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How to involve society into the ethics of non-invasive brain stimulation? Strategies for broader participation of stakeholders

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ABSTRACT

Research and use of emerging neurotechnologies raise challenging ethical questions. We argue that a broad societal inclusion of different groups is needed in neuroethical deliberations which poses methodological challenges. Three requirements for participatory processes in the field of neuroethics include: (i) Integration of different types of knowledge, (ii) Debate about potential futures of neurotechnologies, and (iii) Balancing of technical-medical and societal-social concerns. One approach to meet these requirements is a "design-based and co-creative" participatory process. The approach ensures that all project interactions are easily accessible and relevant to all stakeholders and go beyond a survey of stakeholder opinions. Development and explication of ethical issues is consequently no longer a matter of small groups of specialists but systematically organized among the engagements of different stakeholder groups.

1. Introduction

1.1. Neurotechnologies and neuroethics

Numerous advances have surfaced in the field of neuroscience that cannot be overestimated especially in the field of non-invasive brain stimulation for mental and neurological disorders (Hyde et al., 2022), as well as private and military use for cognitive enhancement (Antal et al., 2022; Davis & Smith, 2019). Urgent questions arise regarding the safe and fair application of non-invasive brain stimulation. Addressing such questions has been the domain of neuroethics-an interdisciplinary field which studies the social, legal, ethical and policy implications of neuroscience research and neurotechnology for self-understanding of the human being, policy making and ethics (International Neuroethics Society [INS], 2023, Northoff, 2009). Technological developments in electroencephalography, functional near-infrared spectroscopy and functional magnetic resonance imaging have made the measurement of changes in brain activity increasingly accurate and convenient (Pinti et al., 2018; Scarapicchia et al., 2017; Soufineyestani et al., 2020). Techniques for brain modulation, such as deep brain stimulation, biofeedback training and non-invasive brain stimulation (NIBS) including transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) (Goetz & Deng, 2017; Herrera-Melendez et al., 2019; Lozano et al., 2019), are increasingly used for both research and therapeutic purposes. The combination of high resolution mapping of brain areas with increasingly precise stimulation has yielded more effective and targeted modulations of brain activity and behavior. Advances in neurotechnological innovation are closely linked to developments in AI (ET 2024). The application of AI in neurotechnology has accelerated technological development in neuroscience, significantly increasing the ability for neurotechnology to powerfully monitor and manipulate brain activity and infer mental states. The increasing use of AI in neurotechnology innovation raises numerous ethical questions that need to be addressed (Ienca & Ignatiadis, 2020). AI has certain characteristics that make its use in the field of neurotechnology particularly challenging from an ethical and regulatory

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perspective, e.g. the fact that AI always requires large amounts of data or that the way it works is often a black box (Berger & Rossi, 2023). In the field of AI, the ethical and regulatory challenges are already being discussed in detail and corresponding regulations have been developed worldwide (e.g. EU Act on AI; US Algorithmic Accountability Act (Mökander et al., 2022)). In the future, it will become increasingly important to apply this initial work to the field of neurotechnologies and to review the extent to which it is sufficient for the application of the regulation of AI in neurotechnologies.

Moreover, NIBS devices are being used successfully for an increasing number of therapeutic applications, including psychiatric disorders, (e.g. depression) and neurological conditions (e.g. chronic pain) (Rossini et al., 2015; Fregni et al., 2021; Rossi et al.) For many diseases, NIBS often represent a therapeutic alternative to drug treatments that typically have fewer adverse effects for the patients. The recent laboratory success in improving cognitive performance through NIBS are prompting companies to target a consumer market for neuroenhancement in healthy subjects as demonstrated in home users of tDCS by Wexler (2018). Suppliers of direct-to-consumer-devices often circumvent applicable rules for clinical trials for medical devices (e.g. European Parliament, 2014), so that the efficacy and safety of these freely available home-use devices cannot be guaranteed. It can therefore be assumed that NIBS will be used much more widely in the future due to its simple, low-risk and cost-effective application. This distinguishes it fundamentally from invasive brain stimulation, which requires risky neurosurgery, and significant resources and expertise, and is therefore strictly regulated.

Various technical safety mechanisms and treatment guidelines have been suggested to make the use of neurotechnologies as safe as possible (Fitz & Reiner, 2013). However, the ethical challenges raised by neurotechnology are yet to be resolved. For example, the rising widespread use of NIBS gives rise to a problem of both national and international equity (Lavazza & Garasic, 2017). Neurotechnologies can be expensive and therefore only accessible to people or nations with the appropriate resources. The application of TMS and tDCS in military and security services (Sehm & Ragert, 2013) as well as in sport and education (Antal et al., 2022), using protocols, which were originally developed for research and clinical applications raise additional ethical issues. Furthermore, the protection of the privacy of thought is becoming increasingly relevant (Ligthart, Accepted/In press - 2024; Lavazza & Giorgi, 2023), through rapid technological advances in neurotechnologies and AI. Personal data such as location, movement or social behaviour can be recorded, when these devices are connected to a smartphone, and used to draw inferences about mood or intentions. As advances in neurotechnology allow an increasingly accurate mapping of brain activity, it may be possible in the future to make conclusions about an individual's thoughts (Ienca, M, Haselager, P., &Emanuel, E.J., 2018). It should be noted, however, that these developments are still a long way off and it is not certain that they will ever become reality (Wexler, 2019). Nevertheless, neuroethicists will need to anticipate how far this technology may violate a person's privacy of thought, particularly upon data sharing with third parties. Other issues such as the influence of low-intensity tDCS over a specific brain area on other unstimulated areas (Bachtiar et al., 2018) or the long-term social consequences from the chronic use of NIBS (c.f. Maier et al., 2021) might also arise.

Extensive tools have been developed for researchers and developers of neurotechnologies to help them reflect on the ethical challenges of their work. The Recommendation of the Council on Responsible Innovation in Neurotechnology (OECD, 2019) is a recent and important example endorsed by all member States of the Organisation for Economic Co-operation and Development (OECD). The OECD lists nine key principles for the responsible development of neurotechnologies, including the unintended use of neurotechnologies, enablement of societal deliberation, and the fostering of scientific collaboration. The Recommendations for Responsible Development and Application of Neurotechnologies (Goering et al., 2021) was a consensus document resulting from a 2-day meeting of over 30 multidisciplinary researchers, developers, ethicists, and legal academics. This publication covers comparable topics and establishes 10 recommendations for the socially and ethically responsible development of neurotechnologies. These include, for example, the demand to establish universal "neurorights", to enable equal access to neurotechnologies, and to avoid potential biases in neurotechnological research. These are important contributions to the ethical debates around the responsible research and innovation of neuroscience by leading multidisciplinary researchers and practitioners in their fields.

For the future, the question arises as to how the development of such documents could be brought even more in line with the principles of the responsible research and innovation framework, which explicitly call for transparency, social inclusion and openness (Sutcliffe, 2011). The following part of the manuscript addresses thus, how multiple stakeholder inclusion in neuroethical discussions can be implemented.

1.2. Inclusion of diverse stakeholders in neuroethical deliberation

The broader use of neurotechnologies can have varied impacts on different parts of society; marginalized or minority populations are less likely to reap the benefits of neurotechnological innovation (Matshabane, 2021). Paradoxically, these populations are also more likely to be subject to the inappropriate use of neurotechnologies to address social issues or treat neurodivergent behaviour. The question then arises: How can we represent diverse experiences and perspectives on the research, development and use of neurotechnologies in neuroethical deliberations to avoid these effects?

The innovation and use of neurotechnologies involves a set of diverse, and often competing, ethical imperatives (Ienca et al., 2018). For instance, patients may desire easily accessible application devices for home use, but regulators may fear the harm caused by the abuse or misuse of neurotechnologies. Another example of conflicting hopes in the field of neurotechnologies is the enhancement debate, especially for use in military and security services (Levasseur-Moreau, Brunelin, & Fecteau, 2013; Sehm & Ragert, 2013). In many cases, pure academic speculation about these ethical considerations is insufficient, as diverse everyday experiences, legal, technological, end-user, societal and economic issues must also be taken into account.

Neurotechnologies pose a particular challenge for neuroethical recommendations due to their potentially large impact on different stakeholder groups including researchers, clinicians, patients, policy makers and industry among others. Since many technological developments are still in their infancy, and exact mechanisms of action remain unclear (Müller & Rotter, 2017), it is uncertain what the use, safety and effectiveness of neurotechnologies may be and how they will affect very different segments and groups within different societies. An advantage of NIBS as a neurotechnology is significantly fewer side effects with a comparable positive therapeutic effect in respect to the use of psychotropic drugs (Rossi et al., 2021; Zhao et al., 2017). Some adverse effects might not be apparent until these technologies are used more broadly within society. This makes the speculation about the future use and impact of emerging neurotechnologies very difficult to predict.

The negotiation about the future handling of NIBS can therefore rightly be regarded as a "wicked problem". In this concept of planning theory by Rittel and Webber (1973), the authors pose two types of problems: a) 'tame' problems, as they exist in mathematics with unambiguous solutions, and b) 'wicked' problems, as they emerge in the policy domain. They are 'wicked' because in a pluralistic society, there can't be a universal 'good' for all and thus no optimal solution can be defined. Rather, the problems are characterised by diverse requirements and contradictions, so that the definition of the problem alone is often a barely solvable task. As a result, no optimal solution can be found by theory alone. Rather they have to be shaped by trial and error. The criteria for the solution are developed in the process of negotiation about

the future handling of neurotechnologies itself and thus falsification in a classical sense is not possible (Rittel & Webber 1973). Consequently, in addition to evaluating the outcome of a decision, it is important that the process that led to the result is analysed and evaluated as well. The evaluability of policy planning shifts from the result to the methodology. This means that if the outcome of a policy planning process is inadequate, the process itself should be evaluated. This may include whether all relevant stakeholder groups involved, were their views understood correctly by the research team etc. In a modern pluralistic society, it is plausible to take into account as many facets as possible when trying to identify a robust solution when dealing with complex social questions, such as those raised by neurotechnologies A method that includes different stakeholder perspectives is participatory action research, which has also been discussed in psychiatry (Friesen et al., 2021) and palliative care (Al-Mondhiry et al., 2022). Participatory action research is a research approach that emphasizes the value of experiential knowledge for problem-solving. By redistributing interpretive power to those affected, the research approach goes beyond traditional qualitative research (Cornish et al., 2023).

The aim of the paper is to address the following points:

- If researchers, developers or regulators in the field of neuroethics or neurotechnology innovation want to think fundamentally about participatory processes and social inclusion, this manuscript offers a novel and comprehensive overview of what needs to be considered.
- If researchers then decide to engage in a participatory process, they can draw on the numerous methodological publications on participatory processes and apply the specifics of neuroethic scholarship described in this paper.
- We further outline which aspects in the specific field of non-invasive brain stimulation need to be considered when planning a participatory research process.

Addressing the issues highlighted above and providing a methodological approach for a systematic inclusion of different stakeholder groups in neuroethical discussion is the main goal of our paper. For that purpose, we use the STIMCODE research project as paradigmatic example. The procedure and the results have been published separately (Maier et al., 2024). In this current publication, the focus will be on overarching methodological issues and not on the concrete implementation of the research project. STIMCODE is funded within the ERA-NET NEURON ELSA-Joint Transnational Call 2020 “Neuroethics” and aims for the participatory development of a code of conduct for non-invasive brain stimulation (NIBS) devices in the European Union. In this participatory research project, several stakeholder groups such as patients, students, home-users, practitioners, philosophers, industry representatives and policy experts are involved. The challenges and requirements for participation in the field of neuroethics and a systematic methodological strategy for participatory development used in this project are described below.

2. Participation in neuroethics

2.1. Challenges for participation

In their vision for a translational neuroethics, Wexler and Specker Sullivan (2021) describe how more integration and inclusion of stakeholder views can address real problems and move away from pure speculation, take different groups into account, and lead to the rapid implementation of neuroethical findings, for example, in practical guidelines and recommendations. Meeting the requirements of integration, inclusivity and implementation is challenging. The complexity of neuroethical issues makes it impossible for experts from one discipline alone to develop answers that sufficiently address all perspectives. The requirements resulting from the different needs of stakeholders are diverse and can be competing. A methodology is needed that pursues a goal and is able to incorporate multiple and divergent perspectives that dynamically responds to new or changing factors. Therefore, we propose to approach neuroethical problems as well as avoid such problems in the future through the methodology of participatory design. Participatory processes are characterised by the fact that, as far as possible, all potentially involved and affected stakeholders are included in a development process (Robertson & Simonsen, 2012). Various methods are suitable for narrowing down the stakeholder groups. It makes sense to first define system boundaries, which could be regional, technological or temporal (Midgley, 2003). In a further step, the Carayannis and Campbell (2009) model should be used to determine which stakeholders from the four dimensions of innovation systems (society, industry, science, politics) could be related to the development. Furthermore, it can be helpful to use a so-called rainbow diagram to define which stakeholder groups are likely to be most strongly influenced by a technology in the future and, on the other hand, which groups will exert the strongest influence (Chevalier & Buckles, 2008).

When negotiating ethical aspects in neurosciences and neurotechnologies, there are some specific characteristics that can make a participatory process particularly challenging:

(a) Currently, there are few legal frameworks for the use of neurotechnologies beyond clinical applications that provide guidance in ethical negotiations.
(b) The general population is not sufficiently aware of the potential harms and challenges of neurosciences and neurotechnologies. Most people do not have any contact with these technologies in their everyday lives.
(c) Laypersons who have already come into contact with the topic are often people with mental or physical illnesses, who should therefore be included with appropriate consideration for their illness. This may include adapting activities to reflect their abilities and maximize their participation.
(d) Different disciplines, such as medicine, ethics, social science, engineering, psychology, psychiatry, physics, industry or philosophy, are involved in research, use and assessment of possible risks. They speak different languages and have different ways of thinking according to their respective disciplines.
(e) In the application, regulation and development of neurosciences and neurotechnologies, there are strong hierarchical differences between individual groups. For example, the relationship between physician and patient is an asymmetrical relationship (Kaba & Sooriakumaran, 2007; Rees et al., 2007). Further research has been done in power differences among stakeholder groups and how they can impact deliberations (Edelman & Barron, 2016; Madden & Speed, 2017; Shimmin et al., 2017; Ward et al., 2010). Asymmetries due to different levels of prior knowledge also exist between manufacturers of neurotechnologies and private customers, practitioners and regulatory authorities. In this environment, it is particularly challenging to weigh and prioritize the wishes and fears of the individual groups.
(f) Ethical consideration in the field of neurotechnology are also culture and gender dependent (Amadio et al., 2018; Roy, 2012). Neuroethical assessments – especially when they revolve around questions such as the self, consciousness and identity – are highly dependent on culture and socialization. However, most people are not aware of the extent to which they are influenced by key factors, as these processes are often unconscious. This makes the evaluation of neuroethical issues particularly challenging, especially with everyday experts who may sometimes show a lower level of professionalism or reflection.
(g) It can be assumed that the development of neurotechnologies will become even faster in the future thanks to major advances in data processing, such as artificial intelligence and quantum computing (Miranda et al., 2022). These advances greatly increase the

predictive power of data sets, such as those collected through neurotechnology. It also makes it particularly difficult to anticipate medium- or long-term developments in the field of neuroscience.

These challenges must be considered in participatory processes in neuroethical research projects aimed at developing sustainable solutions. We propose to conduct the participation process with the methods of co-creation and design-based methods. In comparison to 'classic' participatory processes, where the participants are asked as potential users of a technology or service (and thus remain in a passive role with regard to the solution to be developed (cf. Cargo & Mercer, 2008)), co-creation enables active participation by the stakeholders in formulating the research questions, funding opportunities, shaping the innovation process and the development of results (Sanders, & Jan Stappers, 2008). This leads to development processes in which stakeholders are involved in the ideation process, rather than simply validating existing ideas. Sanders, and Jan Stappers (2008) describe co-creation as "focused more on the exploration and identification of presumably positive future opportunities than it is on the identification and amelioration of adverse consequences". Since neuroethical issues are often abstract concepts, the successful inclusion of stakeholders requires the creation of connections to their individual lives. We argue that this is best achieved through design-based methods, such as the development of specific workshop formats and the design of materials for co-creation. In this methodology, stakeholders are enabled as "experts of their experiences" (Sleeswijk-Visser et al., 2005). It is advisable to activate the specific knowledge of different groups. This may include, for example, jointly developing a 'perfect stimulation set-up' with representatives of the do ito yourself (DIY)-community, or the identification of challenges in patient journeys through methods such as imaginary walkthroughs (cf. Breuer et al., 2024), in which patients visualize the entire treatment process, including preparatory research by the patient, clarification of cost coverage, preliminary consultations, travel to and from the treatment location, treatment setting, after-effects at home and reactions of the social environment, in order not to leave out any important aspect. These methods often employ other possibilities and approaches besides the spoken word to express, reflect and discuss one's thoughts and therefore help participants to share 'tacit' and 'latent knowledge' (Sanders, & Jan Stappers, 2008). Co-creative processes thus also enable the empowerment of marginalized groups that are often overlooked in development processes (Matshabane, 2021).

In a co-creation process, stakeholders are elevated to equal partners in the development process by enabling them to independently develop goals and visions for the innovation of neurotechnologies on the basis of their individual experiences and moral values. Through specific workshop formats tailored to individual groups, different perspectives are brought together and a common language for the specific neuroethical question to be addressed is created. The different stakeholder groups can express their specific knowledge in the offered framework. In this way, the design-based methods enable the stakeholders to articulate their distinct concerns and individual ethics to establish a common point of reference for discussion. The formats must be specifically adapted to the question being considered and the respective stakeholder group in order to ensure common understanding and the successful translation and implementation of the results into practice. For this purpose, multiperspectivity is important in the development of the formats itself, as it can be represented, for instance, by an interdisciplinary composition of the research team. In the follow-up to the workshops, it is crucial to use qualitative evaluation methods such as Mayring and Fenzl (2019). This ensures that the results meet social science standards and that the contents from the workshops are reliably reflected. Additionally, member checking should be carried out to ensure that the relevant points have been derived from the workshop process (McKim, 2023). From the described methodological perspective on participation in neuroethics, three principles can be derived in summary, that underpin the design of our Co-Creative Workshops (see Fig. 1):

- Combination of different types of knowledge
- Enabling collaborative discussion on the future
- Establishing a link between technical-medical questions and societal-social questions

3. Requirements for successful participatory research projects in the field of neuroethics

3.1. Combination of different types of knowledge

As already outlined, the groups to be involved are characterized by different types of knowledge. In our proposed approach, all these forms of knowledge are treated equally. We therefore do not distinguish between laypersons and experts, but rather speak of "everyday experts" and "experts within a certain discipline". In the case of experts within a certain discipline (e.g., practitioners, industry representatives, philosophers, policy experts), there are groups of people who have been dealing intensively with the topic for years and therefore know and can verbalize technical subtleties, but usually with a strong focus on their specific application. Other everyday experts such as patients, potential users, members of the DIY-community, may have some contact with the topic, but they should first be able to deal with the matter and to formulate ideas and thoughts appropriately. Even if individual groups are not in a position to assess, for example, specific risks regarding the application of a neurotechnology, they can still bring other perspectives that are central when considering different contexts of use. For instance, home users often lack the technical background to assess risks accurately, but they can make it very clear why they use the technologies and what their fears, concerns, hopes and wishes are. There are also different groups of experts within a certain discipline who face different challenges when it comes to being involved in discussions on neurotechnologies. On the one hand, there are basic researchers who have an extremely high level of technical or medical expertise. However, due to the focus on the micro-level of the applications (e.g. basic research or a medical application), it is often difficult for these people to conceptualize possible macro-level issues for society as a whole. Experts who deal

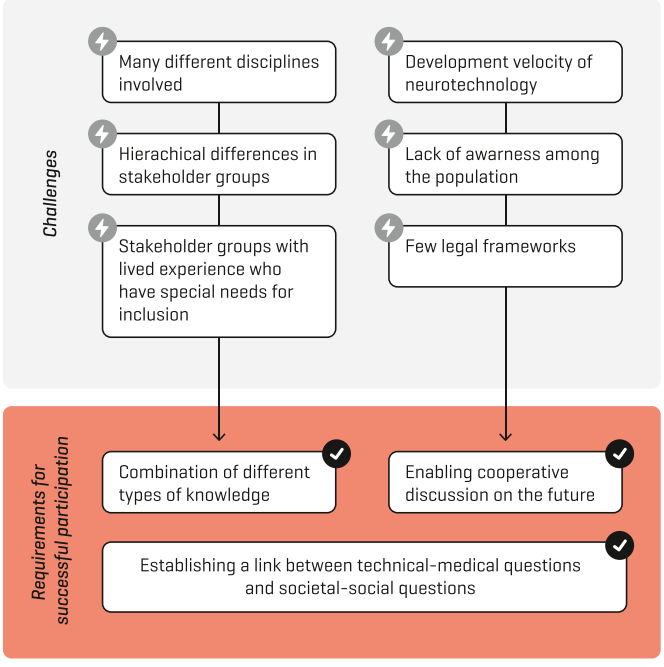

Fig. 1. Overview of the challenges for participation in the field of neuroethics and resulting requirements.

with questions of neuroethics or technology impact assessment often take a macro view and thus often lack the insight into the latest technological knowledge necessary to anticipate technological developments as early as possible. To combine the different types of knowledge, the following points are therefore important:

- Diverse project teams that moderate the participatory process: In order to be able to design the workshops tailored to the specific groups and prepare the results for further use, it is essential that they are prepared by a diverse team with varying expertise. This ensures that language appropriate to the target group is used during workshops and the preparation of results. Particularly when it comes to negotiating global issues, both the project team and the stakeholder groups involved should have a corresponding regional diversification (cf. Matshabane, 2021).
- Use design-based methods to engage stakeholders: For many people, it is difficult to understand complex physical or technological processes and to express vague concerns, ideas, or feelings. Design-based workshop methods are ideal to enable a deep engagement with the topic (Breuer et al., 2024; Maier et al., 2024). They often employ the use of speculative objects. In doing so, they have two specific functions: they enable us to think about possible futures and to criticize current practice. They can serve as a "perceptual bridge" that allows workshop participants to present and discuss abstract content in a concrete way (Auger, 2013). By working with speculative objects, participants are enabled to express their visions or concerns in a common language and develop scenarios together. In this way, conversations about complex contexts can be illustrated and thus simplified and synchronized. They can be objects such as mirrors or wood, but also abstract images. For example, patients were asked to describe their greatest fears about treatment with NIBS using speculative items. For example, one Patient choose a small mirror to represent or the fear of loss of identity through brain stimulation.
- Workshops separated by the type of expertise, which are then "translated" by the project team: Highly diverse stakeholder groups require tailored workshop methods and formats to enable participants to contribute their respective expertise. Since the stakeholder groups involved have different forms of expertise, experiences and interests, it can be useful to separate these groups in the participatory process so that the discussion and findings reflect the views of specific stakeholder groups. This is particularly important for stakeholder groups who have been marginalized within society, or where there are significant power imbalances between stakeholders. For example, some stakeholders, such as those with lived experience, may defer to the technical experts (e.g. scientists, engineers) when discussing a novel neurotechnology. It is then the task of the project team, which should also be made up of diverse experts, to consolidate and summarize these different results from the different groups. Nevertheless, we also acknowledge the power of having the different groups hear the perspectives of another first-hand which has the potential of yielding interesting fertilization of discussion and exchange of views that could be enriching. For instance, it could be useful for neurotechnology developers to hear the cultural or gender considerations directly from service users rather than being paraphrased by project team members who may or not express the opinions clearly. But in most cases, fears, worries, hopes and wishes, as well as complex technical discussions can be worked out in more depth in separate groups.
- Ensuring balanced speaking opportunities: It is essential to ensure that all participants can contribute to the workshops. Separate workshops for each expert group should be supplemented by small group/individual work phases and large group phases (e.g. for presentation and discussion of the work done in small groups) in which the work developed is presented and discussed. The moderator should be mindful of any power imbalances between workshop participants and work to minimise these by encouraging reserved participants to engage in the discussion and ensuring that debates are not dominated by any individuals. This ensures that all participants can contribute. Overall, a friendly moderator, small workshop groups (max. 10 people), and good preparation create a positive and psychologically safe workshop environment that allows for a rich and diverse discussion.

3.2. Enabling cooperative discussion on the future

To examine future ethical questions raised by neurotechnologies, it must be possible to create and discuss possible future scenarios as well as their effects on individuals and society. This can be challenging for different stakeholder groups. Everyday experts often do not have the technical knowledge needed to deal with technical factors relevant to the topic, while basic researchers often think in very specific problem areas, and practitioners, as well as researchers, are often preoccupied with everyday practical questions. It is therefore essential to consider certain points in the context of a participatory process:

- Ensure a sufficient level of knowledge: For the participatory involvement of people who are unfamiliar with the topic, it is important to describe, at the beginning, the technologies to be discussed and explain the underpinning neuronal mechanisms. Care should be taken not to prime the discussion in a particular direction, but to provide the necessary knowledge as a basis for discussion in a neutral manner and according to scientific standards.
- Developing future scenarios within the framework of participatory processes: A central element for a participatory process can be the development of future scenarios. This requires the development of different scenarios for neurotechnology by the respective stakeholders (with the guidance of the research team), that touch on various aspects such as possible applications, places of application, legal regulations, etc. The scenarios are then discussed with the participants where conflicting goals, ethical questions, potential opportunities and potential risks of individual technologies can be investigated. For example, questions could be asked as to how a scenario developed in the workshop could affect other population groups, industry or politics, what preconditions would have to be created to achieve this scenario, or what positive or negative consequences could arise from the scenario. Working with future scenarios can ensure that the discussion does not always focus on current issues, but rather anticipates possible futures as part of a foresight or horizon scanning process. Furthermore, the evaluation of scenarios by the participants can highlight general concerns or desires of certain stakeholder groups that may not be otherwise obtainable.
- Give room for creativity and imagination: It is usually difficult to predict developments in the field by neuroethics, even by experts in a particular field. It is therefore important to develop unusual ideas regarding the nature and possible uses of neurotechnologies and other achievements of neuroscience and to enable the various stakeholder groups to develop ideas for the future through co-creative workshop methods. Creative methods also often make aspects or content accessible that cannot be, or are very challenging to verbalize (Heidingsfelder et al., 2019).
- Consciously set the timeframe for scenario development: If the participatory process is to work with future scenarios, care should be taken to set a specific time frame that is at the same time future-oriented for the participants, but not too distant that only pure speculation would be possible. Timeframes such as 10 or 15 years have proven to be useful, as they are clearly in the future but still conceivable for the participants (Harles & Heidingsfelder, 2021).

3.3. Establishing a link between technical-medical questions and societal-social questions

Depending on the respective touchpoints of the different stakeholders involved in a participatory process, people may find it difficult to move away from a purely medical-technological perspective on neuroscience to include societal-social aspects in their considerations. However, this is necessary to anticipate the potential impact of future developments in the field of neuroscience. For this holistic approach to find its way into a participatory process, the following points should be taken into account:

- Discuss societal-social implications based on technical application scenarios: It is important that people with special expertise in the field of neuroscience (no matter whether scientists or everyday experts patients) are also encouraged to reflect on what effects a certain neurotechnology could have on the society at large as well as life and welfare of the community, as these people have special insights or could uncover connections earlier than other people. An exemplary reflection method, e.g. for neuroscientists, is an adapted version of the input-output-outcome-impact (IOOI) evaluation method (cf. Riess, 2010). The question is which input (specific research results of a researcher) leads to which measurable activities in other areas and which specific effects these could have and which social impact could result from them in the end. This reflection may also consider low or no-tech solutions to dealing with complex social issues, such as simply providing assistive devices or additional social supports that aim to increase quality of life rather than simply "cure" an individual medical problem.
- Consider the dimensions of the Quadruple Helix framework in the individual steps. The four dimensions of the Quadruple Helix are academia, industry, government and culture-based public. The term "helix" means that the dimensions are not separated from each other but are interconnected. These interconnections must be taken into account when planning participatory processes. The Quadruple Helix concept emphasis co-development and co-existence of diverse knowledge and innovation modes along with mutual learning among stakeholders (Carayannis & Campbell, 2009). In the process, individual stakeholder groups should also always consider possible impacts on each other. This can be ensured through appropriate methodological design, such as worksheets that ask to show the links or impacts of the self-developed vision on other stakeholder groups, if the necessary knowledge is available.
- Learn from and involve other disciplines: Especially in an interdisciplinary topic, such as neuroethics, it is very important to focus on the bigger picture. In addition to scientific disciplines such as neuroscience, medicine, engineering, ethics, philosophy, medicine, neuroscience and law, it is also very important to include application-related expertise, for example policy experts, health authorities, industry representatives and practitioners. Complex neuroethical questions can only be adequately addressed by involving various stakeholders, including diverse end-users, from a range of disciplines. For example, the challenge of dealing with the fact that electrodes attached to the scalp to record the underlying brain activity do not adhere as well to coarse hair should be examined from different perspectives: From a legal perspective this may include consideration of whether their use is permissible under anti-discrimination law; from a philosophical perspective, whether there application is fair and equitable; or from an engineering perspective, which technical adaptations could help to overcome this technical challenge.

4. Conclusion and outlook

It can be assumed that ethical deliberations of neuroscience will become increasingly central in the future due to the rapid scientific and technological developments. Therefore, it is crucial to consider how emerging neuroethical questions should be dealt with. As more professionalization and specialization has taken place in the past decades (Politi, 2017), there is no longer a homogeneous group of people who can oversee all aspects of a complex topic such as neuroethics. Participatory processes in the field of neuroethics are complex and challenging. Given the advantages of a participatory process, including obtaining a more holistic picture, greater acceptance of the processes, more sustainability and effective translation of findings to the community, reduction in the probability of error, and higher probability for concrete action in different areas, participatory processes in the field of neuroethics may be the most appropriate method to overcome the challenges described. The specific circumstances for the participatory consideration of neuroethics are also relevant to other fields in medicine and technology development.

In addition to the methodological challenges in participatory processes described in the article, there are also very practical challenges that should be considered when planning participatory processes. For example the precise definitions of stakeholder groups, the difficulty of recruiting people to participate in the process, implementing research/facilitation units that have been shown not to pursue vested interests and the financial and time requirements. Scientific teams should make further efforts towards supporting and conducting participatory research. Grant agencies and research tenders should also take the additional financial costs and time required of participatory processes into account so that more participatory processes with wider societal participation become possible in the future.

CRediT authorship contribution statement

M.J. Maier: Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization. **J. Breuer:** Writing – original draft, Methodology. **P. Ramasawmy:** Writing – original draft, Project administration. **A. Antal:** Writing – review & editing, Resources, Funding acquisition, Conceptualization. **G. Northoff:** Writing – review & editing, Funding acquisition, Conceptualization. **A. Oliviero:** Writing – review & editing, Resources, Conceptualization. **A. Carter:** Writing – review & editing, Supervision.

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Declaration of competing interest

AO is co-founder of Neurek SL (spin-off company of the Hospital Nacional de Parapléjicos Foundation). AA is a payed advisor by the company Pulvinar, USA and received honorars from NeuroCare, Germany. The other authors report there are no competing interests to declare.

Data availability

No data was used for the research described in the article.

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