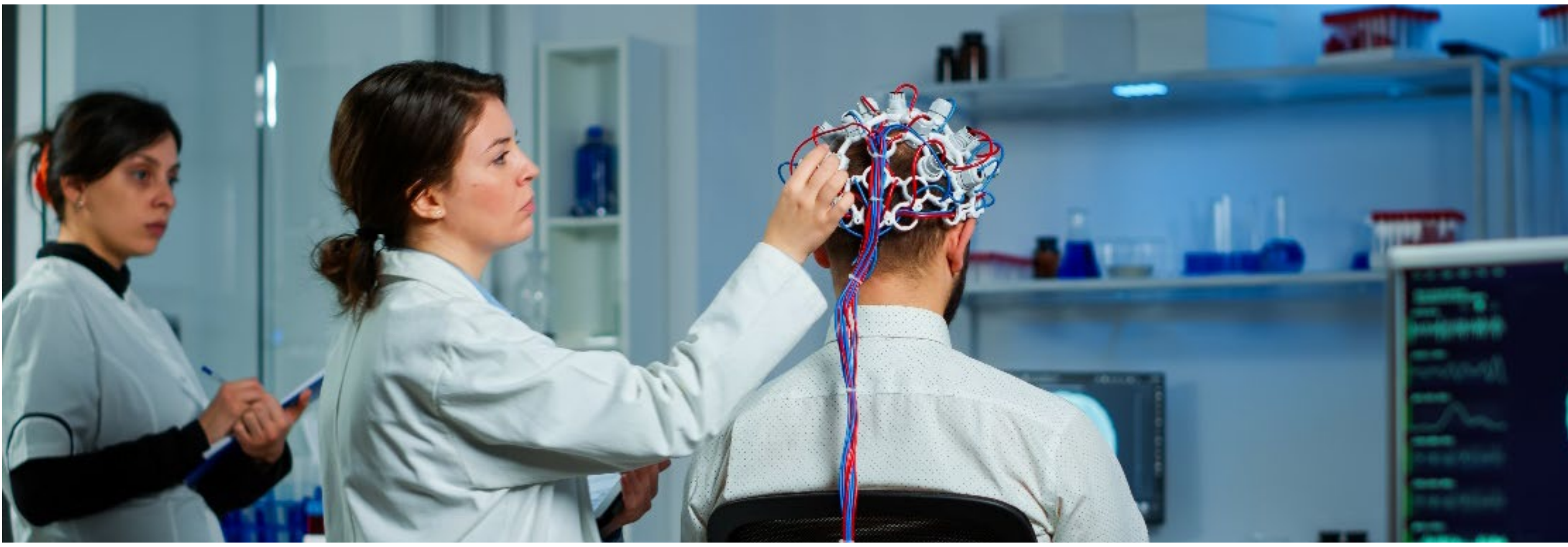
Rathenau Instituut

Neurotechnology



Rathenau Scan

The emergence of neurotechnology that can perhaps read and influence our mental states has captured people's imagination. Technology companies are developing devices for consumers to use at home, in the workplace, or in the classroom. Ethicists and legal specialists warn that cognitive freedom and mental integrity will be threatened if outsiders are able to use neurotechnology to access our mental states.

In this scan, the Rathenau Instituut provides an overview of neurotechnology. We describe the intended applications, opportunities, and risks for public values in the short and longer term, and policy instruments for protecting and promoting those values. The scan concludes by outlining the options that policymakers have for taking action. This Rathenau Scan was produced at the request of the Dutch Ministry of the Interior and Kingdom Relations.

Contents

1. Summary

In this scan, we explain the developments in neurotechnology and consider the opportunities and risks where public values are concerned. The Rathenau Instituut concludes that these opportunities and risks are connected to the widespread commercialisation of wearable neurotechnology that is easy for non-medically trained people to use. The large-scale collection and processing of neurodata entails risks, and it is unclear whether the current Dutch, EU, and international rules offer sufficient protection. If neurotechnologies develop significantly in the longer term, it may become possible to read, influence, and manipulate mental states more precisely. In that case, public values associated with fundamental aspects of being human, such as autonomy and identity, could be threatened.

1.1. What is neurotechnology?

The brain is a complex organ where various mental states originate – concentration, attention, cognitive skills, thoughts, memories, emotions, and dreams. For decades now, there has been significant investment in research aimed at better understanding the processes within the brain that generate these mental states. In the present scan, we use 'neurotechnology' as an umbrella term for various different technologies to measure and/or influence brain activity.

Reason for a Rathenau Scan on neurotechnology

The Rathenau Instituut sees three main reasons for looking closely – especially now – at how far neurotechnology has advanced and at what potential impact it can have on society. First, large technology companies are increasingly entering the field of neurotechnology, expanding the range of consumer devices that work with this technology. Second, technological developments are underway that will make the non-medical use of neurotechnology more readily accessible. The current pace of progress in artificial intelligence (AI) systems means that neurodata will become easier to interpret for non-medically trained individuals. Moreover, the development of 'dry' EEG sensors makes it possible to measure brain activity without having to apply a conductive gel to the scalp, thus considerably improving consumer access to neurotechnology. The third reason for this scan is the current international ethical and legal discussion of the need to expand the existing frameworks of human rights to include specific 'neurorights'. The central issue under discussion is whether new rules are needed to protect people from having their mental states read out, thus directly influencing and possibly even manipulating their behaviour.

How does neurotechnology work?

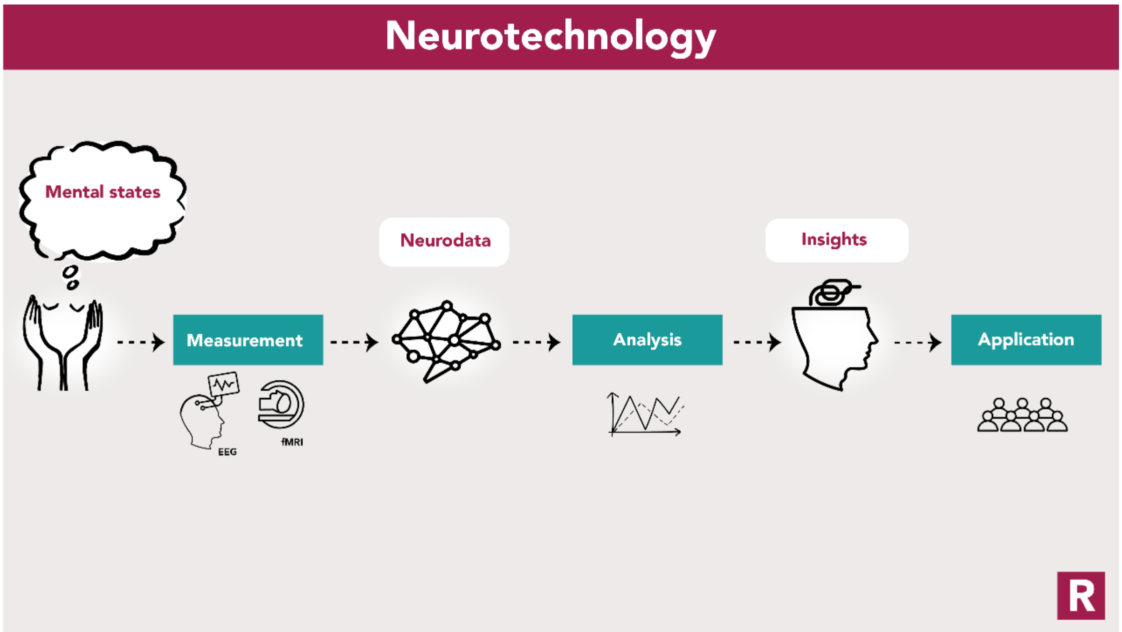
To understand how neurotechnology works, it is useful to distinguish between a number of different processes that are involved (see Figure 1).

Measurement: The brain contains a large number of neurons (nerve cells) that fire electrical signals when they are active. An active area of the brain also consumes additional oxygen. This kind of physiological activity can be observed and converted into digital data using a measurement system. Different technologies, such as EEG, ECoG or fMRI, measure different types of physiological activity. Neurodata is therefore a digital representation of physiological activity – oxygen consumption and electrical activity – within the brain.

Analysis: Neurodata is interpreted by a professional, a consumer, and/or a computer program so as to draw conclusions about the mental state of an individual. In consumer applications, an AI system is often used to identify and display patterns in neurodata. Analysis of neurodata is successful when it generates useful insights into mental states. Researchers can also merge neurodata from different individuals and perhaps combine it with other kinds of data in order to discover how emotions, preferences, or thoughts work at the level of a group.

Application: Insights into the mental state of an individual or group can be utilised in various different ways. The information that neurotechnology provides about someone's mental state can be utilised directly (neurofeedback). The technology can also be used for neuromodulation, meaning that it then actually influences the activity of the brain. Neurotechnology can also be used to control a computer system.

Figure 1: Key concepts and specific features of neurotechnology



One problem with all these technologies is that everyone's brain generates different, unique brain activity. For more complex mental states – for example memories, dreams, and specific emotions such as homesickness – the neurotechnology needs to be fine-tuned to the specific person's brain.

1.2. Applications of neurotechnology

In the present scan, we describe a number of applications of neurotechnologies that are currently the subject of research or experimentation in various fields. In medicine, neurotechnology has a history going back several decades, with applications already having been the object of extensive research, thus affording a better understanding of the opportunities and risks than of those beyond the medical sector; the existing rules correspond to this situation. Our investigation focusses on neurotechnology beyond the field of medicine.[1] More recently, applications have been developed for personal use and in the fields of marketing, law, education, and the workplace (including the defence sector), and elite sports. These fields are subject to different regulations to those for neurotechnology in the medical sector.

Figure 2 (page 6) provides an overview of the applications that we describe in the present scan. The most rapid growth in the use of neurotechnology in the short term will be in ‘dry’ EEG measurement systems that use AI for analysis and that are incorporated into existing hardware such as helmets, headbands, AR/VR glasses, or earbuds. Users can already purchase these with a view to improving their cognitive abilities, mental health, or game experience.

Insights into a person's mental state, such as their attention and preferences, are being utilised to improve marketing. Experimental research is investigating whether neurodata can clarify what someone remembers. This application may be useful in the administration of justice. Experiments have shown that, in specific circumstances, neurofeedback can help improve educational performance, concentration in the workplace, and the performance of top athletes and military personnel. How these results hold up in the world outside the setting of a laboratory still needs to be studied more closely.

Neuromodulation is not yet used outside the medical field. Controlling devices by using EEG is already applied on a small scale in gaming, and is being investigated for various defence applications, such as driving a military vehicle.

1.3. Opportunities and risks for public values

We note that various elements of neurotechnology in the non-medical field entail both opportunities and risks where public values are concerned. For individuals, a better understanding of mental states – such as the ability to concentrate – can have positive effects on mental health. Neurotechnology can also contribute to personal development, for example by improving pupils' ability to learn in an educational setting. It may also be possible to use insights gained from neurodata to improve marketing for commercial or public purposes, resulting in economic vitality and prosperity. We also note, however, that at present claims for the potential of neurotechnology cannot always be substantiated scientifically.

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[1] This is a similar situation to that in cosmetic surgery, in which procedures are performed in private clinics and by medical professionals, but not for any medical purpose.

At the level of society as a whole, neurotechnology could improve safety by monitoring people in dangerous occupations so as to measure their alertness and concentration, and by also enhancing military capabilities.

The downside of these potential benefits for the individual are the risks they involve as regards the privacy of information and mental privacy. A measurement system can be hacked and used in an attempt to obtain personal information. One experiment proved that it was possible to arrive at a good estimate of someone's PIN by showing them pictures of numbers and analysing their neurodata.[2]

By risks to mental privacy, we mean keeping mental states private – such as particular thoughts – that you do not wish to reveal voluntarily. Interesting experiments have been performed in which subjects were able to reconstruct observed images or sounds entirely from neurodata. Nevertheless, the possibilities for ‘mind reading’ are currently limited and it is also unlikely that our personal thoughts will become easily accessible in the future. According to the experts, human experience and thoughts about it cannot be reduced to physiological activity within the brain and the neurodata derived from that activity. Being aware of these subtle distinctions is important in assessing the risks that neurotechnology poses in terms of mental privacy.

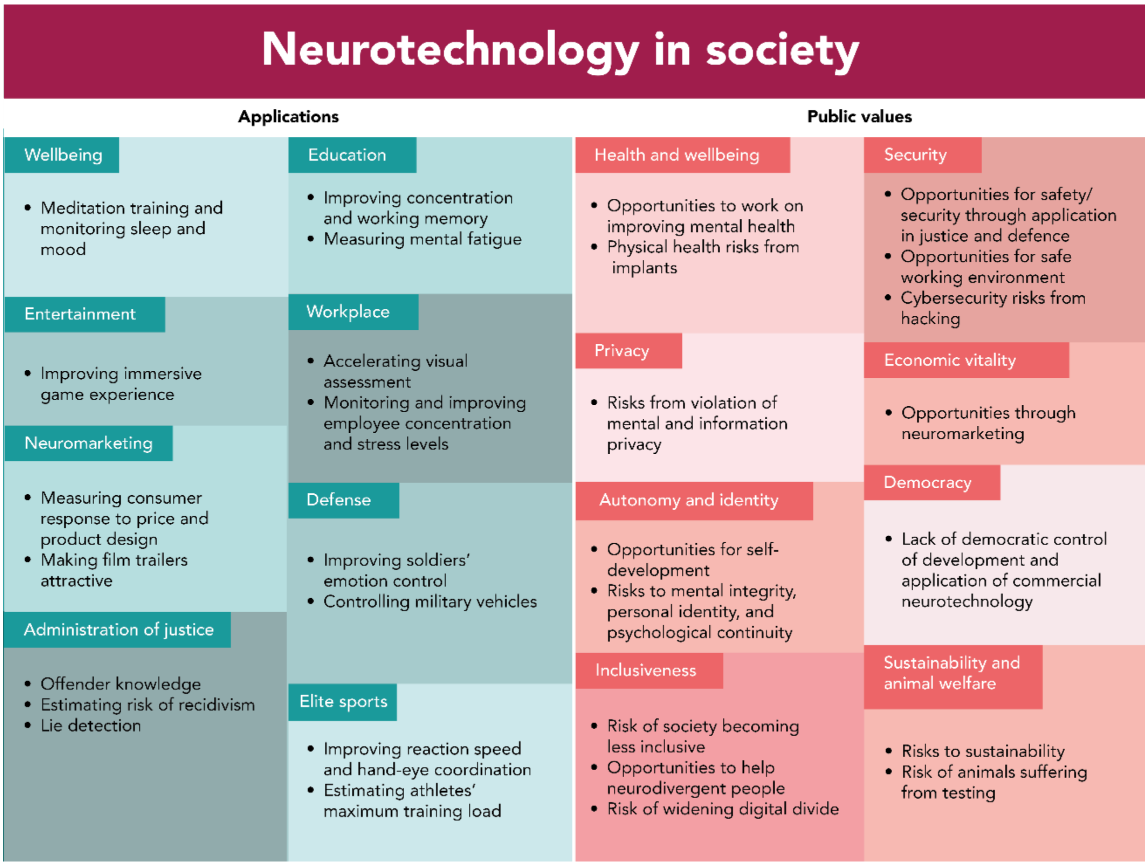
Even so, neurotechnology can indeed pose risks if neurodata is used in a way contrary to the interests of a user or the public interest. What is derived from neurodata need not be entirely consistent with actual mental states in order to have harmful consequences. Working with faulty interpretations may lead to a miscarriage of justice or an incorrect assessment of someone’s alertness in the workplace.

There are also risks associated with the use of AI systems in neurotechnology. A bias in the training data can disadvantage certain groups of people because the technology fails to work for them, or fails to do so effectively. Deploying AI systems can also be at the expense of autonomy. When an AI system directly anticipates patterns in neurodata, it is unclear who is responsible for making a decision.

Widespread implementation of neurotechnology may perhaps lead to opportunities for increasing inclusiveness if neurodivergent individuals are helped to operate more successfully within society. There is also a risk, however, that differences between people will be less accepted because they can be treated. It may be possible in future to correct what is at present regarded as anxiety. That can help individuals, but it can also lead to a greater tendency to regard symptoms as something to be ashamed of.

[2] Martinovic e.a., ‘On the Feasibility of {Side-Channel} Attacks with {Brain-Computer} Interfaces’, 2012.

Figure 2: Neurotechnology within society



Short-term and long-term risks

The main opportunities and risks of neurotechnology seem to fall into roughly two groups. Consumers can already benefit from wearable, non-invasive neuroimaging technology such as EEG. The risks that this technology entails are similar to those that have already been the object of discussion where other data privacy issues are concerned, but this technology goes a step further by literally and figuratively getting 'up close and personal'.

Other neurotechnologies – such as invasive brain implants, devices that directly influence ('modulate') the brain, and non-wearable imaging neurotechnology – offer more options for imaging or influencing mental states, but these are still very much at the development stage, are often less user-friendly, and are required to comply with strict medical guidelines. The wide-ranging risks to society associated with these neurotechnologies are therefore of a longer-term nature and involve greater uncertainty, but they are in fact much more far-reaching.

1.4. Policy analysis

Given the potential opportunities and risks, it is important to put policies and regulations in place so as to prepare for the societal effects that neurotechnology may have.

Unclear privacy legislation

For the short term, there are risks associated with collecting, storing, processing, and analysing neurodata. It is the EU's GDPR and the AI Acts, in particular, that apply here. It is probable that this legislation provides insufficient protection – outside certain specific contexts such as health or politics – for neurodata and the information that can be derived from it about personal preferences. It is unclear when neurodata falls into the category of health data or 'special personal data' in the GDPR, so that additional protection is thus provided for the privacy of those concerned. Non-pathological, emotional information and affective mental states may well fall outside the scope of that protection.

Neurodata also involves inherent challenges with regard to the basic requirements of the GDPR, namely transparency and informed consent, proportionality, data minimisation, purpose limitation, and accuracy. When the neurodata is subsequently analysed, the AI Act may play a role, although this applies only to certain highly specific applications, is subject to conditions that are vaguely formulated, and involves numerous exceptions and a system of self-assessment. Much will depend on how the standards and regulations are implemented.

Neurorights

There are certain issues where the legislation appears to fall short, with insufficient mitigation of the risks, particularly when neurotechnology is utilised on a large scale. This involves risks to the privacy of information (protection of personal data) and mental privacy (keeping all the aforementioned mental states private), autonomy and identity, physical safety and mental health, democracy, and inclusiveness.

Current discussion of neurorights focusses in particular on the issue of whether all the mental states of individuals referred to are sufficiently protected – in the light of emerging neurotechnology – by the current national, EU, and international human rights frameworks. There is as yet no consensus on this. First, it is debatable whether human rights frameworks can adapt sufficiently to the new situations that developments in neurotechnology may entail, or whether changes will be necessary. Second, opinions differ as to whether we already need to respond to developments in neurotechnology that may not actually materialise for a long time, if ever, for example, the covert reading of people's thoughts. Third, it is open to question which is more important: should people be free to improve their mental states with the aid of neurotechnology or should they be protected from outside interference in those mental states?

Options for action on the part of politicians and policymakers

We conclude that various policy instruments can to some extent offer protection against risks to public values from neurotechnology, but cannot do so completely. There are various possible courses of action for protecting and promoting public values in relation to the short-term impact of wearable, non-invasive technologies, as well as the uncertain long-term impact of other neurotechnologies. These are summarised in Figure 3: Options for action – policy.

Figure 3 Options for action regarding short-term and long-term risks of neurotechnology

Options for action – policy

For short-term risks

- Work towards a neurodata protection strategy at European level
- Define how to deal with personalised marketing using neurodata
- Continue to work on European neurotechnology and the associated infrastructure
- Foster public discussion of increasingly intimate emerging technologies, as well as cognitive freedom
- Clarify the gaps in the legislation

For long-term risks

- Formulate a strategy to monitor developments in neurotechnology
- Establish responsibilities in relation to brain implants
- Explore the need for better protection of mental states

2. Technology and the market

2.1. Introduction

In this scan, we explain recent developments in neurotechnology for imaging or influencing the brain. We consider the opportunities and risks that this technology involves as regards public values. Although grand claims are not new where neurotechnology is concerned, and significant investment in it goes back decades, the Rathenau Instituut sees three main reasons for looking closely – especially now – at how far this technology has advanced and at what potential impact it can have on society.

First, there are the various technological developments. Improvements in measurement systems make measuring brain activity easier. The rapid development of artificial intelligence (AI) systems means that neurodata can be analysed and interpreted even without the intervention of professionals. This makes neurotechnology applicable beyond the medical field, and opens up ways of incorporating it into commonly used devices such as headphones, earbuds, and AR/VR glasses. Increasingly, neuroscience research is being published about applications of neurotechnology in areas other than healthcare, such as education, the administration of justice, the defence sector, the workplace, and for entertainment.

Second, we note that various private parties, both large and small, in the consumer market are starting to invest in neurotechnology. These companies appear to see potential for home use of this technology, for example to improve one's mental wellbeing and one's game experience.

Finally, there is worldwide legal and ethical discussion as to whether it is necessary to include specific neurorights within the existing human rights frameworks.[3] The possibility that neurotechnology may invade our inner world and influence our mental state is viewed by international human rights organisations – for example UNESCO's International Bioethics Committee[4], the United Nations,[5] and the Council of Europe,[6] – as a risk with potentially drastic consequences. Not much has yet been written about the broader societal impact of such applications, and there is also uncertainty about how the technology will evolve further. Nevertheless, it is important to be prepared for the impact of the technology on society.

In this scan, we focus on applications beyond the medical field. Given that neurotechnology has so far mainly been used in that field, the medical applications

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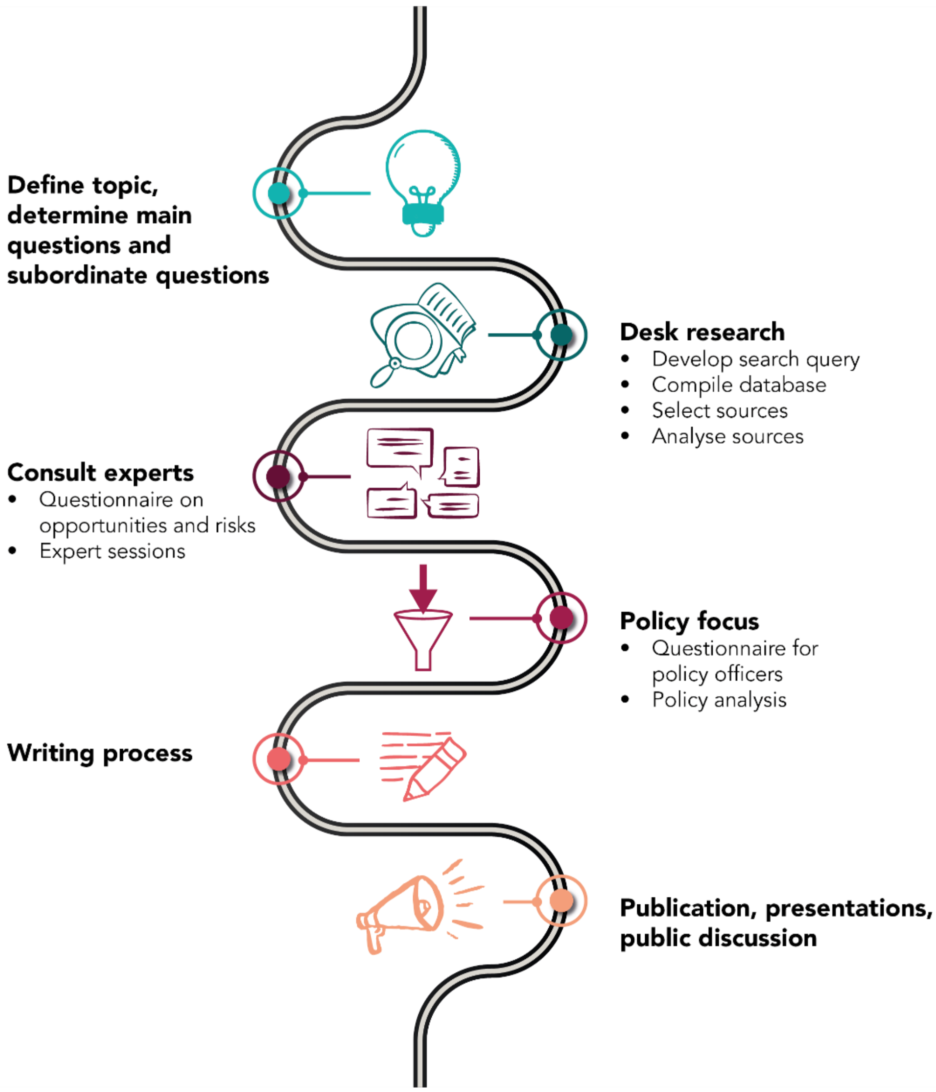
[3] Ligthart, Kooijmans, en Meynen, 'Neurorechten', 4 June 2021.
[4] UNESCO, First draft the Recommendation on the Ethics of Neurotechnology, 2024.
[5] Human Rights Council, 'Report of the Special Rapporteur on the Right to Privacy', October 2018; Human Rights Council Advisory Committee, 'Impact, opportunities and challenges of neurotechnology with regard to the promotion and protection of all human rights', 8 August 2024.
[6] Ienca, 'Common human rights challenges raised by different applications of neurotechnologies in the biomedical field', 2021.

have already been extensively investigated. There is therefore a relatively clear picture of the opportunities and risks for the medical field, and matching regulation.

In this first section, we begin by defining what we mean by neurotechnology. We explain how it works and what it offers compared to other technologies. We then describe the current market for this technology. Finally, we discuss the limitations and development of neurotechnology: how far has it currently advanced, and what expectations are there for the future?

In Figure 4 and Box 1, we explain our investigation methods.

Figure 4: Investigation methods



Box 1 Investigation methods for this Rathenau Scan

The findings in this scan are based on a three-stage investigation. We first created a database for desk research. This consists of a selection of sources since 2019 and forms the basis for our description of the latest developments in various fields and the associated opportunities and risks where public values are concerned. We consulted three kinds of sources: 1) academic literature, 2) ‘grey’ literature, including reports and journalistic sources, and 3) policy sources.

Second, a number of experts were asked to give their views as to which opportunities and risks are the most urgent and important. Nineteen Dutch neurotechnology experts completed a questionnaire on the opportunities and risks identified in the literature. We asked them which opportunities they thought would become apparent in the short or longer term, or perhaps not at all. Ten of the 19 experts then took part in an expert session to discuss the opportunities and risks about which differing opinions had been expressed in the questionnaire. See Appendix A for a list of those consulted and participants in the expert session.

Third, the policies applicable to selected opportunities and risks were identified. A questionnaire on relevant policy instruments for capitalising on opportunities and mitigating risks was distributed to policy officers from various ministries. These findings served as the starting point for a policy analysis based on a further review of the relevant literature. The Rathenau Instituut was assisted in this by a legal expert.

What is neurotechnology?

Neurotechnology is an umbrella term for all types of technology that measure or influence the activity of the central nervous system (which includes the brain). It therefore comprises a broad spectrum of technologies, some of which – for example EEG – measure brain signals through the skull, while others – such as Deep Brain Stimulation (DBS) – involve implanting electrodes into the brain to influence brain activity.[7] Neurotechnology can therefore be both invasive and non-invasive, and both modulating (i.e. directly influencing brain activity) and imaging (visualising brain activity) – see Table 1.

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[7] In some sources, this is also referred to as a ‘brain chip’ or microchip. In the present scan, we use the term 'implant'.

In the literature that we consulted, 'neurotechnology' often refers to BCIs, i.e. brain-computer interfaces.[8][9] A BCI can be regarded as technology that connects the brain to external equipment; it is the link between biology and technology.[10] It can be used, for example, to display someone's brain activity on a computer. Neuromodulation works the other way round, with the BCI converting information into signals that the brain responds to.[11] [12]

Table 1: Various technologies that may include neurotechnology.

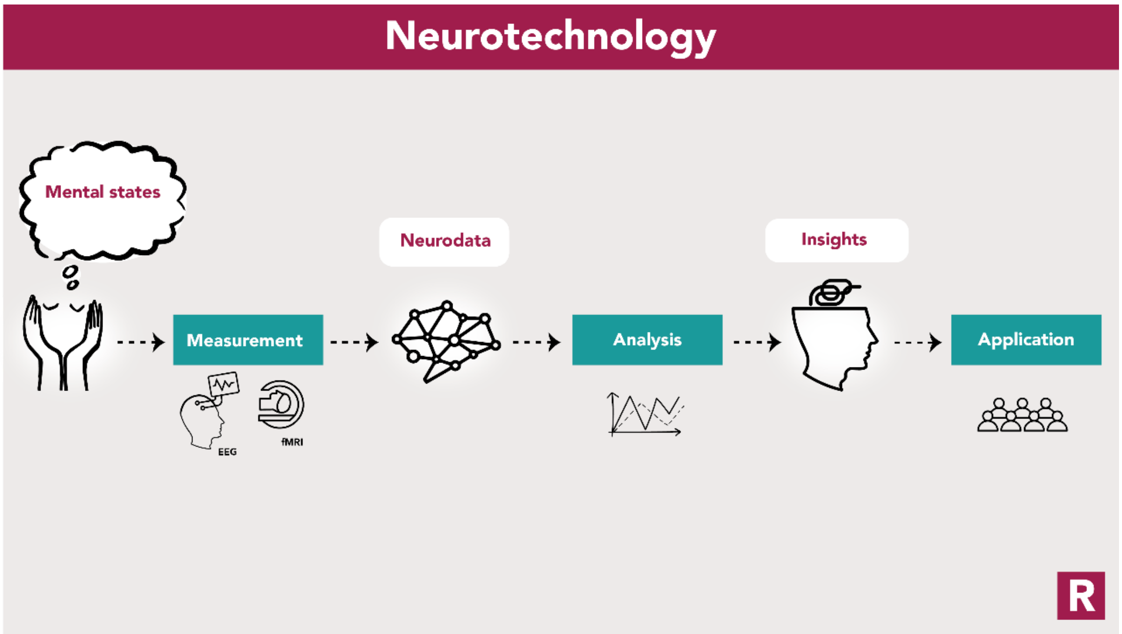
	Invasive (within the body)	**Non-invasive (outside the body)**
Visualising	Intracortical microelectrode arrays (Intracortical MEAs) Electrocorticography (ECoG)	Electroencephalography (EEG) Magnetoencephalography (MEG) Functional magnetic resonant imaging (fMRI) Functional near-infrared spectroscopy (fNIRS) Microelectrode arrays (MEAs)
Modulating	Deep brain stimulation (DBS)	Transcranial magnetic stimulation (TMS)

General functioning of neurotechnology

Neurotechnology is generally intended to acquire an understanding of an individual's mental states, for example, concentration, attention, emotions, thoughts, memories, and dreams. Neurotechnology is a means of mapping mental states (or aspects of mental states) – or at least approximating them as closely as possible – so that they are visible or usable. Despite the major differences between the technologies covered by the term 'neurotechnology', three established processes can be distinguished: measurement, analysis, and application. We summarise these in Figure 1.

[8] According to our definitions, neurotechnology only does not constitute a BCI when interaction with the central nervous system is only outside the brain itself or when measured brain activity is displayed directly without being analysed.
[9] The term 'brain-machine interface' (BMI) is also sometimes used.
[10] Andrews, Sultana, and Perdikis, 'Neurotechnology', 7 September 2024.
[11] Portillo-Lara e.a., 'Mind the Gap', 2, September 2021.
[12] Based, *inter alia*, on. Peksa en Mamchur, 'State-of-the-Art on Brain-Computer Interface Technology', 28 June 2023; Brazal e.a., 'TechDispatch on neurodata', 6 March 2024.

Figure 1: Processes and intermediate products in neurotechnology



Measurement: Different technologies measure different types of physiological activity. To understand how that works, we need to explain how the brain functions. Brain cells and nerve cells (neurons) connect to one another and to other parts of the body. Via nerve fibres, stimuli received from the outside world by the senses are transmitted to the brain, while conversely signals are sent from the brain to control muscles, for example. Signals are processed, stored, and generated in different areas of the brain. For example, there are areas for speech, language, vision, hearing, muscle control, memory, emotions, etc. in different locations within the brain. All these areas are also interconnected within complex networks of nerve cells. These communicate, among other things, with one another via electrical signals that travel from one cell (or nerve fibre) to another.

Changes in electrical signals can be read using electrodes. In the case of EEG, electrodes are positioned on the skull, allowing only electrical signals from surface areas of the brain to be measured, and it is then difficult to say exactly which area of the brain a measured signal is coming from. An EEG can be used to measure brain activity, for example during a particular activity (reading, sleeping, gaming) or as the response to a stimulus (a flash of light).

Other technologies make use of other physiological processes within the brain. fMRI, for example, measures blood oxygen levels. If the oxygen level in a particular area of the brain is high, it means that the nerve cells in that area are active and that area then lights up in a visualisation of the brain. With fMRI, it is only possible to study activities that someone can engage in while lying absolutely still in the scanner, for example looking at a picture.

This kind of biological activity is observed using a measurement system and converted into digital data. Neurodata is therefore a digital representation of biological activity within the brain.

Analysis: If it is to be useful, neurodata must be interpreted by a professional, a consumer, and/or a computer program. Researchers establish links between a mental state and brain activity by having groups of test subjects perform a task while the researchers take measurements using a technology such as EEG or fMRI. In anxiety research, test subjects look at frightening pictures, for example, alternating with pictures that are not frightening. The neurodata then measured is, in the case of fMRI, the area of the brain where the oxygen level increases, while in EEG it is the wave frequency. By studying a large number of test subjects in this way, group-level conclusions can be drawn about which brain signals relate to which mental states.

In some cases, the links that are identified can be generalised convincingly, meaning that the technology involved can be utilised relatively easily, without further adaptation, to measure certain mental states of individuals. This applies, for example, to determining someone's level of alertness, concentration, stress, and – to a certain extent – their emotions by using EEG.

For more complex mental states, including memories and specific emotional states, it is necessary to first be able to establish a link between that person's neurodata and their mental states. That means that neurodata about the person must first be collected and analysed. The development of generative AI makes it possible to make highly specific links between an individual's mental states and their neurodata. In 2023, for example, Japanese researchers succeeded in using brain signals to reconstruct the images that test subjects saw while lying in an fMRI scanner.[13] To do this, AI models were trained using fMRI scans of four subjects who were shown 10,000 images. The model was then able to deduce fairly precisely what kind of image subjects had seen, based on new fMRI scans.

This is an impressive advance, but it is a far cry from reading someone's train of thought if the content is not known beforehand. There is in fact an important theoretical limitation as regards deriving mental states from neurodata. According to the experts and the literature that we consulted, mental states arise from complex interactions between the brain, the rest of the body, and the social and material environment.[14] Someone's actual experience is therefore not simply reducible to their brain activity. Expectations of the extent to which neurotechnologies can recognize mental states such as memories, thoughts, or experiences, must therefore be tempered. Most of the experts thought that it would in any case be a long time before someone's train of thought could be accessed with neurotechnology.

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[13] Nahas, 'AI Re-Creates What People See by Reading Their Brain Scans', 7 March 2023.
[14] Wolpaw, Millán, and Ramsey, 'Brain-Computer Interfaces', 18, 2020.

Application: Analysis of neurodata may be considered to be successful when useful insights into mental states are obtained. Its applications can be roughly divided into four categories, which may overlap to some extent[15]

- *Direct application of information about mental states.* These insights can tell us something about a person's mental states at an individual level, or be used in a general sense at population level to obtain information about how the brain works. To be useful, the insights need to be presented or visualised in some way. The transition from insight to practical application, for example in neuromarketing or the administration of justice (see Chapter 3), always requires interpretation.
- *Neurofeedback.* In the case of neurofeedback, insights into mental states based on analysis of neurodata are presented in such a way that the user can interpret them for themselves. For example, the technology emits a signal when the brain activity associated with concentration falls below a certain level. Having information about your own mental state makes it possible to respond to it (for example by taking a break) and thus to improve it.
- *Neuromodulation.* In neuromodulation, neurotechnology influences ('modulates') brain activity. In some applications, this happens in response to the user's analysis of neurodata, but it may also be the case that the neurotechnology merely modulates. Neurotechnology that affects the brain in real time based on neurodata, without a human being in between, is also known as closed-loop neurotechnology.
- *Controlling a device.* In this type of application, neurodata is used to control a device. This may be a computer, a robot, or an exoskeleton. An exoskeleton is a device that is worn as an extension of the body, for example a prosthesis replacing an arm or leg.

2.2. The possibilities and limitations of neurotechnology

What does neurotechnology offer compared to other technologies?
In the grey and scientific literature that we consulted, neurotechnology is often presented as a technology that provides a unique view into the brain. It has contributed to numerous insights into how the brain works. However, most of the experts we consulted question the extent to which neurodata alone can provide a deeper understanding of a user's mental state than other data sources, such as web browser data or eye movements (eye tracking). They view neurodata as a supplementary source of information about mental states, but not as the key to a person's inner mental world.

Current limitations of the various technologies
In general, it is difficult to obtain sufficient signal strength with neurotechnology to be able to derive meaningful insights into a user's mental states. Moreover, everybody's brain is significantly different, for example due to slight variations in the structure of each person's skull, but also because brain plasticity ensures that someone's pattern of brain activity is constantly changing. For each new user, the analysis method would

[15] Brazal e.a., 'TechDispatch on neurodata', 6 March 2024.

work best if it were trained on the unique brain activity that is measured; that, however, would make neurotechnology less user-friendly and more difficult to apply on a larger scale.[16]

It is important to note here that a signal that is too weak for one application may be strong enough for another. One example is when neurodata is used for a game experience, with the primary purpose being to enhance that experience and not to analyse mental states.

Moreover, the various different types of neurotechnology each have their own challenges.[17] We will briefly explain the pros and cons of applications beyond the medical field for each quadrant in Table 1 (page 12).

For **non-invasive, imaging** neurotechnologies, the signal strength is generally low. If neurotechnology is to derive information about mental states, the signal strength needs to be good. In the case of EEG, the spatial information density is low: the data collected is not detailed as regards the different parts of the brain. The signal captured by one electrode comes from a combination of thousands of neurons (brain cells). This is because in EEG the electrodes that measure electrical signals within the brain are positioned on the subject's scalp. That means that it is only signals from the surface of the brain that can be measured, and not those from deeper areas, and that is exactly where certain mental states originate, for example emotions. Non-invasive technologies that can show brain activity from deeper areas include fMRI and MEG, although these are large and relatively expensive devices that are not easy to use. fMRI also has low temporal resolution, i.e. the data collected shows less detailed changes over time, thus limiting the application of neurofeedback, which requires real-time processing and feedback.

Of the non-invasive, imaging technologies, it is EEG that has the greatest potential for large-scale application beyond the medical field because it is inexpensive, safe, and easy to use – but it does have only low signal strength.

Invasive, imaging neurotechnologies can measure brain activity with higher resolution, making it possible to derive more useful information about mental states. However, the costs involved are high. Implants need to be positioned surgically within the head. This is never without risks and has to be carried out by trained personnel.

Non-invasive, modulating neurotechnology can influence brain activity through the skull. Compared to invasive technology, this has the advantage of lower cost, and there are no safety risks associated with implantation. It is difficult, however, to modulate areas deep within the brain using non-invasive neurotechnology. As a result, it is not

[16] Wu, Xu, and Lu, 'Transfer Learning for EEG-Based Brain–Computer Interfaces', March 2022.
[17] Based on Awuah e.a., 'Bridging Minds and Machines', 22 mei 2024, 22 mei 2024. They refer, *inter alia*, to technical challenges, high costs, challenges regarding ease of use, and safety issues. They also mention ethical, social, and legal considerations involved in neurotechnology, but we deal with these in Chapters 3 and 4 of this scan.

possible to modulate mental states that originate in brain activity in deeper areas of the brain.

Invasive, modulating neurotechnology has higher precision compared to non-invasive modulating neurotechnology and can reach deeper areas of the brain; the disadvantages are the cost and the safety considerations due to implantation.

2.3. Current developments in neurotechnology

A number of recent technological developments are making neurotechnology increasingly interesting for applications beyond the medical field. According to the experts, the wider applicability of neurotechnology in the future will be mainly due to improvements in the methods of analysis. First, as noted earlier, increasing use is being made of AI models, such as artificial neural networks, for analysing neurodata. This is currently the object of a great deal of research.[18] AI models can thus be used to derive more useful information about a user's mental states, for example because 'noise' can be filtered out of neurodata more effectively. Analysis is also faster, something that can be crucial for a near-instant or real-time response to brain activity.

Second, generative AI[19] can enhance the capacity of neurotechnology to infer emotions, memories, or even thoughts by converting brain signals into language.[20] This makes the information derived from neurodata much more accessible to users.

Third, a number of experts see potential in combining neurodata with other data such as internet data and eye tracking, particularly so as to understand behaviour at group level. Neurotechnology can therefore be used to learn more about the preferences and decisions of research subjects who are browsing the internet.[21] By matching advertisements to brain activity, they can be optimised by keying in to possible emotions that have been observed in neurodata.

Where measurement systems are concerned, the signal quality of 'dry' EEG electrodes has improved in recent years.[22] One problem with the user-friendliness of EEG was that a conductive gel needed to be applied to the subject's scalp so as to improve the signal strength. With the recent development of 'dry EEG', this is no longer always necessary, making use by consumers and professionals outside a medical setting more attractive.

Invasive measurement systems are also being improved, for example by investigating the use of materials so as to improve the safe long-term use of implants.[23] Nanotechnology could be used to develop neurotechnology that is tuned to areas of the

[18] Peksa and Mamchur, 'State-of-the-Art on Brain-Computer Interface Technology', 14, 28 June 2023.
[19] Systems such as ChatGPT that can create automated content at the request of a user. See also our earlier scan on generative AI: Rathenau Instituut, 'Rathenau Scan: Generatieve AI', 2023.
[20] Wang and Chen, 'Large-scale foundation models and generative AI for BigData neuroscience', 17 June 2024.
[21] Loyola e.a., 'Leveraging Neurodata to Support Web User Behavior Analysis', 8 November 2016.
[22] Saha e.a., 'Progress in Brain Computer Interface', 25 February 2021. p. 10
[23] Fiani e.a., 'An Examination of Prospective Uses and Future Directions of Neuralink', 30 maart 2021; Saha e.a., 'Progress in Brain Computer Interface', 25 February 2021.

brain in a very precise manner.[24] Researchers in the field of synthetic biology are also working to develop a brain implant that is made (partly) of organic material and is therefore less likely to be rejected by the body.[25]

2.4. Who are developing neurotechnology?

It is worth remembering that while the commercial development of neurotechnology described above is new for consumers and is as yet still a niche market, neurotechnology has a lengthy history within the medical and scientific fields. In 2024 it will be 100 years since EEG research was first conducted on human subjects[26] Even today, the development of neurotechnology still focuses mainly on the medical and scientific fields. A number of analysts estimate the value of the neurotechnology market (including the medical sector) for sales of BCI and the underlying technology at about USD 10 billion or more, and expect it to increase to USD 31–39 billion by 2033.[27] These estimates are accompanied by significant uncertainties, however.[28]

The development of neurotechnology within the medical and scientific fields is largely funded by public money. Over the past decade, for example, a number of large-scale research projects have been undertaken – involving hundreds of researchers from various countries – with neurotechnology playing a central role. The European Human Brain Project, the US BRAIN Initiative, and the China Brain Project were recently completed.[29] The Human Brain Project has led to extensive scientific progress in medical and other neurosciences and in digital mapping of the brain, as well as AI models and robotics inspired by the brain. As a follow-up to this, a European infrastructure is being developed to enable researchers to extensively share neurodata and information about the brain (EBRAINS).[30] In general, one can say that the neurotechnology market beyond the medical field is still small and does not seem to really have a successful commercial application. On the other hand, the market does seem to be picking up: there are companies and organisations that are making significant investments in neurotechnology and that express high expectations for the way it can be applied in the future. These expectations have also been noted by the media.

Over the past 15 years, the market has seen an increase mainly in EEG headsets that consumers can purchase for various purposes. The NeuroSky Mindwave,[31] the Muse S Headband,[32] and headbands from Emotiv[33] promise to improve users' wellbeing or

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[24] Acarón Ledesma e.a., 'An Atlas of Nano-Enabled Neural Interfaces', 14, July 2019.
[25] Sun e.a., 'Living Synthelectronics', 2024.
[26] Haas, 'Hans Berger (1873–1941), Richard Caton (1842–1926), and Electroencephalography', 1 January 2003.
[27] Precedence Research, 'Neurotechnology Market Size To Hit USD 38.17 Bn By 2032', december 2022; Coherent Market Insights, 'Global Neurotech Devices Market Size and Share Analysis - Growth Trends and Forecasts (2024-2031)', februari 2024; Research and Markets, 'Neurotechnology Research Report 2024', 30 January 2024.
[28] Ramsey, 'Chapter 1 - Human brain function and brain-computer interfaces', 1 January 2020.
[29] Human Brain Project, 'Human Brain Project', 2017; National Institutes of Health: The BRAIN Initiative, 'The Brain Research Through Advancing Innovative Neurotechnologies® (BRAIN) Initiative', 2025 2013; Normile, 'China Bets Big on Brain Research with Massive Cash Infusion and Openness to Monkey Studies', 2022.
[30] EBRAINS, 'EBRAINS', 2023.
[31] Neurosky, 'Neurosky.Com', 2025.
[32] Muse, 'Muse™ EEG-Powered Meditation & Sleep Headband', 2024.
[33] EMOTIV, 'About EMOTIV', 2025.

concentration. For about 200 euros, you can buy your own EEG device. Larger technology companies are also starting to move into this market: Apple filed a patent for custom-made earbuds with EEG sensors in January 2023.[34] Meta's 'Orion' AR glasses, announced in September 2024, will be paired with a 'neural wristband' with which arm movements can be measured that control the AR glasses via electromyography (EMG).[35] Although it is questionable whether this is truly neurotechnology, it does show that this market is of interest to Meta.

Zander Labs, which has an office in Delft, receives funding from the Cyberagentur, Germany's cybersecurity agency. Zander's website states:

'By harnessing the ability of passive BCIs to work in the background, we are creating solutions that seamlessly tap into human mental states. This approach transforms everyday interactions with technology and advances the training of the next generation of human-compatible AI systems.'[36]

It is important to emphasise that start-ups of this kind that are working on the integration of AI systems and BCIs are still in a pioneering phase of research. However, it is sometimes big investors that invest in the broader development of the technology. These include Meta, Microsoft, Precision Neuroscience, Blackrock Neurotech, and Neuralink.

The latter three companies are also investing in invasive technology. Neuralink announced in 2024 that it had successfully implanted a BCI in a paralysed individual, who was then able to use it to control a computer. This led to mixed reactions regarding the result achieved. There was also criticism of the unconventional and less than transparent way in which the findings were shared. Neuralink's ambition goes beyond restoring the abilities of paralysed individuals, as its mission statement makes clear:

'Create a generalized brain interface to restore autonomy to those with unmet medical needs today and unlock human potential tomorrow.' [37]

The ambitions of major technology companies show that the commercial sector is investing serious money in the development of neurotechnology. As a result, development is not restricted to the academic domain. The behaviour of technology companies is therefore being followed by a wider public.[38]

2.5. Conclusion

Neurotechnology promises to map and influence people's mental states in a unique manner, but it also still has technical limitations. Even so, more and more private parties

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[34] Azemi e.a., Biosignal Sensing Device Using Dynamic Selection of Electrodes, 9 January 2023.
[35] Stein, 'I Wore Meta's Orion AR Glasses', 25 September 2024; META, 'Fb.Com', 25 September 2024.
[36] Source: Zander Labs, 'zanderlabs.com/', 2025.
[37] Neuralink, 'Neuralink — Pioneering Brain Computer Interfaces', 2025.
[38] Hart, 'Experts Criticize Elon Musk's Neuralink Over Transparency After Billionaire Says First Brain Implant Works', 26 February 2024.

see potential in its use beyond the medical field. Various technical developments have contributed to this, for example the development of ‘dry’ EEG and analysis methods using AI systems. This has made low-threshold access to EEG possible for ordinary people.

We discuss the specific applications that this makes possible in Chapter 3. The neurotechnologies with the greatest potential for widespread use by the general public in the near future are wearable, non-invasive imaging technologies such as EEG.
The ability to read or influence complex mental states such as thoughts in a meaningful way is still the subject of much uncertainty and moreover scepticism among experts. It is highly likely that this will require invasive or non-wearable equipment such as an fMRI scanner, combined with personalised analysis of the neurodata. Even then, there would seem to be limits to what can be derived from neurodata. Because the consequences of utilising neurotechnology are potentially enormous, legal and ethical discussion has arisen at international level as to whether specific neurorights are necessary. We expand on this discussion in Chapter 4.

3. Potential applications of neurotechnology

3.1. Introduction

In the previous chapter, we showed that neurotechnology can be applied in various different ways. The information that it provides about our mental states can be utilised directly, and the technology can also be used for neurofeedback, neuromodulation, or controlling a computer system. In this chapter, we take a closer look at applications within various fields, discussing both the current situation and potential future applications that are being studied.

For many of the applications dealt with in this chapter, it is important for the devices to be wearable and easy to use; that is particularly so for neurotechnology intended for consumers. This is why many of the applications currently on the market or at the research stage are based on ‘dry’ EEG measurements built into existing hardware.

Where neuromodulation and invasive neurotechnology are concerned, applications are at present still limited to the medical field. The applications of the technologies discussed in this chapter are being developed and tested in a controlled research setting and not in the 'real' world. Application outside the medical field is not expected anytime soon due to the safety risks, high costs, and technical challenges.

The applications discussed in this chapter are drawn from our desk research. To arrive at a selection of sources, we conducted searches with various different search engines. Two source types were selected to determine what recent applications exist and are being researched. Academic literature was found using the Google Scholar and PubMed search engines. Review studies, in particular, were included in the selection because this type of publication describes multiple studies. Grey literature, including journalistic sources and reports, were found in the LexisNexis newspaper database and with the Google search engine. We decided to select sources dating from 2019 onwards because they discuss the most recent developments. When a source from the database referred to another source not yet included in the database, that source was added to the selection.

Our desk research revealed applications in the following areas: personal use, marketing, the administration of justice, education, the workplace (including the defence sector), and elite sports. Figure 5 provides an overview of applications of neurotechnology.

Figure 5: Applications of neurotechnology

Neurotechnology for personal use: wellbeing and entertainment

Wellbeing

There are already a number of consumer products on the market that promise to give users a better understanding of their mental health and tips for improving it. This could prevent users from accessing the public healthcare system, for example if they have problems such as stress, anxiety, or aggression. Current applications use a headband to measure an EEG signal. Examples include NeuroSky[39] and Muse[40] that support meditation by providing real-time alerts when the user is distracted. These devices also promise to enable users to understand their sleep condition and mood.

Entertainment

Games for entertainment are one of the most active fields in which neurotechnology is being developed[41] With neurotechnology, players' dedication can become part of the game. Neurodata is used to measure players' emotions, to reduce vertigo and cybersickness from VR glasses, or even to help control a game.

One of the first neurotechnology games was Mindflex, developed by Mattel and NeuroSky, which came on the market in 2009. In that game, players can control a ball

[39] Neurosky, 'Neurosky.Com', 2025.
[40] Muse, 'Muse™ EEG-Powered Meditation & Sleep Headband', 2024.
[41] Portillo-Lara e.a., 'Mind the Gap', September 2021.

using an EEG headband.[42] Other gaming applications include MindRDR,[43] in which players can control the speed of their avatar with an EEG. The greater their measured involvement in the game, the faster the avatar will move[44]
Researchers at the Future of Privacy Forum expect that headphones will be equipped with EEG sensors for gaming, and that in the future fully immersive games will be developed that players can control with mental states such as concentration[45] Although it is unclear whether concentration – as the game developer would have us believe – is actually what is measured by the sensor, what is less uncertain is that EEG measurements will in fact become part of the game. Gamers' experience will thus change anyway.[46]

Neuromarketing
Imaging neurotechnology such as fMRI and EEG measures brain activity associated with attention span and the experience of pleasure and pain, for example. Market researchers are trying in this way to increase the effectiveness of marketing tools and to influence consumers' purchasing behaviour.[47] Neuromarketing is still difficult to implement at the individual level, but marketing can be optimised at the group level. This means adapting a marketing strategy based on neuroscientific insights at the group level, making the group of people exposed to it respond more strongly on average. This can be used to sell products but also to influence voting behaviour, for example.

To understand consumer behaviour better at the individual level, brain scans are combined with other data, such as eye tracking, heart rate, and electrical conductance in the skin (related to stress level). All these signals are associated with the experience of pleasure or pain when making a purchase.[48]

Neuromarketing is applied particularly in three areas:
1. to test the best way to display a price to consumers;
2. to investigate which product (or product design) people react positively or negatively to;
3. for making film trailers attractive.[49]

However, some participants in the expert session questioned whether brain measurements are actually better at predicting or influencing consumer behaviour than other kinds of measurements. Testing marketing messages with an A/B test in which

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[42] Neurosky, 'Store.Neurosky.Com/Products/Mindflex', 2025.
[43] MindRDR, 'MindRDR', 2025.
[44] Peksa en Mamchur, 'State-of-the-Art on Brain-Computer Interface Technology', 28 juni 2023; MindRDR, 'MindRDR', 2025.
[45] Greenberg e.a., 'Privacy and the connected mind. Understanding the data flows and privacy risks of brain-computer interfaces', 2021.
[46] Wolpaw et al, 2020, p. 20
[47] Portillo-Lara e.a., 'Mind the Gap', september 2021; Rawnaque e.a., 'Technological Advancements and Opportunities in Neuromarketing', 21 September 2020.
[48] In the Netherlands, Neurensics and Unravel are marketing agencies that utilise neurodata to improve campaigns: Neurensics, 'Campagne Pretest in het Brein | Reclame onderzoek | Verhoog ROI met fMRI', 2022; Unravel, 'unravelresearch.com', 2025.
[49] Hasson e.a., 'Intersubject Synchronization of Cortical Activity During Natural Vision', 12 March 2004.

different versions of an advertisement are presented to subjects, for example in an online questionnaire, can also provide many useful insights. Moreover, such alternatives are often much cheaper and more accessible for marketers who are not specialists in interpreting neurodata.

Administration of justice
Analysing neurodata can be useful in the investigation phase of criminal cases. It can provide information about a memory, about whether a suspect or interviewee is telling the truth, or offender knowledge – for example whether someone recognises the weapon that was used.

Neurotechnology can also be used to estimate (and reduce) the risk of recidivism after release. As far as we know, these applications are not yet being used in real-life anywhere in the world, but their potential is being investigated[50]

An experimental setup has demonstrated that fMRI can be used to measure specific patterns that indicate lying.[51] This method is criticised by some because, as with the 'traditional' lie detector, lies are not detected directly. Instead, it measures patterns of brain signals that may also be associated with other mental states, such as when formulating a response. Moreover, this method has only been studied at the group level and is not considered reliable at the individual level[52]

Education
There is evidence from research that neurofeedback can contribute to education. EEG-powered BCIs have been shown, for example, to have a positive effect on the concentration, working memory, and other cognitive skills of pupils with developmental disabilities[53] EEG can also be used to measure cognitive overload and mental fatigue and their effect on learning performance[54] Pupils then wear an EEG headband and receive feedback when brain signals are measured that indicate fatigue. Direct feedback based on EEG measurements is also being used in research to improve learning, for example in maths or languages, and to increase concentration.[55] It involves pupils performing a task while EEG measures whether their brain signals match those associated with learning.

These results from research into applications in education are often based only on short-term studies with small groups of pupils, but researchers nevertheless think that neurofeedback could in future also be used to adapt the curriculum to the learning performance and needs of individual pupils or students.

[50] Bijlsma e.a., 'Kansen En Risico's van de Toepassing van Neurotechnologie in Het Strafrecht', 4 May 2022.
[51] Farah e.a., 'Functional MRI-Based Lie Detection', February 2014.
[52] Farah e.a.; Ganis, 'Deception detection using neuroimaging', 2015; Gamer, 'Mind reading using neuroimaging', 2014.
[53] Awuah e.a., 'Bridging Minds and Machines', 22 May 2024, 22 May 2024.
[54] Portillo-Lara e.a., 'Mind the Gap', September 2021.
[55] Peksa en Mamchur, 'State-of-the-Art on Brain-Computer Interface Technology', 28 juni 2023; Taya e.a., 'Brain Enhancement through Cognitive Training', 1 April 2015.

Work environment

Insights gained from EEG can be beneficial in work environments where employees are required to make numerous quick decisions. An application developed by InnerEye can speed up work requiring visual assessment. The company uses EEG to 'capture' the initial response within the brain of an expert who is monitoring images; this is then used to assess those images (for example recognising firearms in airport security X-ray images or tumours in medical scans).[56] The developers' idea is that this can drastically reduce the time needed to assess each scan and thus increase the work rate. This technique is now being explored on a pilot project basis at a handful of airports around the world.[57]

Research findings indicate the added value of neurofeedback to monitor and improve employees' concentration or stress levels. This could improve workplace safety. One example is Smartcap[58], a company developing EEG headbands that can be fitted into helmets or other headgear and that trigger an alarm if a truck driver or factory worker is becoming drowsy. Other systems with the same purpose combine EEG with eye tracking. Researchers expect that this can be used to reduce the number of accidents.[59] The bioinformatics company Emotiv[60] is developing headsets that employees can use to measure their individual stress level, concentration, and level of distraction so as to increase their productivity and wellbeing.[61] AttentiveU uses glasses for the same purpose[62]

Defence

In the military field, neurofeedback could potentially be used to improve soldiers' performance. In the Netherlands, for example, the *Amygdala Neurofeedback in Military Aggression* study (ANiMA) involved training soldiers to control their emotions more effectively and thus reduce aggression. [63] Subjects were asked to look at pictures that could trigger aggression while lying in an fMRI scanner and the activation of their amygdala – the area of the brain associated with emotions and aggression – was measured. A recently published dissertation on this research concludes that fMRI of the amygdala does not in fact offer any predictive value for aggression and that the added value of amygdala neurofeedback with functional MRI is limited.[64]

The US Defence Advanced Research Projects Agency (DARPA) announced in 2021 that it was investing USD 104 million in a programme to develop a non-invasive BCI

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[56] 'Inner Eye | Supercharge Complex', 2025.
[57] Ackerman and Strickland, 'Are You Ready for Workplace Brain Scanning?', 19 November 2022.
[58] Wenco, 'Wencomine.Com/Our-Solutions/Safety', 2025.
[59] Portillo-Lara e.a., 'Mind the Gap', september 2021; Greenberg e.a., 'Privacy and the connected mind. Understanding the data flows and privacy risks of brain-computer interfaces', 2021.
[60] EMOTIV, 'About EMOTIV', 2025.
[61] For example, BAM: 'BAM Nuttall, the British subsidiary of the Dutch Royal BAM Group, which employs well over twenty-five thousand people in its civil engineering and construction divisions, equipped many of its civil engineering and construction divisions, equips many of its employees with SmartCap gear.' BAM Nuttall, 'BAM Nuttall and SmartCap Technologies Collaborate to Monitor Construction Workers Fatigue Levels | Koninklijke BAM Groep / Royal BAM Group', 16 February 2017; Farahany, *The Battle for Your Brain*, 44, 2023.
[62] AttentivU, 'AttentivU.Com', 2025.
[63] Brain Research and Innovation Centre, 'ANIMA', 18 September 2019.
[64] Varkevisser, 'Digging for Fool's Gold', 27 September 2024.

that enables soldiers to control drones and other vehicles during military operations. This allows them to control multiple systems simultaneously.[65] There is speculation about China's interest in military applications of BCI, but little information is available on China's innovation budget and spending with regard to neurotechnology.[66]

Elite sports
Our desk research revealed a number of studies showing that neurofeedback could potentially improve the performance of elite athletes.[67] A number of studies show improvement in the performance of golfers and archers and in the reaction time and eye-hand coordination of different types of athletes, including football goalkeepers. Neurofeedback can also be used to estimate athletes' maximum training load so as to prevent injuries.[68]

For example, the Canadian long-track speed skating team competing in the Winter Olympics in Vancouver trained for reaction speed with the aid of biofeedback, including EEG measurement.[69] Biofeedback was used to investigate when brain signals indicating an auditory response (the skater *hears* the starting pistol) are synchronised with brain signals indicating a motor response (the skater starts moving). This makes it possible to determine the best method for individual athletes to get themselves into the optimal mental state (for example, the right balance between alertness, concentration, and relaxation) prior to the start.

Despite the many studies on various neurofeedback applications to improve the performance of elite athletes, and the positive outcomes of this research, neurofeedback is not yet widely used by athletes, trainers, or coaches.

3.2. Conclusion
For our desk research, dozens of review studies were consulted in the various fields discussed above such as for wellbeing and entertainment, for marketing, the administration of justice, and the workplace (including the defence sector) and elite sports. A great deal of research is being conducted on various non-medical applications of neurotechnology, but most of these applications are still only at an experimental stage. Several studies conducted within small groups under controlled conditions show that neurotechnologies could be valuable. Despite some of these studies dating from more than ten years ago, the applications have often failed to find their way into practice. It is possible that the methods studied are not yet sufficiently geared towards use in practice (which may be challenging), that they are too expensive or complicated, or that practitioners are (still) too conservative and not open to such innovative methods.[70]

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65 Greenberg e.a., ‘Privacy and the connected mind. Understanding the data flows and privacy risks of brain-computer interfaces’, 2021.
66 Livanis e.a., ‘Understanding the Ethical Issues of Brain-Computer Interfaces (BCIs)’, April 2024.
67 Rydzik e.a., ‘The Use of Neurofeedback in Sports Training’, 14 April 2023; Corrado e.a., ‘Improving Mental Skills in Precision Sports by Using Neurofeedback Training’, 29 February 2024.
68 Hammond, ‘What Is Neurofeedback’, October 2011.
69 Harvey e.a., ‘Biofeedback Reaction-Time Training’, 1 January 2011.
70 Schalk e.a., ‘Translation of Neurotechnologies’, 10, 31 May 2024.

In the case of the wearable neurotechnology now available on the consumer market, the effects on wellbeing have not yet been demonstrated. The use of EEG in the gaming industry seems so far to be mainly a gimmick. With non-invasive methods such as EEG, the signal strength is low and there is a lot of ‘noise’. However, research is being carried out on the application of AI systems to suppress ‘noise’, and to combine neurodata in real time with the collection of other data such as eye tracking, click behaviour, heart rate, and breathing frequency. In the short term, this development could improve the quality of the information derived from wearable neurotechnology. This type of application is expected to become increasingly popular for domestic use in the coming years.

4. Opportunities and risks for public values

4.1. Introduction

In the previous chapter, we described the various applications of neurotechnology that are being developed and researched in a number of fields. We now wish to consider the opportunities and risks for public values that this may entail. We will also investigate how certain it is that these opportunities will arise, and within what timeframe.

To carry out this analysis, we used of desk research. The opportunities and risks described below were referred to in one or more of the sources in our database. We asked a number of neurotechnology experts (in an open questionnaire) to assess the opportunities and risks that we had identified in the literature. We also asked them how certain it was that these opportunities and risks would materialise, and within what timeframe. The most striking results were discussed and checked during an expert session.

The public values we discuss are health and wellbeing, safety, security and privacy, economic vitality and prosperity, autonomy and identity, democracy, inclusiveness, and finally sustainability and animal welfare.

4.2. Health and wellbeing

Mental health

Providers of EEG headsets claim to provide insights into consumers' mental health, offering tips for improving it. That could be beneficial for users, although it is currently unclear whether these applications are in fact effective. Some consumers may therefore be too optimistic, and buying this kind of device may be a waste of money. These kinds of applications of neurotechnology also promote the idea that mental health is something we can engineer, whereas that is still very much open to question.
The experts we consulted are concerned that providers of neurotechnology do not make it sufficiently clear to consumers that mental states such as stress are in fact enormously complex and that influencing one particular aspect can have unintended side effects, such as sudden aggressive behaviour.[71] If it becomes possible in the future to have implants inserted outside of a medical context, then the risks to mental health will be considerable.

Where children's mental health is concerned, neurotechnology entails additional risks[72] Up to the age of twenty-five, and especially in children, crucial developmental processes take place within the brain, influencing their emotional, social, and behavioural growth. Neurotechnological interventions in that development have potentially major consequences, the long-term effects of which are unclear. Not much of

[71] Korteweg, 'Met een revolutionaire nieuwe behandeling kwam hij van zijn jarenlange dwangneuroses af', 15 April 2022.
[72] International Bioethics Committee, 'The ethical issues of neurotechnology', 2021.

the research involves children, meaning that there is great uncertainty as to the effects of neurotechnology on this group[73]

Physical health

There are various risks to the physical health of users, especially when neuroimplants are inserted,[74] for example infections or damage to the circulatory system or brain tissue. Brain implants are not currently inserted for non-medical purposes, so this risk does not arise outside the medical sector. That could change in the future, however, given the level of investment in invasive technology by large commercial parties (see also chapter 2 on investment in neurotechnology). Where non-medical applications are concerned, the assessment of risks takes a different form, weighing the benefits against the physical risks.

4.3. Safety and security

Public safety

Neurotechnology could offer ways for improving the assessment of risks in the administration of justice and thus public safety in the future. For example, fMRI and AI systems could potentially be used to predict the risk of repetition of criminal behaviour (recidivism). Up to now, these kinds of predictions seem to be perilously biased.[75] Bias in models can lead to unequal treatment of different groups, for example people from a neighbourhood with a high level of crime. The public values of safety and equality therefore often conflict with one another. Improper use of neurotechnology and relying on it in the administration of justice is a second risk. Neurotechnology based lie detection and memory testing (see Chapter 3) are currently unreliable, partly because suspects can influence the results of such testing.

Another way that neurotechnology may be able contribute to safety is the use of non-invasive stimulation technologies to reduce psychiatric symptoms. This can perhaps reduce violent behaviour, for example, or recidivism. Where the administration of justice is concerned, a carefully considered approach is essential because this method also entails risks regarding the autonomy and mental and physical integrity of convicted persons.[76]

Defensive security

The functioning of military personnel can potentially be improved with neurotechnology, thus enhancing the defensive security of the Netherlands and its allies. The experts we consulted do not expect neurotechnology to turn military personnel into 'super soldiers' with superhuman abilities, as suggested by DARPA. For the defence sector, the added value of neurotechnology will lie mainly in helping soldiers cope better with the stress,

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[73] Pauwels, ‘Neurotechnology and Children’, 18 June 2024.
[74] Obidin, Tasnim, en Dagdeviren, ‘The Future of Neuroimplantable Devices’, April 2020.
[75] Tortora e.a., ‘Neuroprediction and A.I. in Forensic Psychiatry and Criminal Justice’, 2, 17 March 2020.
[76] Bijlsma e.a., ‘Kansen En Risico’s van de Toepassing van Neurotechnologie in Het Strafrecht’, 4 May 2022.

anxiety, and fatigue arising from extreme situations. Because of this limited application of neurotechnology, the experts expect there to be few risks as regards international humanitarian law.

Safe working environment

If neurotechnology can be successfully utilised to better understand employees' attention and stress levels, it could help improve safety at work.[77] In principle, wearable neurotechnology can ensure that employees take breaks at the right time and that high-risk activities are undertaken with a sufficient degree of concentration. Workplace neurotechnology may well be most beneficial in specific occupations where workers operate under high pressure, for example emergency personnel in the fire, police, or ambulance services.

Cybersecurity

Given that everybody's neurodata is unique, one potential future benefit as regards cybersecurity is to use it as a new and more secure means of authentication .[78] But there are also risks involved. Invasive and non-invasive neurotechnology can be hacked.[79] Besides criminals being able to obtain sensitive personal data, there is an additional risk with modulating neurotechnology that a malicious party could influence the user's brain activity.

4.4. Privacy

Privacy of information (data privacy)

Neurodata is intimate data, from which potentially sensitive information can be derived, not only about someone's mental state (see mental privacy) but about other matters too.[80] One study showed, for example, that after users had perceived certain stimuli, their PIN and information about where they lived could be derived from the neurodata recorded by wearable EEG headsets, if the test subjects thought about that information.[81] And neurodata from the BCI game *Flappy Whale* – of which the purpose was to measure subjects' responses to certain marketing signals – could also be used to obtain financial information and personal beliefs.[82]

As with other digital data, it should not be possible for external parties to gain access to neurodata without someone's consent. To ensure the privacy of information, users need to understand what data they share, how it is processed, and what can be derived from

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[77] Portillo-Lara e.a., 'Mind the Gap', 10, September 2021; Douibi e.a., 'Toward EEG-Based BCI Applications for Industry 4.0', 2021.

[78] Frank, Mabrey, en Yoshigoe, 'Personalizable neurological user authentication framework', January 2017.

[79] Greenberg e.a., 'Privacy and the connected mind. Understanding the data flows and privacy risks of brain-computer interfaces', 2021; Booij and Van Bruggen, 'Neurotechnologie in het onderwijs. Voorbeelden van mens-computerinteractie', 15 June 2022.

[80] Chen e.a., 'Several Inaccurate or Erroneous Conceptions and Misleading Propaganda about Brain-Computer Interfaces', 8, 2024.

[81] Martinovic e.a., 'On the Feasibility of {Side-Channel} Attacks with {Brain-Computer} Interfaces', 2012.

[82] Ienca, Haselager, and Emanuel, 'Brain Leaks and Consumer Neurotechnology', oktober 2018; Martinovic e.a., 'On the Feasibility of {Side-Channel} Attacks with {Brain-Computer} Interfaces', 2012.

it. We see inherent complications in neurotechnology in this respect.[83] It is questionable how someone can give informed consent for the processing of brain activity that they produce unconsciously. Nor is it easy to understand the algorithmic analysis of neurodata or to comprehend what can be derived from your brain activity. As is evident from web browsing, social media and other apps, consumers often waive their privacy rights without being properly informed and without being free to make this choice.[84]

Mental privacy

One of the most frequently mentioned concerns in the grey literature that we consulted on neurotechnology is that we are at risk of forfeiting our mental privacy – i.e. keeping our mental states private – because neurotechnology will supposedly be able to read our thoughts.[85] Fascinating studies have been published on mind reading in which researchers have participants listen to a story and, based solely on neurodata, are able to reproduce the story with impressive accuracy.[86] However, this kind of application of neurotechnology is successful only in a research setting. Such studies are performed with fMRI, a large and expensive piece of equipment that requires professional supervision, and in which the subject who is being studied must remain still for a long period of time. The analysis method has to be tailored specifically to the individual participant, meaning that the reconstruction process cannot readily be applied on a large scale. Experts also say that reconstructing perceived images or sounds is something of a completely different order to reading people's thoughts.

Although this type of research appeals to the imagination and technological developments may improve the process involved, the possibilities for 'mind reading' are currently restricted. According to some of our experts, it is impossible even in theory because human experience cannot be reduced to brain activity and the neurodata derived from it. Most of the experts agreed that it would in any case be a long time before it became possible to read someone's train of thought if the content were not known beforehand. Being aware of these subtle distinctions is important in assessing the risks that neurotechnology poses in terms of mental privacy.

Nevertheless, neurotechnology may still pose risks to mental privacy. When people utilise neurotechnology, insights into mental states can to a certain extent be derived from it. It is important to realise this, for one thing because the possibilities and applications of insights into mental states are set to increase, for example the potential use of information about individual mental states by insurance companies or employers. Moreover, the information derived from neurodata is not necessarily consistent (or entirely consistent) with actual mental states. Working with misinterpreted neurodata for sentencing an accused or for measuring an employee's alertness in the workplace can have serious consequences.

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83 Yuste e.a., 'Four Ethical Priorities for Neurotechnologies and AI', November 2017.
84 Kröger, Lutz, and Ullrich, 'The Myth of Individual Control', 7 July 2021.
85 Wiersma, 'Computer leert gedachtenlezen', 21 January 2022.
86 Airhart, 'Brain Activity Decoder Can Reveal Stories in People's Minds', 1 May 2023.

4.5. Economic vitality and prosperity

The development of neurotechnology in the Netherlands and Europe presents economic opportunities. Neurotechnology itself can also be utilised to improve marketing for commercial and public purposes, thereby increasing corporate profitability and the impact of publicity campaigns. At a group level, neurotechnology contributes to neuroscientific understanding of how people make choices, or to understanding their mental state while watching a film or advert. Targeting adverts accordingly may enable companies to boost their sales.[87] At the individual level, marketing can be tailored more effectively to the user of neurotechnology, especially when other types of data are also collected about the particular user. The extent to which marketing can be targeted increases if consumers make long-term use of neurotechnology, for example if developers equip headphones, headbands, earbuds, and VR/AR glasses with EEG.

4.6. Autonomy and identity

When we refer to the value ‘autonomy’, we mean people’s ability to make their own choices. One component of autonomy is self-development. As noted in the previous chapter, there are indications that neurofeedback can help improve cognitive performance in a number of fields.[88] Although these applications are still only at the research stage, they do offer the potential for self-development. Neurotechnology can also be used to control an exoskeleton, making it possible to improve someone’s physical abilities and thus increasing their autonomy.

Another component of autonomy is mental integrity, i.e. individuals’ control over their mental states. Neuromodulation technologies such as transcranial magnetic stimulation (TMS) can alter someone’s mental states by directly manipulating brain signals. This could have positive effects for people suffering from mental complaints such as dejection, aggression, or anxiety, for example.

However, caution is called for where neuromodulation technologies are concerned. Treatment of Parkinson's disease using Deep Brain Stimulation (an invasive technique) turned out to have the unintended effect of altering personality features. Some patients became more impulsive, for example, which can lead to hypersexual behaviour.[89] It is possible that modulating neurotechnology also impairs people's self-control in applications outside the medical field and leads to alienation from their own body because users cannot distinguish between mental states caused by the technology or by their own brain.[90]

Finally, modulating neurotechnologies may pose a risk to personal identity and psychological continuity, particularly when they influence memory.[91] Memories help

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87 Khondakar e.a., ‘A systematic review on EEG-based neuromarketing’, 5 June 2024.

88 The dividing line between self-development and improving mental health is not clear-cut: improving your attention span, for example, can count as both self-development and mental health improvement. In the present scan, we use ‘self-development’ to mean improving psychological functions, whereas ‘mental health improvement’ is about restoring psychological functions to 'normal' levels.

89 Pham e.a., ‘Personality Changes after Deep Brain Stimulation in Parkinson’s Disease’, 2015.

90 International Bioethics Committee, ‘The ethical issues of neurotechnology’, 13, 2021.

91 International Bioethics Committee, 26-27.

form and maintain someone's image of who they are and ensure that they have a coherent idea of what they have experienced over the years. Disrupting this picture could have serious consequences for their autonomy and mental health.[92]
The above risks to mental privacy and autonomy may result from voluntary use of modulating neurotechnology. The harm to these values can be even greater if third parties are able to involuntarily influence brain activity and thus mental states. The literature mentions the risk that people may be obliged or compelled to use neurotechnology, for example for their work.[93] In the EU, this risk is protected against legally by the Artificial Intelligence Regulation (see Chapter 4), so it is not expected that problems will arise in this regard – at least not in the foreseeable future – if the regulation is properly enforced.

A more likely scenario is that opportunities for manipulation will increase, with third parties influencing users by means of profiling based, among other things, on neurodata. One relevant question here is the extent to which neurotechnology is really any different to other technologies that can be used to understand people's preferences or shopping triggers and to further (hyper)personalise adverts.

Many of the opportunities and risks referred to regarding autonomy and identity are currently still largely hypothetical, but it is advisable to take account of the impact they may have as neurotechnology continues to develop.

4.7. Democracy

Elon Musk has a prominent voice in the public debate on the future of neurotechnology. He argues that neurotechnology can provide opportunities for strengthening democracy. According to Musk, implanting neurotechnology so that a paralysed person can control a computer with their mind is the first step towards a greater goal. He claims to be concerned about the rapid development of AI systems, which he expects to eventually become more intelligent than humans, thus posing democratic and even existential risks for humans. Musk believes that for the human species to survive in a world with super-intelligent AI, we must increase human brainpower by linking our brains to AI using neurotechnology,[94] thus creating a new and more intelligent human species. The experts we consulted were extremely sceptical about such statements because if that were ever really to happen, it would not be until very far into the future. They were particularly critical of such assertions because focusing on such long-term developments distracts from the opportunities and risks currently associated with the neurotechnology that is already available.

The experts in fact express concerns specifically about the lack of democratic control over the development and implementation of neurotechnology. Whether and to what

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[92] Erden and Brey, 'Neurotechnology and Ethics Guidelines for Human Enhancement', August 2023.
[93] Greenberg e.a., 'Privacy and the connected mind. Understanding the data flows and privacy risks of brain-computer interfaces', 19, 2021.
[94] Hart, 'Elon Musk Says Neuralink Could Slash Risk From AI As Firm Prepares For First Human Trials', 21 September 2023.

extent the public values described in this chapter are taken into account in the development of neurotechnology may increasingly depend on the choices made by big commercial technology companies such as Musk's. Being at the forefront of development of this technology gives them enormous influence over the conditions, costs, and accessibility of the technology. There are examples, for instance, of patients left with an implant after the provider went out of business, with it being unclear who was then responsible for maintenance of the implant[95] Moreover, a lack of transparency on the part of providers such as Neuralink makes it difficult to control commercial neurotechnology.[96]

Because it uses AI to analyse neurodata, neurotechnology has a bearing on the broader debate about AI and democracy. A recurrent question is who is responsible for decisions made by an AI system. Many AI system are also not transparent, making it unclear how they arrive at decisions. Furthermore, bias in training data can carry over into how AI is applied, which can disadvantage certain groups of people (see the section above about public safety and the administration of justice). Generative AI is also likely to be increasingly integrated into neurotechnology. In a previous scan concerning Generative AI, the Rathenau Instituut found that that technology poses risks inter alia to security, a people-oriented society, fairness, and democracy.[97]

4.8. Inclusiveness

Neurotechnology also presents both opportunities and risks where inclusiveness is concerned. For example, it offers ways to help neurodivergent individuals – i.e. people with ADHD, autism, dyscalculia or dyslexia, or who are highly gifted or highly sensitive – to operate more successfully within society. On the other hand, it may in fact make society less inclusive. And if neurotechnology is utilised to 'correct' symptoms such as anxiety, there is again a risk of increasing stigmatisation.[98] This can have the effect of making differences between people less socially accepted. That risk is particularly high where children are concerned, because developmental difficulties may then tend to be viewed as problems requiring treatment with neurotechnology.[99]

Inclusiveness also depends on how accessible the technology is, and on whether it is equally effective for everyone, which may not be the case. The latter depends, for example, on who neurotechnology and the associated AI systems are designed and tested for. Nor will the benefits of neurotechnology be readily available to the whole of society. Non-invasive neurotechnology is already relatively expensive, and the cost of implants means that they will only be accessible to the well-to-do.[100] In addition, certain

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[95] Drew, 'Abandoned', 6 December 2022.
[96] Wieringa, 'Primeur voor Musk: zijn bedrijf plaatst hersenchip in mens, maar heeft nog grotere ambities', 30 January 2024.
[97] Rathenau Instituut, 'Rathenau Scan: Generatieve AI', 2023.
98 International Bioethics Committee, 'The ethical issues of neurotechnology', 34, 2021.
99 Pauwels, 'Neurotechnology and Children', 21, 18 June 2024.
100 Burwell, Sample, en Racine, 'Ethical aspects of brain computer interfaces: a scoping review', 11 September 2017.

skills will be needed to train and use neurotechnology, skills that not everyone will possess.[101] Neurotechnology may consequently widen the digital divide.

4.9. Sustainability and animal welfare

Not much has been written about the risks of neurotechnology as regards sustainability and animal welfare. Rare materials are used for this technology and it is also likely that the energy consumption needed is high and will continue to increase. This is mainly because neurotechnology makes use of AI systems to analyse data, and a number of studies show that AI models (particularly large language models) consume huge amounts of electricity.[102]

In addition, neurotechnology applications such as implants are first tested by applying them in animals, which often involves suffering. A Neuralink implant study went seriously wrong in this regard, with more than ten great apes dying after experiencing serious suffering, although this was not communicated openly.[103]

4.10. Conclusion

Analysis of the opportunities and risks of neurotechnology where public values are concerned involves significant uncertainties. Based on the relevant literature and input from the experts consulted, we broadly identify two groups of opportunities and risks with varying degrees of certainty and with variations in the timeframe within which they will become apparent.

First, there are long-term risks that are uncertain and will only start to become apparent five or more years from now, but that strike at the core of what it means to be human. Before this becomes a reality, neurotechnologies still need to be developed to a large extent and it is still uncertain whether that will actually happen. If advanced modulating neurotechnologies and implants can be inserted into people in private clinics, the potential benefits for social safety and the opportunities for self-development and marketing will increase. In this scenario, however, neurotechnology also poses serious risks to public values as regards security (hacking), autonomy, identity, inclusiveness, and mental privacy.

Second, there are opportunities and risks that we already need to consider in the short term. In the coming years, more wearable non-invasive neurotechnology, in particular EEG, will come on the market as stand-alone headbands or built into existing devices. Tapping into this data market can increase the power of large technology companies to exert influence. The potential benefits of this can be found in the areas of economic prosperity, mental health and self-development, resulting in greater autonomy. However, the technology also entails risks as regards these values, especially for the mental health of children. But it is in particular the risk to the privacy of information that is at odds with the potential benefits.

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101 Portillo-Lara e.a., ‘Mind the Gap’, September 2021.
102 ‘Electricity 2024 - Analysis and Forecast to 2026’, 2024.
103 Mehrotra, ‘The Gruesome Story of How Neuralink’s Monkeys Actually Died’, 20 September 2023.

5. Policy scan

5.1. Introduction

In this chapter, we discuss the policy instruments that are relevant to the opportunities and risks of neurotechnology (see Table 2, Policy instruments). As noted in Chapter 2, more and more neurodata are being collected within the consumer market and in contexts other than that of healthcare. In this chapter, we focus on gaps that we have identified and which our analysis indicates pose the most significant and urgent challenge.

We performed this policy scan as follows. We distributed a questionnaire asking experts in the field of neurotechnology to rate the degree of uncertainty and urgency of the opportunities and risks of neurotechnology as revealed in our desk research. This resulted in a selection of opportunities and risks that can be considered urgent in view of their possible importance for society and policy development. In a second questionnaire, we then asked policymakers to indicate which policies are relevant as regards the most important and urgent risks. These policies were identified by means of additional desk research for which we consulted mainly policy sources, supplemented by academic and grey literature. We were assisted in this by a legal expert.

We discuss the policy instruments – in this case only legal frameworks – in relation to the neurotechnology processes described in Chapter 2. First, we discuss the policies applicable to the measurement systems used to measure brain signals. We then consider the legal framework for analysing neurodata: the collection and processing of neurodata, followed by the AI systems used in neurotechnology. Finally, we discuss general human rights frameworks that are relevant in the application of neurotechnology, and the debate regarding neurorights. For an overview of the relevant frameworks, see Table 2.

Table 2: Policy instruments

Policy instruments relevant to the opportunities and risks of neurotechnology
Hardware • Regarding medical risk: Medical Device Regulation (MDR) **Software** • AI Act **Collection and processing of neurodata** • General Data Protection Regulation (GDPR) • In some cases, neurodata is protected as 'special personal data' (biometric data or health data) **Use in criminal law** • EU Law Enforcement Directive and national Police Data Act and Judicial and Criminal Records Act **Human rights** The right to privacy; the right to human integrity; freedom of thought, conscience and religion; freedom of expression; the right to a fair trial and the prohibition of torture; the rights of children; human rights in biomedicine and science: • The Constitution of the Netherlands • European Convention on Human Rights (ECHR) • Charter of Fundamental Rights of the European Union • Universal Declaration of Human Rights (UDHR)

5.2. Measuring brain signals (measurement systems)

In this section, we discuss policies that apply in limited cases to the measurement systems used to record neurodata: the Medical Device Regulation (MDR). This legislation protects the physical safety and (mental) health of neurotechnology users in certain contexts. This section is therefore about the hardware and software used to measure brain activity and convert it into neurodata.

The MDR contains provisions on safety regarding the marketing, making available on the market, and use of medical devices. Manufacturers must identify risks and mitigate them as far as possible by means of safety measures. This can be done by providing instructional videos, user instructions, and safety information. Neurotechnological devices must in any case comply with the MDR if they are categorised as medical devices. Categorisation depends on whether at least one of the stated intended purposes is medical. This is regardless of whether the technology is invasive, non-invasive, modulating, or imaging (see Chapter 2 for an explanation of these terms). Both the hardware that measures – oxygen within the brain, for example – and the software that converts the measurement data into neurodata can therefore be categorised as medical devices under the MDR.

If software works with AI systems, it will also be regulated under the new AI Act. An AI system is in fact classified as 'high risk' if it is part of a device covered by existing EU product safety legislation.[104] This neurotechnology must then comply with both pieces of legislation. Providers can combine the testing and reporting obligations that result from this. The purpose of combining the two is to offer optimum protection, given that the MDR does not specifically focus on the risks of AI systems.

Exactly which specific neurotechnology applications are covered by the MDR and other product legislation should be determined by legal and technical experts, or clarified in rulings or guidelines from EU or national regulators.[105] In any case, the EU lists only products that pose risks to physical and medical safety under the MDR. Opinions differ as to whether this is a sufficient system of regulation. According to the legal scholar Elisabeth Steindl, this shows that the legislature is looking ahead to future developments in neurotechnology and is able to find a balance between protecting consumer safety and over-regulation.[106] However, other legal scholars, Jan Christoph Bublitz and Sjors Ligthart, point out that the focus on physical safety means that the legislation fails to protect individuals' mental states.[107]

5.3. Protection of neurodata

Every individual has a unique pattern of brain activity, meaning that neurodata very quickly becomes personal data.[108] Measuring, reading out, analysing, and any further processing of neurodata is therefore also subject to the General Data Protection Regulation (GDPR).[109] Basic principles of the GDPR that personal data processing must comply with are lawfulness, fairness, transparency, purpose limitation, proportionality, and data minimisation. This legislation thus protects the privacy of information in particular. As we saw in Chapter 4, this can be jeopardised when analysing neurodata.[110]

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104 Article 6 and Annex I AI Regulation.

105 Furthermore, an annex to the MDR lists devices that are covered by the MDR even though they do not have a medical purpose, including non-invasive modulating neurotechnology. Other (future) applications of neurotechnology are in some cases covered by product (safety) legislation, which is not considered in the present scan. Applications covered by privacy and AI legislation are discussed later in this section.

106 Steindl, ‘Consumer Neuro Devices within EU Product Safety Law’, April 2024.

107 Bublitz and Ligthart, ‘The new regulation of non-medical neurotechnologies in the European Union’, 7 July 2024.

108 Unless it is completely anonymised, for example for research purposes.

109 Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of individuals with regard to the processing of personal data and on the free movement of such data and repealing Directive 95/46/EC (General Data Protection Regulation), https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016R0679 (hereinafter: GDPR).

110 This legislation elaborates the right to protection of personal data, as enshrined in Article 8 Charter. Once neurodata is read from a device, such as a wearable, via an internet connection, the E-Privacy Directive and the Telecommunications Act (Tw) also apply. If the neurodata is collected in a medical context and eventually shared for patient care purposes or for research or innovation, the European Health Data Space also applies. This regulation creates a *European Health Data Space* (EHDS), in which (electronic) health data can be shared for *primary* use (for the purpose of caring for the individual) and *secondary* use (for purposes other than those for which the data was initially collected, such as research, innovation, and science). Joint rules, standards, infrastructure, and governance frameworks will be established for this purpose. The EHDS utilises the same definition of personal and health data as the GDPR, so that it includes by no means all neurodata (see below). The Tw and EHDS have been excluded given the limited scope of this scan, and because neurodata will also almost always be personal data, meaning that the GDPR applies anyway.

We identify three main concerns, which in the sources consulted lead to the conclusion that neurodata and thus the privacy of information are insufficiently protected by the GDPR. First, basic GDPR protection seems difficult to achieve in actual practice. Second, except when used in certain specific contexts, such as health, neurodata is not categorised as *special* personal data. It is then not considered to qualify for extra protection, so that additional protection rules do not apply. Finally, the use of neurodata in criminal law requires further consideration. We will explore these three points in greater detail in the following sections.

It should first be noted that a good legal framework is not enough: actual practice regarding tracking cookies and social media shows that consumers pay for digital services with their data, based on consent frameworks and other constructions that frequently fail to comply with the GDPR. This may probably not be any different in the case of neurotechnology.[111]

Protecting neurodata involves numerous practical challenges
A study by the European Data Protection Supervisor and other literature suggests that it is questionable whether and how the basic principles of the GDPR can be fulfilled in the case of neurodata. This is due to the particular features of neurodata (and how it is processed).

Lawfulness
The basic principle of lawfulness requires that there be a valid ground for processing. In the case of *normal personal data*, for example, this can be a 'legitimate interest'. This may even be the case if there is a commercial interest in targeted marketing, and thus potentially in neuromarketing.[112] In principle, *special categories of personal data* are subject to a processing ban, which can however be lifted via a statutory ground for exception, for example if the legislation stipulates that processing is necessary for the purpose of public health. In the case of neurodata, a legitimate interest or statutory exception will often not apply. Consent is then the appropriate ground for processing.

Transparency
This is related to the second basic principle of transparency: the GDPR requires open and clear communication about the processing of data. Consent must therefore be given by the person whose neurodata is being processed as follows: 'specific' (for each processing purpose), 'informed' (with knowledge of the organisation, the type of data and the person's data rights),[113] 'unambiguous' (with an affirmative action, so no pre-ticked boxes), and 'freely' (so not under pressure from an employer, or because a medical brain implant will cease working if one does not agree to neuromarketing).[114] In

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[111] Rainey e.a., 'Is the European Data Protection Regulation sufficient to deal with emerging data concerns relating to neurotechnology?', 25 July 2020.

[112] See this recent case, for example: Koninklijke Nederlandse Lawn Tennisbond vs. Autoriteit Persoonsgegevens, October 2024.

[113] One of the rights is that the data subject must be able to withdraw their consent. Before the advent of the GDPR in 2018, for example, Emotiv granted itself an 'irrevocable, perpetual licence' to use, transmit and distribute users' neurodata. With the advent of the GDPR, this had to be discontinued. See Ienca, Haselager, en Emanuel, 'Brain Leaks and Consumer Neurotechnology', October 2018.

[114] Ienca, Haselager, and Emanuel.

the case of special personal data, consent must furthermore be given 'explicitly', for example via a form, e-mail, (electronic) signature, or by clicking 'yes' to explicit statements ('I hereby consent to...').[115] As explained in Chapter 3, given the nature of neurodata – which one produces largely unconsciously and the interpretation of which is complex even for experts – it is questionable whether there can ever be sufficient information provision and truly free and specific consent.

Purpose limitation

Where consent is concerned, the basic principle of purpose limitation is also relevant: neurodata must not be processed for a purpose that is incompatible with the purpose for which it was initially collected. In section 4.4, we referred to the BCI game *Flappy Whale* and a scientific study of EEG headsets. These examples show that someone's PIN, other financial information, and information about where they lived could be derived from neurodata in applications not intended for that purpose.[116] This implies potential for shifting the purpose, i.e. use of a technology or data outside its original area of application. As well-known data scandals have shown (for example regarding Cambridge Analytica and the Muslim Pro app), this can have far-reaching consequences for users.[117]

Proportionality and data minimisation

The GDPR also stipulates the basic principles of proportionality and data minimisation: data processing must not be more invasive and extensive than necessary for the (legitimate) purpose. Neurotechnologies, however, involve processing massive amounts of data. According to the European Data Protection Supervisor (EDPS), that fact – combined with the intimate nature of the data – makes this potentially one of the most intrusive forms of data processing that exist.[118]

Fairness

When is this far-reaching invasion of privacy justified? And can the objective not be achieved with a less invasive method? For example, may targeted marketing based on less intimate data be sufficient?[119] In answering these questions, the basic principle of fairness also comes into play: the data processing must not have any unauthorised harmful consequences for the data subjects or for others, for example in the form of discrimination or other violations of human rights. In chapter 4 we point out that a number of concerns regarding human rights play a role with regard to neurotechnology and the processing of neurodata. Discrimination risks may arise, for example, from the risk of bias when working with AI systems.[120]

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115 Autoriteit Persoonsgegevens, 'Grondslag toestemming'.

116 Ienca, Haselager, and Emanuel, 'Brain Leaks and Consumer Neurotechnology', October 2018; Martinovic e.a., 'On the Feasibility of {Side-Channel} Attacks with {Brain-Computer} Interfaces', 2012.

117 For an explanation of this risk and the scandals, see our earlier Rathenau Scan on immersive technologies: Rathenau Instituut, 'Rathenau Scan: Immersieve Technologieen', 2023.

118 Brazal e.a., 'TechDispatch on neurodata', 6 March 2024.

119 This is referred to as the necessity or subsidiarity requirement.

120 Brazal e.a., 'TechDispatch on neurodata', 6 March 2024.

Accuracy
A final basic principle is accuracy: personal data must be accurate and up-to-date. This is at odds with the uncertainty regarding the representation of neurodata that was described above. The plasticity of the brain means that someone's pattern of brain activity is constantly changing, so how do you guarantee that data remains 'accurate'?

Is neurodata 'special personal data'?
'Special personal data' receives additional protection under the GDPR. However, not all neurodata seems to fall within the relevant categories.[121] For example, neurodata will probably not quickly be considered biometric data because that is only the case when physical or physiological data is processed with the purpose of 'uniquely identifying a natural person',[122] and it is uncertain whether identification and authentication based on neurodata will be possible (in the longer term).[123]

More often, neurodata will count as health data. According to ethics professor Marcello Ienca and technology law professor Gianclaudio Malgieri, that applies in any case when the neurodata is collected within the medical field, but it probably also applies to all neurodata that can reveal a 'pathological mental status'. An example might be neurodata processed by wearables for apps aimed at improving sleep, mental wellbeing, or sports performance.[124] It remains to be seen, however, whether neurodata processed by current consumer apps will qualify as special personal data in actual practice.[125] Claims by developers about measuring mental health are in fact often exaggerated (see Chapter 3).

Besides the contexts referred to above (biometric, genetic, or health applications) within which neurodata is processed, there are a number of categories that receive additional protection. This may include information that can be derived from neurodata with the aid of AI systems, for example when someone's age, ethnicity, political views, religious convictions, or sexual orientation, are concerned.

In most cases, therefore, neurodata – and for example the memories and preferences that can be derived from it – will only receive additional protection if it is processed within certain particular contexts.[126] Rainey argues that both the context and the original processing purpose should not be decisive in privacy legislation but the potential that the data has for revealing intimate information when used or reused.[127] Ienca and

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[121] An overview of the categories can be found in Article 9 GDPR.
[122] Vinders e.a., 'Comparative analysis of national legal case studies. On the emerging technologies of climate engineering, neurotechnologies and digital extended reality', 30 December 2022.
[123] According to some experts, 'brain fingerprinting' is conceivable, for example at work, at airports, or in the administration of criminal justice, and the GDPR category of biometric data is therefore relevant. See, for example, Australian Human Rights Commission, 'Protecting Cognition', 12 March 2024; Rommelfanger, 'Humanistic neurotechnology. A new opportunity for Spain', 2024. although the experts we interviewed do not consider these applications realistic.
[124] Ienca and Malgieri, 'Mental data protection and the GDPR', 1 January 2022.
[125] Ienca and Malgieri.
[126] Article 9 and recital 51 GDPR and see for example The Regulatory Horizons Council, 'Neurotechnology regulation', 2022; Vinders e.a., 'Comparative analysis of national legal case studies. On the emerging technologies of climate engineering, neurotechnologies and digital extended reality', 30 December 2022.
[127] Rainey e.a., 'Is the European Data Protection Regulation sufficient to deal with emerging data concerns relating to neurotechnology?', 25 July 2020.

Malgieri argue that the list of special personal data is simply not complete and needs to be expanded to include, for example, 'emotions' and 'thoughts'.[128] This would provide better protection not only for information privacy but also for mental privacy, both in the context of neurotechnology and also, for example, that of social media and profiling based on tracking cookies.

Use of neurodata in the administration of criminal justice
When neurodata or information derived from it produces special personal data and is used in the administration of criminal justice, the EU Law Enforcement Directive and the Dutch Police Data Act and Judicial and Criminal Records Act apply. Those pieces of legislation allow neurodata to be used for the detection and prevention of offences. In its case law, the Court of Justice of the European Union (CJEU) seems to be seeking a balance between the investigative interests of the police and the rights of individuals, for example suspects. Ultimately, the police are permitted to do a great deal, as long as it is clearly specified in the legislation. Examples include forcing suspects to provide biometric or genetic data and searching through smartphones.[129] It remains to be seen at present whether the CJEU will extend this approach to include neuro-wearables and neurodata.

5.4. Regulation of AI systems

As discussed in Chapter 4, the application of neurotechnology can have an impact on various public values, both at an individual and societal level. In this section, we first discuss the protection of these values in the regulation of AI systems that are used, for example, in neurofeedback and neuromodulation. These systems are subject to the new AI Act[130], the world's first comprehensive AI regulatory framework. Given the 'Brussels effect',[131] this has great potential for contributing to mental privacy and fairer neurotechnologies. However, the legislation can also be criticised and questioned in a number of respects because the scope of some of the provisions is unclear and the many exceptions undermine the legislation.

In section 5.5, we then discuss the broader human rights framework relevant to the (potential) impact of neurotechnology on the values of privacy, autonomy, and identity. Are new neurorights needed? Or are existing rights sufficient, i.e. the right to privacy, freedom of thought, the right to integrity, and the principle of dignity?

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[128] Ienca and Malgieri, ‘Mental data protection and the GDPR’, 1 januari 2022; Santiago e.a., ‘TechEthos D4.1’, 6 July 2022.

[130] Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules concerning artificial intelligence and amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144, and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence Regulation) (hereinafter: AI Regulation). The EU legislation came into force in August 2024 and will be phased in over the next few years. July 2024 saw the publication of the AI Regulation in the Official Journal of the European Union and the legislation entered into force on 1 August of same year. The prohibitions discussed below will already come into force on 1 February 2025. The rules for ‘general purpose AI’ (which includes many generative AI models) will follow in August. In August 2026, most of the rules for high-risk systems will follow, but only in August 2027 the obligations for high-risk systems that form part of products covered by existing product safety legislation such as the MDR.

[131] This term was coined by the Finnish-American law professor Anu Bradford, see Bradford, *The Brussels Effect*, 1 maart 2020. It means that EU legislation often has a global impact through market mechanisms.

Uncertainties regarding the scope of the AI Act

First of all, it is a drawback that the provisions of the AI Act do not specifically cover neurotechnology. Neurotechnology applications could be regulated as being high-risk systems, for example if they are used in education to improve a curriculum or individual learning performance,[132] to assess performance in the workplace,[133] to determine access to essential services and benefits,[134]or are deployed by law enforcement or asylum and migration services, for example for identification, lie detection, or to predict recidivism.[135] But exactly what kind of applications this will apply to is still unclear. The categories have been drawn up according to very specific behaviours in very specific situations, rather than types of AI systems, such as in BCIs.

The categories of prohibited AI systems are also formulated in long, vague sentences, for example the prohibition on subliminal technologies, which could include certain forms of neuromarketing and profiling and personalisation based on neurodata.[136] The provision contains qualifying words such as 'materially', 'reasonably likely', and 'significant'. And when has the behaviour of those involved been influenced in a 'harmful way' and have technologies led to a decision taken that someone 'would not have otherwise taken'?[137] AI applications that derive emotions in the context of work or education, for example, are also prohibited.[138] Whether attention and concentration (which can be measured using neurotechnology) will be categorised as 'emotions' remains to be seen.[139]

Many exceptions

Finally, a common criticism from NGOs, academics, and also the European Parliament is that the final version of the AI Act contains too many exceptions and loopholes. The

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132 Article 6 and Annex III paragraph 3.
133 Article 6 and Annex III paragraph 4.
134 Article 6 and Annex III paragraph 5.
135 Article 6 and Annex III paragraphs 6 and 7.
136 These are AI systems that use subliminal (unobservable) technologies of which individuals are unaware or deliberately manipulative technologies, and whose purpose or effect is to impair autonomy, decision-making and choices, with harmful consequences. The Act's recitals cite BCIs and VR as examples of technologies that make deception easier, given that they allow incentives to be better tailored to users. See Article 5 (1)(a) and recital 29. Other relevant prohibited categories in the context of neuromarketing are potential AI systems that exploit vulnerabilities of individuals, such as a (mental) disability (Article 5(1)(b) and recital 29) and 'biometric categorisation' based on derived sensitive data such as political opinion or sexuality (Article 5(1)(g) and recital 30).
137 For critical observations on the AI Regulation, see European Parliamentary Research Service Scientific Foresight Unit (STOA), *The Protection of Mental Privacy in the Area of Neuroscience*, 2024; Silva, 'The Artificial Intelligence Act', 30 August 2024.
138 Important: Applications with a medical purpose (possibly all neurotechnology covered by the MDR) or safety reason (such as the SmartCaps that use neurotechnology to keep truck drivers awake) are exempted from the prohibition (Article 5(1)(f) and recitals 14, 18 and 44 AI Regulation). And emotion recognition systems outside the context of education and work are therefore not prohibited but count as high risk (Article 6 and Annex III(1)(c)). This could possibly apply to neurotechnology used to improve the experience of gamers or to reduce consumers' aggressiveness or anxiety, but that remains to be seen.
139 Among emotions, the legislation includes happiness, anger, disgust, embarrassment, excitement, shame, and pleasure. It does not however include physical states such as pain and fatigue. It is not an obvious step to categorise attention and concentration as emotions, given that they have more to do with cognitive capacities or states. They are close to emotions, however. Moreover, the European Data Protection Supervisor (EDPS) has occasionally referred to monitoring pupils' attention as an example of a 'facial emotion recognition system' (Vemou, Horvath, and Zerdick, 'Techdispatch. Facial emotion recognition', 2021.), and STOA refers to, 'confusion, boredom and satisfaction' as examples of emotions that can be derived with neurotechnology, while 'attention level' seems to be placed in the category of other mental states (European Parliamentary Research Service Scientific Foresight Unit (STOA), *The Protection of Mental Privacy in the Area of Neuroscience*, 2024.). In short, what the European Commission and EU and national regulators consider to be emotions remains to be seen (Silva, 'The Artificial Intelligence Act', 30 August 2024.).

recitals to the legislation state, for instance, that ‘common and legitimate commercial practices, for example in the field of advertising’ are not covered by the prohibition on subliminal technologies. The legislation also contains many exceptions for AI systems deployed in the context of criminal justice, asylum, migration, and other government functions. For example, AI systems for automated risk profiling in detection are prohibited unless the risk profiling is only used to support human assessment.[140]

The danger posed by vaguely worded rules with many exceptions is also exacerbated by the self-assessment regime. High-risk systems are only permitted to be marketed once the developer has carried out a 'conformity assessment' to show that it meets a whole range of product safety requirements concerning, for example, data quality and cybersecurity. The developer must also document human rights risks and implement anti-bias measures.[141] However, it is primarily up to organisations themselves to determine whether their AI system is high risk and also, in most cases, to carry out the conformity assessment.

Neurotechnology may perhaps not be covered

Briefly speaking, although it appears on paper that many high-risk applications of neurotechnology will be prohibited or strictly regulated, it is possible that they will not be covered. This is evident not only from the literature but is also the view of the legal expert whom we consulted for this scan. Much will depend on the specifics of how the standards laid down in the text of the legislation are given concrete form in the harmonised standards that are currently being drawn up, and in the guidelines for implementing the prohibitions that the AI Office of the European Commission is currently working on,[142] the answers given to questions in judicial practice, and the build-up of knowledge, capacity, and coordination at and between regulators.[143]

5.5. Broader discussion of neurorights

The risks that neurotechnology poses for privacy, autonomy and identity, arising from intrusion into an individual's mental states and opportunities for self-development, are the basis for the debate on 'neurorights' that is taking place worldwide. The literature categorises various rights as neurorights, for example the right to mental privacy, mental or personal identity, psychological continuity, free will, freedom of thought, protection against algorithmic bias, and (according to some) equal access to mental improvement and the benefits of neurotechnology.[144]

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[140] European Centre for Non-Profit Law, ‘Packed with Loopholes’, 3 April 2024.

[141] Only in certain particular cases must an independent certification body carry out the conformity assessment. For an overview of when such a ‘notified body’ is mandatory, see Islam, ‘Article 43’.

[142] European Commission, ‘Commission Launches Consultation on AI Act Prohibitions and AI System Definition’, 13 November 2024.

[143] Enforcement will be the responsibility of the Dutch Data Protection Authority, probably together with all kinds of sector regulators, from the Health and Youth Care Inspectorate and the Netherlands Food and Consumer Product Safety Authority, to the Dutch Authority for the Financial Markets. The Rathenau Scan on generative AI deals in greater detail with the complications of future enforcement of the AI Regulation, see Rathenau Instituut, ‘Rathenau Scan: Generatieve AI’, 2023.

[144] See, for example, Genser, Damianos, and Yuste, ‘Safeguarding Brain Data: Assessing the Privacy Practices of Consumer Neurotechnology Companies’, 2024; Genser, Herrmann, en Yuste, ‘International Human Rights Protection Gaps in the Age of Neurotechnology’, 2022; Goering e.a., ‘Recommendations for Responsible

Essentially, the discussion is about 'cognitive freedom', or 'mental self-determination'; these are the terms used in the literature. The main question is whether – in the light of emerging neurotechnologies (whether or not after an updated explanation by, for example, judges, legal scholars, and academics) – the mental states of individuals are sufficiently protected by national, EU, and international human rights frameworks in their current form, or whether new neurorights are needed. There is as yet no consensus on this. Some experts favour new neurorights, while others think that reinterpreting existing rights is sufficient. Opinions also differ as to the interpretation of new rights: should they focus on risk avoidance or are positive rights also necessary?

Positive neurorights too or just protection against risks?
Both among advocates of a new interpretation of existing rights and advocates of new neurorights, there is disagreement as to exactly what interpretation should be given to the various rights. Some believe that cognitive freedom or mental self-determination must also include the freedom to actively improve one's mental wellbeing and cognitive skills (i.e. a positive right).[145] Moreover, that right could also require that equal access to the benefits of the technology be encouraged, for example by keeping the costs low.[146]

Others, such as UNESCO's International Bioethics Committee and the neurorights pioneers Ienca and Adorno,[147] argue only for a negative right to cognitive freedom or mental integrity. People need to be protected from interference in their mental processes by government and other parties. They argue that a positive right could lead to the stigmatisation of neurodivergent people and an increase in social inequalities for people who 'lag behind' with inferior capacities; we discussed these risks in Chapter 4. Moreover, neuroenhancement can also have undesirable effects on a person's personal identity and psychological continuity, thus putting the positive right at odds with neurorights that are meant to protect precisely this.

Development and Application of Neurotechnologies', 1 december 2021; Ienca en Andorno, 'Towards New Human Rights in the Age of Neuroscience and Neurotechnology', december 2017; International Bioethics Commission, 'Ethical issues of neurotechnology', 2021; 'The Neurorights Foundation'; Yuste, Genser, en Herrmann, 'It's Time for Neuro-Rights', 2021. For an overview of exactly which different rights different academics classify as neurorights, see Table 7 of European Parliamentary Research Service Scientific Foresight Unit (STOA), *The Protection of Mental Privacy in the Area of Neuroscience*, 2024.

145 Besides Farahany, this positive right is also advocated, for example, by Genser, Herrmann, en Yuste, 'International Human Rights Protection Gaps in the Age of Neurotechnology', 2022; Genser, Damianos, en Yuste, 'Safeguarding Brain Data: Assessing the Privacy Practices of Consumer Neurotechnology Companies', 2024; 'The Neurorights Foundation'; Yuste, Genser, en Herrmann, 'It's Time for Neuro-Rights', 2021.. According to Farahany, this right would not need to be absolute and exceptions should be made in the public interest, with a subsidiarity and proportionality test. This could mean, for example, that government would not be allowed to prohibit medical students and doctors from improving their academic and practical performance with neurotechnology, but it could require them to inform their patients about this later (an obligation that is not perhaps proportionate where an accountant is concerned). It could also mean that marketing of wearables for neuro-improvement should not be prohibited, but that the state should be able to impose safety requirements.

146 Farahany, *The Battle for Your Brain*, 2023, and Article 7 Universal Declaration of Human Rights (1948, 10 December), https://www.un.org/en/about-us/universal-declaration-of-human-rights (hereinafter: UDHR). Equal access is linked to the principle that all human rights must be accorded to everyone without discrimination. In this context, the literature also cites the right to the highest attainable standard of physical and mental health. See Article 2 and Article 25 UDHR, 12 ICESCR, 25 ICRPD, and 25 UNCRC, Australian Human Rights Commission, 'Protecting Cognition', 12 maart 2024; Muñoz en Borbón, 'Equal Access to Mental Augmentation', 1 July 2023.

147 Ienca and Andorno, 'Towards New Human Rights in the Age of Neuroscience and Neurotechnology', December 2017; International Bioethics Commission, 'Ethical issues of neurotechnology', 2021.

Existing conventions are relevant, but there are also some gaps
The significance of existing rights for protection against potential risks of neurotechnology is important here. The right to privacy, freedom of thought, and the right to integrity and the principle of dignity are enshrined in conventions such as the Constitution of The Netherlands,[148] the European Convention on Human Rights (ECHR),[149] the EU Charter of Fundamental Rights (Charter),[150] and the Universal Declaration of Human Rights (UDHR).[151]. The forthcoming UNESCO Recommendation on the Ethics of Neurotechnology (expected in November 2025) is also relevant.

Our analysis shows a number of possible gaps within existing rights as regards protection against the risks of neurotechnology:

- Reading out and analysing neurodata by means of any technology is covered by the right to privacy, which is not however absolute.
- Influencing consumers based on that neurodata probably does not fall under the right to privacy and perhaps also not under freedom of thought, conscience, and religion. The latter is uncertain, however, because the 'thought' component of the right is insufficiently developed. The United Nations Human Rights Council and the European Court of Human Rights have never ruled on this matter. Courts, human rights organisations, and academics need to provide clarification in this regard.
- Involuntary, invasive neuro-interventions are incompatible with the right to integrity. The use of neurotechnology in the administration of criminal justice is at odds with the prohibition of torture and the right to a fair trial.
- In the medical context, additional conventions apply, such as the Universal Declaration on Bioethics and Human Rights (UDBHR) and the Oviedo Convention on Human Rights and Biomedicine (Oviedo Convention). In particular, they include rights regarding autonomy, consent, and data protection. They do not however determine when there is a medical context.
- Finally, there is the legal principle of human dignity. According to the legal ethics expert Britta Van Beers, this could provide guidance for a renewed interpretation of human rights, certainly given the way that neurotechnology and other biotechnologies are increasingly becoming consumer products.[152]

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[148] Grondwet, https://wetten.overheid.nl/BWBR0001840/2023-02-22.
[149] Convention for the Protection of Human Rights and Fundamental Freedoms (1950, 4 November), https://www.echr.coe.int/european-convention-on-human-rights (hereinafter: ECHR).
[150] Charter of Fundamental Rights of the European Union (2009, 1 December), https://eur-lex.europa.eu/eli/treaty/char_2016/oj (hereinafter: Charter).
[151] Important: Although the Universal *Declaration* is not binding, it provides important guidance for the interpretation of other legal standards. Moreover, many fundamental rights are set out in *conventions* that do have binding force, for example the International Covenant on Civil and Political Rights (ICCPR), the International Covenant on Economic, Social and Cultural Rights (ICESCR), the Convention on the Rights of Persons with Disabilities (ICRPD), the Convention against Torture and Other Cruel, Inhuman and Degrading Treatment or Punishment (Torture Convention), and the UN Convention on the Rights of the Child (UNCRC). These instruments include a direct obligation for governments to *protect* people's human rights. In some cases, it also results in an indirect obligation for private parties, such as tech companies, to *respect* human rights, a principle that the United Nations is also seeking to put into practice with the *Guiding Principles on Business and Human Rights*.
[152] Van Beers, 'Menselijke waardigheid in tijden van big data en Big Tech', 2024.

Although there are arguments for and against new neurorights, it is essential that discussion should continue about additional protection for cognitive freedom, particularly that of consumers, i.e. outside the medical or criminal justice context. When human rights are at stake, it is essential to strike a balance between the interests of the individual and of society as a whole. Opportunities for self-development and mental health are at odds with the risks to inclusiveness and democratic control discussed in Chapter 4. It is therefore important to investigate further and continue to monitor how neurotechnology can impact these interests (including in the longer term).[153]

Children's rights

Finally, consideration needs to be given to the rights of children. Indeed, it became clear in Chapter 4 that neurotechnology could be particularly harmful to them. Their physical brain, as well as their identity, is still developing, and children are more vulnerable to being influenced. The International Convention on the Rights of the Child states that '[i]n all actions concerning children ... the best interests of the child shall be a primary consideration'.[154] According to the responsible UN Committee, this means that providers of digital services must tailor those services to the developing capacities of children. As regards neuromarketing, the UN Committee argues that this can have more far-reaching consequences than previous targeted marketing technologies and that children should therefore be prohibited from coming into direct or indirect contact with it.[155]

[153] Borbón and Borbón, ‘A Critical Perspective on NeuroRights’, 25 oktober 2021; Muñoz en Borbón, ‘Equal Access to Mental Augmentation’, 1 July 2023.

[154] Article 3 UNCRC.

[155] Australian Human Rights Commission, ‘Protecting Cognition’, 12 maart 2024. and Committee on the Rights of the Child, General comment No. 25 on children’s rights in relation to the digital environment, 2021.

Box 2 Unesco Recommendation on the Ethics of Neurotechnology

Currently, the intergovernmental phase of the UNESCO Recommendation on the Ethics of Neurotechnology is taking place; this is intended to result in a final text in November 2025.[156] It will provide a *governance* framework that Member States can transpose into national policies, with recommendations ranging from regulation, *impact assessments*, prohibitions, and individual rights to incentives, knowledge sharing, and standardisation.[157]

For EU Member States, the General Data Protection Regulation and the AI Act theoretically already fulfil a number of recommendations regarding personal data protection, mitigating risks in the context of work, and education. But as we have already seen, these pieces of legislation may fall short in actual practice. Moreover, they laws do not specifically address neurotechnology and neurodata, whereas the UNESCO recommendations in fact do so.

However, the framework also contains gaps. Little attention is paid, for example, to neurotechnology applications in the administration of justice and the defence sector, despite these involve far-reaching risks to mental and physical safety.[158] The document also fails to address the potential long-term risks associated with the possible large-scale adoption of neuroenhancement technologies, such as user dependency, growing inequalities, and the effects on social interaction that may occur if users process and communicate information differently in the future.[159]

[156] UNESCO, First draft the Recommendation on the Ethics of Neurotechnology, 2024.

[157] The recommendations are divided into a number of clusters of policy actions: government use of neurotechnology and public investment and regulation; data protection; intellectual property; cybersecurity; and public communication, participation and information. Attention is also paid to specific user groups that require additional protection, such as children, the elderly, women, and people with disabilities. The same applies to specific fields of application: education, work, and commerce.

[158] Global Partners Digital, ‘GPD response to consultation on the first draft of UNESCO Recommendation on the Ethics of Neurotechnology’, July 2024.

[159] Eke e.a., ‘Responsible Neurotechnology. ANDM’s response to UNESCO’s Draft Recommendation on the Ethics of Neurotechnology’, 5 August 2024.

5.6. Conclusion

Apart from applications for children, the medical-scientific context and the administration of justice, sufficient protection for users against the adverse effects of neurotechnology may not be offered by national, EU, and international legislation. This is mainly due to the complexity of defining and categorising actual practice from a legal perspective. What is an emotion? What is to be categorised as thought? When does data say something about your health?

The systems used to collect neurodata must sometimes comply with the MDR's security requirements, but it is not always clear when a medical or health context exists. The same applies to the Oviedo Convention, the UDBHR, and the definition of health data in the GDPR. It is also unclear when neurodata falls within that or another category of special personal data, meaning that the privacy of those involved is thus the subject of additional protection.[160] Moreover, neurodata entails inherent challenges with regard to the basic GDPR data protection principles, such as informed consent and purpose limitation. When neurodata is then analysed, the AI Act may come into play, but this only applies to very specific applications that are subject to conditions that are unclearly formulated, with numerous exceptions and a system of self-assessment.

Finally, there is still little consensus within academic circles as to the scope of relevant human rights and the extent to which they protect mental states and thus cognitive freedom. It is therefore crucial that Member States and international human rights organisations continue to discuss the right way to protect cognitive freedom – reinterpreting, reformulating or supplementing national constitutions and international conventions.[161]

At the moment, however, that is equally true for other algorithmic influence. Whether greater protection is needed against neurotechnology than against, for example, data processing via tracking cookies or VR glasses, depends on long-term technical developments: will it ever be possible to actually read thoughts with neurotechnology? Until then, the human rights discussion should focus more on the danger that algorithmic influence poses to cognitive freedom in the broader sense.

In short, it is uncertain whether current legislation can sufficiently mitigate the risks posed by neurotechnology to information privacy and mental privacy, autonomy and identity, physical safety and mental health, and democratic control and inclusiveness. The legislation in any case falls short as regards certain points referred to above, or needs to be clarified by academics, courts, or regulators.

[160] Ienca, Haselager, and Emanuel, 'Brain Leaks and Consumer Neurotechnology', October 2018.

[161] Australian Human Rights Commission, 'Protecting Cognition', 12 maart 2024; Ligthart, 'Mental privacy as part of the human right to freedom of thought?', 2024.

6. Options for action

6.1. Introduction

In this Rathenau Scan, we have described what neurotechnology is and how it works (Chapter 1), what applications of this technology are being developed (Chapter 2), what opportunities and risks neurotechnology entails for public values (Chapter 3), and what policy instruments currently exist to protect and promote public values (Chapter 4).

Having long been utilised mainly within the context of neuroscience research and in the medical field, neurotechnology is now gradually finding its way into other fields, including commercial ones. Big technology companies also appear to want to start collecting and utilising neurodata. Increasingly, experiments with non-invasive neurotechnology are also being conducted in such areas as education, the workplace, the administration of justice, sports, and the defence sector. The opportunities presented by this development are mainly in the area of improving cognitive skills and the (mental) health and wellbeing of individual users. The risks described in this scan are broader, and theoretically touch upon the core of what it means to be human because they involve the freedom of thought and how it is influenced by power relations between providers and the users (or non-users) of neurotechnology.

Our scan shows that wearable, non-invasive imaging technology leads to different opportunities and risks, on a shorter timescale, than non-wearable or invasive technology. In the present chapter, we offer policymakers and politicians various options for action to mitigate the risks involved with neurotechnologies and to thus benefit from the opportunities that it offers (see also Figure 3). We first discuss options for action regarding the short-term risks and then regarding longer-term risks. Both types of risks call for action to be taken in the near future.

Figure 3: Options for action

Options for action – policy

For short-term risks

- Work towards a neurodata protection strategy at European level
- Define how to deal with personalised marketing using neurodata
- Continue to work on European neurotechnology and the associated infrastructure
- Foster public discussion of increasingly intimate emerging technologies, as well as cognitive freedom
- Clarify the gaps in the legislation

For long-term risks

- Formulate a strategy to monitor developments in neurotechnology
- Establish responsibilities in relation to brain implants
- Explore the need for better protection of mental states

Options for action to seize opportunities and mitigate risks in the short term

In the short term, many wearable devices can be expected to come onto the market that work with EEG. The risks that this technology entails are similar to those that have already been the object of discussion where other data privacy issues are concerned, but this technology goes a step further by literally and figuratively getting ‘up close and personal’. With EEG, a great deal of intimate personal data can be measured in many different contexts and can also be combined with other sensitive data. We envisage the following courses of action:

Work towards a neurodata protection strategy at European level

Our policy analysis shows that neurodata may not be adequately protected. In most cases, for example, it probably does not fall within the definition of 'biometric data', which enjoys special protection under the GDPR. Because neurodata is a very intimate form of data, and has applications within more 'sensitive' contexts such as work (dependency relationship), education (children), the administration of justice and sport (unfair advantage), it is important to consider in a EU context how this neurodata should be protected.

Various protection strategies are possible:

- Broaden the term ‘biometric data’ by omitting the requirement of identification as a processing purpose, as is the case in the AI Act.
- Add biological (or neurological) data as a new category of special personal data, as was done in Colorado.[162] Colorado has privacy legislation that is similar to the

[162] Pullen Guercio, ‘Making (Brain) Waves’, 22 January 2024.

GDPR, to which a recent legislative amendment added the category of 'biological data', which includes the subcategory of 'neural data'.

- In order to reinforce legal certainty, formulate specific neurotechnology guidelines for European and national regulators, for companies, and for other organisations that process neurodata.
- Regulators can also proactively bring the mandatory 'prior consultation' to the attention of providers. This means that when new methods of data processing by developers or business users of neurotechnology lead to obvious major or unclear risks, they must first request approval and advice from the regulator (in the Netherlands, the Dutch Authority for the Financial Markets).
- Increase knowledge and capacity among regulators. The large number of digital technology providers and the lack of transparency in their operations mean that enforcement is complicated, and the fines imposed are often not in proportion to the profits that are made.

Define how to deal with personalised marketing using neurodata
Even if one cannot do ‘more‘ with neurodata than with other intimate data such as pupil reflexes and heart rate, neurodata should still be included in a broader discussion of digital marketing. The desired approach to hyperpersonalisation and manipulation based on intimate physiological data requires more debate among politicians, particularly when children are involved. The proposed Digital Fairness Act offers a good opportunity for this.

Continue to work on European neurotechnology and the associated infrastructure
Work towards a European neurotechnology and European alternatives as regards hardware and data infrastructure. This can help guide the development of neurotechnology, keep European governments in control of the collection and sharing of neurodata, and ensure European independence in this regard. Encourage the exchange of knowledge and data sharing between scientists and developers in Europe, as is happening with E-brains, the follow-up to the EU-funded Human Brain Project.

Foster public discussion of increasingly intimate emerging technologies, as well as cognitive freedom
Engage with the wider community about the areas of application that we have described in the present scan, and about the aspects that are and are not desirable. Now is the time for this, given that their development and implementation within society can still be guided. Does society in fact want applications of neurotechnology outside the medical sector or the sharing of neurodata, and subject to what conditions? For the necessary discussion to be meaningful, it is important to inform the public about neurotechnology in a balanced manner so as to avoid contributing to hypes and misinformation.

Engage with wider civil society about cognitive freedom as well. What exactly is freedom of thought? What kind of thoughts are we talking about? Do we want to protect them from manipulation, from being read out, or from both? Who should decide on this?

What will it take to safeguard this? Thinking solely in terms of the possibilities and limitations of technology can in fact stifle discussion and distract from underlying, more fundamental discussions that also apply to other digital technologies that have already been around for some time and are widespread within society. It is not merely neurotechnology and immersive technology that raise questions about influencing, manipulation and cognitive freedom but also social media, online tracking, and algorithmic (hyper)personalisation. Many of the experts consulted were in favour, for example, of extending the concept of inviolability to include the realms of both body and mind, and the interconnection between them. But what does society think?

Clarify the gaps in the legislation
Questions that remain open include, for example: which neurotechnology applications are and are not medical devices within the meaning of the MDR? When does neurodata count as health data under the GDPR? When is there a legitimate interest in neuromarketing? How is consent sought by providers of existing consumer neurotechnology and does this comply with the GDPR? Which applications are covered by freedom of thought? Clarification of these discussions requires further investigation by regulators and courts, legal experts, and technical experts.

Pay special attention to neurotechnology when monitoring implementation of the new AI Acts and testing effectiveness. Monitoring and review have been announced in the Dutch government’s vision regarding generative AI, and action points can be made more specific in that context, including for AI systems applied in neurotechnology.

6.2. Options for action to seize opportunities and mitigate in the longer term

Neurotechnologies, such as invasive brain implants, devices that directly influence (modulate) the brain, and non-wearable imaging neurotechnology, offer more opportunities for imaging or influencing mental states than wearable technology, but are still very much at the development stage. The potential of AI and the entry of major technology players could well accelerate development.

Our review of the literature and consultation with experts fails to provide a definitive answer as to how far neurotechnology could be used to derive more information about the mental states of individuals than is already possible using data that is already collected on a large scale, such as web browsing data. However, if neurotechnology can indeed approximate mental states more closely in the future, it is likely to be implemented relatively quickly and widely. This offers many opportunities, including outside the public sector, within the consumer market. However, the risks associated with using neurotechnology then increase significantly. The broad societal risks associated with brain implants, for example, are therefore of a longer-term nature and involve greater uncertainty, although those risks are far-reaching. To deal with these risks, we envisage the following courses of action:

Formulate a strategy to monitor developments in neurotechnology
As government, keep a finger on the pulse of neurotechnology development. Develop a strategy to monitor developments in neurotechnology, and involve policymakers, neuroscientists, companies, and neuroethicists. This approach will clarify what innovations companies may have in the pipeline and what societal impact these may have.

Establish responsibilities in relation to brain implants
Take account of shifts in the purpose of brain implants. Once an implant has been approved for use on the European market, it is up to the physician to decide whether treatment using it in an individual will be 'effective' as regards that individual's problem. Who is responsible for how the technology is utilised/applied? The assessment process for such implants should involve specific attention to this matter.

Lay down what should happen if an implant provider becomes insolvent – who will then take responsibility for the implant? Where state-of-the art neurotechnology is concerned, it is not necessarily always the case that another party will be able to support or update patients' implants.

Explore the need for better protection of mental states
Options for protecting mental states include:
- Have courts, human rights councils, reporters and commissions, and legal scholars in the fields of national, EU and international law reinterpret the rights that exist in actual practice, and explain them in greater detail in the context of specific emerging technologies such as neurotechnology. Case law on the scope of 'thought' is currently lacking, but could provide clarity.
- Modernise the Constitution following the example of Chile: that country's constitution allocates neurodata the same status as organs. It has prohibited trading in neurodata and mental integrity is explicitly protected.[163]
- Introduce a new constitutional or international right that is less specifically worded than neurorights. This would reduce the risk of rights inflation and also protect people against other technologies and forms of data processing with which their thoughts and behaviour could just as easily be manipulated, such as the recommendation algorithms utilised by social media. One example of this is the right not to be subject to surveillance and covert influence, as previously proposed by the Rathenau Instituut in a report on human rights in the age of robots.[164]
- Be closely involved in formulating the UNESCO framework for neurotechnology, and press during the intergovernmental phase for a final version that can be used to ensure the responsible and safe development and deployment of neurotechnology.

[163] Cornejo-Plaza, Cippitani, and Pasquino, 'Chilean Supreme Court Ruling on the Protection of Brain Activity', 2024; Guzmán, 'Chile', March 2022.
[164] Rathenau Instituut, 'werken aan de robotsamenleving', 2015.

Glossary

Imaging neurotechnology
Neurotechnology whose purpose is to visualise information about mental states by measuring brain activity.

Brain-computer interface
A BCI can be viewed as technology that connects the brain to external devices, i.e. a link between biology and technology. It can be used, for example, to display someone's brain activity on a computer. Neuromodulation works the other way round, with the BCI converting information into signals that the brain responds to.

EEG (electroencephalography)
A non-invasive imaging technique in which electrodes are positioned on the skull to measure electrical activity in a specific area of the brain.

Invasive neurotechnology
Neurotechnology positioned within the skull, thus requiring surgery.

Neurodata
Digital data representing physiological activity within the brain.

Neurofeedback
An application of neurotechnology in which information about the mental states of an individual user is presented in such a way that the user can interpret it. The individual thus gains additional insight into their own mental states in order to improve them.

Neuromarketing
Marketing using information about the brain.

Neuromodulation
Directly manipulating or influencing brain activity with neurotechnology.

Neurorights
Rights that aim to provide protection for the brain, and thus for an individual's mental states. Neurorights are essentially about 'cognitive freedom', or 'mental self-determination'.

Neurotechnology
Neurotechnology is an umbrella term for all types of technology that measure or influence the activity of the central nervous system (which includes the brain). It therefore comprises a broad spectrum of technologies, some of which – for example EEG – measure brain signals through the skull, while others – such as Deep Brain Stimulation (DBS) – involve implanting electrodes into the brain to influence brain

activity. Neurotechnology can therefore be both invasive and non-invasive, and both modulating (i.e. directly influencing brain activity) and imaging (visualising brain activity).

Non-invasive neurotechnology
Neurotechnology positioned outside the skull.

List of abbreviations

AI (systems)	Artificial intelligence systems
AR/VR	Augmented Reality/Virtual Reality
GDPR	General Data Protection Regulation
BCI	Brain-computer interface
DBS	Deep brain stimulation
EEG	Electroencephalography
EHDS	European Health Data Space
EMG	Electromyography
EU	European Union
ECHR	European Convention on Human Rights
fMRI	Functional magnetic resonance imaging
MDR	Medical Device Regulation
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UDHR	Universal Declaration of Human Rights
UN	United Nations

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Policymakers questionnaire

- Policymakers from the following ministries (+ directorate or department if known) completed the policymaker questionnaire:
- Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (BZK) – Publieke waarden & Nieuwe technologie
- Ministerie van BZK – Constitutionele zaken (3x)

- Ministerie van BZK – Digitale Samenleving
- Ministerie van Defensie – Commando materieel en IT, afdeling DATA en afdeling Kennis en Innovatie.
- Ministerie van Economische Zaken (EZ) (3x)
- Ministerie van EZ – Topsectoren & Industriebeleid
- Ministerie van Infrastructuur en Waterstaat (I en W)
- Ministerie van Justitie en Veiligheid (J en V) – Directie Rechtsbescherming, Beleidsteam Privacy
- Ministerie van Justitie en Veiligheid
- Ministerie van Onderwijs, Cultuur en Wetenschap (OCW) – directie Kennis
- Ministerie van Sociale Zaken (SZ)– Directie Arbeidsmarkt en Sociaaleconomische aangelegenheden
- Ministerie van Volksgezondheid Welzijn en Sport (VWS) – directie Geneesmiddelen en Medische Technologie
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Illustrations and photos
Communication department

Cover
Shutterstock, DC Studio

Cite as:
Rathenau Instituut (2025). Neurotechnologie. Den Haag. (Auteurs: Van Baalen, S. R. Edelenbosch, L. Ex, B. Hijstek en F. Van der Weij)

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