Opportunities and Risks of the Application of Neurotechnology in Criminal Justic

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Abbreviations

ACC	*anterior cingulate cortex*
aDBS	*adaptive deep brain stimulation*
IF	amyotrophic lateral sclerosis *brain-*
BCI	*computer interface* computed
CT	tomography *deep brain*
DBS	*stimulation diffusion tensor*
DTI	*imaging* electrocorticography
EcoG	electroconvulsive
ect	therapy electroencephalography
EEG	
ECtHR	European Court of Human Rights
EVRM	European Convention on Human Rights *functional magnetic*
fMRI	*resonance imaging functional near-infrared*
fNIRS	*spectroscopy functional transcranial doppler*
fTDC	*focused ultrasound imaging* behaviour-
fUSI	influencing and freedom-restricting
GVM	measure device for systematic offenders magnetoencephalography
ISD	*magnetic resonance imaging magnetic*
MEG	*resonance spectroscopy*
MRI	multiple sclerosis positron emission
MRS	tomography stereotactic
MS	electroencephalography
CAP	*single positron emission computed*
sEEG	*tomography*
SPECT	
Sr	criminal law
Sv	Code of Criminal Procedure
TBS	provision of *transcranial*
tDCS	*direct current stimulation*
TMS	*transcranial magnetic stimulation*
TRL	*technology readiness level*
TFUS	*transcranial focused ultrasound stimulation*
WODC	Scientific Research and Documentation Center

Prior to

The last decade has been marked by an advance in neurotechnology, particularly in the neuroscientific and medical domains. Because neurotechnology also has potential applications in the justice and security domain, the Scientific Research and Documentation Center of the Ministry of Justice and Security commissioned researchers from UMC Utrecht (UMCU Brain Center) and researchers from the Department of Law of the Netherlands in March 2021. Utrecht University (UCALL and the Montaigne Center) to prepare a report on Opportunities and Risks of the Application of Neurotechnology in Criminal Justice. The research took place between May 2021 and February 2022. The report was delivered on February 28, 2022 and minor corrections were made on March 22, 2022.

The report was partly the result of an important contribution from experts from the Netherlands and abroad. We, the researchers, would like to express our gratitude to the fourteen researchers interviewed in the fields of neuroscience, law and ethics for their expertise and helpful suggestions. In addition, we are very grateful to the four experts who proofread the draft report for the significant time investment and the 'dotting the i'. We would also like to thank the supervisory committee (TE Swierstra (chairman), AM Brouwer, S. Dorrestijn, B. ter Luun, R. Oostenveld and M. Turina-Tumewu) for their valuable and constructive feedback. Finally, a word of appreciation to A. Elbertse, for the accurate and detailed secretariat of the meetings with the supervisory committee.

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Resume

In recent years, much attention has been paid to neurotechnology. These are techniques that contribute to knowledge about the brain and/or that interact with the brain. The attention for neurotechnology is partly caused by the continuous technological progress.
Because neurotechnology (also) has potential for application within the justice and security domain, the Ministry of Justice and Security's Scientific Research and Documentation Center (WODC) has commissioned research into the opportunities and risks of such application of neurotechnology. This report is the result of that research.

This report focuses on the following research question:

'What opportunities and threats can be expected from neurotechnology for the domain of the Ministry of Justice and Security and what impact (legal, ethical and social) can neurotechnology have on policy?'

The research was carried out by researchers from the UMC Utrecht (UMCU Brain Center) and researchers from the Utrecht University Law Department (UCALL and the Montaigne Center).

In answering the research question, the researchers focused on the three most important applications of neurotechnology in the justice and security domain, namely: 1) *investigation and truth-finding;* 2) *risk assessment;* and 3) *intervention.* A technique offers an opportunity if it is effective (and to some extent efficient) in achieving one or more goals that are central to the three applications. A risk consists of tensions with legal and ethical standards and possible unintended, negative side effects of applying newly developed knowledge and technologies. The legal analysis of risks is limited to the human rights enshrined in the European Convention on Human Rights (ECHR). In preparing this report, the researchers based themselves on research of the medical-scientific, legal and ethical literature, interviews with fourteen academics with expertise in neuroscience, neurotechnology, neurolaw and neuroethics, and a proofread of the draft report. by four more academics with relevant expertise. The findings are described in three sections: 1) technology; 2) law and ethics; and 3) synthesis.

Section 1 maps existing and emerging neurotechnologies, their application areas and relevant developments. Within neurotechnology, a distinction can be made between techniques that measure brain activity (EEG, MEG, fMRI, fNIRS, fTCD, PET, SPECT), techniques that can stimulate the brain (tDCS, TMS, TFUS and DBS), techniques that measure and can be stimulated (ECoG, sEEG, endovascular EEG, microelectrode arrays), and techniques that visualize the anatomical structure of the brain (CT, MRI, DTI). Techniques that only measure brain activity can be further divided into methods that record electrical signals (EEG), or related changes in the magnetic signal (MEG), and methods (fMRI, fNIRS, fTCD, PET, SPECT) that focus on the metabolic processes of the brain: vascular reactions, such as changes in blood volume or blood oxygen levels, in areas of the brain that become active when people perform a certain task.

Every neurotechnology has properties that can be an advantage or a limitation, depending on the application. For example, measurements of the electrical signals have a high temporal resolution (they can accurately measure rapid changes in time), while metabolic signals have a low temporal resolution, due to the seconds-long delay between electrical signals and related vascular responses. There are also important differences between neurotechnologies in the spatial (spatial) resolution and specificity and the spatial range. For example, microelectrodes make it possible to measure signals from individual brain cells, but the size of the 'arrays' in which these electrodes are organized limits the spatial range to a few millimetres.

In contrast, EEG and fNIRS can map the signals from the entire surface of the brain, but a (relatively large) area of a few centimeters is covered per sensor. Other distinguishing factors are the degree of invasiveness (for example, is brain surgery required to apply the technique), the ability to reach deeper brain structures, the sensitivity to disturbances and the properties of the measuring device itself (dimensions, degree of portability, price , etc.). In addition, when changes in the brain signals are generated (neuromodulation), there are important differences in the reversibility of the effects.

Many of the techniques mentioned have important scientific value and are (frequently) used in clinical practice, for example for the diagnosis of disorders such as epilepsy (EEG, MEG, ECoG, S-EEG), brain tumors (MRI, PET) or the disease of Alzheimer's (PET, SPECT, DTI), in the treatment of depression (TMS) and movement disorders such as Parkinson's disease (DBS), in the preparation of neurosurgical procedures (MRI, fMRI, fTCD) or in mapping neurological damage (CT, MRI). Other techniques are (almost) exclusively in the neuroscientific domain, either because the clinical relevance and applicability of the techniques in question are still being investigated (endovascular EEG, microelectrodes, tDCS, TFUS), or because they are mainly used to answer more fundamental neuroscientific questions. in situations where other techniques are less suitable (fNIRS).

The current application of neurotechnology in criminal justice is limited to the diagnosis, via clinical diagnostic methods, of neurological disorders such as fronto-temporal dementia using techniques such as MRI and PET. These can be applied, for example, to a pro Justitia behavioral report of a suspect. Neurotechnologies can therefore play a role in the assessment of the suspect's (un)responsibility and the imposition of TBS. In addition, four other techniques are highlighted because of their possible future applicability in criminal justice. Within the domain of *investigation and truth-finding,* for example, research is being conducted into the use of 1) fMRI to identify deception (neuro-lie detection) and 2) EEG to trace perpetrator knowledge via the so-called P300 response (neuro-memory detection). Neuromemory and neurolie detection can make an important contribution to establishing the truth. For the purpose of assessing whether a person is guilty, establishing what actually happened is essential. If it were possible to take a 'look' into the memory of the suspect, this would provide very valuable information. In the context of *risk assessment ,* 3) fMRI is examined to estimate the risk of recidivism. Neurotechnology may therefore become important in the future for deciding which sanction to impose on someone. Furthermore, 4) the stimulation technique tDCS is being studied because of its possible applicability as an intervention method within forensic psychiatry. In the context of various criminal sanctions, neurotechnology may play a role in the future as an *intervention* to reduce the risk of recidivism and thereby contribute to the rehabilitation of offenders.

In a general sense, further developments of existing neurotechnologies appear to be mainly aimed at making non-invasive techniques more widely usable and at the development and validation of fully implantable systems. With regard to techniques with foreseeable applicability within the justice and security domain, developments are expected in the field of increasing the spatial resolution of fMRI, better understanding and more reliable measurement of the EEG-P300 response, improving the predictive value of neuroimaging by combining it with other biological measures and increasing insight into the effectiveness of the use of neurostimulation within forensic psychiatry. In addition, several recently developed techniques (e.g. fUSI, two-photon microscopy and optogenetics) may have relevance for studying the human brain, but these are still (mainly) in the animal research stage.

Knowledge about the structures and functioning of the brain has increased considerably in recent decades, partly thanks to technological developments that make it possible to visualize the brain in a living and active state. This development is already important for criminal (procedural) law and may become even more so in the future. However, the question is to what extent such (future) technical possibilities are also legally permissible. For example, the accused must be treated with dignity (Article 3 of the ECHR; this article prohibits the use of torture and inhuman and degrading treatment), he has the right to remain silent and not be forced to cooperate in his own conviction (Article 6 ECHR) and the right to respect for private life (Article 8 ECHR). The question is whether, and to what extent, new neurotechnologies can be applied in line with these human rights. In the legal part, it is assessed whether neurotechnologies can be applied in line with the applicable law for *investigation and truth-finding, risk assessment* and *intervention.* The five applications of neurotechnology that follow from the technical part are central to this: namely: 1) neuroimaging for the diagnosis of neurological disorders; 2) using fMRI to identify deception; 3) using the P300 from the EEG signal as a means of identifying perpetrator knowledge; 4) the use of neurotechnology to estimate recidivism risk; and 5) the use of brain stimulation in forensic psychiatry.

In the chapter on testing the use of neurotechnologies in the *investigation phase* for the purpose of *establishing the truth,* it is described that no general ban on the use of those techniques follows from the human rights framework, or is to be expected. Both the respect for human dignity and the prohibition of torture, the right to respect for privacy and the principle of nemo tenetur (this principle means that the accused must not be forced to speak or otherwise cooperate in his own conviction) prohibit certain actions not *in abstracto.* A court confronted with results from a particular method – which can therefore be a neurotechnological method – must determine *in concrete terms* whether the use and implementation of the methods are in accordance with the applicable law. The main point of discussion here is whether the results of neurotechnologies can be compared to the spoken word *or* products of mental effort – for which a more extensive protection applies – or, in short, are merely biological responses to stimuli. It is important for this assessment that in criminal procedural law the authorities responsible for criminal proceedings may only act on the basis of a legal basis. In other words, the granting of authority to use a certain method must take place through the law.

Depending on the drastic nature of the method, the legal basis must be designed with more safeguards, such as judicial review prior to implementation of the method in the case of the most drastic methods. With regard to neurotechnological methods, especially neuromemory detection, which provides insight into the invisible memory, should be argued that these are far-reaching methods that must be cast in a legal basis with strict safeguards. These safeguards then regulate the decision to deploy neurotechnological methods.

With regard to implementation, all human rights discussed set limits to the coercion that may be applied. In other words, if the use of a power is legally possible, this does not mean that all implementing acts are *ipso facto* lawful. For example, restraining someone with a lot of (unnecessary) violence so that neuromemory detection can be taken is unlawful. This means that the authorities carrying out a neurotechnological method must behave carefully in the sense that they only use lawful coercion.

When it comes to *risk assessment ,* the same tensions with human rights are partly at play that have been discussed in the context of *investigation and truth-finding .* Brain scans that are used to estimate the risk of recidivism may not conflict with Articles 3 and 8 of the ECHR, just like scans that are used in the context of investigations. The assessment framework for this does not differ substantially. While the use of enforced brain scans in the context of investigations may conflict with the principle of nemo tenetur laid down in Article 6 of the ECHR, this is not evident for the use of such scans for risk assessment . It has not been established that Article 6 of the ECHR offers protection against compulsory cooperation in brain scans for diagnostics and *risk assessment.* It is also important that risk assessments should not lead to unjustified unequal treatment based on group characteristics.

In very exceptional cases, in which there is an acute danger to health, medical treatment *(intervention),* also in the form of forced application of neurotechnology, may be permitted under Dutch law and the ECHR. However, Dutch criminal law does not support forced neuro-interventions to reduce the risk of recidivism, and forced interventions are virtually unthinkable in the light of Articles 3 and 8 ECHR. Neuro interventions that aim to add suffering qualify as humiliating and inhumane treatment within the meaning of Article 3 of the ECHR. In the light of Articles 3 and 8 ECHR, a difficult question is the extent to which neuro-interventions that are imposed, for example, as a special condition in the context of a suspended sentence, are permissible. In that case, a convicted person is free to refuse the intervention, but the consequence of this is that a prison sentence will be enforced. In that case, is there not an enforced, and therefore in principle inadmissible, intervention?

This question cannot be definitively answered on the basis of the current state of the jurisprudence of the European Court of Human Rights (ECtHR). Although an intervention in such a case is not generally qualified as involuntary by the ECtHR, there are also indications that under certain circumstances it may still be involuntary. This may be the case if the convicted person is in a particularly vulnerable position. Conversely, the right to liberty of Article 5 of the ECHR may oblige certain categories of convicts – in particular life sentences and TBS detainees – to be offered treatment that will allow them to resocialize so that they have the opportunity to be released again. be made.

Brain scans that can be used for *intervention* can touch on the negative right to free expression (article 10 ECHR): the right to refrain from disseminating opinions, ideas and information. However, the question is whether the information obtained with brain scans actually relates to opinions, ideas or information within the meaning of Article 10 of the ECHR. If neurointerventions change brain processes of a person involved, freedom of thought and conscience can also come into the picture (article 9 ECHR). That is a right that cannot be infringed.

It is currently unclear whether neuro-interventions influence the psyche in such a way that this right can be spoken of as being infringed.

Finally, a framework of factors relevant to answering the question of whether neuro-interventions are permissible has been outlined. Factors that play a role in this are the aim of the intervention, its drastic nature (including side effects and risks), the degree of coercion applied and the context in which it occurs, the availability of alternatives and the effectiveness of the intervention. It should be borne in mind that the actual application of neuro-interventions can lead to a new dynamic in the jurisprudence of the ECtHR, because of the new questions that this technology raises. It is conceivable, for example, that the hitherto little-pronounced right to freedom of thought and conscience will then play a more important role.

It was briefly discussed that the literature suggests that the existing human rights framework may be inadequate and that proposals have therefore been made to create new fundamental rights, such as a right to mental integrity.

From an ethical perspective, the application of neurotechnology in the justice and security domain in any case touches on privacy, autonomy, physical and mental integrity, and human dignity. Privacy is obviously a central point when information is recorded from the brain. There is, incidentally, some discussion about the extent to which brain data should now be regarded as 'unique' compared to, for example, DNA data. Autonomy is relevant in (at least) three ways. Firstly: does the consent of a suspect or convict with neurotechnology really constitute a free, autonomous choice? Or is there a risk of accepting *'an offer you cannot refuse'?* Second, neurotechnology that changes the brain can also influence a person's choice process. In this way, the autonomy of that person could be threatened/ undermined. Thirdly, if neurotechnology helps people to arrange their lives more in the long term as they would like, then neurotechnology supports their future autonomy. Mental and physical integrity are particularly relevant in neuro interventions. There are calls for better protection of mental integrity against neurotechnological interference through new human rights than is currently the case. An immediate question is whether such protection should be absolute, or whether infringements should be possible under certain circumstances. Human dignity seems to play an overarching – or foundational – role in the considerations mentioned above. In other words, in order to respect human dignity, we need to consider the implications of neurotechnology for privacy, autonomy and mental/physical integrity.

In section 3, the researchers reflect on the findings from sections 1 and 2. They conclude from the research that a number of important steps must in any case be taken before new neurotechnology can be responsibly implemented for investigation and truth-finding ,
risk assessment and *intervention.*

First, further research needs to be done into the effectiveness and reliability of using neurotechnologies for application in criminal justice. More insight is needed into, for example, the predictive value and specificity of brain measures. This could include a question such as: Is the occurrence of a certain brain signal specifically related to a lie, or could it also be based on another process? Because criminal justice often takes place at the level of the individual suspect/convict, future research into effectiveness and reliability will have to make statements at the level of the individual. This requires a different approach than the correlation analyzes and group comparisons that are common in neuroscientific research. Related to this, it is important to determine to what extent statements about effectiveness and reliability can be generalized, or whether certain personal characteristics influence these measures. This is also important to avoid the risk of unjust unequal treatment of suspects. It also needs to be determined to what extent neurotechnologies are vulnerable to manipulation of the outcome or the usability of the data by uncooperative suspects.

A second important topic of research is the safety of neurotechnologies. This concerns the risks of the application of neurotechnology itself, but also the possible physical or psychological side effects. Further research is particularly needed when it comes to techniques that require brain surgery and techniques that could have a long-term or permanent effect on the brain.

In addition to conducting research, the implementation of neurotechnology in criminal justice requires clarification of the legal and ethical frameworks. As described above, much is still unclear about the admissibility of neurotechnology in criminal law.
Because the legal context differs per country, it is important that the Netherlands develops its own vision on the application of neurotechnology in the justice and security domain, which is also tailored to Dutch criminal law. Ideally, this process already takes place while research into and development of neurotechnology is taking place, because it offers opportunities to tailor the developed technology to, for example, requirements for reliability and effectiveness and legal guarantees. The development of this vision can be supported by the ethical debate on the interfaces between neurotechnology in the justice and security domain and the topics of privacy, autonomy, physical and mental integrity, and human dignity. In this light, the researchers have identified three important topics on which further reflection is particularly needed.

First: The minimum requirements for reliability. Whereas neuroscientists often regard a technique as an isolated tool and therefore place high demands on the reliability of the results of research, lawyers argue that in the administration of justice information obtained with neurotechnology will often be combined with other means of evidence and that the entirety of evidence will be used to establish a criminal offense. fact 'beyond a reasonable doubt'. Because this concerns answering a legal question, whereby evidence is assessed in conjunction, it is necessary to consider one's own requirements for application within criminal law.

Second: Further reflection on specific legal questions raised by the application of neurotechnology in criminal law. For example, in all categories the question has arisen under which circumstances neurotechnology may be used against the will of the person concerned. In the context of *investigation and truth-finding* and *risk assessment ,* this question arises in the light of the right to remain silent. In the context of *neuro-interventions,* it is clear that these may not be forced and that the convicted person must choose the intervention of his own free will, but the question is to what extent undergoing a neuro-intervention under threat of deprivation of liberty can be regarded as voluntary .
Further reflection on these and other legal questions is needed. The ethical debate on these subjects can be helpful in this respect.

Third: provision of information to the court. The researchers state that it is essential that judges are adequately informed about the effectiveness, reliability and safety of neurotechnologies when they are used in criminal justice practice.
applied.

Summary

In recent years, neurotechnology has received significant attention. Neurotechnology concerns techniques that contribute to knowledge about the brain and/or that interact with the brain. The attention for these techniques partly results from continuous technological progress. Because neurotechnology (also) has relevance for application within the justice and security domain, the Scientific Research and Documentation Center (WODC) of the Ministry of Justice and Security has commissioned research into the opportunities and risks of such application of neurotechnology. This report is the result of that research.

This report focuses on the following research question:

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The research was conducted by researchers from UMC Utrecht (UMCU Brain Center) and researchers from the Utrecht University Law Department (UCALL and Montaigne Center).

In answering the research question, the researchers focused on the three most important applications of neurotechnology in the justice and security domain, being: *1) investigation and fact-finding;* 2) *risk assessment;* and 3) *intervention.* A technique presents an opportunity if it is effective (and to some degree efficient) in achieving one or more goals that are central to the three applications. A risk is defined as tension with legal and ethical standards and possible unintended, negative side-effects of applying newly developed knowledge and technologies. The legal analysis of risks is limited to the human rights enshrined in the European Convention on Human Rights (ECHR). For this report, the researchers drew on a review of the medical, legal and ethical literature, interviews with fourteen academics with expertise in neuroscience, neurotechnology, neurolaw and neuro-ethics, and a proofreading of a draft version of the report by four other academics with relevant expertise. The findings are described in three sections: 1) technology; 2) law and ethics; and 3) synthesis.

In section 1, existing and emerging neurotechnologies, their application areas and relevant developments are mapped out. Within the range of available neurotechnologies, a distinction can be made between techniques that measure brain activity (EEG, MEG, fMRI, fNIRS, fTCD, PET, SPECT), techniques that can stimulate the brain (tDCS, TMS, TFUS and DBS), techniques that can be used for both measuring neural signals and stimulation of the brain (ECoG, sEEG, endovascular EEG, microelectrode arrays), and techniques that visualize the anatomical structure of the brain (CT, MRI, DTI). Techniques that measure brain activity can be divided further into methods that record electrical signals (EEG), or related changes in the magnetic signal (MEG), and methods (fMRI, fNIRS, fTCD, PET, SPECT) that target the metabolic processes of the brain: vascular reactions, such as changes in blood volume or blood oxygenation, in areas of the brain that are activated when people carry out a certain task.

Every neurotechnology has properties that, depending on the application, represent an advantage or a limitation. For example, measurements of the electrical signals have a high temporal resolution (they accurately measure rapid changes over time), while metabolic signals have a low temporal resolution due to the multi-second delay between electrical signals and related vascular responses. There are also important differences between neurotechnologies in the spatial resolution and specificity and the spatial range. Microelectrodes, for example, allow the recording of signals from individual brain cells, but the dimensions of the 'arrays' in which these electrodes are organized limit the spatial range to a

few millimetres. In contrast, EEG and fNIRS can map the signals from the surface of the entire brain, but per sensor a (relatively large) area of a few centimeters is covered. Other distinctive factors are the degree of invasiveness (for example, the necessity of brain surgery for the application of a certain technique), the possibility to reach deeper brain structures, the sensitivity to disturbances and the properties of the measuring device itself (size, degree or portability, price, etc.). In case neurotechnologies are used to induce changes in the neural signals (neuromodulation), there are important differences in the reversibility of the effects.

Many of the mentioned techniques have important scientific value and are (frequently) used in clinical practice, for example for the diagnosis of disorders such as epilepsy (EEG, MEG, ECoG, S-EEG), brain tumors (MRI, PET) or Alzheimer's disease (PET, SPECT, DTI), in the treatment of depression (TMS) and movement disorders such as Parkinson's disease (DBS), in the preparation for neurosurgical procedures (MRI, fMRI, fTCD) or for the assessment of neurological damage (CT , MRI). Other techniques are (almost) exclusively used in the neuroscientific domain, either because the clinical relevance and applicability of the technique in question is still under investigation (endovascular EEG, microelectrodes, tDCS, TFUS), or because it is mainly used to study fundamental neuroscientific questions in situations where other techniques are less suitable (fNIRS).

The *current* application of neurotechnology in criminal justice is limited to the diagnosis, through clinical-diagnostic methods, of neurological disorders such as frontotemporal dementia using techniques such as MRI and PET. These techniques can be applied, for example, in a pro Justitia behavioral assessment of a defendant. As such, neurotechnology may play a role in the assessment of legal insanity and the decision about a hospital order. In addition, four techniques are highlighted because of their possible *future* applicability in criminal justice. Within the domain of *investigation and fact-finding,* for example, research is being conducted into the use of 1) fMRI to identify deception (neuro-lie detection) and 2) EEG to detect offender knowledge via the so-called P300 response (neuro memory detection). Neuro-memory and neuro-lie detection have significant potential within the realm of *fact-finding.* In order to determine whether a person is guilty, it is essential to establish what actually happened. A 'peek' into the memory of the suspect would provide valuable information in this respect.
In the context of *risk assessment,* 3) fMRI is investigated to estimate the risk of recidivism. As such, neurotechnology may become of relevance for decisions on which sanction should be imposed on an individual offender. Furthermore, 4) the stimulation technique tDCS is being studied for its potential applicability as an *intervention* method within forensic psychiatry. Within the framework of various criminal sanctions, neurotechnology may play a role as an intervention to reduce the risk of recidivism and thereby contribute to the rehabilitation of offenders.

In a general sense, further developments of existing neurotechnologies seem particularly aimed at making non-invasive techniques more widely applicable and at the development and validation of fully implantable systems. With respect to techniques with a foreseeable applicability within the justice and security domain, developments are expected in increasing the spatial resolution of fMRI, in a better understanding and more reliable measurement of the EEG-P300 response, in improving the predictive value of neuroimaging by combination with other biological measures and in increasing knowledge about the effectiveness of the use of neurostimulation within forensic psychiatry. In addition, several recently developed techniques (eg, fUSI, two-photon microscopy and optogenetics) may have relevance for the study of the human brain, but these techniques reside still (mainly) in the stage of animal research.

Knowledge about the structures and functioning of the brain has increased significantly in recent decades, as described above, partly as a result of technological developments that allow visualizing the brain in a living and active state. This development is already important for criminal (procedural)

law, and this importance may develop further in the future. The question is, however, to what extent (future) technical possibilities are also legally permissible. For example, the suspect must be treated with *dignity* (Article 3 ECHR; this article prohibits the use of torture and inhuman and degrading treatment), he has the right to remain *silent* and to not be forced to (actively) cooperate to his own conviction (Article 6 ECHR) and the right of respect for his *private life* (Article 8 ECHR). The question is whether, and to what extent, new neurotechnologies can be applied in line with these human rights.
In the legal part, it is assessed whether neurotechnologies can be applied in accordance with the law when they are used for 1) *investigation and fact-finding;* 2) *risk assessment;* and 3) *intervention.* This assessment evolves around the five applications of neurotechnology that arose from the technical part: 1) neuroimaging to diagnose neurological disorders; 2) the use of fMRI to identify detection; 3) the use of EEG-P300 as a means to identify offender knowledge; 4) the use of neurotechnology to estimate recidivism risk; and 5) the use of brain stimulation within forensic psychiatry.

The chapter on the assessment of the use of neurotechnologies for *investigation and fact-finding* describes that a general prohibition with regard to the use of these techniques does not follow, or is expected, from a human rights framework. The respect for human dignity and the prohibition of torture, the right to respect for privacy and the privilege against self-incrimination (ie, the accused should not be forced to speak or otherwise cooperate in their own conviction) do not, in itself, prohibit certain investigative methods. A judge confronted with the results of a certain method – which may be a neurotechnological method – must specifically determine whether the use and implementation of the method is in accordance with applicable law. The main point of discussion here is whether the results of neurotechnologies can be compared to the spoken word or products of mental effort – for which a more extensive protection applies – or, in short, represent merely biological responses to stimuli. For this assessment, it is important to acknowledge that in criminal procedural law, the criminal law enforcement authorities may only act on a legal basis. In other words, the authority to use a particular method must be provided by law. Depending on the level of invasiveness of a method, such legal basis must provide certain guarantees, such as judicial review prior to implementation for the most drastic methods. With regard to neurotechnological methods, in particular neuro-memory detection that provides insight into the invisible memory, it must be noted that these are far-reaching methods that can only be allowed when there is a legal basis with strict guarantees. These safeguards would then regulate the decision to *use* neurotechnological methods.

With regard to *implementation,* all discussed human rights set boundaries to the level of coercion that may be applied. In other words, if the use of a certain authorization is legally possible, this does not mean that all acts of implementation are *ipso facto* lawful. For example, fixing an individual with significant (unnecessary) violence for the purposes of neuro-memory detection is unlawful. This means that the authorities carrying out a neurotechnological method must behave carefully, in the sense that they only use *lawful coercion.*

Risk assessment is associated with the same tensions with human rights as discussed in the context of *investigation and fact-finding.* Brain scans that are used to estimate the risk of recidivism may not be in conflict with Articles 3 and 8 ECHR, similar to scans that are used in the context of *investigation.* The respective frameworks for this assessment do not fundamentally differ. Where the use of enforced brain scans in the context of *investigation* may conflict with the privilege against self-incrimination laid down in Article 6 ECHR, such conflict is not evident for the use of this type of scans for *risk assessment.* Indeed, it is unclear whether or not Article 6 ECHR offers protection against mandatory cooperation during brain scans for the purposes of diagnosis and risk assessment. Another important topic is that risk assessments should not lead to unjustified unequal treatment based on group characteristics.

In highly exceptional cases, when there is an acute danger to health, forced application of neurotechnology may be permitted under Dutch law and the ECHR. However, Dutch criminal law offers no ground for forced neuro-interventions to reduce the risk of recidivism, and forced *interventions* are virtually unthinkable in the light of Articles 3 and 8 ECHR. Neuro-interventions aimed at inflict softening qualify as degrading and inhumane treatment within the meaning of Article 3 ECHR. In the light of Articles 3 and 8 ECHR, a difficult question is to what extent neuro-interventions that are imposed, for example, as a special condition in the context of a conditional sentence, are permissible. In that case, a convicted person is free to refuse the intervention, but the consequence is that a prison sentence will be executed. Shouldn't such interventions be considered enforced, and therefore, in principle, inadmissible? This question cannot be definitively answered on the basis of the current state of the case law of the European Court of Human Rights (ECtHR). Although, in general, the intervention would not qualify as involuntary by the ECtHR, there are indications that under certain circumstances involuntariness applies, such as when the convicted person is in a particularly vulnerable position.
Conversely, the right to freedom, as laid down in Article 5 ECHR, may require certain categories of offenders – in particular those sentenced for life and those placed under a hospital order – to be offered rehabilitative treatment so that they have the opportunity to be released .

Brain scans that can be used for *interventions* may affect the negative right to freedom of expression (Article 10 ECHR): the right to *refrain* from disseminating opinions, ideas and information. Whether or not the information obtained with brain scans in fact relates to opinions, ideas or information within the meaning of Article 10 ECHR is uncertain. If neuro-interventions change the brain's processes, freedom of thought and conscience may also come into play (Article 9 ECHR). This right cannot be infringed. It is currently unclear, however, whether neuro-interventions affect the psyche in such a way as to constitute an infringement of this right.

Finally, a framework is outlined concerning factors that are relevant to answering the question of whether neuro-interventions are permissible. Factors that play a role here are the aim of the intervention, its level of invasiveness (including side effects and risks), the degree of pressure that is applied and in which context this takes place, the availability of alternatives and the effectiveness of the intervention . It should be borne in mind that the actual application of neuro-interventions may lead to a new dynamic in ECtHR jurisprudence, because of the new questions this technology generates. It is conceivable, for example, that the little pronounced right to freedom of thought and conscience will start to play a more prominent role.

It was briefly discussed that literature shows that the existing human rights framework may be inadequate and that proposals have therefore been made to create new fundamental rights, such as a right to mental integrity.

From an *ethical* perspective, the application of neurotechnology in the justice and security domain affects at least privacy, autonomy, physical and mental integrity, and human dignity. Privacy is obviously a central theme when information from the brain is registered. There is, however, some discussion about the extent to which brain data should be considered 'unique' compared to, for example, DNA data. Autonomy is relevant in (at least) three ways. Firstly: is the consent of a suspect or convicted person really a free, autonomous choice? Or is there a risk of accepting 'an offer you cannot refuse'? Second, neurotechnology that changes the brain may influence a person's decision making process, which may threaten/undermine the individual's autonomy. Third, if neurotechnology helps people, in the long run, to organize their lives as they desire, it in fact supports their future autonomy. Mental and physical integrity are particularly important in relation to neuro-interventions.
It has been argued that new human rights should be used to better protect mental integrity against neurotechnological interference than is currently the case. This immediately raises the question of

whether such protection should be absolute, or whether infringements should be possible under certain circumstances. Human dignity seems to play an overarching – or foundational – role in the considerations mentioned above. In other words, in order to respect human dignity, we need to consider the implications of neurotechnology for privacy, autonomy and mental/physical integrity.

In section 3, the researchers reflect on the findings from sections 1 and 2. They conclude that a number of important steps must be taken before new neurotechnology can be implemented responsibly for *investigation and fact-finding, risk assessment* and *intervention.*

First, further *research* is needed into the *effectiveness and reliability* of the use of neurotechnologies for application in criminal justice. A better understanding is needed of, for example, the *predictive value* and *specificity* of brain measurements. A relevant question in that respect is for example: Is the occurrence of a certain brain signal specifically related to a lie or could it also be associated with another process? Because criminal justice often takes place at the level of the individual suspect/convict, future research into effectiveness and reliability will have to take the level of the *individual* into account. This requires a different approach than the correlation analyzes and group comparisons that are common in neuroscience research. Related to this, it is important to determine to what extent statements about effectiveness and reliability can be *generalized,* or whether certain personal characteristics influence these measures. This is also important to avoid the risk of unfair treatment of suspects. Finally, it needs to be determined to what extent neurotechnologies are vulnerable to *manipulation* of the outcome or usability of the data by uncooperative suspects.

A second important *research* topic is the *safety* of neurotechnologies. This topic concerns the *risks* of the application of neurotechnology itself, but also the possible physical or psychological *side effects.* Further research is especially needed for techniques that require brain surgery and techniques that could have a long-term or lasting effect on the brain.

In addition to conducting research, *implementation* of neurotechnology in criminal justice requires a *clarification of the legal and ethical frameworks.* As described above, much is still unclear about the admissibility of neurotechnology in criminal law. Because the legal context differs per country, it is important that The Netherlands develop their own view on the application of neurotechnology in the justice and security domain, which is also tailored to Dutch criminal law. This process preferably takes place already while research into, and development of, neurotechnology is conducted, because this offers opportunities to tailor the developed technology to, for example, requirements for reliability and effectiveness and legal safeguards. The development of such view can be supported by the ethical debate about the interface between neurotechnology in the justice and security domain and the topics of privacy, autonomy, physical and mental integrity, and human dignity. In this respect, the researchers have identified three important topics that require further reflection in particular.

First: The minimum requirements for reliability. While neuroscientists often regard a technique as an isolated tool and therefore impose high standards on the required reliability of the results of research, lawyers argue that information obtained with neurotechnology in the administration of justice will often be combined with other means of evidence and that the entirety of evidence will be used to demonstrate a criminal offense 'beyond reasonable doubt'. Because this concerns the answer to a *legal* question, where evidence is assessed in conjunction, it is necessary to develop specific requirements for application within criminal law.

Second: Further reflection on specific legal questions raised by the application of neurotechnology in criminal law. For example, for all applications, the question has arisen under what circumstances neurotechnology may be used against the will of the subject. In the context *of investigation and fact finding* and *risk assessment,* this question arises in the light of the right to remain silent. In context of *neuro-interventions,* it is clear that these may not be enforced and that the convicted person must choose the intervention voluntarily, but the question is to what extent undergoing a neuro intervention under threat of deprivation of liberty can be called voluntary. Further reflection on these and other legal questions is needed. The ethical debate on these topics may be helpful in this regard.

Third: Provision of information to the judge. The researchers argue that it is essential that judges are adequately informed about the effectiveness, reliability and safety of neurotechnologies when they are applied in the practice of criminal justice.

Contents

1 Introduction

(a) Cause

Medical technology with which brain activity can be visualized or with which the brain can be stimulated – also summarized with the term neurotechnology – is receiving a lot of attention. For example, commercial parties are developing brain implants with the aim of enabling consumers to communicate with computers, or even with cars or other people (Corbyn, 2019). However, the feasibility of many of these plans, and the extent to which these solutions can be widely deployed, is as yet unclear. For example, despite promising results (Moses et al., 2021), Facebook has terminated a program researching the use of implanted electrodes to communicate "directly" with computers, allegedly because it did not deliver a product quickly enough (Regalado, 2021). In addition to questions about feasibility, the possible large-scale application of neurotechnology outside the strictly medical domain also raises all kinds of ethical and legal questions.

One area in which neurotechnology is already being used is criminal law. For example, in the notorious criminal case concerning the attempted extortion of the De Mol family, MRI and PET scans were used to determine that the suspect suffered from fronto-temporal dementia (Rechtbank Midden-Nederland 2 July 2015, ECLI:NL:RBMNE: 2015:4866). He was considered severely impaired. However, outside of this type of use, namely as a medical diagnostic tool, neurotechnology is not (yet) applied in criminal justice in the Netherlands. However, scientific research does indicate that neurotechnology could eventually be used more broadly in criminal justice. For example, a recent Rotterdam study shows that the application of *transcranial direct current stimulation* (tDCS) can reduce aggression in certain groups of offenders and thus contribute to a reduction of the risk of recidivism (Sergiou et al., 2020). Because neurotechnology is receiving a lot of attention, but is still in its infancy when it comes to application in criminal law, the WODC came up with the idea of having relevant ethical and legal aspects investigated prior to the further introduction of neurotechnology in criminal law. This report is the result of that.

(b) Research question

The research described in this report was commissioned by the Scientific Research and Documentation Center (WODC) of the Ministry of Justice and Security in the context of technology adaptation ('handling technological developments better') with regard to the application of neurotechnologies in the justice and security domain.

The following research question is central:

'What opportunities and threats can be expected from neurotechnology for the domain of the Ministry of Justice and Security and what impact (legal, ethical and social) can neurotechnology have on policy?'

It is being investigated which possible applications of various neurotechnologies in the criminal justice domain are conceivable in the short and medium term. Secondly, the legal, ethical and social questions raised by the possible application of neurotechnology in criminal law are examined.

(c) Neurotechnology hype

Criminal law usually concerns government actions that citizens are forced to undergo. For example, a suspect has no choice when it comes to using coercive measures and a convicted person must also undergo punishments and measures. Even if it is taken into account that criminal law is concerned with the investigation and punishment of sometimes serious criminal offences, the perception that the government forces a 'look into the brain' of citizens, or even influences the functioning of the brain, can make one shudder . to call to action. A factor that may increase this fear is the recent flood of reports about all kinds of neurotechnological applications. Part of the increasing attention can be explained by actual new developments, for example in the field of sensor technology, and the new opportunities that can be created, such as solving communication problems for people with severe paralysis through brain control of communication aids. However, the way many neurotechnological developments are presented to society, and the implications ascribed to them, both by the media and by some of the research and industry representatives, seems to contribute to a 'neurotechnology hype' . This can create an unrealistic picture in society of the pace at which neurotechnology is developing and of the range of possible applications of neurotechnology. As a result, patients may be mistakenly hoping that a neurotechnological solution for their brain disorder will become available in the short term, and citizens may get the impression that we will soon be able to read each other's minds. A wrong image of neurotechnology can not only arouse fear, but in the long term also lead to disillusionment if developments are slower than expected or applications are more limited. It is therefore important that researchers, the business community and the media contribute to a more realistic debate about the possibilities and impossibilities of neurotechnology.

With this research report, the authors want to paint a realistic picture of the opportunities and risks of using neurotechnology in criminal law. In line with the assignment of the WODC, the possibilities of today, tomorrow (period < 5 years) and the day after tomorrow (period 5-15 years) are examined. It goes without saying that when the time horizon is further into the future, statements become more uncertain.

(d) High-risk criminal law

The possible application of neurotechnology in criminal law coincides with the emergence of what can be termed 'high-risk criminal law'. Especially in the last two decades, criminal law has become increasingly focused on preventing recidivism through risk assessment and behavioral interventions. The sanctions system has been radically expanded in recent years with the aim of preventing recidivism as much as possible. The idea that criminal law primarily serves to retaliate for an injustice committed in the past has been somewhat pushed into the background.

The debate in the criminal justice literature about this broad development has only just begun (Bijlsma, 2021; De Jong, 2021). It can be suspected that the development of high-risk criminal law leads to a tendency to actually use technology that can be used to estimate and manage recidivism risks, in particular AI and neurotechnology. These technologies can lead to specific dilemmas. A much-discussed dilemma in the application of AI for risk assessment is, for example, the danger of discrimination by 'biased' algorithms. This research focuses on the opportunities and risks of neurotechnology.

(e) Demarcation

It was decided to answer the research question on the basis of the three most important application areas of neurotechnology in the justice and security domain, namely 1) *investigation and truth-finding;* 2) *risk assessment;* and 3) *intervention.* Investigation *and truth-finding,* as well as *risk assessment ,* involve extracting information from the brain. In *intervention,* the brain or brain functions are changed.

(i) Investigation and Truth Finding

Investigation and truth-finding includes the investigation of criminal offenses and the gathering of evidence. This may involve techniques that may provide evidence of involvement in a criminal offense (e.g. memory detection; Van Toor, 2017) or that are relevant to other questions that need to be answered in the criminal process, in particular identifying intentions (with to commit a criminal offense) or the assessment of legal capacity and accountability (Meynen, 2020). *Investigation and truth-finding* are highly relevant in the criminal justice and security domains of forensic investigation, prevention, enforcement and investigation, and the administration of justice and law enforcement. However, *investigation and truth-finding* can also be relevant in other areas of justice and security, for example in the context of the implementation of immigration policy and the fight against attacks, extremism and terrorism.

(ii) Risk Assessment

For *risk assessment,* too , the criminal law domains can be considered in the first place. An assessment of the risk of recidivism is necessary, among other things, for decisions about pre-trial detention and the imposition and enforcement of various criminal sanctions (suspended sentence, placement in an institution for systematic offenders, detention and the behavioral or freedom-restricting measure). However, risk assessments at an individual level are also important in other areas of justice and security, such as the implementation of emergency aid and the fight against attacks, extremism and terrorism. Different neurotechnologies may be suitable for risk assessments (e.g. fMRI; Tortora et al., 2020, Aharoni et al., 2014).

(iii) Intervention

Intervention concerns neurotechnologies that can change – and sometimes improve – brain functions. These can be both non-invasive (e.g. *transcranial magnetic stimulation* 'TMS', or tDCS) and invasive techniques (implantable *brain-computer interface* 'BCI', *deep brain stimulation* 'DBS') (Ryberg, 2020, Vincent et al., 2020). In the criminal justice domain, such techniques may in the future contribute to the treatment of detainees or to treatment in the context of a measure that influences behavior or restricts freedom or a conditional sentence. Neuro-interventions can also be relevant for a justice and security domain such as emergency aid.

The present report focuses on criminal justice. Most justice and security domains are related to this and it is especially in this context that neurotechnologies may be applicable and the most important dilemmas arise.

(f) Operationalization

Neurotechnologies are operationalized in this research as *'techniques that contribute to knowledge about the brain and/ or that interact with the brain and/ or the nervous system',* in particular techniques that 1) image or measure brain and/or brain activity, 2) influencing the brain through brain stimulation, or 3) converting brain activity into actions that are fed back to the owner of the brain signals, so-called *brain-computer interfaces* (Ramsey & Millán, 2020). It should be noted that the focus of this report is on sensor technologies (imaging, measurement or stimulation techniques). There are also important developments in the field of artificial intelligence and *machine learning.* Although these developments are important for, for example, the interpretation of brain signals as measured by different types of sensors, the specific treatment of artificial intelligence is not part of the assignment and of this report.

With regard to the estimates of the maturity of a certain technique, i.e. how far the technique is from a practically applicable instrument, we make a classification in accordance with the *technology readiness levels* (TRL) as used in the Horizon 2020 program of the European Union (European Commission, 2014; see also Appendix 2).

Opportunities and risks are operationalized in instrumental, legal, ethical and societal terms. A technique offers an opportunity if it is effective (and to some extent efficient) in achieving one or more of the goals that are central to the three categories, ie: can contribute to 1) investigation and truth-finding ; 2) *risk assessment;* and/or 3) *intervention.*
Risks consist of tensions with legal and ethical standards and possible unintended, negative side effects of applying newly developed knowledge and technologies. In the legal domain one can think of human rights, such as the prohibition of inhuman and degrading treatment (article 3 of the European Convention on Human Rights 'ECHR'; Van Toor, 2017, p. 119-210), the right to a fair trial (article 6 ECHR, in particular the right to remain silent and the nemo-tenetur principle; Van Toor, 2017, p. 369-442) and the right to respect for private life (article 8 ECHR; Van Toor, 2017, p. 211- 368, Ligthart et al., 2020) and national legal frameworks (e.g. the Code of Criminal Procedure). The Constitution contains fundamental rights that may be at stake in the application of neurotechnology in criminal justice, such as the right to the inviolability of the body (Article 11 Gw). However, we do not consider the Constitution in this study, because there is overlap between the rights laid down in the Constitution and the ECHR. Due to the prohibition of review of Article 120 of the Constitution, the Constitution plays a lesser role in criminal law than the ECHR, while the human rights enshrined in the ECHR are subject to extensive jurisprudence from the European Court of Human Rights (ECtHR). This is not to say that the Constitution is irrelevant. Furthermore, current positive law is central. Reference is only made in passing to the ongoing discussion of whether the application of neurotechniques requires new fundamental rights or whether the existing constitutional framework is sufficient (for example, when a fundamental right is interpreted slightly differently) (see extensive Ligthart, 2021b). In the ethical field, this research mainly focuses on bioethical frameworks (Beauchamp & Childress, 2019) and more specifically on principles and values such as autonomy, privacy, physical and mental integrity and human dignity. In the social field, this concerns the (expected) effects of the introduction of any new policy on people's behaviour.

(g) Approach

To answer this research question effectively, three sub-projects were carried out, each of which led to a separate section in this report.

Section **1 (Technology)** maps the different neurotechnologies and their clinical and scientific application areas and describes current and future developments. In this way, a clear picture is obtained of the different types of techniques that can (possibly) be applied in a criminal law context. This is important because the techniques differ greatly. The description of the techniques is also important because it puts wild future scenarios into perspective. In this way, this step contributes to the accuracy of the debate and forms the basis for the second part of the study.

Section 2 (Neurotechnology in **criminal justice: law, ethics and society)** examines the legal, ethical and societal implications and dilemmas of using the neurotechnologies in the justice and security domain, focusing on legal analysis as it within the judicial domain. An attempt is made to provide a global overview of the opportunities and risks of the application of neurotechnology in criminal law. The emphasis is on the question of how the possible use of neurotechnology relates to human rights, because these contain the minimum requirements that this use must meet. For this, it obviously matters how deeply a certain technique physically and mentally intervenes in the life of a (suspicious or convicted) person. On the basis of the current state of the law, clear boundaries can then already be indicated. For example, it is already inconceivable that the government physically enforces the insertion of a brain implant in a criminal context. Relatively unproblematic applications of neurotechniques can also be identified. Finally, it becomes clear that the human rights framework still leaves important questions open. This is understandable, because the legal system has not yet been confronted with the specific dilemmas posed by the application of neurotechnology in law. By identifying these dilemmas, this research contributes to the debate on the opportunities and risks of using neurotechnology in criminal justice. By supplementing the legal analysis with an ethical and sociological one, the 'blind spots' of the constitutional legal framework can be given a possible colour. Particularly in ethics, the debate on neurotechnology in a criminal justice context has progressed.

Section 3 (Synthesis) forms the synthesis of the first two sections, in which the findings regarding the *state of the art* of current and emerging techniques, opportunities and risks are translated into an answer to the research question.

It is important to note that this research is exploratory in nature. It attempts to make an initial, general inventory of central themes and points of attention that can be further explored in follow-up research.

2. Method

The research was carried out by researchers from the UMC Utrecht (UMCU Brain Center) and researchers from the Utrecht University Law Department (UCALL and the Montaigne Center).

(a) Section 1. Technology

The question regarding existing and emerging neurotechnologies, their application areas and relevant developments is discussed in section 1. The research was carried out by the UMCU team and covered three phases.

a) For an initial inventory of neurotechnologies currently in use and neurotechnologies that are at a more experimental stage, the UMCU team drew on its own expertise and recruited ten renowned experts from industry and academia (see Appendix 3a) interviewed about current and emerging techniques and their possible application areas. In order to get a good picture of possible applications in humans, the emphasis in this first inventory was on clinical and cognitive neuroscientific areas. This information is important for an adequate assessment of the possibilities and potential of each of the techniques.

b) The second phase consisted of a literature search, focusing on the techniques identified in the first phase. Both non-invasive and invasive techniques were addressed. For each neurotechnology, a description has been made of the nature of the measurements and the way in which interaction with the brain takes place or could take place. In addition is/are: a. The possible applications of the

techniques in both clinical and cognitive settings

neuroscientific domain mapped;

b. The reported relevance to, and possible applications within, the justice and safety domain summarized;

c. An estimate was made of the *technology readiness level* (TRL) with regard to the most relevant applications of neurotechnology in the justice and security domain; d. An estimate was made

of the possible further developments of the techniques and their impact on the various application options in the short (<5 years) and longer (5-15 years) term. As part of this, a qualitative assessment based on the fundamental properties of the technique has also been worked out (think of things like degree of invasiveness, electrophysiological or vascular basis of the technique, etc.).

e. To include literature for an inventory of neurotechnologies, primary use was made of the search engine PubMed (PubMed, nd), in which the neuroscientific literature is almost completely represented. Keywords were used that relate to the neurotechnologies identified in the first phase. Found literature was filtered by the researchers based on the information in the summaries. Literature outside the theme is excluded. The reference lists of the included literature were searched for any missing literature. Depending on availability, the literature search made use of review and overview articles describing the nature of the technique, its possible applications, or describe the *technology readiness level* (TRL). With regard to the most recent developments, such overviews are absent and a separate assessment has been made for each technique on the basis of the primary research literature.

c) Section 1 of this report (Technology) has been drawn up on the basis of the results of phases a and b.

(b) Section 2. Neurotechnology in criminal justice: law, ethics and society

Section 2 is an inventory of legal, ethical and social implications of the use of neurotechnology in the justice and security domain, with an emphasis on legal analysis.
The social implications are not described separately, but form part of the legal and ethical analyses; after all, the justice and security domain is a social domain.
Obviously, as mentioned above, neurotechnology can have a broad social impact, but this research focuses on the justice and security domain. The research was carried out by the UU team in three, partly parallel, parts: interviews, literature research and an integrative overview of the findings.

a) For an initial inventory of opportunities and risks for the justice and security domain of neurotechnologies that are currently in use and of neurotechnologies that are in a more experimental stage, the UU team has drawn on its own expertise and has conducted four national and international academics with expertise in the field of neurolaw and neuroethics (in practice, these are partly overlapping fields/ expertises, see Appendix 3b) were interviewed about the legal, ethical and social implications of current and emerging techniques and their (possible) areas of application. A summary of the first results of section 1 was provided to these experts prior to the semi-structured interview. For each category, as described in the operationalization of the problem statement *(detection and truth-finding, risk assessment* and *intervention),* the experts were asked for their opinion on legal, ethical and social aspects of the various neurotechnologies for the justice and security domain.

b) The second part consisted of a review of legal and ethical literature. This research is primarily focused on international literature. The debate about neurolaw and neuroethics mainly takes place there. Google Scholar and WorldCat were also used for this. For the legal part, analysis of legal sources was also used: treaties, laws, case law and national literature. These sources are included in the HUDOC database of the European Court of Human Rights, gedet.nl, Rechtspraak.nl and Rechtsorde.nl. Here too, the research is structured according to the categories as described in the operationalization of the problem statement *(detection and truth-finding, risk assessment* and *intervention).* With regard to each category, the use of neurotechnologies has been described in terms of instrumentality and legal, ethical and societal opportunities and risks in the light of the results of the literature search.

c) Based on the results of parts a and b, Section 2 of this report (Neurotechnology in criminal justice: law, ethics and society).

(c) Section 3. Synthesis

In section 3, the problem definition is jointly answered by the UMCU team and UU team: *'What opportunities and threats can be expected from neurotechnology for the domain of the Ministry of Justice and Security and what impact (legal and ethical) can neurotechnology have on policy? ?'* In this section, the results of the first two sections, regarding the opportunities for neurotechnology to contribute to the policy areas of the Ministry of Justice and Security and the severity of the associated legal, ethical and societal risks, were weighed and evaluated. The *technology readiness level* (TRL) is also involved in this consideration. The Synthesis also contains recommendations for further research

included.

After a draft version of the entire research report had been drawn up, it was submitted for proofreading to four experts from the relevant fields (Appendix 3c). The draft research report was adjusted in response to the feedback thus obtained.

Section 1. Technology

3. Interaction and Imaging

This section provides an overview of the current state of the art of various neurotechnologies. Neurotechnologies are defined in this report as techniques that contribute to knowledge about how the brain works and/or that interact with the brain.

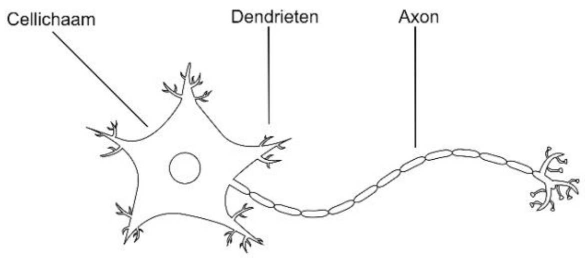


Figure 1 - Sketch of a neuron (source).

The building blocks of our nervous system are called neurons, of which the human brain contains about 86 million (Azevedo et al., 2009). As shown in figure 1, a neuron consists of several parts. The dendrites are the gateways of the neuron, the place where the information enters. The broad end of the neuron is the cell body. In the cell body

the information coming in from the dendrites is collected. From the cell body, the information is then forwarded to other neurons. This is done by means of electrical signals that travel along the axon from the cell body and that are accompanied by magnetic fields. Communication between the ends of axons and the dendrites of other neurons is through chemical messengers (neurotransmitters), such as dopamine or serotonin. In addition to transmitting signals via axons, communication between neurons can also take place via direct electrical connections, in which charged particles can travel from one cell to another via small tubes.

The changes in electrical signals in the brain can be measured with discs or needles made of conductive material, so-called electrodes. Electrodes can be placed in different places on or in the head, such as on the scalp, on the brain surface or in the brain itself.
The spatial resolution (the degree of spatial detail) and the specificity of the measurement (the extent to which it can be deduced from a measurement where exactly a signal comes from in the brain) depend on the placement, size and characteristics of the electrodes. A needle electrode placed in brain tissue can measure the activity of individual neurons, while an electrode placed on the scalp measures the activity of large groups of neurons.

The brain can also be stimulated with electrodes. By running an electrical current between electrodes, nearby neurons can be stimulated to fire and brain activity is either induced or blocked.

Interaction with the brain through electrophysiological signals, or through the magnetic field generated by these signals, is the basis of the first group of neurotechnologies we discuss. These technologies therefore respond directly to brain activity.

Another way of measuring brain activity focuses on the metabolic processes in the brain. Like muscles, neurons use more oxygen and nutrients when they become more active. By measuring changes in the amount of oxygen or glucose in the blood flowing through the brain, neural activity in the brain can be determined. In this way it is possible to measure brain activity from outside the skull (non-invasively). However, because these measurements are a vascular derivative of the neural activity, the interval between an event in the brain and the effects in the metabolic signals is quite long, and rapidly succeeding brain processes cannot be visualized as well.

When one is not interested in brain activity, but in the anatomical structure of the brain, other measurement methods can be used. Create these methods for example, using MRI or CT scans to create images of the brain. Various measures can be derived from these images using various analysis techniques.

The following chapters discuss the most relevant neurotechnologies. For each technique, the way in which the technique interacts with the brain is briefly discussed, followed by the most important scientific and clinical applications of the technique. Special attention has been paid to neurofeedback, the process by which a test subject learns to adjust his own neuronal activity on the basis of direct feedback. Neurofeedback is at the basis of promising innovations such as *brain-computer interfaces* (BCIs), which establish direct connections between the brain and a computer.

First, the neurotechnologies that work on the basis of electrical or magnetic signals are discussed. A distinction is made between techniques that are only suitable for measuring brain activity, techniques that can both measure and stimulate, and techniques that are only suitable for stimulation. Then the technologies that measure the metabolic activity of the brain are discussed. Finally, the technologies that provide insight into the structural anatomy of the brain are discussed. In chapter 5 we then provide an overview of current knowledge about the application of neurotechnology within the three justice and security domains mentioned, namely *investigation and truth-finding, risk assessment* and *intervention.* Chapter 6 describes the expected developments in the short and longer term.

4. Neurotechnologies

(a) Interaction with brain activity

(i) Electrophysiological interaction

Techniques to measure

Electroencephalography

1) Design

When neurons are active, they produce small electrical pulses. When large groups of neurons in the cortex – the outermost layer of the brain – are active at the same time, a potential difference is created that can be detected using electrodes placed on the scalp. The potential changes are measured relative to a reference electrode with a stable potential – often placed on the bone behind the ear (the mastoid). This way of measuring brain signals is called electroencephalography (EEG) (Berger, 1929).

Figure 2 - A subject wearing an EEG cap (source).

Figure 2 shows the setup of an EEG measurement. In such measurements, 2 to as many as 256 electrodes are placed loosely or as part of a hat in contact with the scalp. It is essential that the electrodes make good electrical contact with the scalp. Usually this is achieved by means of conductive gel, but nowadays there are also systems available where this is no longer necessary. The electrodes are connected via wires to an amplifier, which then sends the signals to a computer.

Since an EEG system is relatively cheap and mobile, and can be measured from outside the skull, it is one of the most commonly used ways to measure brain activity. In addition, EEG is one of the neurotechnologies that can measure the direct electrophysiological processes resulting from brain activity, making the time resolution of EEG high (on the order of milliseconds)
(Lopes da Silva, 2013). However, a disadvantage of EEG is that its spatial specificity is low. This means that it is difficult to accurately determine where in the brain an EEG signal comes from. This inaccuracy is related to a fundamental uncertainty in determining the sources of the potential changes, the strong connectivity of cortical regions (Sporns et al., 2007) and the spatial blurring of the signals due to electrically poor conductivity of the scalp and skull. In addition, the EEG signal is sensitive to muscle movements of the face and blinking of the eyes, although these muscle-related artifacts can now be filtered out of the signal quite well during the measurement itself.

2) Applications

Clinical
An important part of the EEG signal is characterized by recognizable rhythmic patterns. For example, deep sleep is characterized by large, slow waves in the EEG signal, while the waves in the awake state are relatively small and follow each other in rapid succession. By looking for deviations from these patterns, EEG can be applied diagnostically. Any deviations in the signal

can be related to neurological abnormalities such as sleep disorders, epilepsy or the presence of a brain tumor (Gazzaniga et al., 2009, p. 148).

Scientific EEG is
used in various scientific research on the healthy and diseased brain, such as in the field of perception, memory, epilepsy, autism or schizophrenia (Lopes da Silva, 2013). In these experiments, test subjects are often exposed to certain stimuli (incentives) or have to perform tasks. Because the amount of noise in the EEG signal is relatively high, the stimuli or commands must be repeated a number of times. Subsequently, an average EEG signal change can be calculated, from which it can be deduced what the actual underlying neural response to the stimulus or command is.

Because EEG systems are relatively mobile, the technique is often used in research into neuroergonomics – the study of the brain's behavior in everyday life. Within neuroergonomics, for example, research is being done into whether workload, fatigue or wandering thoughts can be detected on the basis of brain signals (Borghini et al., 2014). In particular, a change in the slow waves in the brain appears to be predictive of missing certain environmental stimuli (Dockree et al., 2017; O'Connel et al., 2009). It is expected that the products developed from neuro-ergonomics can benefit consumers (Brouwer, 2021), and contribute to sectors such as education, transport or psychiatry (Dehais et al., 2020).

Neurofeedback/
BCI *Brain-computer interfaces* (BCIs) are systems in which brain activity is measured and then translated into a control signal for a computer, such as a mouse click (Wolpaw et al., 2002). The user thus receives direct feedback about the brain signal and can adjust it as he sees fit. A BCI can serve several purposes: a BCI can replace, restore, improve or supplement lost body functionality, or be used as a research tool in healthy subjects or patients (Brunner et al., 2015).

There are different strategies to manage a BCI.

The first strategy is to get a test subject or user to perform a certain action in order to generate a specific pattern of brain activity. An example of this is the movement of the right hand, which produces a consistent activation pattern in the EEG above the left motor cortex. A computer algorithm can be trained to recognize the patterns of brain activity associated with real or imagined movement. For example, BCIs based on performing or imagining movements during EEG are used to help patients with stroke rehabilitation (Abiri et al., 2019).

The second strategy is based on a specific marker in the EEG signal, which can be measured 300 milliseconds after a subject sees or hears something recognizable or abnormal. This is the P300 response. Although the neurological basis of this response is still unclear, its existence has been conclusively established (Linden, 2005). In a classic P300 paradigm, two different tones are presented to the subject. One occurs more often than the other (e.g. 80% vs. 20%), and the subject is instructed to respond to the rare tone (Ritter & Vaughan, 1969). When a rare tone is presented, the P300 can be measured. The P300 response can be applied in BCIs (Brouwer & van Erp, 2010; Farwell & Donchin, 1988; Höhne & Tangermann, 2014; Waal et al., 2012). For example, Farwell & Donchin (1988) presented a 6x6 matrix of letters and numbers, with different columns and rows highlighted alternately. When the column or row that contains the letter that the subject wants to communicate lights up, the P300 can be measured.
In this way, the letter to be communicated can be determined. Because the P300 could be used

to determine the knowledge present in a suspect, the possible role of the P300 in establishing the truth is frequently investigated. Chapter 5 devotes extensive attention to this.

Third, direct reactions to visual stimuli, such as flashes of light, can be seen in the EEG signal. BCIs can also be controlled using these signal changes, for example by recording the EEG signal while a test subject looks at flashing letters on a computer screen. The letter that someone is looking at can be determined based on the changes in the EEG signal as a result of the blinking pattern of the letter (Li et al., 2021).

In the interviews with experts it emerged that EEG, via neurofeedback/BCI, could also be used to support learning processes. The systems for this are relatively simple to use. For example, the company Neurable has incorporated EEG into *noise-cancelling* headphones, and the recorded EEG signal can, according to the company, provide information about achieved focus and work routine (Freight, n.d.). In addition, an expert interviewed mentioned that the EEG signal could show which stimuli you have not consciously perceived, where you should have (such as when developing driving skills, when a cyclist is missed in the side mirror). Understanding EEG brain waves could also help improve other cognitive skills (Gruzelier, 2014; Viviani & Vallesi, 2021). However, whether EEG neurofeedback also provides long-term improvement of cognitive skills outside the laboratory is still unclear. For example, researchers conducted a systematic literature review of the use of EEG neurofeedback in sports (first applied in archery (Landers et al., 1991)). The researchers concluded that consistent improvement of sports performance through EEG neurofeedback has not yet been demonstrated (Mirifar et al., 2017). The use of EEG feedback for stress reduction also appears to be ineffective for the time being (Van Boxtel et al., 2012). The results of EEG feedback in ADHD seem more promising (Krepel et al., 2020).

3) Technical developments

Since EEG systems are nowadays relatively easy to make portable and wireless (e.g. Shambroom et al., 2011), and the use of conductive gels is no longer necessary, user-friendly systems can be made. In addition, EEG is relatively cheap and safe. This has stimulated the development of various applications for home use. Several companies offer EEG systems in combination with special BCI software, focusing specifically on BCI research and implementation *(MindAffect - Home,* n.d.; *OpenBCI - Open Source Biosensing Tools (EEG, EMG, EKG, and More),* n.d. ; 'Products Overview | g.Tec Medical Engineering,' n.d.). In addition, there is a consumer market for all kinds of applications based on the EEG signal, such as within the *gaming* industry (Kerous et al., 2018), for concentration training (Freight, nd) and for meditation *(MuseTM - Meditation Made Easy with the Muse Headband,* n.d.). However, these consumer systems often do not meet the standards set for clinical EEG systems and the quality of the signal is suboptimal in most cases. However, it is expected that high-quality EEG sets will become available on the consumer market in the foreseeable future. EEG is also used in the research field of *neuromarketing,* where it is studied how subjects respond to advertisements or packaging, for example.

For several years now, it has been investigated whether EEG can be used as a source for biometric identification (Chan et al., 2018; Gui et al., 2019). Gui et al. (2019) mention a number of advantages of this, the most important point being that the EEG signal is significantly more difficult to steal than a fingerprint or iris scan. Based on simple properties of the EEG signal, it is possible to identify individuals from a group of about 100 subjects (Demuru & Fraschini, 2020). There are researchers who expect further developments in *hardware,* signal processing and computer algorithms (e.g. based on *machine learning* (eg. Hogendoorn & Burkitt, 2018)) will in the near future lead to the emergence of commercial person recognition systems based on EEG (Chan et al., 2018), for example by quantifying certain aspects of the signal (Wessel & Aron, 2013). However, there are also doubts about the ultimate accuracy and usefulness of such systems. In the interviews, it was mentioned that the EEG signal is subject to change and is influenced by aging (Voytek et al., 2015) or by psychological or physiological pathology.

Magnetoencephalography

1) Design

Magnetoencephalography (MEG) is a measurement method that is basically similar to EEG. When neurons are active, they also produce a small magnetic field along with the electrophysiological signal. The magnetic field created when groups of neurons are active simultaneously can be picked up with a MEG scanner (Cohen, 1968) (Figure 3). Like EEG, MEG is a direct measure of neural activity and has a high temporal resolution. However, with MEG, the sources of activity can be determined in greater detail, since magnetic signals are not disturbed by the intervening brain structures, the skull and scalp (unlike the signals measured by EEG). It is estimated that MEG measures the combined activity of approximately 50,000 brain cells in the cortex, representing a circle approximately one millimeter in diameter (Proudfoot et al., 2014).

Figure 3 - A test subject in an MEG scanner (source).

An MEG measurement is a more complex affair than an EEG measurement. During an MEG measurement, the patient or test subject wears a helmet with sensors. The sensors send signals to superconducting sensors that are mounted in a large tube with a cutout for the head (see Figure 3).
These superconducting sensors are very sensitive. The changes in the magnetic field they can measure are about a million times smaller than the Earth's magnetic field. To achieve such sensitivity, the superconducting sensors must be cooled with liquid helium.
This naturally has consequences for the dimensions of the equipment and for the costs of use and maintenance. In addition, the MEG scanner must be located in a room that is shielded from electromagnetic waves, so that the measured signal is not disturbed by external signals (for example as a result of electrical appliances or moving metal objects, such as cars). The test subject must also keep his or her head as still as possible, since head movements from a size of 5 mm can already strongly disrupt the signal (Gross et al., 2013). Finally, unlike EEG, the sensitivity of MEG depends on the spatial orientation of the tissue where the activity takes place. As a result, the activity that takes place in the convolutions of the brain is more measurable than the activity on the surface of the brain (Gazzaniga et al., 2009, p. 152).

2) Applications

Clinical
In contrast to EEG, MEG is a more suitable method for non-invasively mapping the location of sources of brain activity. The technique is therefore widely used in the preparation of neurosurgical interventions, such as for the localization of the source of epilepsy (Stufflebeam, 2011).

Scientific MEG is
widely used in neurocognitive research, especially when it is important to be able to measure rapid changes in activity throughout the brain (Gross, 2019). For example, it is possible to look at the changing patterns of brain activity while reading text (Schoffelen et al., 2017) or performing other tasks. In addition, MEG is also used

to investigate neurological disorders such as Parkinson's disease (Fernández et al., 2002).

Neurofeedback/
BCI The possibility of using MEG signals for BCI has been investigated in a number of studies (Mellinger et al., 2007; van Gerven et al., 2009), for example in the context of stroke rehabilitation (Buch et al. , 2008). However, due to the practical limitations associated with MEG measurements, the technique is rarely used for neurofeedback/BCI purposes.

3) Technical developments

The development of a new type of sensors, *optically pumped magnometers,* is highly relevant for MEG research (see for example: Boto et al., 2018; Hill et al., 2020; Paek et al., 2020; Pratt et al., 2021) . These sensors do not need to be cooled with liquid helium, which has a number of important practical advantages. Firstly, they make the installation and use of MEG considerably easier and cheaper. In addition, the new sensors do not have to be mounted in a fixed helmet, but can also be attached to a kind of EEG hat. This potentially broadens the applicability of MEG. However, the MEG measurement must still take place in a shielded room.

In addition, steps are also being taken in the development of MEG sensors that can be used to measure in greater detail and deeper into the brain (Barbieri et al., 2016; Caruso et al., 2017). For example, Caruso et al. (2017) showed that needle-shaped MEG sensors can be used to measure individual neurons in the visual brain areas of a cat. In the future, this could lead to wireless, implantable MEG systems (Zaeimbashi et al., 2021).

Electrocorticography

1) Design

Instead of via the scalp, electrophysiological signals from the brain can also be measured with electrodes that are placed directly on the brain surface via a surgical procedure. This method is called electrocorticography (ECoG) (Caton, 1875) (Figure 4). ECoG electrodes are embedded in a layer of silicone and are available as strips of, for example, 4 or 8 electrodes in length, or as mats of various sizes. The typical distance between two electrodes is 1 cm, but since a few years mats are also available where the electrodes are smaller and closer together (high-resolution ECoG, Figure 5; Hiremath et al., 2017). The ECoG signal consists of the summation of the signal from the several hundred thousand neurons immediately below each electrode (Dubey & Ray, 2019; Hermes & Miller, 2020). ECoG provides a direct and detailed measurement of brain activity.

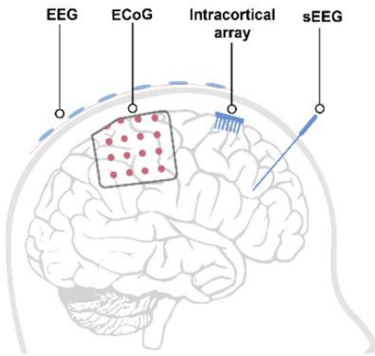


Figure 4 - ECoG compared to other neurotechnologies. SEEG and microelectrode arrays will be discussed later. Thanks to MP Branco.

However, placing the electrodes requires a neurosurgical procedure. Depending on the quantity and dimensions of the strips or mats to be placed, a craniotomy – a hatch in the skull – is performed (for placing mats), or holes are made in the skull (for placing strips).

Because brain surgery is necessary, ECoG electrodes are generally only placed for a direct medical reason, such as for determining the source of epilepsy. In this clinical use of ECoG, the electrodes are wired to a signal amplifier and a computer. For situations outside the hospital, for example for neurofeedback/BCI applications (see below), implantable amplifiers have also been developed that can send the signals wirelessly to outside the body.

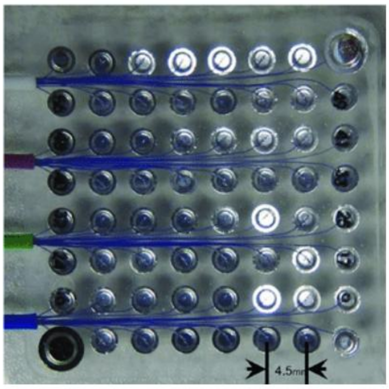


Figure 5 - A high-density ECoG mesh (Hiremath et al., 2017).

2) Applications

Clinical

Clinically, ECoG is mainly used within the framework of the diagnosis of epilepsy. In some patients with epilepsy, medication is not or insufficiently effective. An alternative is to surgically remove the source of the epilepsy in the brain. To determine where this source is located, non-invasive measurements such as EEG are sometimes not sufficient. In that case, an implant with ECoG electrodes can be chosen. The patient with the implanted electrodes then remains hospitalized, with the signals from the ECoG electrodes being measured 24 hours a day, until an epileptic seizure occurs (with a maximum of approximately two weeks), which allows the location of the epileptic source to be determined. become. During this period, the ECoG electrodes are often also used to map brain areas that are essential for language or motor skills, for example. This is done by means of electrical stimulation of the brain via the ECoG electrodes (Lesser et al., 1984). Based on the patient's response during these stimulations, the function of the brain area under the stimulated electrodes can be determined. In this way it can be ensured that no damage is done to brain areas that are essential for language or motor skills during the removal of the source of the epilepsy.

Stimulation with ECoG electrodes also appears to be effective in treating patients with phantom limb pain (the pain people can feel in amputated limbs). ECoG stimulation of the motor areas in the brain can reduce this pain (Tsubokawa et al., 1993).

The company NeuroPace has also developed a clinical treatment for epilepsy based on fully implantable ECoG and deep brain stimulation (DBS, see below) (Morrell, 2011).
When the electrodes measure epileptic activity in the brain, it is possible to stimulate directly at the source of the activity to suppress the epileptic seizure even before it has started. The system is still effective in the group of implanted patients after more than nine years (Nair et al., 2020).

Scientific While
the epilepsy patient with implanted ECoG electrodes is waiting in the hospital for an epileptic seizure, he or she may be asked whether he or she wants to participate in scientific research.
ECoG measurements of brain activity are of great value to neuroscientists and have contributed substantially to the understanding of many cognitive processes such as working memory or language (Jacobs & Kahana, 2010), as well as spontaneous brain activity (Berezutskaya et al., 2020; Canolty et al. al., 2006). However, an important limitation for conducting scientific research in this setting is that the location of the placed electrodes is determined by the clinical question. It is therefore not possible to measure as desired at every point on the cortex. In addition, patients often have underlying conditions, such as epilepsy, which can affect the quality and generalizability of the measured brain signal.

Within the framework of scientific research with ECoG, the brain can also be stimulated. Among other things, this is investigating the possibility of developing a prosthesis for the blind, using stimulation by ECoG electrodes on the visual cortex (Bosking et al., 2017). In addition, a portable system was developed in the past to stimulate the visual brain areas with ECoG electrodes based on images from a video camera. This allowed the patients to distinguish coarse patterns (Dobelle, 2000). However, infections and technical problems occurred relatively often (Rush & Troyk, 2012).

Neurofeedback/
BCI In addition to the clinical application of ECoG for the treatment of epilepsy (see above, NeuroPace), ECoG systems are also used in research into *brain-computer interfaces,* where brain signals are used to control, for example, a robot arm (W. Wang et al. , 2013) or exoskeleton (a system of mechanical support) (Benabid et al., 2019). ECoG systems have now also been developed that can send the measured brain signals wirelessly to a receiver. This means that the measurements can be made without the subject or patient being connected to a computer with a cable and can also take place outside the hospital or laboratory. For example, it is possible for a completely paralyzed amyotrophic lateral sclerosis (ALS) patient to independently and wirelessly control a speech computer with the ECoG brain signal (Vansteensel et al., 2016).

An important goal within BCI's research field is the decoding of speech. By means of analyzing brain signals, such as measured with ECoG, it is determined which words someone pronounces or tries to pronounce. This type of BCI application could enable completely paralyzed people to communicate quickly through brain activity related to speech production. It is remarkable that until recently Facebook supported such research financially. The research group involved recently published a manuscript describing a participant with ALS who was implanted with a *high-density* ECoG mesh. Due to his condition, this patient can no longer pronounce words. The researchers asked the patient to imagine saying fifty commonly used words a number of times. With this data, the researchers trained an algorithm that, based on the brain activity of the patient, could correctly identify which word the patient was trying to communicate in 40% of the cases (the probability level was 2%). In addition, sentences could be formed based on the set of fifty words. Using a language program that assessed which words in the English language would most likely be used one after the other, an accuracy of up to 75% was achieved (Moses et al., 2021). Although this research demonstrates important scientific progress, Facebook hoped to distil a commercial product from this research field in the foreseeable future, but the company recently withdrew from the research because it was unsuccessful (Regalado, 2021).

3) Technical developments

Much work is currently being done to develop smaller ECoG electrodes that can be used for

can be measured over a longer period of time and in greater detail (Shokoueinejad et al., 2019). For example, much ECoG research is performed with *high-density* ECoG, where the distance between electrodes is approximately 4 mm (Hermes & Miller, 2020). Another example is 'NeuroGrid', where the distance between electrodes is only 0.3 millimetres. NeuroGrid not only measures the activity of groups of neurons, but also the signal of individual neurons (Khodagholy et al., 2015). Since the electrodes and signal transmitters are also becoming increasingly safer due to their small dimensions, it has been argued by, among others, some interviewed experts that the risks can theoretically become acceptable for implantation without medical necessity (see also Chang, 2015).

Stereotactic electroencephalography

1) Design

The techniques discussed so far interact with areas on the surface of the brain. To measure the electrical signals that come from deeper brain structures, such as the amygdala or the hippocampus, electrodes can also be placed deeper in the brain tissue. This requires a computer-controlled operation, where electrodes are applied while navigating on the basis of MRI images of the brain and blood vessels (adapted by Gholipour et al., 2020). This method is called stereotactic EEG (sEEG) (Figure 6, adapted from Grande et al., 2020). During implantation, needles with several sEEG electrodes are placed in the brain with an accuracy of about 3 mm. For clinical applications, an average of 5 to 15 needles are placed, each with 8 to 18 electrodes (Herff et al., 2020). The distance between the electrodes on one needle is approximately 1.5 to 3.5 mm (van der Loo et al., 2017).

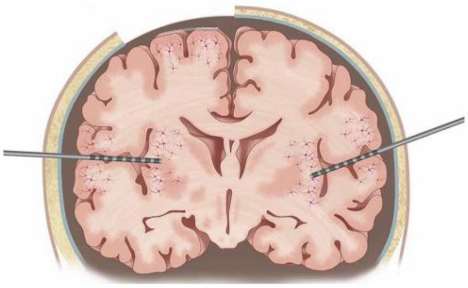


Figure 6 - An illustration of sEEG (adapted from Grande et al., 2020).

2) Applications

Clinical

SEEG, like ECoG, is mainly used for localizing the source of epilepsy.
Depending on the location of the suspected source, sEEG is increasingly chosen. This is especially the case when the epilepsy appears to originate from deeper brain structures (George et al., 2020; Gompel et al., 2021). The insertion of sEEG goes through drill holes (a few mm in diameter) in the skull, which means that the chances of medical complications are smaller than with ECoG, which often requires a larger opening in the skull (Iida & Otsubo, 2017; Youngerman et al. al., 2019). Depending on the region of the brain to be mapped, sEEG is sometimes also used in combination with ECoG. In this way, measurements can be made both on the surface and deep in the brain.

Scientific Due to
an increased clinical use of sEEG, the technique is also increasingly being used for neuroscientific research, which involves both measurement and stimulation (George et al., 2020; Herff et al., 2020). A number of studies have shown that memory can potentially be improved with brain stimulation. For example, it has been demonstrated that stimulation with sEEG can improve spatial memory (Suthana et al., 2012). Hamani et al. (2008) described a study in which a patient's hypothalamus was stimulated intraoperatively. This evoked vivid memories from his childhood and after the operation his autobiographical memory appeared to be significantly better than before the operation (Hamani et al., 2008). Research is currently being done into improving memory in patients with memory impairment after brain damage by measuring and stimulating brain activity in the memory areas of the brain (Hampson et al., 2018; Kahana et al., 2021).
However, according to an interviewed expert, the results of this study are not yet unequivocal.

Neurofeedback/
BCI The use of sEEG for BCI purposes is being actively researched, but so far has no concrete applications (Herff et al., 2020). The procedures of the implantation of sEEG show a lot

similarities to those of implantation of deep brain stimulation electrodes (DBS, see below). The possibility of permanent electrode implants for DBS suggests that this should also be possible for sEEG (e.g. for BCI applications), but concrete evidence of the feasibility is still lacking (Herff et al., 2020).

3) Technical developments

Work is being done to measure more detail with sEEG electrodes. For this purpose, thin wires can be placed at the tip of the sEEG needle that can function as separate electrodes. In this way, both the activity of individual neurons (with the wires) and the activity of groups of neurons can be recorded (with the sEEG electrodes). With this method, for example, the Netherlands Brain Institute is investigating how memories are formed in the hippocampus (Reddy et al., 2020).

Endovascular electroencephalography

1) Design

To minimize the risks of electrode implantation, work has recently been done on the possibility of placing electrodes in the brain in a stent (Oxley et al., 2016). A stent is a type of spring (like in a ballpoint pen) that is placed to keep a blood vessel open. Stents are widely used in the treatment of narrowing of the blood vessels in the heart (Cakulev et al., 2009) and brain (Chimowitz et al., 2011; Puffer et al., 2013). A research group from Australia has developed the 'Stentrode', a stent containing 16 measuring electrodes (Oxley et al., 2016) (Figure 6).

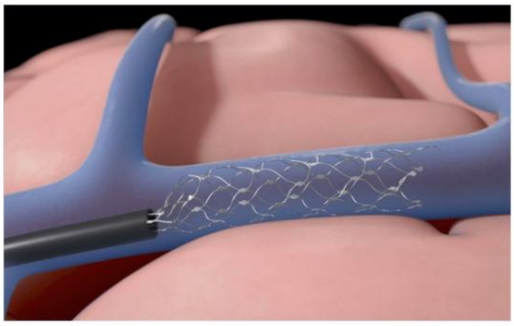


Figure 7 - A model of the Stentrode in a blood vessel above the brain (source).

At implantation, the stent is folded into a tube and inserted through the jugular vein. The tube is then advanced to a blood vessel in the brain, after which the stent is removed from the tube. Via the electrodes on the stent, brain activity can be measured from the inside of the blood vessel and the brain can even be stimulated. Due to its size, the use of the Stentrode is limited to the largest blood vessel surrounding the brain (the superior sagittal sinus).

2) Applications

Clinical
The Stentrode currently has no clinical applications.

Scientific See
neurofeedback/BCI.

Neurofeedback/
BCI The Stentrode was developed for BCI applications and was recently implanted for the first time in two people with ALS (Oxley et al., 2021). The Stentrode was connected to a device under the collarbone. This subcutaneous device then sends the brain signals wirelessly to another device that is placed on the collarbone. The signals are then sent to a computer. The participants were trained to make 'mouse clicks' with the brain signals, or to zoom in on a computer screen, by thinking about the movement of the hand or foot.
They could move the mouse on the computer screen via an *eye tracker,* a device that measures where the user's eyes are focused. For example, the participants in this study were able to control a computer through a combination of eye movements and brain signals.

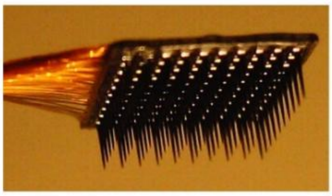
3) Technological developments

In the future, the Stentrode is also intended to be used to stimulate the brain in order to improve the use of BCI systems (Oxley et al., 2016). This seems conceptually feasible, as initial studies have already shown that endovascular stimulation of the brain via the Stentrode is possible and may even offer an alternative to brain stimulation via DBS electrodes (Gerboni et al., 2018; Neudorfer et al., 2020).

Microelectrodes

1) Design

Microelectrode arrays consist of small needles (the microelectrodes) about 1.5 millimeters long (KE Jones et al., 1992) (Figure 8, van Kelly et al., 2007). The most commonly used arrays contain approximately 100 needles. These needles can be placed in the surface of the cortex. With the tip of the needles, brain activity from the cortex can be measured or stimulated. The development of microelectrode arrays has been very important from a scientific point of view, because for the first time it was possible to measure the electrical activity of groups as well as of individual neurons. This allows the functioning of the brain to be studied in particularly high detail. The disadvantage of microelectrodes is that they can only measure a small surface area (the hundred needles are distributed over an area of approximately 18 mm2). That is why it is not possible with conventional microelectrode arrays to study, for example, the communication between brain regions, as is possible with ECoG.



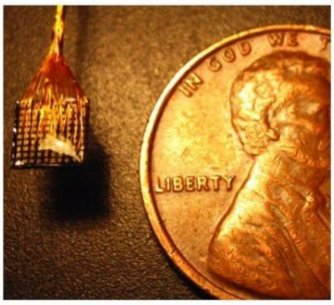


Figure 8 - Top: close-up of a standard electrode array. Bottom: electrode array next to a coin (Kelley et al., 2007).

The microelectrode arrays are placed in the cortex during brain surgery, after which they are connected to a connector that is placed in the skull. So far, wireless mobile systems are not widely available and the connector must be connected to a computer via a cord. An extensive study has shown that in monkeys the electrodes are usually no longer usable after six months (Barrese et al., 2013). In humans, the microelectrode arrays probably last a lot longer. Two research labs with a long-term study of the use of microelectrode arrays in participants with paralysis recently demonstrated that the arrays can still be used after 1500 (Hughes et al., 2021) and 1800 (Colachis et al., 2021) days. However, instability and gradual degradation of microelectrode array signals are also a limitation in humans. Evidence has been found for electrode encapsulation and for deterioration of the electrode material after prolonged implantation (Woeppel et al., 2021 and references therein).

2) Applications

Clinical

Microelectrodes are not yet used in a clinical setting.

Scientific See
neurofeedback/BCI.

Neurofeedback/
BCI The direct and detailed measurements with microelectrode arrays form a particularly suitable basis for making BCIs. The extensive information that can be extracted from the brain in this way makes it possible to generate complex, multidimensional BCI control signals. However, the microelectrode arrays have to be placed in the cortical brain tissue during brain surgery, which is not without risk. That is why these arrays are only placed within the framework of scientific research in patients who are often (largely) partially paralyzed. Participation in research aims to enable patients through the

brain signals to control a BCI and interact with the outside world. For example, researchers have shown that it is possible to have a robot arm perform complex movements using the signal from implanted microelectrodes (Collinger et al., 2013), such as picking up a piece of chocolate and bringing it to the mouth. In addition, microelectrodes have been used in brain-controlled communication, in which patients operate a cursor via brain signals to select letters on a screen (Jarosiewicz et al., 2015). In another recent study, participants were asked to imagine themselves writing letters (Willett et al., 2021). A computer was trained to recognize the patterns in the measured brain signals and to translate them into letters. In this way, a writing speed of up to 90 letters per minute was achieved (for comparison: in a healthy population, typing on a smartphone is 115 characters per minute (Willett et al., 2021)).

Several microelectrode arrays have been placed in a number of patients, so that measurements and stimulation can take place simultaneously (Armenta Salas et al., 2018; Flesher et al., 2016). In this way, for example, a robot arm can be controlled using measurements from the motor cortex, and at the same time the sensory cortex – the brain region responsible for the sense of touch – can be stimulated. By applying these stimulations when the robot arm touches something, the patient is given the feeling that his own hand is actually touching something (Flesher et al., 2016). The control of a robot arm appears to be much more accurate and faster using this artificial sense of touch than without (Flesher et al., 2021).

In addition, experiments are underway in both monkeys and humans on the use of microelectrodes in blindness to restore a rudimentary form of visual perception. A microarray has now been implanted in the visual cortex of a 57-year-old woman (Fernández et al., 2021). She was able to recognize the letters and borders of the objects in her environment, which were presented to her through stimulation from the implanted electrodes. The method has great potential to contribute to the future treatment of blindness.

3) Technical developments

Much research is currently being done into making BCIs based on microelectrodes more user-friendly (ie wireless and thus fully implantable). For example, it has recently been shown that patients can use a wireless microelectrode BCI at home (Simeral et al., 2021; Weiss et al., 2020). It has also been demonstrated that signals from the electrodes can be sent wirelessly outside the body, allowing for more limited clinical supervision (Borton et al., 2013; Simeral et al., 2021; Yin et al., 2013, 2014).

Other developments focus on increasing the number of electrodes. Neuralink, a company of Elon Musk, recently presented a new type of implant with almost 100 thin wires, each containing 32 electrodes, which amounts to a total of approximately 3000 measurement points (Musk & Neuralink, 2019). To increase the accuracy of the placement, a robot is used for the implantation of the individual wires. Neuralink recently demonstrated in a video that a monkey with the implanted BCI system was able to play the game of Pong. However, this level of functionality is not new; such results had already been achieved twenty years earlier by research groups implanting monkeys with standard electrode arrays (Carmena et al., 2003).

Musk aims (among other things) to develop a BCI with which people can communicate with each other based on brain signals, without speaking (Manuel, 2021). This means that inner speech must be able to be decoded and the brain must be stimulated in such a way that the perception is generated as if someone were speaking to you. The possibility of achieving this in the foreseeable future is seen by many as unrealistic (Jackson, 2020). At present, most BCIs work by decoding motor movements, because relatively much is known about the functioning of the motor cortex. Language production and perception in the brain are higher order functions with a more complex representation in the brain. It is still unclear whether decoding language for BCI applications is achievable with the current state of the art.

In addition to Neuralink's work, there are two other noteworthy developments in the field of microelectrodes: neuropixels and neural dust. Neuropixels consists of thin wires with about 1000 measurement locations, which has recently been shown to measure the activity of about 200 individual neurons in the human brain (Paulk et al., 2021). Neural dust consists of very small electrodes that could theoretically be used to measure brain activity wirelessly. The measurements are sent outside the body via ultrasound. The effect of these electrodes has only been demonstrated in the peripheral nervous system of rats (Seo et al., 2016).

A number of clinical studies are already underway in the field of visual prostheses based on microelectrode arrays (Niketeghad & Pouratian, 2019). Recent Dutch research in monkeys has shown the effect of a 1024 electrode array as part of a visual prosthesis (Chen et al., 2020). Due to its size, this array could also cover a large part of the visual cortex in humans, greatly improving the functionality of visual prostheses.

Transcranial electrical stimulation

1) Design

There are several forms of transcranial electrical stimulation, or methods of electrically stimulating the brain from the surface of the head. *transcranial directly*

current stimulation (tDCS) is the most commonly used form of this non-invasive electrical stimulation of the brain. This is done via two electrodes that are applied to a sponge on the scalp. These electrodes are connected to a stimulator, which sends a weak electrical current between the electrodes for a longer period of time (eg 1 mA, for 20 minutes). This current changes the electrophysiological balance of neurons, which makes them easier or more difficult to activate, which influences the activity of the neurons.
brain is affected.

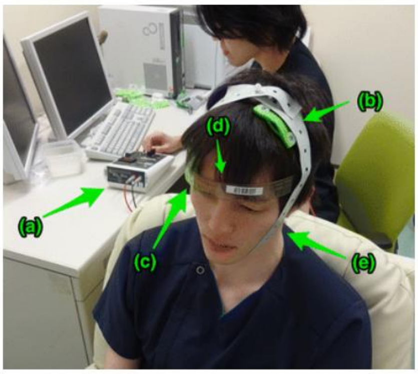


Figure 9 - The setup of tDCS; a) show the stimulator, b) and c) the electrodes and d) and e) a headband and rubber band (source).

When applied by experts, tDCS is a safe technique for both children
and adults (Bikson et al., 2016; Buchanan et al., 2021). Possible side effects are limited to things like itching of the head. In addition, compared to other non-invasive stimulation techniques, it is relatively cheap and easy to use. A major disadvantage, however, is the fact that some local stimulation is not possible. Even when relatively small electrodes are used and the distance between the electrodes is small, model calculations show that about 10 cm2 of cortex is reached with 50% of the maximum stimulation force (Faria et al., 2011).
Because tDCS does not directly trigger neural activity, but affects electrophysiological balance, the effects are believed to take several minutes to become noticeable, and the effects may persist for up to several hours (Reinhart & Woodman, 2015).

As the name suggests, tDCS operates with direct current. However, there are also alternative systems that use alternating current *(transcranial alternating current stimulation)* or noise *(transcranial random noise current stimulation)* for stimulation (Paulus, 2011). Electroconvulsive therapy (ECT) is another form of non-invasive electrical stimulation. A kind of epileptic seizure is induced by means of strong, short-term electrical stimulation (of 500-800 mA (Kropotov, 2016)).
This technique can be applied to psychiatric patients, especially severe depression or schizophrenia, when other forms of therapy have failed or no longer work. In the Netherlands, ECT is a recognized treatment (Dutch Association for Psychiatry, 2010).

2) Applications

Clinical
TDCS is currently not used clinically.

Scientific The
use of tDCS has been documented as far back as 1802. Stimulation would have a positive effect on rehabilitation in patients after a stroke (Hellwag & Jacobi, 1802). Nowadays, much research is being done on the use of tDCS for the treatment of neuropsychiatric

disorders, in particular because of the possible long-term effects. The results of this are often still unclear, although there is now evidence that tDCS has positive effects on patients with unipolar depression (Sudbrack-Oliveira et al., 2021). Also, a number of studies have shown that tDCS enhances concentration and functioning of working memory (Brunoni et al., 2012).

There is a great deal of variation in the methods used in tDCS research. Different research groups use different parameters for stimulation, which makes it difficult to compare research. In addition, due to the lack of clarity about the exact underlying effect of tDCS, there is skepticism regarding the effects found (Horvath et al., 2015; Vöröslakos et al., 2018).

Neurofeedback/
BCI A number of studies have shown that tDCS can be used in combination with an EEG-BCI. This involves stimulating motor areas with tDCS while subjects imagine movements to control a BCI. This appears to increase the accuracy of the BCI (Wei et al., 2013). Using DTI and functional MRI data, it has been demonstrated that tDCS during EEG-BCI has a positive effect on white matter development and cerebral blood flow in stroke patients (Hong et al., 2017).

3) Technical developments

At a technical level, developments are taking place with regard to tDCS, which makes it possible to stimulate more accurately. For example, *high-density* tDCS has been developed by placing compact electrodes (<5 cm2) in a ring-shaped arrangement (Datta et al., 2009). In addition, methods have been developed to precisely model the current flowing through the brain in tDCS (see, for example, Rawji et al., 2018).

An interviewed expert mentioned temporal interference (TI) as an important recently developed technique (see: Grossman et al., 2017) to stimulate the brain in a non-invasive way. Two electric fields are created around the head, each with two electrodes. Both fields fluctuate at a different frequency. An interference pattern is created at the point where the fluctuations intersect. In the brains of mice, it has been shown that the interference can have an effect on brain activity, also in deeper regions of the brain (Grossman et al., 2017).
It is also interesting that the stimulation can be controlled by adjusting the strength of the electric fields – so without moving electrodes. Whether the technique can also be applied in humans is still being investigated (e.g. Rampersad et al., 2019).

Due to its relative simplicity, a tDCS system can also be used outside the lab or hospital by patients or healthy people. For example, it has recently been shown that tDCS can be applied at home by chronically ill patients with the aim of reducing pain and sleeping problems (Riggs et al., 2018). There are also a number of commercial parties that offer systems for non-invasive electrical stimulation. For example, Humm has designed a system based on alternating current stimulation, which promises increased concentration when used (Humm, 2019). However, Humm's study that supports this claim has not been published in a scientific journal, so quality control by experts is lacking. The same goes for Flow, a tDCS headset that could be used to treat depression at home *(Flow TDCS Device - Flow Neuroscience,* nd). Flow also lacks an expert-controlled study. According to an expert interviewed, these developments are not alarming. It can be assumed that the effects of stimulation be limited and short-lived, so it probably won't do any harm. The expert compared the stimulation by tDCS to drinking a cup of coffee.

Transcranial magnetic stimulation

1) Design

Transcranial magnetic stimulation (TMS) is a method of temporarily activating or deactivating specific regions of the cortex from outside the head (Barker et al., 1985). This method uses a coil of wire wrapped in an insulating sheath. Running a current through the coil creates a magnetic field (Figure 10). When the coil is placed on the head, this magnetic field travels through the scalp and skull, inducing a current in the brain that activates the underlying neurons. The technique is non-invasive, safe and has minimal side effects (Rossi et al., 2009).

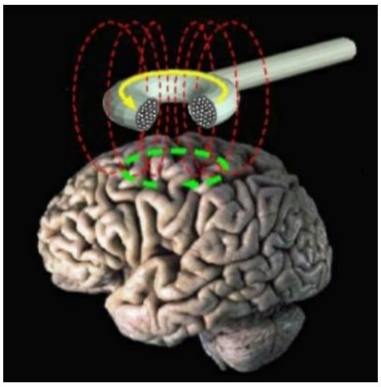


Figure 10 - Model of TMS operation. By sending current through the coil, a magnetic field is created with which the brain can be stimulated (source).

With the current coils, depending on the position of the coil, a volume of about 1-1.5 cm3 can be activated at the surface of the cortex (Gazzaniga et al., 2009, p. 153). Accuracy decreases rapidly in deeper layers of the brain. At a depth of 1.5 cm, the spread of the magnetic field is more than 10 cm2 (Deng et al., 2013). In addition, an expert interviewed noted that the brain mechanisms that TMS and other forms of stimulation act on are not yet well understood, and stimulation does not always result in consistent effects.

For example, depending on the number of TMS pulses given, the reaction time of eye movements can improve or deteriorate (Neggers et al., 2007; Van Ettinger-Veenstra et al., 2009).

To stimulate regions in the brain that are specifically responsible for a certain brain function, the exact location of stimulation can be determined beforehand using PET or fMRI (Hallett, 2007). TMS can also be combined with EEG to find out the changes in cortical potentials as a result of the stimulation (Fernandez et al., 2020; Hallett, 2007).

Most of the knowledge about how TMS works is gained through stimulation of the motor areas in the brain, which results in muscle activity. However, single stimulation in many other parts of the brain has no obvious direct effect, except in the visual areas, where subjects report seeing flashes of light after stimulation (Ridding & Rothwell, 2007). The TMS pulses can also be given in quick succession *(repeated* TMS; rTMS). High frequencies are supposed to excite, while lower frequencies are depressing. The effects of this are often felt up to about 30 to 60 minutes after stimulation, but longer-lasting effects have also been reported (Lefaucheur et al., 2014).

2) Applications

Clinical

RTMS is approved in the United States and several European countries as a treatment for depression (Hardy et al., 2016). The magnetic field during this treatment is as strong as that of a standard MRI scanner (1.5-2 Tesla) (Rossi et al., 2009). RTMS is also offered outside regular care as an additional or alternative treatment for depression and obsessive thoughts *(rTMS Treatment Amsterdam,* n.d.).

Scientific TMS is
widely used for basic brain research (Hallett, 2007). This can be done, for example, by stimulating the motor areas and then measuring the degree of muscle activity as a result of stimulation (via electrodes that are attached to the limbs). For example, it has been demonstrated that TMS elicits more muscle activity when subjects speak words related to movement (Oliveri et al., 2004). This shows that the affected motor areas are easier to activate, and probably involved, in language processing of words related to movement.

Another major theme of TMS brain research is the creation of transient 'virtual lesions' (Pascual-Leone et al., 1999). By briefly stimulating the brain, the normal functioning of a part of the cortex is briefly disrupted. In this way, causal relationships between behavior and brain function can be demonstrated. For example, a single stimulation in the visual cortex around letter presentation may result in a subject not recognizing letters (Corthout et al., 1998).

It is currently being investigated whether rTMS could be used for the treatment of various disorders, such as Parkinson's disease, migraine (Lefaucheur et al., 2014; Ridding & Rothwell, 2007) or for the treatment of autism (Oberman et al., 2016). A study is currently also being conducted into the use of rTMS for obsessive thoughts at the Amsterdam UMC *(Research into OCD - ZonMw Digital Publications,* n.d.). The aim is to stimulate the brains of patients in such a way that they become receptive to behavioral therapy again.

Neurofeedback/
BCI TMS in combination with neurofeedback is a relatively new field of research, in which only a few studies have been performed (Koganemaru et al., 2018; Majid et al., 2015; Mihelj et al., 2021; Ruddy et al., 2018). For example, it has been demonstrated that TMS in combination with neurofeedback enhances muscle activity during imagined finger movements (Mihelj et al., 2021). Moreover, the imagined finger movements could be better deduced from a simultaneously recorded EEG signal. This means that TMS neurofeedback can potentially contribute to rehabilitation and/or BCI research.

3) Technical developments

A relevant development is the use of *deep* TMS with an H-shaped coil. This allows deeper areas in the cortex to be reached. For example, *deep* TMS can stimulate areas that have been shown to be involved in depression, but cannot be reached with conventional rTMS (Levkovitz et al., 2015). Furthermore, a recent literature review shows that *deep* TMS also shows promising results in studies of patients with obsessive thoughts – although more extensive studies are needed to consolidate the effects.

Importantly, custom TMS equipment is currently being developed to allow patients to use TMS at home. For example, patients with acute migraine can use *single pulse* TMS when the migraine flares up (Bhola et al., 2015). rTMS also appears to be safe and long-term (twice a day for six months) to be performed by patients at home without direct medical supervision, according to a study on the effects of rTMS on cognitive properties in patients with Alzheimer's disease (Mimenza-Alvarado et al., 2021).

Transcranial focused ultrasound stimulation

1) Design

Transcranial focused ultrasound stimulation (TFUS) is a relatively new technique that can be used to stimulate the brain in a non-invasive way (Fry et al., 1958; Tufail et al., 2010). This is done by sending a sound wave with a very high frequency (inaudible to humans) (figure 10, van Yu et al., 2021). Depending on the stimulation parameters, TFUS interacts with biological tissue in different ways (Rabut et al., 2020). With specific settings, TFUS can activate or inhibit neurons. In humans, the area of the stimulated brain area is usually a few square millimeters in size (Ghanouni et al., 2015). Stimulation with TFUS is thus much more localized than other non-invasive stimulation techniques. Moreover, with TUS it is also possible to reach deeper brain regions (see, for example, a recent study in macaque monkeys on targeted stimulation of the amygdala (Folloni et al., 2019)).

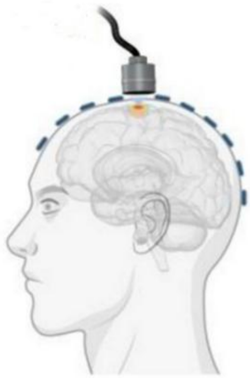


Figure 11 – A drawing of transcranial ultrasound stimulation (Yu et al., 2021).

Much is still unknown about the optimal use of TFUS in humans (Fomenko et al., 2018; Rabut et al., 2020). In humans, for example, it is still difficult to stimulate equally locally in all test subjects (the thickness of the skull and structure of the cortex can differ considerably between people). In addition, the optimal stimulation parameters and the exact way in which the stimulation interacts with the brain are still unknown (Fomenko et al., 2018; Rabut et al., 2020). There are also potential auditory or sensory side effects from the stimulation. This makes adequate design of scientific studies, with for example a *sham* condition, important (Rabut et al., 2020). It has been shown that TFUS is a safe technique: it does not entail any significant complications (Legon et al., 2020).

2) Applications

Clinical
TFUS is not yet used clinically.

Scientific To date,
TFUS has only been used in a few human studies (Fomenko et al., 2018; Kubanek, 2018), but the use of the technique in humans is on the rise. In a pilot study, improvement in mood and some relief of chronic pain after TFUS stimulation was reported (Hameroff et al., 2013). In addition, targeted stimulation of the thalamus has awakened a patient from a state of very limited consciousness (Monti et al., 2016). Meanwhile, researchers have studied the effects of stimulation on the motor cortex (Legon, Bansal, et al., 2018; Yu et al., 2021), somatosensory cortex (W. Lee, Chung, et al., 2016; Legon et al., 2014), visual cortex (W.
Lee, Kim, et al., 2016) and the thalamus (Legon, Ai, et al., 2018). For example, Lee, Kim, et al. (2016) used fMRI and EEG to demonstrate that TFUS elicits brain activity in the visual cortex and related brain regions. The subjects also reported seeing flashes of light after the ultrasonic stimulation.

Neurofeedback/
BCI TFUS is not yet being investigated in neurofeedback/BCI settings.

3) Technical developments

Clinical studies are currently underway for the use of TFUS in the treatment of epilepsy, Alzheimer's disease, Parkinson's disease and disorders of consciousness (Fomenko et al., 2018). On a scientific level, this non-invasive stimulation could contribute a lot to the knowledge about the function of deeper brain regions in healthy subjects, and about the role of these regions in neurological disorders (Kubanek, 2018).

Deep brain stimulation

1) Design

Deep brain stimulation *(DBS)* involves surgically placing electrodes in one or more deep regions of the brain (Figure 12). For example, for the treatment of Parkinson's disease with DBS, this is often the *subthalamic nucleus.*
In addition, a pacemaker is placed under the skin near the collarbone. This is connected to the electrodes in the brain so that they can deliver a constant and long-lasting electrical signal.
In this way, precise stimulation (with precision in the order of millimeters) is possible, with the intention of changing the activity in the stimulated brain region and connected network, so that the desired treatment effects occur.

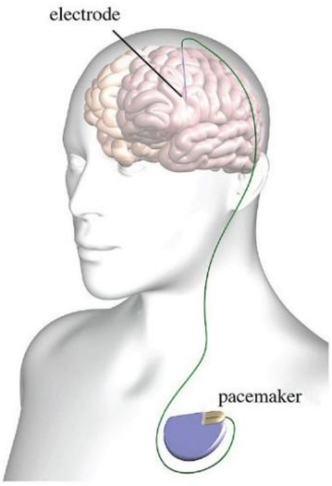


Figure 12 - The design of deep brain stimulation (source).

DBS is a relatively safe method (Lozano et al., 2019), but brain surgery for implantation obviously involves risks. After surgery, stimulation settings can be adjusted to optimize treatment effects. However, adjusting the settings can be a time consuming process of *trial and error .* The implantation of a DBS system is also a relatively expensive procedure that requires a team of experts, and patients are bound to an implant for life.

2) Applications

Clinical
DBS is currently mainly used in the treatment of movement disorders, such as Parkinson's disease, tremor and dystonia (Habets et al., 2018; Kogan et al., 2019; Lozano et al., 2019), and in the suppression of epileptic seizures with NeuroPace's previously described systems, where ECoG measurements drive brain stimulation with DBS (Morrell, 2011; Nair et al., 2020).

Scientific DBS is
used to better understand the neurological disorders treated with the technique. This is possible because information about the underlying mechanisms can be derived from the variability in the effectiveness of different types and locations of stimulation (Lozano et al., 2019). Also, the knowledge gained from DBS has contributed to the development of BCIs, especially regarding the practical implications of permanent electrode implants in humans (Benabid et al., 2011).

The exact mode of action of DBS is not yet fully understood (Lozano et al., 2019), but DBS may have clinical applications for a wide range of neurological and psychiatric disorders (Benabid et al., 2011; Harmsen et al., 2020). Research is currently being done into the possibilities of using DBS in the treatment of Alzheimer's disease (Harmsen et al., 2020) and for psychiatric disorders such as depression (Crowell et al., 2019), compulsive disorders (Greenberg et al. , 2006) and Tourette syndrome (Martinez-Ramirez et al., 2018). The use of DBS is also being explored in the context of reducing disruptive behaviour. For example, DBS was applied to four patients with an autism spectrum disorder and life-threatening forms of self-mutilation. Three patients showed long-lasting, substantial relief from symptoms (Park et al., 2017; Stocco & Baizabal-Carvallo, 2014; Sturm et al., 2013). The symptoms of the other patient, after initial improvement, returned to their previous level after six months (Stocco & Baizabal-Carvallo, 2014).

It was mentioned in the interviews that the development of DBS for psychiatric disorders requires a considerable amount of research work. Unlike with movement disorders, the success of the treatment is not directly measurable (such as in the reduction of tremor through DBS application in Parkinson's disease), but changes in symptoms can only take place in the longer term.

An important innovation within DBS is the possibility to adjust the stimulation parameters based on signals measured at the patient, in order to optimize the effects of DBS. This is called *closed-loop* or *adaptive* DBS (aDBS) (Habets et al., 2018). These signals can be based on brain activity, for example as measured with ECoG, but the data from a motion sensor or a mobile application can also serve as an input signal. ADBS is mainly used in Parkinson's disease, tremor and epilepsy (Krauss et al., 2021; Morrell, 2011).

Neurofeedback/
BCI DBS is currently not used in neurofeedback/BCI settings.

3) Technical developments

Researchers indicate that little technological progress has been made in DBS over the past twenty years, but they now foresee a turnaround. Rapid improvements in electrodes and batteries, pacing paradigms and the use of aDBS are expected to improve the safety and effectiveness of DBS (Krauss et al., 2021).

(ii) Metabolic measurement methods

Functional magnetic resonance imaging

1) Design

Functional magnetic resonance imaging (fMRI) is a special form of MRI. Where one with conventional structural MRI is interested in the shape of the brain, the *activity* of the brain can be visualized with fMRI. This activity is inferred from the amount of oxygen in the blood flowing through the brain. This is because the magnetic properties of hemoglobin, the protein that carries oxygen in the blood, change when it binds or releases oxygen. This change in magnetic properties can be measured during an fMRI scan. The more oxygen there is in the blood, the stronger the signal that is measured (Kwong et al., 1992; Ogawa et al., 1992).

Figure 13 - An MRI scanner. It also allows fMRI scans to be performed (source).

With fMRI, brain activity can be mapped in great detail, down to the level of less than a millimeter (e.g. Huber et al., 2020). Another important advantage of fMRI is that it is not limited to measurements on the surface of the brain, but that measurements can also be made deep in the brain. fMRI research can also be performed with almost any regular MRI scanner. Since these are present as standard in modern hospitals, the use of fMRI as a research method is relatively accessible.

A major disadvantage of fMRI is that the signals that are measured are linked to vascular changes and the resulting changes in oxygen supply. This is delayed by a few seconds compared to the increase in brain activity. It is therefore difficult to use fMRI to determine with any accuracy when certain brain activity took place. In addition, MRI scanners are noisy and subjects must also be able to lie still for a long time, which is not experienced as pleasant by most people. FMRI research with, for example, young children or people with claustrophobia is therefore difficult.

The consistency of fMRI measurements also emerged in the interviews. This is because the reproducibility of fMRI measurements is limited. This means that repeating an fMRI scan, with an identical experiment and the same subject, does not necessarily yield identical readings. The extent to which this affects the applicability of the measurements is an important scientific point of discussion (Compère et al., 2021; Elliott et al., 2020; Kragel et al., 2020). In addition, the conclusions drawn by different research teams based on the same data can also differ considerably (Botvinik-Nezer et al., 2020). To optimize the reproducibility of fMRI scans, much attention is currently being paid to establishing *best practices* in conducting fMRI research (Nichols et al., 2017; Poldrack et al., 2017).

2) Applications

Clinical
Clinically, fMRI is often used in preparation for neurosurgical procedures, to map areas that the neurosurgeon does not want to damage when removing a tumor or an epileptic source. These include the brain regions involved in language (e.g. Jansma et al., 2015) or motor skills (e.g. Krainik et al., 2001).

Scientific FMRI
is one of the most widely used methods to map brain activity in humans (Smith, 2012), as it is a non-invasive technique and activity in the entire brain can be imaged simultaneously in quite great detail. For example, it is possible to study in detail which brain regions are involved in emotions (e.g. Sladky et al., 2013), motor control (e.g. Vink et al., 2005) or vision (e.g. Schellekens et al., 2016). In patients, for example, it can be investigated how the activity of the motor brain areas changes during multiple sclerosis (MS) (Pantano et al., 2005).

In addition, there are indications that fMRI can also be used to determine whether someone is conscious. A 2010 study showed that it is possible to use fMRI to conduct yes/no communication with someone whose consciousness was difficult to determine by other means. This was done by asking this person to think about certain activities (playing tennis, or navigating through a city) (Monti et al., 2010). Researchers have also succeeded in predicting, with an accuracy above chance, seven seconds in advance whether a subject was going to press a certain button, before the subject reportedly became aware of his intention (Soon et al., 2008) . The exact significance of this finding is still under discussion (Mele, 2020).

Neurofeedback/
BCI Despite the intrinsic slowness in the fMRI signal, fMRI is also used in neurofeedback paradigms. During an fMRI scan, people are shown a representation of their activity in a brain region, on the basis of which they can try to consciously change this signal (Weiskopf et al., 2003). For example, on the basis of timing and different types of brain activity (e.g. calculating, or representing movement), test subjects succeeded in calling up 27 different recognizable patterns and thus spelling words letter by letter using fMRI activity (Sorger et al., 2012). In addition, it has been suggested that, via fMRI neurofeedback, certain connections between brain regions can be strengthened. In an extensive literature review, researchers describe that neurofeedback based on fMRI (and also EEG) has a positive effect in patients with various psychiatric disorders (Trambaiolli et al., 2021). The interviews mentioned a study in which patients with depression learned, based on fMRI neurofeedback, to activate either brain regions associated with emotions or brain regions associated with the visual system. It was expected that the patients who learned to influence the emotional regions of the brain would show greater relief from symptoms. However, there was no significant difference between the two groups, and overall the measure of the severity of depression decreased by 43%. The authors suggest that neurofeedback already has a positive effect on the patient through the feeling of control over the disease (Mehler et al., 2018).

In addition to these direct neurofeedback/BCI applications, fMRI is also used to examine the detailed representation of certain brain functions to determine whether they are appropriate could be for BCI with implanted electrodes. fMRI is also used to determine the ideal site for implanted BCI electrodes prior to surgery.

3) Technical developments

Much work is being done to improve ways to measure and analyze high-resolution fMRI data (Viessmann & Polimeni, 2021). Usually fMRI images are made with a field strength of 3 Tesla, but scanners with a field strength of 7 Tesla are increasingly being used, which can be used to measure the brain in greater detail. This has demonstrated, for example, that it is possible to use fMRI images of the visual brain regions to determine which of four letters (an 'H', 'T', 'S' or 'C') (Senden et al., 2019), or three symbols (a '+', 'x' or 'o') (Van den Boom et al., 2019) subjects imagined.

Furthermore, developments are underway in the field of *resting-state* fMRI. Resting *-state* fMRI measures changes in the fMRI signal while a person lies in the scanner without any stimuli being presented or a task having to be performed. The measured signals can thus be used to map the functional connections in the brain, which increases insight into how the brain works. In addition, there is evidence that individuals can be identified based on the patterns of these compounds (Finn et al., 2015).

Functional near-infrared spectroscopy

1) Design

Figure 14 - A child wearing an fNIRS cap (Lloyd-Fox et al., 2017)

Functional near infrared spectroscopy (fNIRS), like fMRI, infers neural activity from the oxygen content of the blood, but does so with near-infrared light (Gratton & Fabiani, 1998). Oxygenated blood absorbs the near-infrared light in a different way than deoxygenated blood. FNIRS is measured by placing a cap with optodes (light sources and detectors) on the head (Figure 14, from Lloyd-Fox et al., 2017). Depending on the importance of, among other things, the portability of the system, the number of optodes is adjusted (see, for example, figures 14 and 15). So FNIRS is relatively portable, relatively insensitive to head movement, and a lot less expensive and easier to use than fMRI. However, an important disadvantage of fNIRS is that the measurements are less detailed, because the optodes measure the signal from an area of approximately 2-3 cm2 (Pinti et al., 2020). In addition, measurements can only be made on the surface of the brain.

2) Applications

Clinical
FNIRS is not currently used clinically.

Scientific FNIRS
is mainly used in research into the functioning of brain areas in populations where other techniques are more difficult to use, such as small children. As a result, fNIRS has become a very important technique in brain development research (Lloyd-Fox et al., 2010; Vanderwert & Nelson, 2014) and in psychiatric research (Ehlis et al., 2014). The relative portability of the system also allows for use outside the lab, for example to investigate walking behavior in patients with Parkinson's disease (Maidan et al., 2016) or with cerebral palsy (Kurz et al., 2014).

A special form of fNIRS is also sporadically used during brain surgery for measurements directly from the surface of the brain, i.e. without the signal being disrupted by the skull (Mitra et al., 1997; Noordmans et al., 2018; Obrig et al. , 2000; Rayshubskiy et al., 2014).
This produces an accurate signal that can be used for neuroscientific research.

Neurofeedback/
BCI Neurofeedback based on fNIRS is a relatively new development, but the first *proof-of-concept* studies indicate that this is possible (Kohl et al., 2020). In the long run, fNIRS could be a practical alternative to EEG or fMRI in clinical applications of neurofeedback (Kohl et al., 2020).

3) Technical developments

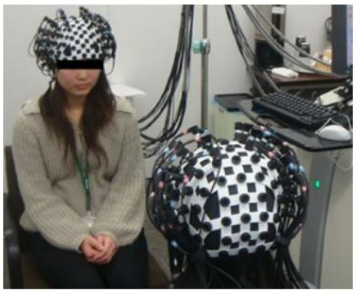


Figure 15 - Hyperscanning with fNIRS (Osaka et al., 2015).

There is currently a lot of attention for lightweight fNIRS systems (Pinti et al., 2020). For example, the company Kernel recently launched a lightweight system for BCI based on fNIRS *(Kernel,* 2021). Until recently, Facebook also sponsored research at Johns Hopkins University that aimed to measure the fNIRS signal quickly and accurately enough to control a computer.
However, this project was not successful (Regalado, 2021). In addition, recent developments of new configurations of optodes are considered promising (Pinti et al., 2020). This makes it conceptually possible to make 3D measurements and increase the accuracy of the measurement to the level of fMRI (Ferradal et al., 2014). Furthermore, there are developments in combining fNIRS with EEG, in order to obtain more information with fNIRS about the temporal aspects of the activity found (Leamy & Ward, 2010). Experiments are also being carried out with optodes that are sensitive to the blood flow of the scalp, the signal of which can be used to clean up the measurement of blood flow in the brain (Sato et al., 2016).

A final relevant development is hyperscanning with fNIRS (Czeszumski et al., 2020; Pinti et al., 2020). During hyperscanning, the signals of two or more subjects are measured simultaneously (Figure 15, van Osaka et al., 2015). Hyperscanning is also commonly done with EEG and more rarely with MEG or fMRI. The relative freedom of movement of fNIRS subjects makes fNIRS hyperscanning suitable for studying social interactions. For example, brain activity of several subjects can be directly linked to certain social situations, and synchronization of brain activity can be measured, for example, when subjects sing together (Osaka et al., 2015) or when eye contact is made (Hirsch et al., 2017).

Functional Transcranial Doppler Sonography

1) Design

Functional transcranial Doppler sonography (fTCD) is a non-invasive measurement method that uses ultrasound above the thin bone structure between the eye and ear (Figure 15, van Naqvi et al., 2013). By measuring differences in the frequencies between the transmitted and received sound waves, fTCD can infer the rate of blood flow in the brain (Aaslid et al., 1982), in order to monitor the activity of brain regions around the large blood vessels in the brain. monitor. It is a cheap and safe technique that allows continuous measurement and can also be used outside the hospital or lab.

Figure 16 - A drawing of functional transcranial Doppler sonography (Naqvi et al., 2013).

There are three major drawbacks to fTCD (Naqvi et al., 2013; Purkayastha & Sorond, 2013). First, the technique is only sensitive enough to measure the large blood vessels of the brain. Secondly, the quality of the measurement strongly depends on the expertise of the researcher and it requires a lot of training to properly interpret the outcome. Finally, the signal can only be detected above relatively thin bone structures. In about 10 to 20 percent of people, the skull is too thick for a good measurement (Naqvi et al., 2013; Purkayastha & Sorond, 2013).

2) Applications

Clinical and scientific

Because measurements with fTCD do not require the explicit cooperation of a test subject or patient and measurements can easily be carried out over a longer period of time, it is a suitable method, for example, to monitor the cortical blood flow of patients in the intensive care unit (Naqvi et al., 2013). fTCD is also used in the diagnosis and investigation of cerebrovascular disorders (Naqvi et al., 2013; Purkayastha & Sorond, 2013). Examples include the assessment of the risk of stroke in patients with sickle cell anemia (Adams, 2005) and the monitoring of blood flow following intracranial hemorrhages (Rigamonti et al., 2008). FTCD is also sometimes used to determine the dominant brain hemisphere for language processing. This can be of interest for both research and clinical purposes. If an fMRI measurement is not possible or impractical for this purpose, fTCD can be a valuable alternative (Deppe et al., 2000; Somers et al., 2011).

Neurofeedback/

BCI FTCD is currently not used for neurofeedback/BCI applications.

3) Technical developments

Very relevant is the development of *focused ultrasound imaging* (fUSI). This technique, like fTCD, uses ultrasound to create images of the brain and will be discussed in detail in Chapter 6. Another variant of this is photo-acoustics, which stimulates with light and detects the ultrasound (Nasiriavanaki et al., 2013).

Positron emission tomography

1) Design

Figure 17 - A PET scanner (source).

Positron emission tomography (PET) can be used to map the metabolic processes of the brain. To make this possible, a tracer must be placed in the blood (orally or intravenously) that consists of radioactive elements. These elements

decay quickly and therefore disappear quickly from the body. When the element decays, it ejects a positive particle (positron) from the atomic nucleus. This positron will quickly collide with a negative particle (electron), and when this happens two photons are created, which fly off in opposite directions. A PET scanner can detect these photons and determine where the collision occurred. Depending on the chosen tracer, different processes in the brain can be visualized. For example, radioactive oxygen can be used to measure brain activity. Because more oxygen-rich blood goes to active brain areas, the PET scanner will register more photons in areas where there is more neural activity. The scanner measures from different angles, so that a three-dimensional image of the brain can be made. In this way, a PET scan can measure activity in the whole brain, with a resolution of about 5-10 mm3 (Gazzaniga et al., 2009; p. 154).

According to an interviewed expert, the reliability of PET measurements is a major advantage over fMRI. This means that two PET measurements up to a very great height yield the same results. However, PET scanning has a number of practical drawbacks. Apart from the necessary presence of a PET scanner, the radioactive tracer must be manufactured locally in a cyclotron and injected into a test subject before the element decays (for example, the half-life for the widely used isotope 15O is only two minutes) .

2) Applications

Clinical and scientific With
PET scans, depending on the chosen tracer, various physical processes can be mapped. This makes PET important in the diagnosis and investigation of various neurological and/or psychiatric disorders (Meyer et al., 2020; Schain & Kreisl, 2017). For example, PET can show inflammation in the brain, or tumors can be detected by their increased metabolic activity, while early Alzheimer's disease shows a decrease in metabolic activity. According to an expert interviewed, signs of Alzheimer's disease can be demonstrated with PET 20 years before the clinical diagnosis is made.

Mapping the behavior of neurotransmitters in the brain is also an important application of PET. For example, the differences in dynamics of the binding between cocaine and methylphenidate (G. -J. Wang et al., 2019) or the binding of THC in the ventral striatum have been investigated (Bossong et al., 2015).

PET data can also be combined with data from a CT or MRI scan, in order to better localize the PET results and improve diagnostics (Ehman et al., 2017; Pyatigorskaya et al., 2020).

For scientific purposes, where brain activity is measured based on oxygen supply, fMRI is now much more commonly used than PET (Gazzaniga et al., 2009; p. 155), due to the practical drawbacks associated with PET.

Neurofeedback/
BCI PET is currently not used for neurofeedback/BCI applications.

3) Technical developments

T. Jones & Townsend (2017) describe a number of technical innovations that could significantly improve PET scans, such as further development of tracers that can be shared more easily between medical centers, so that not every center needs a cyclotron. In addition, it has recently been shown that minimum time between two PET scans can be reduced from 5-10 seconds to 1-2 seconds (G. Wang, 2019).

Single positron emission computed tomography

1) Design

Like PET, *single positron emission computed tomography* (SPECT) can map the metabolic processes in the brain. SPECT is very similar to PET, but unlike PET, it measures the decay of a tracer element with just one photon. This photon is direct

coming from decay. As a result, the SPECT scan is less detailed than PET, but the measurements can be repeated more quickly. The equipment required for SPECT is also cheaper than for PET and several tracers can be used simultaneously with SPECT (Lu & Yuan, 2015).

Figure 18 - A SPECT scanner (source).

2) Applications

Clinical and scientific Just
like PET, SPECT can be used with specific tracers for scientific research or the clinical diagnosis of neuropsychiatric disorders, such as schizophrenia or Alzheimer's disease. SPECT is considered very accurate in the diagnosis of Parkinson's disease (Buchert et al., 2019). Buchert et al. (2019) therefore propose using SPECT to diagnose Parkinson's disease in cases of doubt, and then using PET to determine the subtype of the disease.

Neurofeedback/
BCI SPECT is currently not used for neurofeedback/BCI applications.

3) Technical developments

There are several developments in the field of SPECT hardware and the algorithms used to reconstruct the images (Cuocolo et al., 2018). For example, Stam et al. (2018) have demonstrated that it is possible to create high-resolution SPECT images in order to better visualize neurobiological markers of Parkinson's disease.

(b) Anatomical structure

Computed tomography

1) Design

A computed tomography (CT) scan is an advanced version of the conventional X-ray scan. The CT scanner consists of two major parts, the radiation source and the radiation receiver, which are directly opposite each other. The radiation source emits X-rays. Depending on the density of the intervening tissue, part of the radiation will be blocked before being detected by the receiver. Because the source of the radiation and the receiver revolve around the patient during a CT scan, it is possible to take measurements from different angles and thus create a three-dimensional reconstruction of the scanned body part. To increase the contrast of the CT scan, a doctor may decide to take a contrast agent orally or intravenously

Figure 19 - A CT scanner (source).

to administer.

A CT scan has an accuracy of about half a millimeter in the three dimensions (Lin & Alessio, 2009). Although this is a relatively high resolution, the anatomical boundaries between brain lobes are difficult to see on a CT scan. Structural MRI (see below) is therefore preferred for more detailed measurements. However, a CT scan is excellent for imaging larger structures and abnormalities in the brain.

2) Applications

Clinical and scientific
Compared to an MRI scan, a CT scan is cheaper, more accessible and faster. CT is therefore frequently used to investigate or diagnose acute neurological damage (Gazzaniga et al., 2009; p. 131), for example after a stroke (Campbell & Khatri, 2020; Krishnan et al., 2017).

Neurofeedback/
BCI CT is currently not used for neurofeedback/BCI applications.

3) Technical developments

Ongoing technical developments enable higher resolution CT scans in a shorter time frame to better visualize structures (Krishnan et al., 2017).

Structural MRI

1) Design

MRI makes use of the magnetic properties of hydrogen atoms, which are abundant in almost all bodily tissue. When a person lies down in the strong magnetic field of an MRI scanner, the hydrogen atoms in the body tissue orient themselves along the magnetic field lines. When a radio pulse is generated by the scanner, the hydrogen atoms are knocked out of their equilibrium position. When they return to their equilibrium position, energy is released, which can be picked up by the MRI scanner. In this way it is possible to create high-resolution (<1 mm) anatomical images of the brain.

2) Applications

Clinical

MRI scans are clinically mainly used to map neurological damage (Gazzaniga et al., 2009; p. 131), such as in cerebral palsy (Bax et al., 2006). By making repeated MRI scans, the effects of a treatment over time can also be visualized. For example, after taking medication for Alzheimer's disease, a reduction in the decrease in brain tissue could be seen.

In addition, an expert mentioned that the clinical use of quantitative measures determined on MRI (see also below) - not only looking at the image of the scan, but also recording the underlying physical measures - for example for the quantification of atrophy or shrinkage of the brain in dementia, is mentioned in clinical guidelines, but has not yet been widely implemented. The experts emphasize that the *hardware,* scan settings and interpretation of the scans can vary between centers and that this complicates the use of quantitative measures in MRI.

Scientific On a scientific level, diagnostic imaging techniques such as structural MRI have made significant progress in understanding various neurological/psychiatric disorders (Zhuo et al., 2019). For example, measures can be found at group level that indicate ADHD (Durston et al., 2004), depression (Koolschijn et al., 2009; Zhuo et al., 2019) and schizophrenia (Haijma et al., 2013). An expert cites as an example that the size of certain brain areas in patients with schizophrenia deviate from the healthy population by 1 to 6%.

It is important that the predictive value of markers must be large enough to make statements about the development of a disease at an individual level. The experts say that the added value of these types of scans, on top of conventional measures (genetic research, neuropsychological tests), is often still limited. To date, therefore, there is only limited translation of these measures to clinical applications.

In this context, the experts say that longitudinal measurements (e.g. every two years) are more reliable and more informative than one measurement, given the enormous variability in the general population. In this context, MRI lends itself well to follow the development of brain dimensions within the individual.

3) Technical developments

An interviewed expert mentioned that structural MRI is making impressive progress in terms of automatic processing of information from different laboratories and that this means that high-quality data can increasingly be shared between medical centers.

Another expert noted that there is a movement in the clinic towards a more quantitative interpretation of MRI images. That means that, rather than just interpreting an image qualitatively, doctors try to capture the anatomy or function more quantitatively, increasingly supported by automatic analysis, e.g. with AI. According to the expert, there is also a lot of movement from medical technology companies in this area, which means that the number of *tools* to calculate these types of measures will increase. It can be expected that more multicenter studies will be conducted to show how reliable a marker is. These types of studies should also demonstrate whether the measures are sufficiently robust for differences in hardware and image acquisition protocols used.

An interesting study based on quantitative MRI has shown that brain anatomy can be used to identify individuals from a group of nearly 200 subjects (Valizadeh et al., 2018). The researchers did this with relatively simple classification methods, based on three different structural MRI scans per subject taken over a period of two years. Aloui et al. (2018) also succeeded in using three-dimensional MRI images as biometric identification. In this study, individuals could be identified very accurately from a group of 220 subjects.

Other forms of MRI are also relevant to mention here. *Magnetic resonance spectroscopy* (MRS) is an MRI technique that provides information about the chemical composition of brain tissue (Bottomley et al., 1985). MRS only takes a few minutes to scan and can therefore be used in addition to other MRI measurements (Manias & Peet, 2018). MRS uses the magnetic properties of hydrogen atoms to determine the relative concentrations of various metabolites in the brain. For example, the biochemical composition of healthy brain tissue differs from that of tumor tissue (Peet et al., 2008). MRS can contribute to the clinical diagnosis of various neurological disorders, but the added value of MRS in relation to other techniques and the possibilities for standard clinical implementation of MRS are still being investigated (Manias & Peet, 2018). In addition, three-dimensional *amplified* MRI has recently been developed (Abderezaei et al., 2021; Terem et al., 2021), with which three-dimensional images of the brain can be made and the pulsation of the brain with the beats of the heart can also be clearly seen . In this way, neurological disorders that influence the biomechanics of the brain can be looked at in a new way.

Diffusion tensor imaging

1) Design

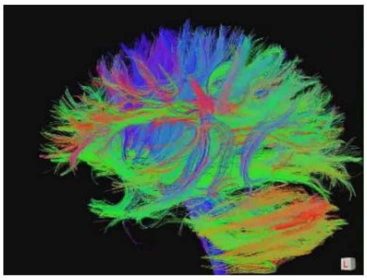


Figure 20 - Example of a DTI scan (source).

In addition to the anatomical structure of the brain, MRI scanners can also be used to map the white matter pathways in the brain. The method used is *diffusion tensor imaging* (DTI) (Le Bihan et al., 1986). DTI is based on the movement of water molecules, which move randomly back and forth through diffusion. In the white matter of the brain, however, diffusion perpendicular to the direction of travel of the white matter tracts is limited. By measuring the variations in diffusion along different directions, it is possible to determine the direction of the white matter pathways (Moseley et al., 1990). By measuring this throughout the brain, it is eventually possible to reconstruct the white matter pathways (DaSilva et al., 2003) (Figure 20). On average, DTI measures with an accuracy of about 1 to 3 mm (Mori & Zhang, 2006).

However, there are a number of limitations to DTI measurements (Mori & Zhang, 2006). First, it can be deduced from the direction of movement of water molecules that an axon is present, but not in which direction the signals run through the axon. Second, it is more difficult to accurately reconstruct intersecting neural pathways and requires long-term measurements. Finally, the technique is sensitive to head movements and requires extensive signal processing to correct for this.

2) Applications

Clinical and scientific DTI
is mainly used as a research method, but is occasionally used clinically as well.
For example, the technique can image the damage to the white matter as a result of neurological disorders and the response to treatment (Tae et al., 2018). DTI is therefore a relevant technique in various neurological disorders, such as MS, epilepsy, Alzheimer's disease and strokes. DTI is also used to determine how brain regions are connected. This is, for example, highly relevant in research into brain development (Mukherjee et al., 2002). Measurements that show how brain regions are interconnected via white matter tracts can be used in scientific research into neurological disorders, such as depression (Liao et al., 2013).

3) Technical developments

Tae et al. (2018) describe a number of technical improvements of DTI, such as faster scans (which will lead to lower sensitivity to head movements), higher accuracy and standardization of measurement settings. According to the researchers, these improvements will increase the use of DTI in clinical research.

(c) **Summary table**

Technology	Type of information	Advantages	Cons
Interaction with brain activity			
	Electrical interaction		
		To measure	
EEG	*Electrical activity of groups of neurons in the cortex*	*Non-invasive *High time resolution * Cheap *Portable systems available	* Low spatial resolution * Not spatially specific * Area measurements only * Sensitive to movement and muscle activity
MEG	*Magnetic activity of groups of neurons in the cortex*	* Non-invasive * High time resolution * High spatial resolution	* Duration * Not portable * Area measurements only
		Measure and stimulate	
ECoG	*Electrical activity of groups of neurons in the cortex*	* High time resolution * High spatial resolution possible * Spatially specific * Fully implantable systems available	* Brain surgery necessary * Only area measurements
Stereotactic EEG	*Electrical activity of groups neurons*	* Little invasive * High time resolution * High spatial resolution possible * Spatially specific * Measurements from the whole brain	* Brain surgery necessary * Limited spatial range
Endovascular EEG	*Electrical activity of groups of neurons around a large blood vessel*	* Little invasive * High time resolution * High spatial resolution * Fully implantable systems available	* Limited spatial range
Microelectrodes arrays	*Electrical activity of a single or small number neurons*	* High time resolution * Very high spatial resolution * Spatially very specific	* Brain surgery necessary * Limited spatial range * No fully implantable system (yet) available for the central nervous system

Stimulate			
tDCS	*Changes in the electrical balance, affecting neurons be easier or more difficult to activate*	* Non-invasive * Cheap * Portable * Effects can last for a long time	* Very low spatial resolution (not spatially specific) * Range limited to brain surface
TMS	*Magnetic activation of groups of neurons*	* Non-invasive	* Not portable *Low spatial resolution (not spatially specific) * Range limited to brain surface
TFUS	*Activate from groups of neurons with a sound wave*	* Non-invasive * High spatial resolution * Reaches deep brain structures	* Not portable
DBS	*Electric activation of groups neurons*	* Very high spatial resolution * Chronic implant * Reaches deep brain structures	* Brain surgery necessary * Expensive, drastic surgery
Metabolic measurement methods			
fMRI	*Change of oxygen level in the blood*	* Non-invasive * (Very) high spatial resolution * Reaches deep structures	* Duration * Not portable * Low time resolution
fNIRS	*Change of oxygen level in the blood*	* Non-invasive * Cheap * Portable	* Low time resolution * Low spatial resolution * Area measurements only
fTCD	*Speed of the blood flow in the brain*	* Non-invasive * Cheap * Portable	* Low time resolution * Low spatial resolution * Area measurements only * Not applicable when the skull is relatively thick

CAP	*Change of metabolic and physiological values in the blood*	* Non-invasive * Repeated measures highly comparable	* Duration * Not portable * Low time resolution * Injection of radioactive tracer
SPECT	*Change of metabolic and physiological values in it blood*	* Non-invasive	* Not portable * Low time resolution * Low spatial resolution * Injection of radioactive tracer
Measurements of anatomical structure			
CT	*Three-dimensional reconstruction of X-ray scans*	* Can be performed relatively quickly	* Not portable * Low spatial resolution * X-ray exposure
Structural MRI	*Visualization of various based structures by hydrogen density*	* Very high spatial resolution	* Duration * Not portable * Not applicable to people with certain implants for safety reasons
DTI	*Visualization of white matter pathways based on the motions of hydrogen atoms*	* Very high spatial resolution	* Duration * Not portable

5. Neurotechnology in the domains of justice and security

This chapter discusses the most important applications of neurotechnologies within the three justice and security domains, namely *investigation and truth-finding; risk assessment;* and *intervention.* Based on this information, the *technology readiness level* (TRL) will be determined.
As described in the offer, the TRL will be operationalized as described in the Horizon 2020 program of the European Union. The interpretation of the concepts can be read in table A1 (Appendix 2).

(a) Investigation and Truth Finding

Within the domain of *detection and truth-finding,* the literature study highlighted three applications of neurotechnology most prominently: 1) the use of fMRI to identify deception, 2) the use of the P300 (see above) from the EEG- signal as a means to identify perpetrator knowledge and 3) *neuroimaging* for the diagnosis of neurological disorders. These applications are discussed below.

(i) fMRI for identifying deception

Using brain measurements to identify deception ('neuro-lie detection') is different from conventional lie detection methods that measure blood pressure or heart rate, for example, because brain measurements do not focus on emotion . This can be an advantage: after all, experiencing emotion does not always mean that someone is lying – for example, it can also indicate the fear of not being believed. Brain measures, on the other hand, are supposed to capture the physiological changes during cognitive processes that are associated with a possible lie (Farah et al., 2014).

For the identification of lies, fMRI is the most commonly used research technique, although EEG is also being investigated in this context. Using fMRI, it has been demonstrated in research settings that specific patterns of brain activity can be identified in groups of subjects under experimental conditions that indicate deception (Ganis et al., 2003; Hakun et al., 2008; Kozel et al., 2005; Langleben et al. al., 2002; TMC Lee et al., 2002; Spence et al., 2001).

However, the use of fMRI for lie detection in practice has been strongly criticized by a number of scientists (Editorial, 2008; Farah et al., 2014; Gamer, 2014; Ganis, 2014; Rusconi & Mitchener Nissen, 2013; Simpson, 2008). A first fundamental problem mentioned is that brain measurements – just like conventional lie detection techniques – do not show lies *per se* .
The measured physiological processes in the brain may also be associated with other psychological processes, for example doubt about the answer to be formulated. Farah et al. (2014) describe in an extensive meta-analysis that most studies use a paradigm in which subjects are instructed to lie in specific trials, while in others they are instructed to tell the truth. By contrasting the 'lie' trials with 'true' trials, differences in brain activity can be associated with lying. Farah et al. (2014) observe that the brain regions that are active during the instructed lies are often also the brain regions generally associated with inhibiting a response. The authors describe that on the basis of this paradigm it cannot be determined which psychological processes, other than lying, elicit the same pattern of brain activity. Similar to the emotion measured with

conventional lie detection techniques, the presence of this type of brain activity during an fMRI measurement does not necessarily mean that someone is lying. In addition, the authors write, most studies contain *confounding* factors in the study design that could also explain differences between the conditions, such as differences in the amount of attention or memory a subject devotes to the trials in which he is supposed to lie versus the to speak truth. Indeed, an fMRI study found that simply keeping certain stimuli in mind – without needing to tell the truth or lie – activates the same brain areas commonly associated with lying (Gamer et al., 2012).

Apart from these methodological questions, much remains to be done before fMRI lie detection can be reliably applied outside controlled research settings. A first important point of criticism is that most studies on lie detection with fMRI have been limited to group analyzes (Farah et al., 2014; Gamer, 2014; Ganis, 2014). However, to be truly applicable, the fMRI signal must be reliable and predictive on an individual level – without *confounding* factors in the study design. As far as we know, this has not yet been demonstrated (Farah, 2014; Gamer, 2014; Ganis, 2014). This is also related to the previously discussed intrinsic shortcoming of fMRI: the limitation in consistently replicating previous findings (Ganis, 2014). A third important point of criticism concerns ecological validity (Farah et al., 2014; Gamer, 2014; Ganis, 2014).
This means that a technique can work well in a controlled laboratory setting, but that its effect has not yet been properly validated outside that setting. The context in which a research participant participates in this type of experiment in a laboratory is of course very different from that of a suspect in a criminal case. A related point is that subjects in research settings are most likely to be cooperative when participating in the experiment. A defendant in a lawsuit could, by not cooperating, render the fMRI signal useless for lie detection. The need for cooperating subjects for an adequate fMRI scan was also emphasized by an expert interviewed. Indeed, it appears to be relatively easy to train test subjects against lie detection with fMRI, for example by imperceptibly moving a finger or toe during certain stimuli (Ganis et al., 2011).

A number of companies have stated that fMRI makes it possible to reliably detect lies, for a variety of purposes, such as detecting insurance fraud (Talbot, 2010). There have been two (so far known) attempts to use fMRI scans as evidence in court in the US (Madrigal, 2010c; Murphy, 2009; Talbot, 2010). In both cases this was rejected by the court (Madrigal, 2010a, 2010b; Talbot, 2010).

In summary, the use of fMRI to identify deception has been extensively researched in laboratories, but practical applications are limited and controversial. The fMRI TRL for identifying deception is therefore estimated to be 4 *(Technology validated in lab).*

(ii) EEG-P300 for identifying perpetrator knowledge

The capabilities of EEG-P300 for *detection and truth-finding* has been explored since the 1980s.
This is based on the hypothesis that the subject reacts physically to relevant knowledge that only the perpetrator could have. An abnormality in bodily response, such as heart rate, or the P300 response, could be an indication of involvement in a crime. Deviations could be measured, for example, when a perpetrator sees a photo of the murder weapon between photos of other weapons. In a meta-analysis, the P300 was compared to skin conductance, heart rate and respiration for this purpose (Meijer et al., 2014). The accuracy of P300 was found to be comparable to

skin conductance in a *mock crime* experiment. Importantly, however, it is (also) possible with EEG-P300 to take simple *countermeasures* to negate the accuracy of the measurement (Rosenfeld, 2005; Rosenfeld et al., 2004). These are measures where someone tries to disrupt the measurement. It is therefore important to set up the research in such a way that the subject is forced to pay attention to the stimuli, in order to avoid *countermeasures* (Farwell et al., 2014). In addition, it goes without saying that a sound research design and good stimulus material are necessary for a correct interpretation of the results.

Despite leading research with EEG-P300 in the US and Israel, actual applications of the technique are controversial and limited within the legal process – the technique is not used in practice in either country. Van Toor (2017) describes that truth-finding based on EEG-P300 was applied once in India in a trial – the EEG recording was seen as conclusive evidence and the suspect was convicted of murder. However, this was strongly criticized (Giridharadas, 2008) and was later declared unconstitutional by the Indian Supreme Court. Japan seems to be the only country in the world where (neuro) memory detection is included in criminal procedure (Van Toor, 2017).
Portable polygraph systems are used for this, with which, in addition to autonomous measures (eg electrocardiogram or skin conductance), EEG can also be measured (Osugi, 2011). Some autonomous measures, unlike EEG, can be measured with relatively little noise and outside a controlled laboratory environment. As a result, some believe that such autonomous measures are preferable within criminal investigations (Matsuda et al., 2019).

There is also interest from a commercial angle in the use of EEG-P300 for *investigation and truth-finding.* For example, the company Brainwave Science claims that on the basis of the P300 it could be deduced with 100% accuracy whether a person was involved in a crime *(Brainwave Science - Crime-Fighting Technology for Law Enforcement,* n.d.). However, this claim is controversial and the scientific basis behind the claims of Farwell and Brainwave Science have been widely criticized (Editorial, 2008; Meijer et al., 2013; Rosenfeld, 2005). Evidence was allegedly provided in one US court case using the Brainwave Science system, but this evidence was ultimately disregarded in the judgment (Rosenfeld, 2005).

In summary: The use of EEG-P300 to identify offender knowledge has been extensively researched in laboratories, but practical applications are limited and controversial.
Taken together, the TRL of EEG-P300 within *investigation and truth finding* is estimated at 4 *(Technology validated in lab).*

(iii) Neuroimaging for diagnosis of neurological disorders

As discussed in the previous chapter, *neuroimaging* is frequently used in clinical practice as a tool for diagnosing disorders or diseases. Various neurological or psychiatric disorders are also important within the justice and security domain (particularly with regard to cognition and accountability, such as in dementia). In particular, according to an expert interviewed, PET would be very specific in diagnosing Alzheimer's disease by detecting the presence of certain proteins. Brain scans, when interpreted by experts, can be used in criminal cases to determine disorders or illnesses in suspects.

An earlier inventory by the Scientific Research and Documentation Center (WODC) over the period 2000-2012 found that 'neuro evidence' was used in more than 200 cases (De Kogel & Westgeest, 2015). Information was considered neuroevidence in this study when it referred to information from neurotechnologies (in this study: CT, EEG, MRI or PET scans), neuroendocrinological tests (e.g. hormonal values), neuropsychological tests or made reference to neurobiological predispositions or brain damage. The authors indicated that the legal questions for which neuroevidence was most commonly used concerned accountability, but that neuroevidence was also used, for example, in the context of risk assessment. In 97 cases published on Rechtspraak.nl, direct reference was made to a neurotechnology. De Kogel & Westgeest (2015) cite an example where EEG measurements were presented by the defendant's defense, claiming that the accuser's memory would not be reliable because she would suffer from severe brain damage. Another example of this is the case of the attempted extortion of the De Mol family. For example, it can be read on Rechtspraak.nl (Rechtbank Midden-Nederland 2 July 2015, ECLI:NL:RBMNE:2015:4866):

'Various experts have examined the suspect. Their conclusion is that the suspect suffers from fronto-temporal dementia, type of behavioral variant. According to the experts, this condition meant that the Defendant had hardly any moral awareness of his actions. The suspect was guided by – childlike – sentimentality. He did not foresee the consequences of his actions and lacked empathy for the victims. It is very unlikely that the suspect can fake his brain disorder, as shown by the MRI scan and PET scan shown during the hearing and research by the behavioral experts.'

It is also interesting here that the MRI and PET scan are explicitly mentioned in the context of reliability (namely because of the possibility of faking).

In fact, *neuroimaging* is used in the courtroom in the same way as is customary in clinical practice (as also mentioned above for the various techniques). In other words, it concerns a standard medical application, namely the diagnosis of a neurological disorder, and not a use of the technology that is specific to the context of a criminal case.

In summary: *Neuroimaging* is regularly used in legal practice to diagnose neurological disorders. The TRL of *neuroimaging* for diagnosing neurological disorders is therefore estimated at 9 *(Actual system proven in operational environment).*

(b) Risk assessment

(i) Neurological markers for estimating relapse risk

In *risk assessment,* it is important to note that the current tools cannot provide a completely correct prediction, and that there is considerable room for improvement (Fazel et al., 2012; Meynen, 2020). It is therefore hoped that *neuroimaging* can provide a supplement on this point, improving the quality of recidivism estimation. For example, an expert interviewed suggested that brain scans may contribute to more efficient use of resources if people can be stratified into certain groups – for example, if a higher risk of recidivism has been established (partly) on the basis of brain scans.

However , with regard to *risk assessment,* according to the experts interviewed, hardly any markers in the brain are currently known that are associated with an increased risk of delinquent behaviour. An expert explained that, for example, at group level there are associations between less well-developed brain areas (as measured by MRI) and very seriously deviant social behavior in children and adolescents (Zhang et al., 2019). However, these are weak associations and they cannot account for prediction on an individual level. With regard to predicting delinquent behavior, three studies in particular can be mentioned, namely Aharoni et al. (2013), Zijlmans et al. (2021) and Delfin et al. (2019). The former performed an fMRI experiment in which prisoners (n = 96) had to control their impulse to press a button. The authors found that lower activity in the *anterior cingulate cortex* (ACC) during this experiment was associated with an increased chance that the detainee would be arrested again within four years (Aharoni et al., 2013). The chance that the detainees would be re-arrested was 60% versus 46% for those with relatively low and high ACC activity, respectively. Later, the same research group also included two EEG markers in the analysis in part of the same population. One of these *('error processing')* turned out to have predictive value, the other not (Steele et al., 2015).

Zijlmans et al. (2021) included physiological measures, two EEG markers and fMRI activity in the ACC, in addition to traditional recidivism risk factors, in a model to predict recidivism in delinquent young adults (n = 127). Of the neurobiological measures, one of the EEG markers (also *'error processing')* appeared to be associated with the risk of recidivism. It is also important that the neurobiological values significantly improved the predictive value of the recidivism risk estimate. However, in contrast to Aharoni et al., 2013, fMRI activity in the ACC in this study showed no association with reoffending risk. The authors suggest that this may be due to the different age groups used in the studies (the cohort of Zijlmans et al., 2021, was significantly younger than that of Aharoni et al., 2013), or differences in the methodology used.
In addition, as mentioned earlier, replication of fMRI results is always difficult (Bennett & Miller, 2010). Delfin et al. (2019) used a model with classical risk factors for recidivism in a forensic psychiatric population (n = 44) and later added another neurobiological measure, namely SPECT. The use of the classical factors in combination with SPECT data appeared to improve the model's prediction of the risk of recidivism. For example, the proportion of correct classifications went from 0.64 (without using SPECT data) to 0.82 (using SPECT data) – an increase of 28%. A very interesting study, but still based on group level.

As for the diagnosis of complex psychiatric disorders (Zhuo et al., 2019), a risk assessment based solely on brain scans does not seem feasible, according to interviewees. Brain scans are also influenced by a multitude of factors. In addition, the experts point out that the brain functions as a network – there is not one brain region that is responsible for one type of behavior – and it is not possible to fully map that network (fMRI is too slow for this).

Nevertheless, the techniques referred to under *investigation and truth-finding ,* which are mainly used for relevant medical diagnostics, can also provide valuable information within the domain of *risk assessment .* For example, when prefrontal brain damage is demonstrated, this can be seen as an indication of an increased risk of recidivism – prefrontal brain damage is associated with uninhibited behavior (De Kogel & Westgeest, 2015).

In summary: The use of neurotechnologies for estimating recidivism risk has been studied, but is currently not applied in practice. The TRL of neurotechnologies for estimating recidivism risk is therefore estimated at 4 *(Technology validated in lab).* When brain scans are used in the context of neurological disorders (see above), this may be higher. However, then the neurobiological findings are placed within a broader clinical context, and within that they can contribute to an assessment of the risk - not as a standalone measure of risk.

(c) Intervention

(i) Brain stimulation in forensic psychiatry

As far as is known, there are currently no neurotechnological interventions that are used in forensic psychiatric practice or elsewhere in criminal law. In principle, there appear to be possibilities for brain stimulation within forensic psychiatry, but the results of studies are not yet unequivocal.

The use of invasive brain stimulation within forensic psychiatry has been investigated in a few studies. For example, Torres et al. (2020) applied DBS to seven patients with pathological aggression. The authors reported that within two years the clinical picture of five patients had improved significantly.

Researchers at Erasmus University concluded after a literature review that tDCS can increase the empathic capacity of perpetrators of violent crimes and reduce aggression and/or violent behavior (Sergiou et al., 2020). However, the researchers argue, the effects of tDCS are variable across different stimulation parameters, and more research is needed to consolidate the effects of tDCS. In a later study, the researchers applied *high-density* tDCS (twice twenty minutes a day for five days) to a forensic population, and found no increase in empathy, but a significant reduction in reactive aggression compared to the control group, with a moderate to large effect (Sergiou et al., 2021). Furthermore, stimulation with tDCS in frontal brain regions has also been found to have a variable impact on the production of lies, while the production of true answers remains unchanged. Opposite effects may arise depending on the location and settings of the stimulation (Karim et al., 2010; Mameli et al., 2010; Priori et al., 2008). For example, Priori et al. (2008) reported that reaction time when telling a lie increased after tDCS, while Mameli et al. (2010) saw reaction time decrease.

The use of brain stimulation in forensic psychiatry has received very limited research and is currently not used in practice. The TRL of brain stimulation in forensic psychiatry is therefore estimated at 4 *(Technology validated in lab).*

6. Possible future developments

In this chapter, an assessment is made of the possible further developments of neurotechnologies, where relevant for the justice and security domain. A distinction is made here between developments in the shorter (<5 years) and the longer term (5 to 15 years). Finally, three innovative neurotechnologies (fUSI, two-photon microscopy and optogenetics) will be discussed, which have not yet been applied to human brain research, but which are expected to be relevant for that purpose in the future. Partly because this chapter concerns estimates about the future, about which there are obviously few or no scientific studies available, much use is made of the insights of the experts interviewed.

In general, non-invasive neurotechnologies are developing at a rapid pace. This is evident, for example, from the rapidly increasing range of tDCS and EEG systems for private individuals. A number of experts expect that these privately available EEG sets may function at the clinical standard level within 5 years. In addition, experts expect that EEG could be used in the future to link the brain signal to behavior or to measure changes in the EEG signal over a longer period of time. EEG would then probably not be used so much to enable certain actions (such as controlling a robot arm), but rather to improve, via neurofeedback methods, properties that we already possess, such as concentration. For example, two car manufacturers, Mercedes and Nissan, are currently working on integrating an EEG signal while driving to improve driving experience and performance (Humphries, 2021; The Bitbrain Team, 2018). There are also technological developments for fNIRS and MEG that make it possible to apply the techniques more widely. For example, new types of MEG sensors will probably mean that many research centers for which conventional MEG is currently too expensive will eventually be able to use MEG scans. This is relevant for both scientific and clinical applications where MRI cannot be used and where EEG does not provide sufficient spatial information. The wider availability of non-invasive neurotechnologies likely means that they will increasingly be used for non-medical applications, such as neuromarketing. One of the interviewed researchers expected that problems could arise within 10 to 15 years when data obtained within neuromarketing is misused, for example to personalize advertisements.

Given the complexity of the technology, the development of implantable neurotechnologies is expected to be relatively slower than that of non-invasive techniques. In addition, the time to actual social impact is also influenced by the regulations surrounding implants. However, one expert noted that the advancement of implantable neurotechnology has long been hampered by a lack of substantial investment in the field. That tide now appears to be turning. In this respect, another expert called the development of *neural dust* (wireless, implantable micro-sensors with a size of the order of mm's) relevant. Also, an expert expects that the implantable system from Neuralink (an Elon Musk company) will reach the level of the currently most advanced BCI systems in about five years. Once the Neuralink system has demonstrable relevance and is actually used clinically to solve certain medical problems, it will be able to act as a catalyst for further developments of implantable neurotechnologies.

A number of large commercial parties (such as Google, Facebook and Huawei) have made significant investments in neuroscience research/neurotechnology. This development enables bold long-term projects. In addition, a number of large technology companies (e.g. Google, Microsoft and IBM) are venturing into the use of artificial intelligence in healthcare (Lundervold & Lundervold, 2019). For example, the English company DeepMind is trying to automatically classify tissue from brain tumors based on 700 CT and MRI scans of patients (Baraniuk, 2016). DeepMind, which has previously been criticized for its handling of the medical data of 1.6 million patients from London hospitals (Revell, 2017), is now part of the American Google Health (Vaughan, 2019). X, a sister company of Google, has also set itself the goal of creating its own EEG system and using artificial intelligence to distil clinically relevant information from data sets, such as diagnosing depression (Felten, 2021).

(a) Possible future developments of neurotechnologies within the justice and security domains

(i) Investigation and Truth Finding

FMRI for identifying deception As described in chapter 4, a lot of work is being done on the technical optimization of MRI scanners and the development of *best practices* for analyzing fMRI scans (Smith, 2012). The Netherlands and Europe are also participating in these developments. For example, one of the two working MRI scanners with a field strength of 9 Tesla has recently been installed in Maastricht. Images were also recently made for the first time in Paris with an 11 Tesla scanner (Gaubert, 2021). With these field strengths, it will soon be possible to study the brain in greater detail.

However, the technical developments are unrelated to the methodological problems facing lie detection based on brain signals, in particular based on fMRI. Also, the translation of the use of brain signals for lie detection from a research environment to reliable operation in practice has not (yet) been made. La Tona et al. (2020) show that there are no studies yet that assess the evidential value of fMRI lie detection in practice. The authors state that fMRI lie detection currently lacks the necessary accuracy, specificity and ecological validity to be reliably applied in a forensic setting.

EEG-P300 for identifying perpetrator knowledge
EEG-P300 seems to be a promising technique for determining whether a suspect has perpetrator knowledge. As described in chapter 5, it is very important to set up the research correctly and to create good stimulus material, so that the possibilities for taking *countermeasures* are minimal and the results can be interpreted unequivocally. Furthermore, the results of the research must be presented in a correct manner, taking into account the limitations of the method. Future neurobiological research will focus, among other things, on further studying the P300 response and mapping the various factors that can influence the signal, such as task design, contextual information and individual differences between subjects (Leue & Beauducel, 2019).

Neuroimaging for Diagnosing Neurological Disorders Neuroimaging data is increasingly used in the courtroom. De Kogel & Westgeest (2015) showed that in the period from 2009-2012 there was a tripling of the number of legal questions on Rechtspraak.nl in which neurotechnologies (in this study: CT, EEG, MRI or PET scans) were used , compared to the period 2000-2003 (on average 1 in 1000 in 2000-2003 versus an average of 3 in 1000 in 2009-2012). Between 2000 and 2009, slightly more brain scans appear to have been made in the Pieter Baan Center; these were mainly MRI scans (Harmsel & Molendijk, 2016). At the moment, about one in five people examined at the Pieter Baan Center undergoes a brain scan (Kempes, 2019; Meynen, 2020). The developments described in chapter 4 (technological improvements in neurotechnologies and increased coordination between different medical centers) will probably ensure that this increase continues in the short and long term. It is important to emphasize that relevant diagnoses are currently made on the basis of multiple measures/data, and not on the basis of a brain scan alone.

(ii) Risk Assessment

Neurological markers for estimating relapse risk In order to strengthen the associations between biological measures and clinical pictures, according to interviewed experts, MRI data will increasingly be added to other measures, such as genetic information and cognitive tests. Artificial intelligence can then be used to demonstrate stronger connections between biological information and diseases (Woo et al., 2017). One expert suggested that it is plausible that the diagnosis of psychiatric disorders will increasingly be computer assisted. An important warning from an expert here is that the data used to train the algorithms must be representative of the context in which they are applied - only then can it be estimated how the algorithm will behave. The expert compared this to vaccine development: it is not wise to give a vaccine that has only been tested on adults directly to children.

The neurological markers for estimating recidivism risk will probably gain more predictive value, not only through the combination of different measures, but also through further technological development of neurotechnologies and improved insight into brain processes. Neurotechnologies could therefore play a role in actually estimating the risk of recidivism in about 5-10 years.

(iii) Intervention

Brain stimulation in forensic psychiatry As described in chapters 4 and 5, there is active research into the use of non-invasive (rTMS, tDCS) and invasive (DBS) brain stimulation for psychiatric or forensic purposes. Meta-analyses of the use of brain stimulation in the treatment of addiction (Luigjes et al., 2019), chronic pain (O'Connell et al., 2018) and eating disorders (Duriez et al., 2020) show that the effects are not are unequivocal, and that more randomized clinical trials are needed to establish the effects of stimulation with certainty.

We expect that within 5 years there will be more certainty about the effects of established stimulation techniques (rTMS, tDCS, DBS) for psychiatric and for some forensic applications. The development of TMS and tDCS systems that can be used independently is expected to continue and therefore non-invasive stimulation will more often be performed outside the hospital or laboratory, in principle also in a forensic setting. This means that within 5 years there may probably be the first opportunities to offer rTMS or tDCS as a treatment to a forensic population, for example as a supplement to or replacement of psychotropic drugs.

The technological developments surrounding DBS will ensure that the implantation procedure will carry less risk. Together with the expected consolidation of the understanding of the effects of stimulation, this will probably lead to a longer term (5-15 years) use of DBS in a broader population of patients. An approach of DBS that offers perspective is context-related stimulation of the brain. In recent research, electrodes were implanted at multiple locations in the brain in a patient with depression and it was found that the response to the stimulation depended strongly on the context and state of the patient (Scangos et al., 2021). It was also suggested by the experts that non-invasive stimulation could potentially be used to select patients who might benefit from electrode implantation. This could further improve the use of DBS.

TFUS is still in its infancy, but we expect to spend the next 5 years working on finding the optimal mode of stimulation in human subjects. TFUS is spatially more specific than TMS or tDCS, especially in deeper layers of the brain. In addition, because TFUS is non-invasive, there are significantly fewer risks associated with using TFUS than with DBS. In the longer term, TFUS may therefore be used as a non-invasive alternative to DBS.

(b) The development of new neurotechnologies

In addition to the described techniques, more recently completely new concepts and technologies have seen the light of day. For the sake of completeness, we describe here 'Focused ultrasound imaging' and 'Two-photon microscopy' and 'optogenetics', noting that the relevance of these techniques for criminal law is not yet clear.

(i) Focused ultrasound imaging

A number of experts specifically mention the development of focused ultrasound imaging (fUSI) as highly relevant – it is expected that fUSI can make a significant contribution to neuroscientific research (Bercoff et al., 2011; Macé et al., 2011). As discussed above, measurements with traditional *Doppler imaging* are relatively slow (50 frames per second) and relatively noisy. With fUSI, thousands of shots can be taken per second. In combination with the current increased computing power, it is therefore now possible to visualize the changes in blood flow as a result of neural activity with fUSI (Rabut et al., 2020; Tanter & Fink, 2014). The exact relationship between the fUSI signal and neural activity is under further investigation (Rabut et al., 2020).

It is important to know that the high-frequency fUSI sound waves are damped by bone (Pinton et al., 2012). In humans, fUSI has therefore only been used to monitor brain activity via the fontanelles (the openings between parts of the skull) of newborns (Demene et al., 2017) or via a hatch in the skull during surgery (Imbault et al. , 2017; Soloukey et al., 2019). Also, despite its high accuracy, fUSI is still an indirect measure of neural activity, and its speed of measurement is intrinsically limited by the time it takes for blood flow to respond to an increase or decrease in brain activity.

There is still a lot of room for improvement within fUSI (Rabut et al., 2020). Rabut et al. (2020) mention that a lot of research is being done into three-dimensional imaging of the entire brain, into the use of contrast medium to increase the sensitivity of the measurements and thus enable measurements through the skull and to the development of chronic fUSI-BCIs. Indeed very recently the possibility of using fUSI for BCI has been demonstrated in monkeys, where the measuring devices were screwed onto the head and measurements were obtained through an opening in the skull (Norman et al., 2021). In this movement planning study, it was shown that it was possible to deduce the intention of the movement from the fUSI signal before actually performing it, with more than 85% accuracy.

(ii) Two-photon microscopy and optogenetics

A number of promising techniques are being developed that work on the basis of light. For example, two-photon microscopy uses near-infrared light to produce images of individual neurons in living laboratory animals (Zipfel et al., 2003). It is also possible to genetically modify neurons. In this way, the neuronal activity can be influenced by a beam of light, with a precision of milliseconds. This technique is called optogenetics and is used in live laboratory animals (Adamantidis et al., 2007; Banghart et al., 2004). For example, optogenetics can be applied within a closed system, where the amount of stimulation is automatically adjusted to signals measured from the neuron itself (Grosenick et al., 2015). This could be a particularly relevant way to study causal relationships in neuron function.

Two-photon microscopy has been used to distinguish a sample of human brain tumor tissue from healthy tissue (Poulon et al., 2018). The authors hope that their method can soon also be applied to living people. It has also been demonstrated in a proof-of-concept study that two-photon microscopy can be combined with very high-field fMRI (16.4 Tesla) to produce highly accurate images of the brain of a living mouse (Cui et al . ., 2017).
The authors claim that the system can also be used with other field strengths and could therefore also be used in human research.

Optogenetics has recently been applied for the first time in a human clinical setting. A patient went blind due to a dysfunctional retina (a light-sensitive layer in the back of the eye). Optogenetics has been used to make the cells in the retina sensitive to light again. For example, with the help of special glasses, the patient can regain partial vision (Sahel et al., 2021). In the future, the possibility of very precise stimulation of optogenetics could be used to improve DBS (Delbeke et al., 2017).

7. Decision Section 1

This part of the research focused on the technologies and their specific properties, operation, side effects and (im)possibilities. A broad inventory was made of potentially relevant neurotechniques and then focused on a number of these techniques that are/appear to be most important for criminal law, such as EEG-P300 for detecting deception and fMRI for lie detection. We also looked to the future and made an estimate of future technological developments – with all the considerations that go with it. The reason for doing this was that the assignment of the WODC stems not only from the question of what is possible 'today', but also what – in the light of (supposed) developments in neuroscience – 'tomorrow' and 'the day after tomorrow'. could be possible. After all, the use of neurotechnologies is potentially drastic, so you want to be well prepared in terms of opportunities and risks. Now that this inventory has been made, section 2 will follow on the legal, ethical and social aspects of the use of neurotechnology in the justice and security domain.

This obviously also involves the same technologies as described in section 1, but clearly in less detail. Certainly not all the techniques discussed above will be explicitly discussed in section 2, because section 2 looks more generally at possibilities and risks from normative frameworks. For example, from the point of view of the right to respect for privacy, it does not have to matter much which technique exactly is used to extract information from the brain – it therefore makes no sense to separately consider all (potential) neuroimaging techniques that make this day possible . .
In other words, from now on the normative – legal, ethical and social – frameworks are central.

Section 2. Neurotechnology in criminal justice: law, ethics and society

8. Investigation and Truth Finding

(a) Neurotechnology in criminal investigations

Knowledge about the structures and functioning of the brain has increased considerably in recent decades, partly thanks to technological developments that make it possible to visualize the brain in a living and active state. This development is already, and may be even more important in the future for criminal (procedural) law (De Kogel & Westgeest, 2013; Ligthart et al., 2017; Ligthart et al., 2021). For example, neurotechnologies can be helpful in proving subjective components (District Court Zutphen 9 November 2007, ECLI:NL:RBZUT:2007:BB7529 and District Court 's-Hertogenbosch 5 September 2007, ECLI:NL:RBSHE:2007:BB2861) – these are the elements of a criminal offense that must be proven for a conviction that concern the psyche of the suspect, such as *intentional* act - and in the assessment of the suspect's (un)responsibility (Hof The Hague 22 February 2010, ECLI: NL:GHSGR:2010:BL7187). Research is also being done into neuromemory and neurolie detection with fMRI and EEG (as described in the technical part).

This branch of science is interesting for criminal (procedural) law, including in the investigation phase. In principle, neuromemory and neurolie detection can make an important contribution to establishing the truth. For the purpose of assessing whether a person is guilty, establishing what actually happened is essential. If it were possible to take a 'look' into the memory of the suspect, this would provide very valuable information.
The starting point is that perpetrators have stored offender knowledge in their memory, while innocent persons (in principle) do not have that information. What could be better for finding the truth than directly consulting those memories without the person having to speak? And if the suspect (or witness) does speak, establishing veracity with a neurolie detection can also strengthen the truth-finding.

However, this is not without (legal) struggles (Van Toor, 2017; Ligthart et al., 2021). For example, the suspect must be treated *with dignity* (Article 3 ECHR), he has the right to remain silent and not be forced to cooperate in his own conviction (Article 6 ECHR) and the right to respect for his private life (Article 8 ECHR). . The question is whether, and to what extent, new neurotechnologies can be applied in line with these human rights. For example, an analogy can be drawn with downloading data from a computer versus extracting information from a human brain: are we not 'degrading' being human , in the sense that people must be able to make independent decisions about sharing of personal information? There are similar considerations with regard to the right to remain silent. If the suspect is asked to respond, he can always choose not to say anything. However, the brain cannot stop responding to stimuli at the suspect's desire. In this chapter, these kinds of questions are discussed for the purpose of assessing whether neurotechnologies can be applied in line with the applicable law for the purpose of establishing the *truth.*
The three applications of neurotechnology that follow from the technical part are central to this: 1) the use of fMRI to identify deception, 2) the use of the P300 from the EEG signal as a means to identify perpetrator knowledge and 3) neuroimaging for diagnosing neurological disorders. Each technique or method is not specifically discussed, but they are grouped together because the human rights violations of different techniques or methods are the same.

This chapter is structured as follows. First, the national legal framework1 is briefly discussed . On the basis of the Code of Criminal Procedure (hereinafter: Sv), all procedural acts, including the use of investigative methods, must be carried out on a formal legal basis. Article 1 CCP stipulates that criminal acts only take place in the manner regulated by law. This is called the principle of legality. In addition, investigative methods are tested for their legality: national laws in a formal sense may not be assessed against the Constitution, but in the light of international treaties. For the Netherlands, the European Convention on Human Rights (hereinafter: ECHR) usually fulfills the role of an assessment framework for the lawfulness of all kinds of government acts. That is why, secondly, this chapter takes a detailed look at the three most important human rights for the assessment of investigative methods from the ECHR. Successively come the prohibition of inhuman or degrading treatment; the right to respect for private life and the right to a fair trial. Freedom of thought and conscience (Article 9 ECHR) and freedom of expression (Article 10 ECHR) are discussed in this study in Chapter 10, but are also considered relevant for the standardization of investigative powers in the future (Bublitz, 2014 ; Ligthart, 2021b, 114-196). Ligthart (2021b, p. 134) mainly sees room for Article 10 of the ECHR – despite the fact that there has been little case law on this (p. 146) – because the European Court of Human Rights (ECtHR) usually rules that 'obliging *an individual to disclose simple facts in the context of a criminal procedure do not typically qualify as the disclosure of any 'thoughts' in the meaning of Article 9 ECHR'.* He also notes that, *'regarding defendants in criminal proceedings, it is – to say the least – questionable whether the Court would actually consider complaints about coercive brain-reading under the head of Article 10 ECHR. In its case-law on Article 6 ECHR – concerning the privilege against self-incrimination – the Court has developed a comprehensive approach tailored to coercing defendants to produce information in criminal trials' (Ligthart,* 2021b, p. 147). It is therefore obvious here to consider Article 6 ECHR in detail, and not to discuss Articles 9 and 10 ECHR, the importance of which has not been established under current law.

The paragraphs below on rights from the ECHR are all structured in the same way. First, it is explained what the law means and which criteria are used for testing investigative methods. These criteria are then applied to the three methods described in the technical section, so that it can be concluded whether and to what extent the forced application of neurotechnologies is acceptable under current law2. The focus is on forced application of the method discussed here, because voluntary application of certain methods (in principle) does not constitute a human rights violation if the person has correctly waived his rights.3 The techniques discussed here can of course also be used at the request of be carried out on a suspect, for example to prove his or her innocence (so Van Toor (2017, p. 103) reports that the P300 produces more reliable results when establishing

[1] As explained in the introduction, the fundamental rights from the Constitution are not discussed.
2 For a more conceptual, legal-philosophical review, see Van Toor 2017.
3 The ECtHR also sets requirements for a *waiver* of the exercise of fundamental rights in a criminal procedure (see, inter alia, ECtHR 17 July 2007, 48666/99 *(Kucera* v. *Slovakia),* par. 199, 122; ECtHR 28 July 2009, 47709/ 99, par. *(Rachwalski & Ferenc* v. *Poland),* paras. 432-433). The distance must be *free and informed,* among other things .

of *absence* of offender knowledge compared to the determination of *presence* of offender knowledge).

(b) National legal framework for investigative methods

The Code of Criminal Procedure itself sets some requirements for the implementation of investigative methods. Two of these, which are generally important in the use of investigative methods, are discussed in this section, namely the principle of legality contained in Article 1 DCCP and the duty to report.

According to Article 1 CCP, all criminal proceedings, including the implementation of investigative methods, must be based on and carried out in accordance with a legal provision. This is called the (criminal) legality principle. This leads to two requirements for Dutch criminal procedure, namely (i) a quality requirement and (ii) an implementation requirement.

The first requirement of legality entails an assignment to the legislator. He must create legal provisions that form the basis for the acts of the executive. The more onerous procedure for establishing a law in a formal sense – in which the government and the States General jointly determine the law, instead of, for example, a ministerial regulation made by one or more ministers – ensures a certain quality guarantee. The discussion that takes place during plenary debates on laws should lead to the not frivolous creation of (far-reaching) criminal procedural powers that infringe fundamental rights (Corstens, Borgers & Kooijmans, 2021, p. 23 et seq.). In addition, it is thought that the weighing of interests made by the government and the States General together will most likely not lead to licenses or blank checks. The granting of (unlimited) power entails the danger of gross restriction of freedom of suspects and third parties and possibly also of abuse of power (by arbitrarily handling the power) (Corstens, Borgers & Kooijmans, 2021, p. 23 et seq.). It is therefore important that the formal legislature grants limited powers to the executive, in this case investigative authorities.

The second legality requirement is aimed at the executive. After the legislature has established powers for the executive in laws in a formal sense, the principle of legality requires the executive to exercise its powers in accordance with the law (and the law). Cleiren (1992; 2015) refers to this requirement as *'bound by the law'* . Taken together, this means that investigative methods may only be carried out if there is a legal basis, and the method must be carried out as stipulated in the law (and any implementing decrees).

At present, there is no legal basis for the implementation of fMRI and EEG for neurolie or neuromemory detection, while this is necessary due to the more than limited infringement caused by the use of those methods. If no legal powers exist, then it is necessary for the legislator to close this gap (if there is a more than limited violation of fundamental rights – that is the case with the neurotechnological investigation discussed here – or if there is a danger to the integrity of the investigation) before the executive gets to work with these methods.

(c) Neurotechnological detection and the ECHR

In addition to these first two requirements that follow from national law, the application of neurotechnology must comply with international human rights. In the Dutch legal order, this is often tested against human rights from the ECHR, which is also the case in this study. The first human right in which neurotechnological detection is tested is respect for human dignity and the prohibition of torture and inhuman or degrading treatment.

(i) Neurotechnological research in the light of respect for human dignity and the prohibition of torture and the prohibition of inhuman or degrading treatment

Despite the fact that the notion of human dignity does not explicitly appear in Dutch legislation and the ECHR, it is an important concept worldwide. De Baets states in 2007 (p. 72, 76) that in about 75 percent of the constitutions he examined (N=193) the concept of (human or personal) dignity occurs explicitly. In the following five years, this percentage rose to 84 percent (Shulztiner & Carmi 2014). In addition, it plays a role in the interpretation of fundamental rights in the constitutions and treaties in which it does not appear explicitly.

The Dutch Constitution and the ECHR belong to the (very small) minority of constitutions worldwide and treaties in which human dignity does not explicitly appear. Although the notion of human dignity is absent in the ECHR, human dignity is put forward in the case law of the ECtHR as a *guiding principle* in the interpretation of the protection afforded by human rights (e.g. ECtHR (GK) 10 April 2007, 6339 /05 *(Evans* v. *United Kingdom)* par. 89 and ECtHR 5 July 2011, 41588/05 *(Avram et al.* v. *Moldova* par.

36). This is especially the case with Article 3 ECHR; the prohibition of torture and the prohibition of inhuman and degrading treatment. Degrading treatment is inhumane treatment, because it ignores humanity and treats man as an object. Because human dignity is frequently used as a guiding principle in the interpretation of Article 3 of the ECHR, this chapter deals with both the concept of human dignity and the prohibition of degrading and inhuman treatment together.

Degrading treatment forms the lowest grade of possible violations of Article 3 of the ECHR, and is therefore important as a lower limit for the present study. The question here is when this lower limit has been exceeded – in other words, when there is *humiliation,* or *inhumane* treatment – and then whether the forced application of neurotechnological detection exceeds this limit and can be labeled as humiliating. Below, based on the case law of the ECtHR, a brief explanation is given of the situations in which there is a violation of Article 3 of the ECHR in the area of the prohibition of degrading treatment.

Cases in which the ECtHR uses human dignity as a guiding principle in actions performed during the investigation phase can roughly be divided into three categories: complaints about *detention conditions* (see, among others, ECtHR 22 December 2008, 46468/06 *(Aleksanyan* t. *Russia) ;* ECtHR 24 October 2013, 5288/08 *(Lapsov* v. *Russia);* ECtHR 31 October 2013, 46282/07 *(Grossman* v. *Russia); unnecessary violence* against persons whose freedom is restricted (see, among others, ECtHR 23 July 2013, 6343/11 *(Gorea* v. *Moldova);* ECtHR 3 October 2013, 47137/07) *(Tahirova* v. *Azerbaidjan);* or who have been deprived of their liberty (see, inter alia, ECtHR 3 May 2012, 23880/05

(Salikhov v. *Russia);* ECtHR 18 October 2012, 37679/08 *(Bures* v. *Czech Republic);* ECtHR 25 July 2013, 32133/11 *(Kummer* v. *Czech Republic))* and *other degrading treatment* (for an overview of case law in this area, see ECtHR 7 July 2011, 39229/03 *(Fyodorov & Fyodorova* vs. *Ukraine),* par. 60) . It is mainly the second and third categories that are important for this chapter. The second category is self-explanatory: unnecessary violence against persons in the power of government officials constitutes an infringement of human dignity. The *Kummer* case (ECtHR 3 October 2013, 47137/07) can serve as an example. In it, the (under the influence and aggressive) suspect was handcuffed to an iron ring in the wall and with his other hand to the opposite wall. In addition, his legs were tied with a leather belt. *'The Court considers that such a situation must have aroused in the applicant feelings of fear, anguish and inferiority and was an attack on his dignity' (par.* 69). The ECtHR categorized this treatment as degrading treatment: the complainant was only aggressive towards others and did not appear to be dangerous to himself, so some confinement would also have been sufficient to curb the aggression. The chaining was therefore an unnecessary, inappropriate use of force.

In addition to cases in which unnecessary violence is used, the last category of Article 3 ECHR violations in which the ECtHR deems human dignity violated is a residual category. In *Fyodorov & Fyodorova,* the ECtHR provides an overview of the complaints it has dealt with that fall into this category (ECtHR 7 July 2011, 39229/03, par. 60). In general, the conclusion can be drawn that these are treatments without (process) purpose, but only to add suffering or to stigmatize. Examples include a public display with handcuffs on so that the public can observe the suspect in this way, attending the trial in an iron cage without 'sufficient security justifications',4 examining the body *without* a legal purpose and the shaving hair as a disciplinary punishment. These acts have no procedural purpose: for example, restricting a suspect's freedom of movement is justified if it prevents him from posing a danger to himself or others, but not to stigmatise.

Two aspects can be distilled from this brief description of cases (see in detail Van Toor 2017, chapter 5) that are classed as humiliating treatment. use of unnecessary violence) and an equality or objectivity aspect (the use of (far-reaching) measures without a legitimate aim). Feelings of powerlessness, fear and inferiority can be evoked on both aspects, which means that unnecessary violence and unequal treatment can be categorized as degrading treatment. This can arouse feelings of fear and inferiority because the suspect finds himself in the power of the government and has to deal with (violent) acts without purpose.

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4 See in particular ECtHR (GK) 17 July 2014, appl. no. 32541/08 & 43441/08 *(Svinarenko & Slyadnev* v. *Russia),* in par. 138: *'Regardless of the concrete circumstances in the present case, the Court reiterates that the very essence of the Convention is respect for human dignity and that the object and purpose of the Convention as an instrument for the protection of individual human beings require that its provisions be interpreted and applied so as to make its safeguards practical and effective. It is therefore of the view that holding a person in a metal cage during a trial constitutes in itself – having regard to its objectively degrading nature which is incompatible with the standards of civilized behavior that are the hallmark of a democratic society – an affront to human dignity in breach of Article 3.'*

Violence is a clear violation of physical safety. If the violence is not strictly necessary, it reduces the suspect to an object. In certain actions, such as the use of brute force to administer an emetic without adequate medical guarantees (ECtHR (GK) 11 July 2006, *NJ* 2007, 226, noting Sch), the human dimension has completely disappeared from view. Incidentally, not only physical violence is problematic. Psychological violence can also evoke feelings of fear and inferiority. Threatening violence (which could be categorized as torture) to discover the whereabouts of a kidnapped boy (ECtHR (GK) 1 June 2010, NJ 2010, 628, m.nt.
YB) is not physical violence, but can of course evoke feelings of impotence, fear and inferiority, as a result of which the suspect feels treated not as a subject but as an object.

It also applies to criminal investigations that suspects may not be treated differently on the basis of, for example, skin colour, religion, ethnicity or other non-individualized characteristics. Investigation methods should be applied irrespective of these characteristics, but on the basis of a degree of suspicion that can be individualized, concretized and objectified. If that forms the basis for criminal proceedings, then equal cases are treated equally.

This means that it must be tested whether the application of neurotechnological detection methods evokes feelings of fear or inferiority because of unnecessary violence or unlawful unequal treatment. There can be no question of a total ban on forced neurotechnological investigation on the basis of this criterion under Article 3 of the ECHR (cf.
Ligthart, 2019a, p. 97-98). In essence, the application of EEG and *fMRI/ neuroimaging* (hereinafter referred to as 'brain scan') in the detection phase does not, in principle, conflict with respect for human dignity and does not result in degrading (or inhuman) treatment. For example, for the application of an EEG for which freedom of movement must be completely deprived, the suspect may be restrained in such a way that reliable administration of the method is possible.
In the case of seriously resisting suspects, it may be impossible to perform a brain scan or EEG. This is because both methods require as little exercise as possible for a reliable collection, while restraining a resisting suspect probably cannot take place without a fight[5] . In addition, an fMRI and EEG also require cognitive cooperation: thinking about all sorts of things that are irrelevant to the test can considerably obscure the results (Rosenfeld et al., 2004).

In addition, it is important that the application of the methods is based on an individualisable, concrete and objectifiable suspicion. It is contrary to Article 3 of the ECHR to subject all persons from a certain religious group or ethnic minority to an EEG for identification, because the idea is that the suspect must be found in that population.

Together this means that a clear framework must be created – and this is also required by Article 1 CCP discussed in the previous section – under which circumstances a brain scan or EEG may be used. This requires that the execution takes place for a *criminal* purpose. Further

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[5] Incidentally, the resisting suspect naturally runs the risk of committing a criminal offense due to the fact that he opposes the execution. Consider, for example, the offense of rebellion or the refusal of an official order.

the application should only take place on the basis of facts that can be individualized, concretized and objectified. It is also important that, for example by General Administrative Order (as is also the case for the collection of bodily material for DNA testing), further rules are drawn up in which way an expert (doctor; neuropsychologist) is involved in the collection, prior medical checks and medical supervision during the execution, to what extent the suspect is informed about the application of a neurotechnological investigative act and how a resisting suspect can still be subjected to a brain scan or EEG.

(ii) Neurotechnological research in the light of the right to respect for private life

In addition to Article 3 ECHR, Article 8 ECHR, which regulates the right to respect for private life, also offers (suspected) citizens protection against unauthorized government intervention. However, where Article 3 ECHR concerns an absolute right - this is a right to which no exception is possible - Article 8 ECHR is a relative –, is right. In criminal investigation practice, the justification criteria for violations of Article 8(1) of the ECHR have therefore become more important than the question of whether a government act infringes the right to respect for private life (Taylor Parkins - Ozephius et al., 2021). After all, it is usually not up for discussion *whether* a criminal investigation infringes someone's privacy, but *to what extent* the privacy is restricted. This starting point – in principle investigative acts infringe the privacy of the suspect or a third party – makes it clear that the criteria under which the right to respect for private life may be infringed have therefore become more important than the law itself. For investigative acts that violate physical integrity as part of the right to respect for private life (Harris et al. 2009; see e.g. ECtHR (GK) 4 December 2008, NJCM Bulletin 2009, 4, note *Van* der Cease) such as a brain scan and EEG, but also the collection of bodily material for DNA testing, this means that the justification criteria from Article 8 paragraph 2 of the ECHR must be looked at in particular for a lawful application. It is evident that physical examination is an invasion of someone's privacy.

An infringement of the right to respect for private life is legitimate if the following criteria are met: the infringement must 1) occur in accordance with a legal provision; 2) pursue a legitimate aim and; 3) are necessary in a democratic society. The criterion 'in accordance with a legal provision' can be divided into three sub-criteria. Firstly, the infringement must be based on a legal provision *(see,* for example, ECtHR (GK) 10 May 2001, 25781/95 *(Husayn* v. *Polen),* par. 295). This means that there must be a legal basis on which the act infringing the right to respect for private life is based (see, for example, ECtHR 27 November 1992, 13441/87 *(Olsson* v. *Sweden (no.* 2), par. 81; ECtHR 12 May 2000, 35394/97 *(Khan* v. *United Kingdom),* para. 27; ECtHR 5 November 2002, 48539/99 *(Allan* v. *United Kingdom),* para. 36), and that provision should be *sufficient* for more serious infringements be *specific* (Harris et al., 2009, p. 400) Secondly, the ECtHR requires that the legal provision is of *sufficient quality* (see for example ECtHR (GK) 26 November 2013, 27853/09 *(X* t. *Latvia),* par 58. It is therefore insufficient in some circumstances *for* a legal basis to exist. The legal provision must be of sufficient quality to prevent arbitrary use of the power contained in the provision. This depends, among other things, on the foreseeability *of* the conduct of government officials under the provision and *safeguards* against arbitrary conduct under the provision important (See, for example, ECtHR 12

January 2010, 4158/05 *(Gillan & Quinton* v. *United Kingdom),* para. 77; ECtHR 5 June 2014, 33761/05 *(Tereshchenko* v. *Russia),* par. 135) . 09 *(MK* v. *France),* par. 29).

The second criterion from Article 8 paragraph 2 ECHR assesses the purpose of the infringement of the right to respect for private life. The goals that justify an infringement of the right to private life are exhaustively included in Article 8 paragraph 2 ECHR, but are interpreted very broadly. These include the importance of national and public security and the prevention of disorder and criminal offences. The 'prevention of criminal offences' also includes the detection and investigation (ECtHR (GK) 3 April 2012, 42857/05 *(Van der Heijden* v. *Netherlands),* par. 54) of criminal offences. Investigative acts that infringe the right to respect for private life therefore meet the requirement of a legitimate purpose.

The third criterion that must be met to justify an infringement of the right to respect for private life is that the infringement is necessary in a democratic society. This assessment comes down to striking a *fair balance* between the purpose being served and the individual right being infringed. This reasonable weighing of interests also runs like a red thread throughout the treaty (ECtHR 7 July 1989, 14038/88 *(Soering* v. *the United Kingdom),* par. 89. See also ECtHR (GK) 12 May 2005, 46221/99 *(Öcalan v . Turkey) ,* par . _ _ _ , par. 57). In the *fair balance test,* the ECtHR assesses whether Member States 1) make policy within the *margin of appreciation* to 2) meet a *compelling social need* 3) by infringing the right to respect for private life in a *proportionate manner .* An example of the assessment of the balance of interests made by the state *(fair balance)* and possibly less onerous options played a central role in the S case. *& Marper* (ECtHR (GK) 4 December 2008, *NJCM-Bulletin* 2009, 4, with reference to Van der Staak). In England, Wales and Northern Ireland (the only Council of Europe member states (para. 110)) bodily material and fingerprints were stored indefinitely in a database, even if the suspects were ultimately not prosecuted and even if they were acquitted. The ECtHR understands that the use of technological developments is essential in the fight against crime, but that does not mean that storage is absolutely necessary (par. 105, 112, 114). A decisive factor in deeming the conduct of part of the United Kingdom to be contrary to Article 8 of the ECHR is that completely undifferentiated competence for the storage of human tissue and fingerprints (para. 125). As a result, the Member State has not weighed up the compelling social need and individual, private interests against each other *fairly* (par. 125).

As discussed above, it also follows from the right to respect for private life that a clear legal framework for the forced application of brain scans and EEG to the suspect during the investigation phase is necessary. The infringement of the right to respect for private life must

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[6] Incidentally, an unlimited power makes it difficult to foresee what behavior can be based on that power. See also *Tereshchenko* v. *Russia* and ECtHR 12 June 2008, appl. no. 78146/01, par. 125 *(Vlasov* v. *Russia).*

namely in accordance with a legal basis. Carrying out these two methods violates (at least) the physical integrity of the suspect, and thus violates the right to respect for private life. This is only lawful if the application of the method is based on a legal basis of sufficient quality (and that action is taken in accordance with that provision). Incidentally, it is evident that this serves a legitimate purpose: namely the detection and tracing of criminal offences. However, when creating the legal basis, attention must be paid to the *fair* balance test, in which attention must be paid, among other things, to the duration of the storage and how to deal with data from suspects who later turn out to be innocent, but also to which criminal offenses far-reaching investigative powers may be exercised (cf. Ligthart, 2019b). In any case, just like Article 3 ECHR, Article 8 ECHR does not provide an absolute prohibition on investigative acts that infringe physical integrity, such as brain scans and EEG.

(iii) Neurotechnological investigation in light of the right to a fair trial

In addition to Articles 3 and 8 ECHR, Article 6 ECHR plays an important, if not the most important, role in assessing the lawfulness of investigative methods. This has to do with the fact that Article 6 ECHR also assesses whether evidence may be used against the suspect or must be excluded (Van Toor 2020). In principle, any violations of Article 3 or Article 8 of the ECHR have no direct significance for the evidence in the criminal case against a suspect,7 but they do if it is also established that the *use* of evidence obtained through the unlawful act violates the right to a fair trial. This could be done through a violation of the right to remain silent and the nemo tenetur principle: in principle, the suspect may not be forced to speak or be forced to cooperate in any other way in his own conviction (Van Toor 2016).

For example, the ECtHR has ruled several times that (high) (and repeatedly imposed) fines to obtain documents are unfair (ECtHR 25 February 1993 *(Funke* v. *France),* 10828/84; ECtHR 2 May 2001 *(JB* v. *Switzerland) ,* 31827/96); is a duty to speak enforced with possible imprisonment unfair (ECtHR 17 December 1996 *(Saunders* v. *United Kingdom),* 19187/91); and is the use of evidence obtained through violations of Article 3 ECHR unfair (ECtHR 5 November 2020, 31454/10 *(Cwik* v. *Poland)).*

Especially the second category – a forced statement – is important for this research: to what extent can the suspect be forced to reveal (correct) memories, which normally can only be obtained by the authorities when the suspect speaks? That is what neurolie detection and neuromemory detection are all about.8 However, whether this is in conflict with the right to remain silent or the nemo-tenetur principle is not easy to answer.

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7 As an example, see the *Michael P. / Anne Faber case,* in which the suspect was confronted with a threat of violence by means of the deployment of a police dog (which is a violation of Article 3 of the ECHR). This unlawfulness is compensated by means of a reduced sentence. HR 23 June 2020, ECLI:NL:HR:2020:1092.

8 Identification via EEG is not considered here for the time being. In principle, Article 6 of the ECHR does not seem to play a role in this (provided that the decrease in the EEG takes place in a lawful – *id est,* with appropriate violence – manner). The same applies to identification by voice or DNA testing.

The first question to be answered is whether obtaining information about memories through fMRI or EEG corresponds to obtaining an oral statement (the right to remain silent) or obtaining bodily material (the nemo-tenetur principle). With regard to the first category – the spoken word – a much stricter assessment framework applies than for the second category. The first category, in the case law of the ECtHR, is referred to as material *that exists dependent on the will of the accused ,* while the second category concerns *material that exists independently of the will of the accused* (ECtHR 17 December 1996, 19187/91 *(Saunders* v. *United Kingdom),* para. 69). When obtaining material that exists *depending* on the will of the suspect, there is actually no room to obtain it against the will of the suspect. In other words, only very minor coercion may be used to obtain this type of material (ECtHR 17 December 1996, 19187/91 *(Saunders* v. *United Kingdom),* par.

69). This is different for material that exists *independently* of the will of the suspect: bodily material may be obtained with appropriate force; documents can be collected through a lawful search and seizure; even swallowed globules of drugs could be obtained with appropriate force. All this is justified under the nemo tenetur principle (ECtHR 17 December 1996, 19187/91 *(Saunders* v. *United Kingdom),* par. 69).

Because one category is subjected to a much more stringent test than the other category, it is necessary to see under which category neurolie detection and neuromemory detection fall.

With regard to neurolie detection, during the making of a statement, fMRI, for example, is used to check whether the statement made corresponds to the 'truth', or at least whether the suspect believes that he is stating the truth. Because the suspect *has to* speak during neurolie detection – because without a statement made no truth or falsehood can be established – it is evident that neurolie detection falls under the category of material that exists *according* to the will of the suspect.

Neuromemory Detection uses a recognition task to investigate whether someone has "guilty knowledge." During the task, the suspect is 1) physically restrained while he undergoes an 2) EEG (or other physical) measurement – in the following we call this, in line with Van Toor (2017), the biological trace –, and after analysis of the biological trace it can be concluded that the suspect 3) has guilty knowledge – we call this, in line with Van Toor (2017), the cognitive trace –. Because both a biological trace and a cognitive trace are obtained, the categorization of neuromemory detection is not as straightforward as the categorization of neurolie detection.

Farrell (2010; 94) states that: *'asking a defendant for responses to questions while conducting a scan would clearly seem to violate this principle (against self-incrimination,* our addition), *the answer is less obvious in a situation where a brain scan tracks subconscious or passive perceptions to photos or statements but the defendant remains silent'.* A neuromemory detection test assesses whether someone has guilty knowledge by comparing brain activity in two

different parts of a task. It therefore corresponds to the second part of Farrells

remark (to follow subconscious or passive perceptions, but the accused is silent). The task the person performs involves listening to multiple choice questions and the answers to them.

One of the answers is *meaningful* because it contains guilty knowledge, the other answers are plausible distractors. The brain activity in response to the meaningful item is compared to the brain activity in response to the distractors. The assumption is that the perpetrator has the details of the crime scene and therefore reacts physiologically differently when confronted with guilty knowledge.

In principle, the person being examined does not have to perform any physical action during the examination (although neuromemory detection tests are also taken in which this is the case). The test can be performed completely auditory. The person is not required to speak or otherwise cooperate intellectually during the study. He must "tolerate" hearing questions and answers while his brain activity or some other physiological response is being measured. Whether the suspect recognizes the meaningful item is determined by his brain activity or physiological response. The suspect cannot suppress or change the reaction. Since the subject cannot control or stop the reaction after recognition, the only logical conclusion is that the biological trace collected with neuromemory detection exists *independently* of the suspect's will. In this sense, brain waves and physiological responses are physical evidence, as are blood, hair, and cells (as cited as examples in the *Saunders case).* The biological trace thus exists independently of the will of the suspect.

In addition to the biological trace just analyzed, the authorities also indirectly obtain a cognitive trace by taking neuromemory detection. Through the analysis of the physiological response, it becomes clear that the suspect has certain *knowledge .* The EEG-P300 response – the biological trace – is in itself worth nothing in a criminal case. Only when the P300 has been examined and an expert states that the results show that the suspect possesses knowledge of the perpetrator, is neuromemory detection a method that yields incriminating information. This aspect – that neuromemory sensing "reveals" contents of the mind is the point that is most problematic in the light of the right to remain silent and the nemo-tenetur principle, because the cognitive trace can at first sight only be compared to the spoken word . With both the cognitive trace and the spoken word, substantive information is obtained that is stored in the memory because the questions are answered (directly or indirectly). However, the cognitive trace is not exactly the same as the spoken word because the suspect has less control over the storage, remembering and retrieval of information in the brain, while he has further control over whether he reproduces memories through the spoken word . At first glance, these similarities and differences make it difficult to categorize the cognitive trace as either existing entirely independently or entirely dependent on the will of the suspect.

As a starting point for the assessment of the categorization of the cognitive track, we take some positions that other authors have put forward in the literature. Farahany (2012) compares the memories to documents that are in a safe. The stored memories can be found in a mental 'vault', and are not accessible to third parties, but exist independently of the will of the suspect. In this sense, the information from the mental vault should be protected in the same way as documents in a real vault. Easton (1998) points out that the distinction between a biological and a cognitive trace is based on a Cartesian dualism between mind and body, while this dichotomy is patently incorrect. This would lead to the biocognitive trace being seen as a 'simple' bodily response and protected in the same way as body tissue, hair, blood, *etc.* Other authors point to the content of the cognitive trace and make a comparison with an explanation (Farrel (2010); Fox (2009)).

The question of whether or not the cognitive trace depends on the will of the suspect is not easy to answer because two competing, completely mutually exclusive views are possible.

The cognitive trace as such is not obtained from the decrease of the EEG. Only by analyzing the biological trace can expert witnesses draw conclusions about the presence or absence of guilty knowledge. This conclusion is thus an indirect consequence of the neuromemory detection test, a result of analysis of a biological trace, and we concluded above (in line with case law on other bodily material) that this biological trace exists independently of the will of the suspect because the suspect cannot influence the pattern of brain activity or its physiological response to meaningful items during the administration. Since the cognitive trace is not obtained as such, but only through analysis of the biological trace, it can be concluded that the cognitive trace exists (at least in part) independently of the suspect's will.

On the other hand, the nature of the information obtained can be emphasized. Perpetrator knowledge is by definition knowledge that (usually) only the perpetrator possesses. This information cannot currently be obtained in any other way than by the suspect making a statement, so obtaining it always depends on the will of the suspect. The neuromemory detection test thus obtains information from the suspect that could otherwise only be obtained if he makes a statement. If confronted with the murder weapon during an interrogation situation, he may state that he is unfamiliar with the weapon or refrain from making any statement. The suspect does not have this choice if he undergoes a neuromemory detection test (although he can try to manipulate the results of the neuromemory detection test, but this does not always prevent recognition of offender knowledge from taking place (but possibly only that the results are more difficult to interpret) (Rosenfeld, Soskins, Bosh & Ryan, 2004)). With the introduction of this test in criminal law, the right to remain silent is at least partially circumvented. During an interrogation it is no longer necessary to assess whether the suspect is guilty, the authorities can perform a neuromemory detection test on the (perhaps even sleeping; Meijer & Van Toor 2020) suspect and obtain the same information. By making this comparison and emphasizing that neuromemory sensing provides insight into memories, albeit in a roundabout way, it can also be concluded that the acquisition of the cognitive trace is dependent on the will of the

suspect.

This means that the administration of neurolie detection must in any case be assessed comparable to other material that exists depending on the will of the suspect, while that for neuromemory detection is still unclear. With regard to legality, this means that only very limited coercion can be used to force the suspect to undergo neurolie detection: in principle, the suspect may not be forced to speak, while this is necessary for establishing the (un)truth. As a result, there seems to be *no* room for the reduction of neurolie detection in Dutch criminal procedure. *Mutatis mutandis* applies to neuromemory detection if the cognitive trace is categorized as material that exists *contingent* on the will of the suspect. If the cognitive trace is categorized as material that exists *independently* of the will of the suspect, there is some scope for conducting neuromemory detection with appropriate physical coercion, but not with the threat of punishment. It is necessary to do so that relevant safeguards exist that reduce the nature and degree of coercion.9 To this end, a connection could be sought with existing powers that infringe bodily integrity *or* with which bodily material is obtained.

(d) Conclusion

It clearly follows from the human rights framework described in this chapter that no general prohibition exists, or can be expected, with regard to the use of neurotechnological methods in a criminal procedure context. Both the respect for human dignity and the prohibition of torture, the right to respect for privacy and the nemo-tenetur principle do not prohibit certain actions *in the abstract.* A court confronted with results from a particular method, which can therefore be a neurotechnological method, must determine *in concrete terms* whether the use and implementation of the methods is in accordance with the applicable law.

It is important for this assessment that in criminal procedural law the authorities responsible for criminal proceedings may only act on the basis of a legal basis. In other words, the granting of authority to use a certain method must take place through the law.
Depending on the drastic nature of the method, the legal basis must be designed with more safeguards, such as judicial review prior to implementation of the method in the case of the most drastic methods. With regard to neurotechnological methods, especially neuromemory detection that provides insight into the invisible memory, it must be stated that these are radical methods that must be cast in a legal basis with strict safeguards. These safeguards then regulate the decision to *deploy* neurotechnological methods .

With regard to *implementation ,* all human rights discussed in this chapter set limits to the coercion that may be used. In other words, if the use of a power is legally possible, this does not mean that all implementing acts are *ipso facto* lawful. For example, restraining someone with a lot of (unnecessary) violence so that neuromemory detection can be taken is unlawful. This means that the authorities carrying out a neurotechnological method must behave carefully in the sense that they only use *lawful coercion .*

9 ECtHR 11 July 2006, appl. no. 54819/00 (Jalloh vs. Germany). Under German criminal procedure law (Article 81a StPO), all physical interventions relevant to the determination of the offense are permitted, provided that the intervention is performed by a doctor using the normal methods of his science and in the absence of health risks. The administration of an emetic is therefore possible because it gathers important evidence for the criminal process, *provided that* the procedural safeguards are followed.

9. Risk Assessment

In Dutch criminal law, special prevention – preventing a convicted person from committing criminal offenses again – is playing an increasingly important role (Bijlsma, 2021; De Jong, 2021). The TBS measure is the oldest and perhaps best-known example of a sanction based on special prevention. In the last two decades, a number of new measures have been introduced aimed at preventing recidivism. This concerns the placement in an institution for systematic offenders (ISD, art. 38m Sr), the freedom-restricting measure (art. 38v Sr) and the behavior-influencing and custodial measure (GVM, art. 38z Sr). Punishments are also increasingly aimed at special prevention. For example, since 2015, the probationary period for conditional release can be extended indefinitely if there is a risk of offenses that affect physical integrity (art. 6.1.18 paragraph 2 DCCP) . Neurotechnology is relevant to this 'high-risk criminal law' in two respects. Neuro-interventions may reduce the risk of recidivism. The legal aspects of this are discussed in Chapter 10. Neurotechnology can also contribute to an assessment of the risk of recidivism and thus help to answer the question of whether a sanction aimed at special prevention should be imposed. This topic is discussed in this section.

Risk assessment is currently carried out using actuarial risk assessment instruments, in which risk factors are 'scored' and which result in a convict being classified in a certain risk category. Sometimes a risk assessment is made on the basis of the clinical judgment of a behavioral expert, whether or not in addition to an actuarial risk assessment. The technical research showed that *neuroimaging* may lead to an improvement in the quality of risk assessments, but also that few markers have been found in the brain that are associated with an increased risk of delinquent behaviour. Risk assessment using neurotechnology is currently not being used in practice, but it may be possible within the next five to ten years. The TRL of risk assessment using neurotechnology was estimated to be 4.

In part, *risk assessment* involves issues that have already been discussed under truth-finding (Chapter 8). In the light of the prohibition of torture and inhuman or degrading treatment (art. 3 ECHR), no other requirements are set for brain scans in the context of risk assessment than in the detection phase. Inhuman and degrading treatment is prohibited in both cases. As discussed, the right to respect for private life enshrined in Article 8 of the ECHR requires a clear legal framework for the use of brain scans. This also applies to brain scans used for risk assessment. It is mainly on these points that the use of neurotechnology for risk assessment seems to distinguish itself from actuarial and clinical risk assessment. In these forms of risk assessment, the physical integrity of the person concerned, as protected by Articles 3 and 8 ECHR, is not at stake.

When it comes to the guarantees arising from the right to a fair trial (art. 6 ECHR), the answer is less clear. The decision to impose a certain sanction, TBS for example, is based on an assessment of the suspect's risk of recidivism. This raises the question of whether a suspect can be obliged to provide insight into his or her recidivism risk *(Parliamentary Papers II* 2016/17, 20, 36 937, p. 1-2). Can a suspect be subjected to a brain scan against his or her will to estimate the risk of recidivism?

The nemo-tenetur principle discussed earlier may play a role here: the suspect cannot be forced to incriminate himself. According to Teeven, former State Secretary for Security and Justice, this principle stands in the way of obligatory cooperation in diagnostic methods

(Parliamentary Papers II 2010/11, 29 452, no. 138; see also Lieftink, 2018). However, the State Secretary does not provide any substantiation for this, and the link between the nemo tenetur principle and forced cooperation in diagnostics or appraisal is not that simple. This is because diagnostics relating to a disorder or risk assessment have no influence on the *question of evidence* (has the suspect committed a criminal offence?). The question is therefore whether these assessments fall under the nemo-tenetur principle, which essentially protects the suspect against being forced to make incriminating statements. This *burdening* can be generally understood – a heavier sanction is also disadvantageous for the suspect – but the nemo-tenetur principle seems to be primarily a principle of the *law of evidence* . The conviction may not be accompanied by an enforced incriminating statement.

However, the rationale and scope of this principle are rather unclear (Ligthart, 2021a; Stevens, 2005, 2; Van Toor, 2017, H7). Stevens (2005, 1) lists various definitions in her dissertation, from which, among other things, differences in possible scope can be deduced. The suspect would not have to cooperate in the *criminal process* (so decisions regarding sanctions would also fall under the nemo-tenetur principle). Another definition focuses on the *conviction:* the suspect cannot be forced to contribute to it and then the focus is strongly on the nemo tenetur principle as a principle of evidence (and not as a general procedural principle). Stevens (2005, 2) then comments that, according to the ECtHR, the principle of nemo-tenetur 'sets certain limits on investigative powers and evidence'. There is no imposition of sanctions in this quote.

In the judgment in the *Gäfgen* case (ECtHR 1 June 2010, 22978/05), delivered a few years after Stevens' dissertation, the ECtHR hinted that coerced information should not influence the imposition of sanctions (par. 179) and that a statement made in violation of Article 3 ECHR must not affect the determination of the relevant facts (para. 166). At other points in this judgment, as well as in other judgments, the ECtHR's considerations about the scope of the nemo tenetur principle are quite strongly formulated in the key of the evidence. For example, in *Gäfgen* (par. 167) the ECtHR considered that *'the use at the trial of real evidence obtained as a direct result of ill treatment in breach of Article 3, the Court has considered that incriminating real evidence obtained as a result of acts of violence, at least if those acts had to be characterized as torture, should never be relied on as proof of the victim's guilt' (our* emphasis). It is beyond the scope of this study to elaborate on the rationale and scope of the nemo-tenetur principle. However, it does not go without saying that the principle prohibits forced cooperation in diagnostics or appraisal. After all, diagnosis of a disorder and risk assessment are usually not used for determining guilt, but for the question of whether, for example, TBS can be imposed. It is not certain that the nemo-tenetur principle extends to the imposition of sanctions.

Another principle of evidence law that plays a role in the assessment of forced cooperation in risk assessment is the presumption of innocence. Partly to prevent the innocent from being convicted, Article 6 paragraph 2 of the ECHR (the presumption of innocence) sets strict requirements for proof of a criminal offence. If there is reasonable doubt about the guilt of the suspect, he or she must be acquitted (Bemelmans 2018, 234-238). These strict requirements do not apply in the sanctions assessment phase (ECtHR 8 June 1976, 5100/71 *(Engel* v. *Netherlands),* par. 90). The determination of risk of recidivism therefore does not have to be made beyond reasonable doubt, because in that case it does not concern a determination of guilt for a criminal offence. However, it is unclear how 'powerful' the evidence for facts that are important for the sanctions must be (Bijlsma, 2021).

Inherent in risk assessment is that it is surrounded by great uncertainties. According to a much-cited meta-study (Fazel et al., 2012), hazard assessments using existing risk assessment instruments yield relatively many false positives. A false positive in this context is a convicted person who

is designated as high-risk by the risk assessment tool, but will not in fact reoffend.
Of every ten people who risk assessment instruments classify as high-risk, about six will *not* reoffend.
Because the constitutional framework offers little protection against the imposition of sanctions based on the risk of recidivism, it has been argued that, analogous to the presumption of innocence, a 'presumption of harmlessness' should be introduced with a matching standard of proof (Ashworth & Zedner, 2014, 259; Bijlsma, 2021). Improving risk assessments using neurotechnology (possibly in combination with *machine learning)* can contribute to a reduction in the number of false positive assessments and thus prevent incorrectly imposed preventive sanctions (cf. Meynen, 2020). At the same time, (AI) neuroprediction is not free from dangers associated with other forms of risk assessment, such as the risk of discrimination through *bias* and the assessment of individuals on group characteristics (Tortora et al., 2020).

Risk assessment is used to make decisions that result in deprivation of liberty or release. This may involve pre-trial detention due to the risk of recidivism (art. 67a paragraph 2 sub 2 Sv), the imposition of a sanction or, conversely, the (conditional) release of a suspect. Article 5 ECHR protects against arbitrary deprivation of liberty.
Deprivation of liberty may therefore only take place in the cases listed in Article 5 of the ECHR. This includes, for example, serving a prison sentence after a conviction.
The ECtHR does not seem to have any objections in principle to the classification of suspects or convicted persons in different risk categories, but an objective basis must exist for unequal treatment based on group characteristics (ECtHR 13 July 2010, 7205/07 (Clift v. *UK)) .*
Decisions on detention or release based on risk assessments that are 'biased' towards certain population groups can therefore lead to a violation of Article 5 ECHR in combination with Article 14 ECHR (in which the prohibition of discrimination is laid down).

In summary, we conclude that *risk assessment* using neurotechnology partly raises the same issues as the application of neurotechnology in *investigation and truth-finding.* One question, however, is whether the nemo-tenetur principle applies to cooperation in risk assessment. The risk of recidivism does not have to be established with the same degree of certainty as the guilt of a criminal offence. Risk assessment should not lead to unjustified unequal treatment.

10.Intervention

(a) Neuro-interventions in the criminal justice domain

Judicial neurointerventions are defined in this study as: techniques that alter brain functions with the aim of reducing danger. It concerns the prevention of recidivism in a criminal law context and/or to promote the rehabilitation of convicted persons (hereinafter also referred to as: 'rehabilitative neuro-interventions', or simply 'neuro-interventions'). The convicted person is often given the choice between undergoing treatment on the one hand and (further) undergoing (for example) a prison sentence on the other. As described in the next section, this type of intervention cannot be enforced outside of rare, acute emergencies, as that would be contrary to Articles 3 and 8 of the ECHR. Nor does Dutch legislation provide a basis for coercive treatment in a criminal law context.

The technical sub-report (section 1) concluded that neuro-interventions are not yet being applied in the judicial domain at this time. However, applications of neuro-interventions in the criminal justice domain are conceivable, for example in the form of brain stimulation aimed at controlling aggression and promoting empathy. The TRL of brain stimulation in the criminal justice domain has been estimated at 4. This means that the technique has been validated in laboratory situations, but that the necessary steps must be taken before it can be applied in practice. It is expected that within the next five years there will be more certainty about the effects of these techniques on the risk of recidivism.

The physical infringement of the validated techniques ranges from two electrodes placed on the scalp (rTMS, tDCS) to electrodes surgically placed deep in the brain and a battery under the skin at the collarbone (DBS). However, not only the physical side is important for the legal implications of the application of neurointerventions. Because neuro-interventions stimulate the brain, they influence the psyche of the person involved. This aspect of neuro-interventions is also important for the legal valuation of the intervention.

(b) National legal framework for neuro-interventions

Sanctions law offers various options to induce a person involved to receive behavioral expert or medical treatment (including neuro-interventions) with a view to preventing recidivism and/or rehabilitation. Special conditions may be attached to a (partially) suspended sentence (art. 14c paragraph 2 Sr) or conditional release (art. 6.2.11 paragraph 3 Sv) that the convicted person undergoes treatment by an expert or a healthcare institution or participates in a behavioral intervention.10 These conditions can also be linked to the GVM of article 38z Sr (art. 6.6.23b paragraph 2 Sv). Treatment can also be attached as a special condition to a (conditional) placement in an institution for systematic offenders (art. 38m; 38p paragraph 5 Sr). Finally, treatment takes place within the framework of the

10 Some modalities that are somewhat less relevant in this respect (suspension of pre-trial detention, conditional dismissal, punishment order, pardon) also have the option of imposing special conditions. However, the Public Prosecution Service Instructions *(Stcrt.* 2020, 62572) limits outpatient treatment for the punishment order to a maximum of twenty meetings. It should not imply an obligation to take medication. The Instruction for dismissal and use of grounds for dismissal *(Stcrt.* 2020, 62570) prohibits attaching conditions in the medical sphere to a conditional dismissal. These modalities will not be considered further here.

implementation of TBS. This may be in the form of a condition attached to a conditional TBS: treatment by an expert or taking prescribed medication (art. 38a paragraph 1 Sr). In the case of TBS with compulsory treatment (art. 37b paragraph 1 Sr), a treatment plan is drawn up aimed at 'removing' the risk of recidivism caused by the disorder in such a way that the TBS can be (conditionally) terminated (art. 16 paragraph e.g.).

Characteristic of the aforementioned criminal law frameworks is that the treatment cannot be enforced. In the context of TBS with compulsory treatment, the starting point is that treatment only takes place if the patient does not object (art. 16a sub c Bvt). Failure to comply with special conditions will result in a (remainder of) sentence, measure or alternative detention being enforced. The (continuation of) deprivation of liberty therefore exerts a strong urge on the convicted person to undergo the treatment. In the legislative history of conditional sanction modalities, it has been repeatedly emphasized that *coercion* infringes fundamental rights, but that this is not the case in the case of the *coercion* emanating from (continuation of) deprivation of liberty. See, for example, this passage from the explanatory memorandum to the GVM:

> *'Since the bill does not provide for a power to take compulsory medication, the taking of medicines, for example, cannot be enforced. There is therefore no question of a violation of the inviolability of the body (Article 11 of the Constitution and Article 8 of the ECHR). Within the framework of a broader treatment, however, there are good opportunities for voluntary treatment with medication, including libido-inhibiting medication. This part of the treatment is of course not optional. Here, as is the case with regard to the condition of admission to a care institution, there is no question of coercion, but of coercion arising from the nature of the condition imposed.'*
>
> (*Parliamentary Papers II* 2013-14, 33 816, 3, p. 30. See also *Parliamentary Papers II* 2009-10, 32 319, 3, p. 10.)

The only exception to the rule that treatment in a criminal law context cannot be enforced is that treatment in the context of TBS with compulsory treatment as a 'last resort' can take place despite the patient's resistance if the danger cannot otherwise be removed within a reasonable period of time or if this is necessary to avert the danger caused by a person within the TBS institution (art. 16b Bvt). The latter intervention mainly has the character of forced mental health care as it is also provided under the Compulsory Mental Health Care Act.

(c) Neurointerventions and the ECHR

(i) Neuro-interventions and the prohibition of inhuman or degrading treatment or punishment

Interventions of a medical and/or rehabilitative nature can create tension with Article 3 of the ECHR (Schabas, 2015, p. 183). Article 3 ECHR contains an absolute prohibition on torture and inhuman or degrading treatment or punishment. An infringement thereof is never justified. Incidentally, Article 3 of the ECHR deals with treatment – treatment – in general, not (exclusively) with medical treatment. For example, forced shaving of detainees has been regarded as degrading treatment in violation of Article 3 of the ECHR (ECtHR 11 December 2003, 39084/97 *(Yankov* v. *Bulgaria),* par. 108-122). To fall within the scope of Article 3 ECHR, a minimum level of *ill-treatment* must be exceeded. This review takes place on the basis of a large number of factors, including the duration and the physical and psychological effects of the treatment or punishment and (sometimes) the nature of the victim, for example if there is a special vulnerability (Schabas, 2015, p. 171-174).

Medical compulsory treatment of mentally incapacitated patients for which there is a medical necessity does not fall within the scope of Article 3 of the ECHR. In *Herczegfalvy* t. *Austria* (ECtHR 24 September 1992, 10533/83, par. 79-84) the ECtHR rules that force-feeding, force-feeding of neuroleptics (antipsychotic drugs) and the isolation and handcuffing to a 'safety bed' of a psychiatric patient forcibly committed because of the medical necessity of these interventions was not inhuman or degrading treatment. In *VC* t.

Slovakia (ECtHR 8 November 2011, 18968/07, par. 106-120) the ECtHR rules that sterilization of a competent patient without full consent and while there was no question of ' *imminent risk of irreparable damage to the applicant's life or health'* violates was with respect for human freedom and dignity and thus with Article 3 of the ECHR. That does not change the fact that the medical staff did not act with the intention of harming the patient.

Judicial neurointerventions with a rehabilitative purpose and that have the minimum level of severity of Article 3 ECHR, however, do not serve to avert an acute danger on the basis of medical necessity and therefore in many cases do not meet the requirements of Article 3 ECHR for medical compulsory treatment. It is uncertain whether the ECtHR will drop the requirement of medical necessity for forced treatment in a criminal justice framework, including rehabilitative neurointerventions (Forsberg, 2021). For that reason, forced neuro-interventions with more drastic physical or mental consequences aimed at rehabilitation are at least at odds with Article 3 of the ECHR. Given the far-reaching physical and mental consequences of at least some neurointerventions, it is quite conceivable that physical enforcement without medical necessity, but with a rehabilitative purpose, results in inhuman and degrading treatment or punishment (Bublitz, 2018, p. 299-300; Kirchmair, 2019, pp. 29-31; Shaw 2018, pp. 257-261). The starting point of Dutch law that forced interventions with a medical character but with a rehabilitative purpose, such as neuro-interventions, are in principle not allowed (insofar as they exceed the minimum level of ill *treatment),* is therefore correct.

Neuro-interventions with *the sole* aim of punishment in the form of distressing (retribution) are inhumane and degrading, and should presumably be regarded as torture (Shaw, 2018, p. 261-262). There are no such interventions in Dutch law either.

The question is whether *coercion* (instead of coercion) to undergo a neurointervention is contrary to Article 3 of the ECHR, for example because deprivation of liberty is (further) enforced if the intervention is refused (Shaw, 2018, p. 459). That is not necessarily the case. In *Dvoracek* t. *Slovakia* (ECtHR 6 November 2014, 12927/13) the patient admitted to a psychiatric hospital was presented with a choice between the use of libido-inhibiting medication and psychotherapy for the treatment of a paraphilia associated with a genetic disorder. The psychotherapeutic treatment would take a relatively long time and would therefore result in a longer hospital stay, which forced Dvoracek to use the medication.

According to the ECtHR, however, there was no question of compulsory medication (par. 106). The fact that Dvoracek was faced with a difficult choice between the use of medication and an unattractive alternative is not necessarily in conflict with Article 3 of the ECHR. It may have been important that the treatment offered to Dvoracek had a medical reason and did not take place in a criminal context (par. 94. See also Forsberg 2018, 60; 2021, 396; Shaw 2018, pp. 258-259). At the same time, there is also jurisprudence that suggests that in the case of people who are in the hands of the criminal record authorities also find coercion can lead to a violation of Articles 3 and 8 ECHR (see the next section on this).

Article 3 ECHR contains not only a prohibition of inhuman or degrading treatment or punishment by the government, but also the positive obligation of the government to prevent citizens from subjecting other citizens to inhuman or degrading treatment, for example in the form of offenses involving the physical damage integrity (this obligation is also related to Article 2 of the ECHR, which protects the right to life) (Schabas, 2015, pp. 127-129; 191-194). Article 3 ECHR requires, among other things, that the government ensures an effective system of criminal law enforcement that can prevent recidivism (ECtHR 25 June 2009, 46423/06 *(Beganovic* v. *Croatia),* par. 85-86). If neuro-interventions can be applied in such a way that they reduce the risk of recidivism, they can contribute to fulfilling the positive obligation laid down in article(s) 3 (and 2) ECHR.

Enforced criminal neuro-interventions without acute medical necessity and neuro-interventions with retaliation – adding suffering – as the aim are contrary to Article 3 of the ECHR. Dutch criminal law currently offers no basis for such interventions. Article 3 ECHR seems to leave room for attaching a neuro-intervention as a special condition to sanctions. The fact that the imminent (further) execution of a sentence or measure exerts pressure on the suspect to undergo the intervention is not necessarily objectionable. However, as discussed in the next section, the ECtHR does not allow all forms of coercion under Articles 3 and 8 of the ECHR. It is also conceivable that the specific nature of some neuro-interventions gives the ECtHR reason to assess pressure situations more strictly, for example because a certain neuro-intervention requires brain surgery.

(ii) Neuro interventions and the right to respect for private life

Article 8 ECHR protects the right to respect for private life. The notions of self-determination and personal autonomy are important to the interpretation of Article 8 ECHR by the ECtHR (ECtHR 29 April 2002, 2346/02 *(Pretty* v. *United Kingdom),* par. 61). Decisions about medical treatment are therefore protected by the right to private life (Schabas, 2015, p. 371-374). This protection is far-reaching:

> *'The freedom to accept or refuse specific medical treatment, or to select an alternative form of treatment, is vital to the principles of self-determination and personal autonomy. A competent adult patient is free to decide, for instance, whether or not to undergo surgery or treatment or, by the same token, to have a blood transfusion. However, for this freedom to be meaningful, patients must have the right to make choices that accord with their own views and values, regardless of how irrational, unwise or imprudent such choices may appear to others. […] It was emphasized that free choice and self-determination were themselves fundamental constituents of life and that, absent any indication of the need to protect third parties – for example, mandatory vaccination during an epidemic, the State must abstain from interfering with the individual freedom of choice in the sphere of health care, for such interference can only lessons and not enhance the value of life […].'*
>
> (ECtHR 10 June 2010, 320/02 *(Jehovah's Witnesses of Moscow ea* v. *Russia),* par. 136.)

Neuro-interventions are medical in nature and violate a person's physical and psychological integrity. Physical and psychological integrity is protected by Article 8 ECHR (ECtHR 12 November 2013, 5786/08 *(Söderman* v. *Sweden),* par. 78-85; Schabas, 2015, 369-370). Although the ECtHR does not define psychological integrity precisely, it certainly includes mental health (ECtHR 26 November 2009, 25282/06 *(Dolenec* v. *Croatia),* par. 165). Neurointerventions can affect the mental health of those involved and thus infringe the right to private life (Ligthart et al., 2021). In addition, the personality in a broader sense enjoys protection under Article 8 of the ECHR (ECHR 10 June 2010, 320/02 *(Jehova's Witnesses of Moscow and* Others v. *Russia),* par. 117).

Forced medical treatment is without doubt an interference with the right to private life, in particular the right to physical integrity (ECtHR 3 July 2012, 34806/04 *(X.* t. *Finland),* par. 212). The ECtHR assesses compulsory medical treatment primarily on the basis of the criteria of Article 3 of the ECHR (cf. ECtHR 8 November 2011, 18968/07, *(VC* v. *Slovakia),* par. 144).

However, not only coercive treatment can be a restriction of the right to private life, but also the exercise of a strong urge to undergo medical treatment can be included (ECtHR 8 November 2011, 18968/07, (VC v. *Slovakia)).* This applies in particular in the case of persons who are in the hands of the criminal authorities and if negative consequences are associated with non-cooperation (see, inter alia, ECtHR 22 July 2003, 24209/94 (YF v. Turkey) ; ECtHR Apr 14, 2020, 75229/10 *(Dragan Petrovic* v. *Serbia)).* For example, the ECtHR ruled that the consent to a gynecological examination of a detainee after heavy pressure was exerted on her was not voluntary and therefore constituted an infringement of the right to private life (ECtHR 13 August 2008, 52515/99 (Juhnke v. *Turkey)) .* Although there is no reason to think that neuro-interventions that are attached to a sanction as a special condition always infringe Article 8 of the ECHR, it is clear that in some cases coercion can lead to a violation. The distinction made in Dutch law between coercion (involuntary) and coercion (voluntary) is therefore too broad, while the jurisprudence of the ECtHR is too casuistic to make more general statements on this subject (Bijlsma & Ligthart, accepted).

Insofar as setting a neuro-intervention as a special condition is a violation of Article 8 ECHR, it must meet the requirements of Article 8 paragraph 2 ECHR. First, the violation of fundamental rights must be provided for by law and that law must be surrounded by sufficient safeguards (cf. ECtHR 3 July 2012, 34806/04 *(X.* v. *Finland),* par. 216). The various sanction modalities to which neuro-interventions can be attached as a special condition were previously outlined. In those cases, the interventions are therefore provided for by law. Second, the restriction must be necessary in a democratic society and serve one of the legitimate purposes referred to in paragraph 2. The restriction must arise from a *pressing social need* and be proportionate to the aim pursued. Legitimate goals included in Article 8 paragraph 2 of the ECHR are the prevention of criminal offenses and the protection of health.

Rehabilitative neurointerventions can contribute to the legitimate goal of crime prevention. It is conceivable that (under certain circumstances) neuro-interventions that are undergone under duress constitute a violation of Article 8 ECHR, but are justified on the basis of the second paragraph (cf. Bijlsma 2019, p. 69-70). Several factors will play a role in assessing whether a neurointervention is necessary in a democratic society. The existence or non-existence of less drastic alternatives is important. The magnitude of the infringement that the intervention makes on the physical and psychological integrity of the person concerned must be in proportion to the nature of the criminal offense that the intervention is intended to prevent. The effectiveness of an intervention can play a role in the assessment of necessity (Forsberg, 2021, 399-403). Ten

Finally, it is also relevant that some neuro-interventions influence the psyche of the person concerned. Given the ECtHR's emphasis on self-determination and personal autonomy, it is not inconceivable that it would set strict requirements for the justification of such interventions (cf. Bublitz, 2018, 301-302), although this issue could also be raised in connection with the right to freedom of thought and conscience protected by Article 9 of the ECHR.

It is unclear to what extent criminal neuro-interventions infringe the right to private life protected by Article 8 ECHR. Because the suspect himself chooses whether or not to comply with the condition, it is not evident that Article 8 of the ECHR has been infringed.
At the same time, the urge that emanates from the (further) enforcement of deprivation of liberty may nevertheless lead to a violation of Article 8 of the ECHR. That infringement may be justified on the basis of the second paragraph of Article 8 of the ECHR, but that strongly depends on the circumstances of the case. The specific nature of neurointerventions probably also plays a role in that assessment.

(iii) Neuro-interventions and freedom of thought and conscience

Article 9 ECHR protects freedom of thought, conscience and religion, the *forum internum.* The case law of the ECtHR on this article mainly concerns restrictions on the exercise of religion (Schabas, 2015, 419-420). However, in connection with detection methods and neurointerventions, freedom of thought and conscience are particularly relevant (Bublitz, 2014; Ligthart, 2021, p. 114-152). A neurointervention that stimulates the brain can potentially influence thought formation. Article 9 ECHR enjoys absolute protection:

> *'The fundamental nature of the rights guaranteed in Article 9 § 1 of the Convention is also reflected in the wording of the paragraph providing for limitations on them. Unlike the second paragraphs of Articles 8, 10 and 11 of the Convention, which cover all the rights mentioned in the first paragraphs of those Articles, that of Article 9 of the Convention refers only to 'freedom to manifest one's religion or belief'. In so doing, it recognizes that in democratic societies, in which several religions coexist within one and the same population, it may be necessary to place restrictions on this freedom in order to reconcile the interests of the various groups and ensure that everyone's beliefs are respected […]. At the same time, it emphasizes the primary importance of the right to freedom of thought, conscience and religion and the fact that a State cannot dictate what a person believes or take coercive steps to make him change his beliefs.'*
>
> (ECtHR 12 April 2007, 52435/99 *(Ivanova* v. *Bulgaria),* par. 79.)

Vermeulen & Van Roosmalen (2018, 748) write about this:

> *'This protection guarantees that the state may never interfere in this most intimate and inner sphere, for instance by dictating what a person has to believe, by taking coercive steps to make him change his beliefs ('brain washing' etc.), or by using inquisitorial methods to discover what his personal thoughts and convictions are.'*

It is important that it is unknown what the precise scope is that the ECtHR assigns to the terms 'thought' and 'conscience'. They must know a *'level of cogency, seriousness, cohesion and importance'* in order to be protected by Article 9 ECHR (ECtHR 1 July 2014, 43835/11 *(SAS* v. *France),* par. 55).

Article 9 ECHR therefore does not seem to protect *every* thought and moral notion, no matter how trivial (Ligthart, 2020).

Rehabilitative neurointerventions aim to influence the psyche and can therefore affect thoughts, thought formation and conscience. It is currently unclear whether the latter is really the case in the case of neuro-interventions. The absolute protection offered by Article 9 of the ECHR in this area means that forced neuro-interventions with an effect on thoughts and conscience may conflict with Article 9 of the ECHR (Bublitz, 2014, 9). It is then required that it concerns thoughts *etc.* that fall within the scope of Article 9 paragraph 1 ECHR. Because the scope of these concepts is unclear, it is not certain under which circumstances neuro-interventions are in conflict with Article 9 paragraph 1 ECHR (Ligthart, 2020; Ligthart et al., 2021). Nor is it clear how far-reaching neurointerventions are in this respect. What is special about some neuro-interventions is that they *directly* (physically) influence the brain. They do not work in *an indirect* (psychological) way, such as arguments or psychotherapy. Because neurointerventions can influence thoughts beyond the rational control of the subject, they may be more problematic from an Article 9 ECHR point of view than more 'classical' methods of influence (cf. Bublitz, 2020a; Ligthart et al., 2021).

The aim of the intervention may also be relevant here. When it comes to medically necessary interventions, there seems to be some scope for limiting the rights laid down in Article 9 of the ECHR (Bublitz, 2014, 10). In *Mockute* t. *Lithuania* (ECtHR 27 February 2018, 66490/09) the coercion exercised on a psychiatric patient forcibly committed as part of her treatment to change her religious views is considered an interference with the right to freedom of religion. The ECtHR then assesses whether this interference was justified on the basis of Article 9(2) of the ECHR. Although the answer is negative (partly with reference to the consideration from *Ivanova* v. Bulgaria cited above), the review suggests that a restriction may be justified under very special circumstances. The question is whether this also applies to criminal neuro-interventions, in which the focus is not so much on the therapeutic interest of the person involved, but above all on the interest of society in preventing recidivism.

It is unclear whether neuro-interventions interfere with the mental life of the person concerned in such a way that article 9 ECHR is at stake. Insofar as that would be the case, there seems to be (virtually) no room for forced neuro-interventions. Also in connection with Article 9 of the ECHR, the question arises whether the choice that a convicted person has between the intervention and (further) deprivation of liberty means that there is no question of a restriction, or whether the pressure exerted by the deprivation of liberty on the convicted person is such that a limitation must be spoken.

(iv) Neuro-interventions and freedom of expression

Article 10 ECHR protects the right to freedom of expression. Neuro-interventions using brain scans map brain processes. The ECtHR does not exclude that Article 10 ECHR also contains the right to *refrain* from disseminating opinions, ideas and information (ECtHR 23 October 2018, 26892/12 *(Wanner* v. *Germany),* par. 39). Insofar as neuro-interventions (will) offer insight into the mental processes of a person involved, they could affect a possible negative right to free expression (Ligthart, 2020). However, it is not evident that the registered brain processes should be seen as opinions, ideas or information (Ligthart et al., 2021). The right to freedom of expression may be restricted if this is necessary in a democratic society in view of one of the purposes described in paragraph 2 (including the prevention of criminal offenses and the protection of health).

(v) Neurointerventions and the positive commitment to rehabilitation

In connection with detention that is (partly) based on the risk of recidivism emanating from a person, the ECtHR has determined that the government has a positive obligation to offer the person concerned the possibility of rehabilitation (Meijer, 2017). The execution of a life sentence may eventually become contrary to Article 3 of the ECHR if the convicted person is denied access to treatment that may contribute to rehabilitation (ECtHR 26 April 2016, 10511/10 (Murray v. *Netherlands),* par. 108). Such an obligation may also apply in the case of security measures such as the TBS. The ECtHR has ruled that it may be contrary to Article 5 of the ECHR to continue detention solely on the basis of the risk of recidivism if appropriate therapies are not offered to reduce the risk. The convicted person must have a chance of rehabilitation and thus release (ECtHR 7 September 2017, 45953/10 *(DJ* t.

Germany), par. 58). This reasoning may also be relevant for other sanctions, although the ECtHR has not commented on this. After all, a reason for imposing a suspended sentence may be that the court does not consider deprivation of liberty necessary if the risk of recidivism is sufficiently reduced by means of treatment (for example a neuro-intervention). The question can be raised whether deprivation of liberty is justified if the convicted person is not given the opportunity to use an alternative.

The positive obligation to rehabilitation may mean that the government is obliged to offer certain neuro-interventions if this enables a convicted person to reduce his or her risk of recidivism to such an extent that rehabilitation and thus release is possible.

(d) Discussion

In the foregoing, constitutional law issues related to neurointerventions in a judicial context have been discussed. It is clear that this is a complex force field. On the one hand, there are fundamental rights that require restraint or perhaps sometimes refraining from using neuro-interventions (art. 3, 8, 9 and 10 ECHR), on the other hand, positive obligations can sometimes force neuro-interventions to be offered (especially Article 5 ECHR). The interplay between these partly conflicting norms still needs to crystallize further in case law. It is important to note that the ECtHR assesses each case on its merits. Due to this case-based approach, in which the national context also plays an important role, it is difficult to make general statements about the (in)admissibility of forms of neuro-interventions in a judicial context. In addition, neurointerventions make it possible to directly intervene in brain processes in ways that were not possible before. This can create a new, unpredictable dynamic in ERHM case law. For example, it is conceivable that the previously little-pronounced right to freedom of thought and conscience will become more important (Bublitz, 2014; Ligthart et al., 2021).

Within these limitations, it is possible, based on the analysis in the preceding paragraphs, to identify factors that are likely to be important in assessing how a judicial neuro-intervention relates to the fundamental rights protected by the ECHR:

- *The aim of the intervention.* In exceptional cases, where there is an acute danger, it is possible to enforce treatment with a purely medical purpose. In a criminal justice context, where the goal is rehabilitation by reducing the risk of recidivism, physically enforced neurointerventions are highly problematic and presumably not allowed. Neuro-interventions with a purely punitive purpose (addition of distress) are not permitted.

- *The drastic nature of the intervention, including any side effects and risks.* Neurointerventions have been defined above as 'techniques that alter the brain with the aim of reducing danger'. This includes non-invasive techniques such as tDCS, TMS and FUS, but also techniques that require brain surgery, such as DBS. Some of these techniques could be used with the aim or side effect of influencing thoughts or possibly even personality. The more far-reaching an intervention is and the longer the effects last, the more likely there will be an infringement of fundamental rights. Both the physical and the mental effects are important in this factor.

- *The degree of coercion applied.* In a judicial context, it is not about the normal situation in which a patient has to make a decision about whether or not to follow a treatment, but the person concerned is often under pressure because refusal to undergo the intervention leads to (continuation of) deprivation of liberty. According to the Dutch legislator, this urge does not stand in the way of the voluntary nature of undergoing the intervention, but the ECtHR is more nuanced about this. The degree of coercion exerted on a person varies. A relatively light suspended sentence exerts less pressure on a convicted person to undergo an intervention than a threatened placement in a *long*- stay unit or continuation of a life sentence because there are no other treatments outside the intervention that can lead to a sufficient reduction risk of recidivism in order to proceed to release. The less pressure is exerted on the person concerned and the more the person concerned's freedom of choice is paramount, the less problematic an intervention will be. The context can be important here. There may be an obligation to offer a certain intervention in connection with those sentenced to life imprisonment and TBS detainees, even if the alternative is continuation of the deprivation of liberty.

- *The availability of (less drastic) alternative interventions (subsidiarity) and the relationship between means and goal (proportionality).* When assessing whether an infringement of a fundamental right is necessary in a democratic society, the ECtHR tests against the principles of subsidiarity and proportionality.

- *The effectiveness of the intervention.* The more effective an intervention is in reducing the risk, the more likely its application will be justified. After all, this means that the application can better meet the aim pursued and will therefore be deemed necessary or more likely to justify a restriction of fundamental rights.

These factors interact with each other. It is not inconceivable that neuro-interventions that make a very limited violation of fundamental rights do not require the consent of the person concerned. For example, nutrition seems to be able to reduce aggression in penal institutions (and possibly also the risk of recidivism) (Zaalberg, 2018). Because the way brain functions is influenced by nutrients, replacing an unhealthy food supply in a penitentiary with a varied, healthy supply can be regarded as a neuro-intervention as defined above. Unilateral adjustment of the food supply in a prison to reduce violent incidents does not appear to be problematic from a constitutional point of view, partly in view of the positive obligation to rehabilitation (Ligthart et al., 2019). This consideration may already turn out differently if it concerns the administration of nutritional supplements that detainees cannot avoid. The non-invasive forms of brain stimulation (tDCS, TMS) that can be applied in a judicial context to (for example) reduce aggression (Sergiou et al., 2021) may be conceivable as a special condition for various sanction modalities. The suspect must of course agree to this.

At the other end of the spectrum are the interventions that require brain surgery in which electrodes are placed in the brain (such as DBS). This involves a deep intervention in the physical and mental integrity of the person concerned. Situations in which such a risky procedure can be performed without permission are actually unthinkable, except perhaps as a last resort in a medical emergency. At the same time, it cannot be ruled out that such an intervention (in the future) is a last chance to rehabilitate a person sentenced to life imprisonment or to prevent a TBS detainee from ending up in a long stay *ward* . In that case, on the basis of Article 5 ECHR, it may be problematic to withhold this treatment from the person concerned, even if it cannot be said that the decision to undergo the intervention is made without strong pressure (after all, the alternative is potentially lifelong imprisonment). Setting such an intervention as a special condition to (for example) a suspended sentence appears to be problematic. It is difficult to imagine that in that case no less far-reaching alternatives are available and, moreover, the risk of recidivism is of a completely different nature than is the case in the case of a person sentenced to life imprisonment or a TBS. In that context, urging a convicted person to have an implant placed through the threat of a prison sentence is problematic from a human rights perspective.

(e) Final remark: new fundamental rights

This research focuses on the existing human rights framework. It should be noted here that it is argued in the literature that this framework may offer too little protection against the application of neurotechnology, also in a criminal law context. Constitutional amendments are therefore being prepared in Spain and Chile that should lead to the codification of new fundamental rights that provide protection against certain forms of use of neurotechnology (and artificial intelligence) (Ligthart et al., 2021, 1790). The idea behind this is that the existing constitutional frameworks offer citizens insufficient protection. While judicial neurotechnologies can be associated in various ways with classical fundamental rights such as the right to a fair trial, the prohibition of inhuman or degrading treatment or punishment and the right to respect for private life, the precise protection these fundamental rights offer against the use of neurotechnology (as yet) unclear (see the previous chapters). Classical fundamental rights mainly protect the physical, external sphere (physical integrity, freedom of expression, *etc.).* However, neurotechnologies make it possible to intervene *directly* in the internal sphere, not only physically in the brain *(brain),* but also in the psyche *(mind).*

Therefore, proposals are made for recognizing a fundamental right to mental freedom, privacy and/or integrity, which protects the right to dispose of one's own mind and to decide on the application of neurotechnologies (Bublitz, 2013; 2018; 2020; Bublitz & Merkel, 2014; Douglas, 2020, pp. 381-382; Douglas & Forsberg, 2021; Ienca & Andorno, 2017; Sententia, 2006). Other proposals advocate adaptation of existing fundamental rights. In particular, a reformulation and elaboration of the currently underdeveloped right to freedom of thought and conscience could provide protection against involuntary application of neurotechnology (Bublitz, 2014; McCarthy-Jones, 2019). Finally, the point of view is defended that (dynamic interpretation of) the entirety of existing fundamental rights (particularly Articles 3, 6, 8 and 10 ECHR) can offer sufficient protection (Ligthart et al., 2021; Michalowski, 2020). with *brain reading:* Ligthart, 2020; Ligthart et al., 2020).

11.Ethics

The part of ethics that examines the normative aspects of neurotechnology is referred to as *neuroethics* (Clausen & Levy, 2015; Ienca, 2021b). Neuroethics is concerned with ethical dimensions of the use of neurotechnology in all areas of society, including healthcare, warfare, criminal justice, and commercial products (Clausen & Levy, 2015). The ethical relevance of (future) application of neurotechnology within the justice domain is widely recognized (Petersen & Kragh, 2017a; Petersen & Kragh, 2017b; Canavero, 2014; Umbach et al., 2015; Kirchmair, 2019; Meynen, 2019a, b, 2014; NIH, 2019; Greely, 2013; Chew et al., 2018). It can be said that the ethical considerations regularly touch on the legal ones, but often in slightly different wording and terminology. For example, where lawyers can talk about human rights, as for example contained in the European Convention on Human Rights (ECHR), ethicists can refer to ethical values and principles or fundamental rights (Ienca & Andorno, 2017; Lavazza, 2018). Ethicists and lawyers also sometimes work together in their research, which means that the line of thought is partly legal and partly ethical (Ienca and Andorno, 2017).

Sometimes a lawyer also writes a neuro-ethical contribution, sometimes an ethicist writes about the ECHR. In short, it is not always easy to define what constitutes an ethical and what constitutes a legal analysis. In any case, the text below will primarily look at ethical values and principles and will not take the legal frameworks as a starting point; more precisely, the text is organized according to ethical principles, not according to the three domains *of detection and truth-finding, risk assessment* and *intervention.*

Central themes from ethics are: privacy, autonomy, physical and mental integrity, and human dignity. These are not the only ethical issues mentioned in relation to emerging neurotechnologies; similarly, *agency,* identity, and freedom of thought are regularly discussed (Goering et al., 2021; Yuste et al., 2017; Ienca, 2021b). [11] In addition, the different concepts are not always clearly delineated from each other. [12] In the following it will not be attempted to provide an exhaustive overview of the ethical discussion; the aim is to briefly identify some key ethical points for the justice and security domain. It becomes clear that each of the ethical values is, at least in principle, relevant to *investigation and truth-finding, risk assessment,* as well as *intervention.*

(a) Human dignity

One of the experts interviewed indicated that human dignity is what *ultimately matters* in protecting fundamental rights with regard to these neurotechnologies: seeing people not as objects, but as ends within themselves, referring to the Enlightenment philosopher Immanuel Kant . So you would have human dignity as one

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[11] For example: *identity, agency* (Yuste et al. 2017), psychological continuity ('a *special neuro-focused instance of the right to identity',)* and also 'cognitive liberty' (Ienca 2021b, a). In our analysis, we focus on the normative concepts of privacy, autonomy, mental and physical integrity and human dignity. Incidentally, there are also clear connections between the aforementioned terms and the concepts we discuss, such as between 'cognitive liberty' and autonomy: 'there is a general consensus *in the literature that cognitive liberty entails a person's autonomous, unhindered control over their mind' (Ienca* 2021b).

12 Lavazza connects privacy with autonomy (Lavazza 2018). See also (Rainey et al. 2020) for such a link. Wajnerman Paz links mental privacy with psychological integrity (Wajnerman Paz epub ahead of print) And authors also link 'mental privacy' with 'freedom of thought' (Ienca 2021b).

overarching – or, if you like, foundational – understanding of the ethical values to be discussed below. For example, Shaw (2018), Sieber (2019) and Holmen (2021) also seem to use it. Although the theme is mentioned (Lavazza, 2018; Müller & Rotter, 2017; Shaw, 2018), it is, at least in our impression, generally less elaborated in the ethical13 literature on neurotechnology than, for example, privacy, autonomy (including consent) , and mental and physical integrity. At the same time, as a foundational or overarching concept, it is closely connected with this. Human dignity is relevant for both *investigation and truth-finding,* as well as *risk assessment* and *intervention .*

(b) Privacy

Goering et al. (2021) define privacy as follows: *'a right that others do not access one's personal information and personal space'.* As far as neurotechnology is concerned, it mainly concerns those techniques that 'retrieve information from the brain', which is also referred to as *brain reading* (Roelfsema et al., 2018). More precisely, it concerns techniques *insofar as* they extract information from the brain (see the technical part in which a distinction is made between techniques that measure brain activity, both measure and stimulate, or only stimulate). It is obvious that some techniques both intervene in the brain and extract information from it. An example is *adaptive* or *closed loop deep brain stimulation* (Gilbert et al., 2018). On the one hand, brain activity is registered and analyzed, on the other hand, the brain is stimulated (partly) on the basis of this input and thus changed. Information about someone's brain is also obtained with this technique, and privacy is relevant to that extent. This means that privacy, although primarily relevant for *investigation, truth-finding* and *risk assessment* (which, after all, collect information) can also be relevant for *intervention.*

The idea is that *brain reading* is not just about information that is private, but information that is pre-eminently private, namely data about our mind, which touch on our thoughts and intentions/tendencies (Meynen, 2020b; Goering et al. ., 2021). Incidentally, at the moment we cannot simply read thoughts and intentions/tendencies from brain signals, but research is being done. In any case, privacy is a central ethical concern with these technologies (Lavazza, 2018). the term *mental privacy* is also used (Ienca & Andorno, 2017). This [14] For the privacy that is particularly at stake in neurotechnology, can be interpreted as follows: *'Mental privacy is the expression generally used to denote people's right against the unconsented intrusion by third parties into their brain data as well as against the unauthorized collection of those data' (Ienca,* 2021b). Ienca and Andorno point out that neurotechniques can not only extract mental information from the brain, but that people can also be identified on the basis of their brain (activity) (for identifiability and brain scans, see also Eke et al., 2021) , as is currently the case with DNA or fingerprints – thus adding another dimension to privacy considerations.

According to Roskies (2015), two questions are relevant for a neuroethical analysis of privacy in the light of *'brain reading',* the first she qualifies as scientific, the second as ethical: 1) Which

13 A legal article in which dignity is clearly thematized in relation to Art. 3 ECHR is (Kirchmair 2019)
14 Insofar as applications within the medical domain are concerned, the information can also be referred to as *confidentiality* (Meynen 2019a).

information is obtained with a certain technique? 2) What is then done with it?
Roskies (2015) emphasizes that for an analysis of what is and what is not allowed with regard to a particular neurotechnique, a good understanding of the possibilities and limitations of the technology is essential. In addition to the margin of error of the measurement and its generalizability, ecological validity also plays a role in this. This last point raises the question of whether a technique that may work well in a laboratory setting also functions well in the *context of actual use* – perhaps in court. That situation can be very different, for example because – in the case of a criminal case – a suspect tries to manipulate a measurement, while test subjects in a laboratory setting (probably) do not (Meynen, 2019a). This is therefore about the generalizability of the results. Subsequently, the possible harmfulness of the technology, consent (it matters whether someone agrees or not with the technology – see also *autonomy)* and alternative ways of obtaining the same information (Roskies, 2015) are important .

There is debate about whether the information obtained through neurotechnology should be regarded as unique or special (Schick, 2005). For example, DNA can also contain very sensitive personal information, and it cannot be ruled out that in the future much more personal information – also with regard to desires and preferences that people have – may become available through DNA. Incidentally, non-biological data can also contain personal information that can reveal a lot about our preferences, such as our internet behavior (Meynen, 2020b). Whether the neuro-data is unique or not compared to other sources of information, privacy is a central ethical issue with regard to this technology.

There are concerns that the current legal frameworks (particularly ECHR) do not sufficiently protect people against invasions of privacy by neurotechnology (see also the legal chapters). Ienca and Andorno (2017) therefore advocate a right to mental privacy – or brain privacy – that *'aims to protect people against illegitimate access to their brain information and to prevent the indiscriminate leakage of brain data across the infosphere.'* When you subscribe to such a fundamental right, the question then arises whether this right must also be *absolute* (Roskies, 2015). Ienca and Andorno (2017) point out that there are of course other ways in which biological information is obtained from people involuntarily, such as DNA in the context of detection. The question then is whether an argument can be made that shows that brain data is so special that it should remain completely outside the reach of the judicial authorities.

(c) Autonomy

Respect for one's autonomy is a central bioethical principle (Beauchamp & Childress, 2019).
We want people to be able to make *their own* decisions about their lives, for example about their medical treatment. In principle, therefore, medical treatment can only be given if someone gives *informed consent.15* That person must therefore be well informed and then freely choose to give informed consent.

15 There are exceptions, such as when a patient is unconscious and action must be taken.

Autonomy also plays an important role with regard to neurotechnology. This concerns the autonomy of the person who undergoes the technology, on whom it is applied, for example a convict. Its autonomy is, it turns out, ethically relevant in several ways.

First, it concerns the choice of a suspect or convict to allow neurotechnology.
You could say that as long as a convicted person *agrees* to the use of the technique – for example a brain scan to estimate the risk of recidivism – the use of the technique is permissible. After all, there is *consent.* But there are reservations about this. To what extent is the *autonomous* choice of the convicted person threatened by the fact that the offer to apply a neurotechnique is made in an involuntary context, such as in a prison, for example as a condition of early release? Can you really see the choice as voluntary, or are you in fact dealing with, in the words of the *godfather, 'an offer you can't refuse'?* (Meynen, 2020a)

In fact, the coercive nature of the criminal justice context makes autonomous choice a central concern (Douglas, 2014). For example, Fuss and his colleagues (2015) state in an article on the use of deep brain stimulation in sex offenders that its use should not be associated in any way with parole (incidentally, there is currently no deep brain stimulation available for this indication, so it is a hypothetical consideration).
But the question is whether their proposal is realistic (Meynen, 2019b). After all, if the risk decreases through the use of a technique, someone could go outside sooner. And if that person can go out earlier, why not let that person go out earlier? And should we then ignore that very important consequence for a person – even if that person asks about it, for example? And more generally, when you discuss a neurotechnique to reduce recidivism with someone who, for example, is forced to stay in a forensic institution, then it is obvious to also discuss such a drastic technique in the light of resocialisation, something in which a forensic institution is constantly being worked towards? (See also (Meynen, 2020a)). In addition, rehabilitation is not only important for the judiciary and society, it is also something that is probably very relevant for the person involved. But when you start discussing these technologies in the context of resocialisation – and more precisely early release – then a *'sacrifice you can't refuse'* is looming . And then the question is whether you are dealing with real *consent .* This point applies to *investigation and truth-finding* as well as *risk assessment* and *intervention.*

Besides the perspective of *consent,* there is a second way in which autonomy is relevant in relation to these interventions. The neurointervention itself could influence someone's autonomy. The *closed-loop deep brain stimulation* has already been mentioned above, in which the device itself – for example via an algorithm – can regulate the brain stimulation. With that stimulation, the person himself is therefore out of the game, the deep brain stimulation device is 'in control'. The question then is what it does to someone's autonomy when the device is in fact 'at the controls' (Gilbert et al., 2018; Kellmeyer et al., 2016; Ligthart et al., accepted). To assess the impact of DBS on someone's autonomy, it has been advocated to also look at the experiences of patients (Roelfsema et al., 2018). More generally, neurointerventions could influence how someone makes decisions, and that can have ethically objectionable influence on someone's autonomy.
It is clear that this ethical concern about the autonomy of *intervention* is important.

A third point has been raised with regard to autonomy. Namely, in scenarios in which the neurointervention enhances a person's *future* autonomy by improving the person's ability to control their own life (Ligthart et al., accepted). Ligthart et al. write: *'For example, suppose the rehabilitation of an offender has failed several times because of behavioral patterns that he apparently cannot shake off – much to the offender's own regret. In this way, he will* *never be able to build the life in the community he desires. If a correctional CBD [closed-loop brain device] targets those mental/ brain states that undermine the offender's rehabilitation, the CBD might be considered to empower the offender, increasing his autonomy, at least in the sense of having control over one's life.'* So although there is a problem with autonomy in the present (is your choice really autonomous and the consent valid?), autonomy could be strengthened by it in the future. This possible positive effect on someone's autonomy is also ethically relevant. Although the example focuses on an intervention *(closed loop* DBS), in principle certain forms of neurotechnological monitoring in the context of *risk assessment* could enable convicts to gain more control over their lives during rehabilitation. After all, this monitoring could offer the person the opportunity to adjust his behavior before something goes wrong that would make his rehabilitation fail.

With regard to autonomy, one of the interviewees also mentioned the 'double vulnerability' of people with a disorder in detention, more specifically in forensic patients: they are detained/detained and also have a mental disorder. How does this affect the consent they can give?

An autonomy-related point that is briefly mentioned here concerns the responsibility for action. When someone under the influence of a neurotechnological *(closed loop)* device performs a certain (possibly even criminal) act, who is responsible for it - the producer of the device or the person who performs the act? (Clausen et al., 2017; Yuste et al., 2017) In other words, if the device becomes autonomous, what does that do to the person's responsibility?

(d) Mental and physical integrity

Mental and physical integrity is also a central theme, which can be linked to *'freedom of thought' (Douglas,* 2014, 2019; Lavazza, 2018; Yuste, et al., 2017; Petersen & Kragh, 2017a).

The distinction between mental and physical integrity may seem dualistic, as if there is a strict separation between mind and body, but it is not intended that way. It's more about two types of ethical concerns. One concerns the inviolability of the body. The other concerns the point that we want our thinking, or more broadly, our mental life, to be *free* , unaffected. These are two types of concerns, which in themselves are not intended to say anything about the connection between mind and body. Concerns about physical integrity apply in particular to interventions in the brain, i.e. techniques that change something, but in principle *neuroimaging* techniques could also violate the integrity of the body if, for example, they require surgery.

A distinction can be made between two ways in which physical integrity can be violated, namely the intended brain change (i.e. changes in the structure of the brain or the function of neurons), and additional changes, such as surgery to insert DBS electrodes into to bring. For example, an incision will have to be made in the skin and the skull pierced. This is necessary to place the electrodes in the right place so that they can bring about the intended change in the brain.

A distinction can also be made between reversible and irreversible changes.
Where traditional psychosurgery (such as lobotomy) caused irreversible changes in the brain (through destruction of tissue), nowadays DBS can become reversible.

intervention, in the sense that the stimulation can also be stopped (or changed) (although the degree of reversibility is debated (Pugh, 2019); surgically placed parts are obviously more difficult to 'reversible' than the stimulation).

Douglas (2014) has argued that it is not said that imposed medical interventions in the context of rehabilitation of convicts are always unacceptable. He points out that interventions are already taking place within the justice and security domain: convicts with an addiction are required to use medication in some legal systems, and sex offenders are sometimes required to take libido-lowering medication.

While physical integrity is certainly relevant to neurotechnology, it is mental integrity that is most specific to neurotechniques. Ienca and Andorno (2017) argue that mental integrity in particular deserves better protection than it currently has legally. They recognize that mental integrity is protected in itself in Europe: *'The right to personal physical and mental integrity is protected by the EU's Charter of fundamental rights (Article 3), stating that 'everyone has the right to respect for his or her physical and mental integrity.'* Their objection, however, is that there is no explicit reference to neurotechnology: *'The provision focuses in particular on four requirements: free and informed consent, the noncommercialization of body elements, and the prohibition of eugenic practices and human reproductive cloning. No explicit reference is made to neurotechnology-related practices.'* In their opinion, therefore, specific attention should be paid to neurotechnology with regard to mental integrity. They also define what constitutes a threat to *mental integrity : 'For an action X, to qualify as a threat to mental integrity, it has to: (i) involve the direct access to and manipulation of neural signaling (ii) be unauthorized –ie must occur in absence of the informed consent of the signal generator, (iii) result in physical and/ or psychological harm'* 2017). A slightly different formulation of mental integrity that focuses more on cognitive [16] (Ienca & Andorno, abilities can be found in (Lavazza 2018): *'Mental integrity is the ability to formulate thoughts, judgments and intentions, make plans and implement them without direct external interference of any kind due to neurotechnology.'* In fact, this formulation also comes close to autonomy. clear that mental integrity and autonomy touch each other, or partly overlap. When someone's brain or *mind* is [17] (Incidentally, manipulated or when someone's thoughts are interfered with, this can of course affect, undermine that person's autonomy.)

The right to mental privacy and the right to mental integrity need not be absolute (Lavazza, 2018; Ienca & Andorno, 2017). When you state that the right is absolute, then you are in a sense quickly done. However, the problem is that such an absolute position can be difficult to defend, for example because it can be difficult to indicate exactly why this source of information now deserves absolute protection and others – such as DNA, internet (search) behavior – do not. And with regard to mental integrity, you can say that medication is already being used in forensic psychiatry (Petersen & Kragh, 2017a). For example, libido-inhibiting medication is used in forensic psychiatry in some people, which has (or can have) an impact on (the intensity of)

16 We note that the third criterion is specifically about *harm* , so it goes beyond mere change of psyche or body.

17 In a paper on autonomy in the light of (neuro)technology, McCarty Jones (McCarthy-Jones 2019) refers to Metzinger's formulation of mental autonomy: 'the specific ability to control one's own mental functions, like attention, *episodic memory, planning, concept formation, rational deliberation, or decision making, etc.' (Metzinger* 2013)

one's sexual desires. If, on the other hand, you state that it is a relative right, you must indicate where exactly the boundary lies.

(e) Additional Ethical Considerations

A point of a more general nature that the ethicist Ryberg (2021) emphasizes is that we must keep an eye on the *actual* application of neurotechnology in the justice and security domain. He points out, for example, that some interventions – psychopharmacology and psychosurgery – might be defendable in theory (in an ideal situation), but that history shows that things can go wrong in practice. At the same time, his view is not that *because* things went wrong in the past, such techniques would never be acceptable again. Attention to factual application and circumstances also means that, as far as Ryberg is concerned (2020), we should take a good look at the shortcomings of the current way of dealing with crime, punishment and the prevention of recidivism. For example, he points to conditions in prisons that are also less than ideal – or far from ideal – although this may vary from country to country. And he mentions another interesting point, which is the role of doctors. Insofar as neurotechnologies are to be applied in practice by doctors, their medical ethics apply. And when there appear to be *medical-ethical* objections to application by doctors, this can de facto block the use of these techniques (Ryberg, 2020). At the same time, one interviewee noted that if interventions were used to treat disorders, illnesses this would be less problematic than if the techniques were used purely to influence behaviour.

One interviewee indicated that it is important if we want to gain more insight into the practical permissibility of techniques in the judicial domain to also talk to the people who are concerned or may be concerned (e.g. forensic patients) about how they feel about this and also with victims and therapists, lawyers and judges. Then describe techniques to them in some realistic way for the moment. You can then better understand how they think about 'reading' and interventions. It is not so much about whether they think it is possible or not, but how do people think/reason about this? What arguments do they have? In line with this suggestion, research has recently been carried out with a specific group of forensic patients (Knack et al., 2020). This showed, among other things, the importance of fully *informed consent.*

It was also mentioned by an expert that techniques can/will initially have an experimental character, and that these techniques may have a positive effect on society, but that they may turn out less well for the group undergoing the intervention. At the same time, research ethics demands the protection of the subject, not of society. This may have consequences for the admissibility of certain experimental applications.

You can also imagine that *neuroimaging* with a view to recidivism reveals a medical problem (such as a tumour) in the person in question. Suppose you have applied *neuroimaging* under duress , should you inform someone (a suspect/convict) of this medical condition? Does he or she have the right to (not) know?

An additional concern with regard to neurotechnology is *bias* by algorithms (artificial intelligence) (Goering et al., 2021; Ienca, 2021b, a). For example, it has been reported that certain algorithms used within the justice domain were biased, for example with regard to race and gender (Tortora et al., 2020). This is obviously an essential point of attention. At the same time, because this concern is not specific to neurotechnology – but applies more broadly to artificial intelligence applications – we will not elaborate on it here. Nevertheless, it's good to be here because there is a good chance that neurotechnology, which can ultimately be used in criminal law, will work with algorithms.

In addition, the neurotechnologies under consideration are generally still in development. So you could say: wait until they arrive, then we can start thinking about it. An argument for starting an ethical/legal analysis earlier anyway is that if you wait for the techniques to be there, you are in fact too late: ' *If we wait for this technology to be fully developed before deciding how to regulate it , by the time it is already developed, the technical features and social practices associated with it may become too culturally entrenched to be easily modified.' (Wajnerman* Paz, epub ahead of print, see also Mecacci & Haselager, 2019).
Wajnerman Paz cites *Facebook* and *Cambridge Analytica* as examples of a situation where we were 'too late' in ethical and legal thinking about the normative aspects and regulation of new technology.

(f) Conclusion

Consideration is already being given to the ethical aspects of (emerging) neurotechnologies, including with regard to the justice and security domain. This concerns both techniques that register brain activity and techniques that change it. Privacy is a central issue – although there is some discussion about the extent to which brain data should now be seen as 'unique' compared to, for example, DNA data. To articulate the specific nature of privacy concerns, mental privacy is also referred to. This concerns the registration of the data, its storage and possible distribution.

Autonomy is relevant in (at least) three ways. Firstly: does the consent of a suspect or convict with neurotechnology really constitute a free, autonomous choice? Or is there a risk of accepting *'an offer you can't refuse'?* Second, neurotechnology that changes the brain can also influence a person's choice process. In this way, the autonomy of that person could be threatened/undermined. Thirdly, if neurotechnology helps people to arrange their lives more in the long term as they would like, then neurotechnology supports their future autonomy.

Mental and physical integrity are particularly important during *intervention.* The literature advocates better protection of mental integrity through neurorights than is currently the case. An immediate question is whether such protection should be absolute, or whether infringements should be possible under certain circumstances.

Human dignity seems to play an overarching – or foundational – role in the considerations mentioned above. In other words, with a view to respect for human dignity, the implications of neurotechnology for privacy, autonomy, and mental/physical integrity are being considered.

Additional ethical points can be mentioned: have an eye for how technologies work in practice in the justice and security domain – do not approach the normative questions only from a theoretical perspective, but also look at the (sometimes harsh) reality of prisons, for example. In addition, take *bias* into account when using algorithms in neurotechnology.

Section 3. Synthesis

This report focuses on the opportunities and risks of neurotechnologies for the justice and security domain. As described earlier, a technique presents an opportunity if it is effective (and to some extent efficient) in achieving one or more of the goals central to the domains covered: detection and truth-finding, risk *assessment and* intervention .
Risks consist of tensions with legal and ethical standards and possible unintended, negative side effects of applying newly developed knowledge and technologies.

In section 1 we discussed the technologies themselves. We described the current neurotechnologies and their use in the clinical and neuroscientific domain, as well as the latest developments in improving existing technologies and the more recently emerging technologies. In the description, a distinction is made between techniques that work on the basis of magnetic, electrical and metabolic signals and techniques that can measure, stimulate or both brain signals. We also discussed technologies that can visualize the anatomical structure of the brain.

A number of the technologies described in section 1 are relevant to the justice and security domain. For example, research is being done into the possibilities of detecting deception or knowledge of the perpetrator using fMRI or EEG, for example, or of using neuroimaging to diagnose neurological disorders or to estimate the risk of recidivism. In addition, it is being investigated whether brain stimulation can improve the clinical picture of forensic psychiatric patients or, more generally, can contribute to reducing the risk of recidivism. Although neurotechnologies can conceptually offer a wide range of opportunities for improving or facilitating the administration of justice, they are hardly applied for *fact finding, risk assessment* or *intervention,* with the exception of the use of neuroimaging to diagnose neurological disorders in suspects, according to medical diagnostic procedures. The TRL of most of the technologies relevant to the justice and security domain was therefore estimated at level 4: *technology validated in lab.* On the one hand, this can be explained by the fact that the effectiveness and reliability of neurotechnologies for the administration of justice has not yet been sufficiently demonstrated and that our knowledge of the brain is still relatively limited. On the other hand, there are important intrinsic limitations to the various neurotechnologies that make their use in the administration of justice difficult. At the same time, it turned out that a number of techniques could possibly be applied in practice in the not too distant future (<5 years or 5-10 years).

In section 2 we described legal, ethical and societal aspects of the possible application of neurotechnology. The legal analysis identified areas of tension with fundamental rights as laid down in the European Convention on Human Rights (ECHR). Firstly, it is important to note that if neurotechnology infringes fundamental rights, the ECHR requires a legal basis for this. For some applications (e.g. neuro-interventions) that basis can already be found in the law. For other applications (e.g. neuromemory detection) such a basis does not currently exist and will have to be introduced before neurotechnology can be applied. According to the system of the ECHR, an infringement of fundamental rights must also be necessary in a democratic society and be justified. The use of neurotechnology may be justified because criminal offenses can be committed with it will be prevented. It has been established for all domains that the application of certain forms of neurotechnology can be at odds with the prohibition of inhuman and degrading treatment (art. 3 ECHR). This prohibition allows no exceptions. It must be assessed for each method of application of neurotechnology whether it remains within the limits of Article 3 of the ECHR. The application of neurotechnology may infringe on the right to private life, because physical and psychological integrity may be at stake. Specifically for *neuro-interventions ,* Articles 3 and 8 ECHR leave virtually no scope for applying them against the will of the person concerned, whereby an open question is to what extent free consent to a neuro-intervention is actually possible in criminal law. For the domains *of investigation and truth-finding* and *risk assessment ,* the right to a fair trial is important (art. 6 ECHR). Article 6 of the ECHR contains, among other things, a prohibition on forcing someone to make a statement about his or her involvement in a criminal offence: the right to remain silent. Neurolie detection in particular is at odds with this. The right to remain silent, as it is now explained, does not automatically stand in the way of forced cooperation in *risk assessment.* Finally, we discussed a number of proposals to create new fundamental rights specifically with a view to neurotechnology, for example a right to mental integrity. The idea behind this is that the existing constitutional framework offers insufficient protection against the use of neurotechnology.

The ethical analysis showed that the application of neurotechnology in criminal law (in any case) touches on four ethical values: privacy, autonomy, physical and mental integrity and human dignity. The discussion about this partly overlaps with the legal analysis, but also adds points of view. In the context of human autonomy, it is important that neurotechnology can on the one hand limit autonomy (because the technology 'steers' behaviour), but on the other hand it has been argued that it can actually promote it (for example because people get a better grip on their behaviour/life).

Based on section 1 and section 2, we map out a number of recommendations for the responsible implementation of neurotechnologies in the justice and security domain in the future.

Effectiveness and reliability

Before neurotechnology is applied in the justice and security domain, its effectiveness and reliability must be sufficiently demonstrated. Because the administration of justice often takes place at the level of the individual suspect/convict, neurotechnologies that are used for this purpose must also be sufficiently effective and reliable at *the individual level .* This applies both to techniques that are used to gather knowledge about the suspect/convict (within *investigation and truth-finding* and *risk assessment)* and to techniques that may be used to reduce recidivism, for example within the treatment of forensic psychiatric disorders *(intervention).* It is therefore important that future research does not (only) focus on correlations and comparing groups (as is currently often done), but also explicitly addresses individual effectiveness and reliability. Determining causal relationships, for example between abnormalities in brain signals or structures and the risk of delinquent behaviour, can of course be of added value. In the research on this, attention should also be paid to the fact that the brain functions

as a network and that it is unlikely that abnormalities in one brain region, or one type of brain signal, are fully predictive of, for example, the risk of recidivism. In addition , *generalizability and diversity* play a role. This means that research will have to identify whether there are individual characteristics that change the effectiveness and reliability of certain types of neurotechnology. In this light, it is also important that a risk of unjustified unequal treatment may arise if effectiveness and reliability vary based on personal characteristics, a danger that is problematic, for example, when it comes to characteristics such as gender or ethnicity. Furthermore, more understanding is needed about the *specificity* of brain measures: Is the occurrence of a certain brain activation pattern, or brain signal such as the EEG P300 response, specific enough to establish a lie or perpetrator knowledge, or can other processes also be involved? underlie the relevant responses in the brain? Finally, it must be determined to what extent neurotechnologies used for *detection and truth-finding,* or for *risk assessment,* are vulnerable to *manipulation* of the outcome or the usability of the data by uncooperative suspects.

Safety

In addition to effectiveness and reliability, *safety* is an important factor to consider when implementing neurotechnology responsibly. For example, in the case of techniques intended to alter brain signals (brain stimulation), it must be determined whether, in addition to the desired effect, they have undesirable physical or psychological *side effects .* This is always true, but especially when it comes to *invasive* neurotechnologies that require surgical intervention. It is then crucial to accurately map out the risks involved and to determine whether the advantages outweigh the disadvantages. In addition, it will always have to be considered whether the same goal cannot be achieved with a less drastic, non-invasive (and/ or conventional) approach. Another factor to consider in determining safety is the extent to which the effects and side effects are reversible: a technique that produces a lasting effect in the brain will generally be less easy to use than a technique with a short-term effect .

It is clear from the above that important questions still need to be answered before specific neurotechnologies can be used in the justice and security domain. Research is needed to answer those questions. The design and implementation of such research must of course fall within the established ethical and legal frameworks.

Implementation

In addition to *investigating* the effectiveness, reliability and safety of neurotechnologies, it is necessary to *clarify the legal and ethical frameworks .* We have mapped out the minimum requirements from a human rights perspective for the use of neurotechnology in criminal law in section 2 and have already been described earlier in this synthesis. However, it also turned out that important questions remain unanswered. The ECtHR has not commented directly on the (in)permissibility of the use of neurotechnology in criminal law. It is also conceivable that the specific nature of neurotechnology will create a new dynamic in the human rights discourse, for example because the right to freedom of thought and conscience is given more emphasis or even through the introduction of new fundamental (neuro) rights.

Because the legal context differs per country, it is important to develop your own vision on the application of neurotechnology in criminal law that is also specifically tailored to Dutch criminal law. The ethical debate as described in section 2 can be helpful here, because it has already given concrete consideration to the limits of the application of neurotechnology in criminal law. Here we mention a few points about which further thinking is necessary, but which could not be answered within the framework of this study.

The first is the question of what the minimum requirements should be for the reliability of neurotechnology. This choice is not trivial. For example, neuroscientists generally set high standards for the reliability of the results of research, as was apparent during the interviews in this study. Legally, however, the same degree of certainty is not always required. A offense must be proven 'beyond reasonable doubt', but an evidence must be seen in the light of the *whole* of evidence. Relatively low reliability from a scientific point of view can be 'compensated' in an individual criminal case by other means of evidence, such as witness statements. It is important to note that the condition of proof beyond reasonable doubt does not apply to the determination of the risk of recidivism or to the effectiveness of an *intervention.* For *risk assessment ,* predictions with existing risk assessment tools are not very accurate. If these predictions can be improved with the use of neurotechnology, then relatively limited scientific reliability need not stand in the way. At the same time, the more fundamental problem is that it can be problematic to base criminal sanctions on relatively inaccurate predictions, whether made with or without the help of neurotechnology. A considerable margin of error means that a relatively large number of people can wrongly be imposed a penalty based on prevention.

During implementation, it must also be considered whether or not a certain technique may be used against the will of the suspect. Specifically, further thinking is required about the way in which neurotechniques relate to the right to remain silent. This study also showed that ECtHR case law seems to set stricter requirements than Dutch law for voluntary consent in neurointerventions, although no sharp boundaries can be derived from ECtHR case law. Here, too, further thinking is necessary, in which the ethical discussion about the meaning of consent in neuro-interventions can be helpful.

Finally, we argue that it is essential that judges are adequately informed about the effectiveness, reliability and safety of neurotechnologies when they are applied in practice. This is essentially important for any technique that is used in the administration of justice, but given the hype that can play out around forms of neurotechnology, adequate information provision is extremely important.

Finally

This report contains an initial inventory of the opportunities and risks of neurotechnology in the justice and security domain. It is becoming clear that there are important follow-up questions and that answering them still requires a lot of research on a technological level (for example, to demonstrate effectiveness, reliability and safety), but also with regard to the most pressing ethical and legal questions regarding the actual implementation of neurotechnology for *detection and truth-finding, risk assessment* and *intervention.* The results of this research can guide the design of the necessary new legislation for the responsible implementation of neurotechnology in these three domains.

Appendix 1 – Glossary of Terms

Brain computer interface	A system in which a user can control a computer based on direct feedback with brain signals.
cortex	The outer layer of the brain. The cortex consists mainly of gray matter.
Craniotomy	A hatch in the skull, made during brain surgery, so that electrodes can be placed on or in the brain.
Electrodes	Plates or needles made of conductive material that can be used to measure brain activity or to stimulate the brain electrically.
Grey dust	Brain tissue consisting mainly of the cell bodies and dendrites of neurons. These show up as gray on MRI scans.
Hyper scanning	Measuring brain signals of several subjects at the same time. Mainly used in the study of social Interaction.
neuron	Nerve cell in the brain.
White matter	Brain tissue consisting mainly of the axons of neurons. These are surrounded by the insulating material, myelin, which shows up as white on MRI scans.

Appendix 2 – Interpretation of the TRLs

Table A1 - Interpretation of the technology readiness levels as described in the Horizon-2020 programme.

TRL	Definition	Interpretation
1	*Basic principles observed*	Fundamental research conducted
2	*Technology concept formulated*	Practical applications of the technique formulated
3	*Experimental proof of concept*	First *proof of concept* demonstrated
4	*Technology validated in lab*	*Proof of concept* extensively tested in the lab
5	*Technology validated in relevant environment*	Functioning of the technique investigated in a relevant test environment
6	*Technology demonstrated in relevant environment*	Extensive testing and demonstration of technology in relevant test environment
7	*System prototype demonstration in operational environment*	Demonstration of the technique in the user environment
8	*System complete and qualified*	The technology has taken on a definitive form, the effect is strongly substantiated
9	*Actual system proven in operational environment*	The technique has been used in the user environment

Appendix 3a – Interviewed experts (Section 1)

Table A2 - The experts interviewed for section 1 and their affiliations

Interviewee	Affiliation
Bart van Berkel	Professor *of Molecular Brain Imaging* at Amsterdam UMC
Hilleke Hulshoff Pol	Professor of Neuroscience at UMC Utrecht
Jason Farquhar	CTO at Mindaffect
Jonathan Wolpaw	Professor of Biomedical Sciences at New *State University* York, director of the *National Center for Adaptive Neurotechnologies*
Jose del R Millan	Professor of Electrical & Computer Engineering and Neurology at the University of Texas, Austin
Phillip Starr	Professor of Neurosurgery at the University of California, San Francisco
Peter Roelfsema	Professor of Cognitive Neuroscience of Brain Stimulation at Amsterdam UMC and VU, Director of Dutch Brain Institute
Rainer Goebel	Professor of Cognitive Neuroscience, Maastricht University
Tim Denison	Professor of Technical Sciences and Clinical Neuroscience at the University of Oxford
Wiro Niessen	Professor of Medical Imaging at Erasmus MC and TU Delft

Appendix 3b – Interviewed experts (Section 2)

Table A3 - The experts interviewed for section 2 and their affiliations

Interviewee	Affiliation
Chris Bublitz	Postdoc, *Faculty of Law - Dept of Criminal Law & Philosophy of Law,* University of Hamburg
Dorothee Horstkotter	Assistant Professor Faculty of Health, *Medicine and Life Sciences,* University Maastricht
Robert Andorno	*Associate Professor of Bioethics and Biomedical Law at the Faculty of Law & Senior Research Fellow and Coordinator of the PhD Program in Biomedical Ethics and Law, Faculty of Medicine, University of Zurich, Switzerland*
Thomas Douglas	*Professor of Applied Philosophy, Oxford Uehiro Center for Practical Ethics, University of Oxford*

Appendix 3c – Proofreaders

Table A4 – Experts in neurotechnology, law and ethics who proofread the draft version of the report to verify accuracy and completeness

Interviewee	**Affiliation**
Leon Kenemans	Professor of Biopsychology and Psychopharmacology, Utrecht University
Pim Haselager	*Professor of Artificial Intelligence, Donders Institute for Brain, Cognition, and Behavior, Radboud University Nijmegen*
Richard van Wezel	*Professor in Visual Neuroscience, Donders Institute for Brain, Cognition, and Behavior, Radboud University Nijmegen*
Sjors Ligthart	*Assistant Professor, Department of Criminal Law, Tilburg University*

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