherent narrative.

**Table 3** Neurorights and capabilities

| Neurorights | Associated capabilities | Examples of capability threats neurorights protect against |
|---|---|---|
| Cognitive liberty | Practical reasoning; Life narrative; Environment | Malicious brain hacking; Algorithmic bias in predictive brain technologies; Neuro-discrimination against those who are not augmented |
| Mental privacy | Health/mental health; Affiliation | Brain monitoring without consent; Information theft |
| Mental integrity | Health/mental health; Bodily integrity; Senses, imagination, and thought; Emotions | Brain stimulation to influence behavior, thoughts, emotions, or memory; Neuropsychiatric side effects of neurotechnology |
| Psychological continuity | Health/mental health; Emotions; Affiliation; Life narrative | Illicit memory erasure; Brain alterations that disable our ability to know what we did and be accountable; Automation that frustrates users' ability to exercise volitional control over actions |

**Technology Changes Capabilities** It might be argued that neurotechnology is apt to change the central things that people can do and be. In light of this, the threshold and flourishing tests are moving targets, which undercuts their ability to normatively guide in a stable and helpful fashion. According to some transhumanists, humans have a "transformative essence," and are constantly driven to improve themselves and expand their capabilities (Bostrom, 2003, p. 3). Coeckelbergh puts the point this way: "if capabilities are *already* changing and have always changed…The normative question is no longer *if* we should change human nature but *how* we should change it" (Coeckelbergh, 2011, p. 86, emphasis added).

In response, emerging neurotechnologies may force us to decide what we *want* to be able to do and be. Yet this does not defeat the general capability analysis. Instead, whatever we choose, the threshold and flourishing tests apply to the central things that human beings can do and be. For example, if human beings living in 3022 have an extended capacity for affiliation, which includes brain-to-brain communication, then reasonable efforts should be made to protect this new capability at a threshold level.

Still, a critic might contend that threshold and flourishing tests are on shakier ground than we think. BCI will accelerate capability change well beyond the relatively slow-paced change built-in to modern evolutionary theory. This will mean that the two tests require more frequent updating, and can no longer function as reliable guides (Lewens, 2012; Powell, 2012; van de Poel & Kudina, 2022; Hull, 2009).

In reply, if human capabilities change more rapidly, all normative standards must adapt, not just the capability view. For example, if typical functioning for humans in the year 3000 includes the ability to read others' thoughts, the neuroright protecting mental privacy would need to be adjusted to account for this. This hardly shows that neurorights are useless; instead, it indicates that their specification must change to keep pace. To further clarify, we distinguish a *general normative framework* (e.g., capabilities or neurorights) from its *specification* (e.g., a capability list with threshold and flourishing tests, or a list of neurorights). A general framework can remain constant, even if its specification shifts. For example, affiliation is a central capability, yet the way people affiliate may change.

**Misapplying the Capability View** A further objection holds that our analysis uses a capability framework to do what it was not designed to do. Capability approaches are generally concerned with protecting capabilities, while cases 3 through 5 are about altering capabilities.

In reply, as noted (Section 1) integral to the capability view as we present it is the idea that human capabilities can and do change, making any list of capabilities provisional. Neuroenhancements do not introduce something new, that a capability view is ill-equipped for.

Admittedly, a limitation of both capability and neurorights views is that they were not designed to tell us which capabilities *ought* to be pursued; instead, both focus on protecting whatever capabilities a person has. In this respect, both views are incomplete and must be supplemented with a fuller normative analysis designed to do this work.

## 6 Conclusion

In conclusion, we set forth an ethical analysis of intelligent neurotechnology using a capability framework. We demonstrated the practical relevance of this framework by applying it to current and potential future applications of BCI and proposing ethics tests and benchmarks based on it. We argued that a capability framework carries advantages over utilitarian analyses and offers a more robust account than neurorights alone. We encourage future research exploring how a capability account can contribute to assessing the responsible use of intelligent neurotechnologies.

**Acknowledgements** This paper was presented at the University of Bochum, Institute for Philosophy, conference on "Public Justification, Science, and Medicine," Bochum, Germany, June 2022.

**Author Contribution** Each author contributed substantially to the conception and analysis of the work; drafting or revising it critically; final approval of the version to be published; and is accountable for all aspects of the work.

**Data Availability** Not applicable.

**Code Availability** Not applicable.

## Declarations

**Ethics Approval** Not applicable.

**Consent to Publish** Not applicable.

**Competing Interests** The authors declare no competing interests.



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