



Moral attitudes and willingness to enhance and repair cognition with brain stimulation



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ABSTRACT

Background: The availability of technological means to enhance and repair human cognitive function raises questions about the perceived morality of their use. However, we have limited knowledge about the public's intuitive attitudes toward uses of brain stimulation. Studies that enlighten us about the public's willingness to endorse specific uses of brain stimulation on themselves and others could provide a basis to understand the moral psychology guiding intuitions about neuromodulation and opportunities to inform public education and public policy.

Objective: Hypothesis: We expected that subjects would be less willing to enhance or repair cognitive functions perceived as more "core" to "authentic" self-identity, prioritize brain stimulation uses for themselves, and more willing to enhance "core" functions in others. Across specific hypothetical uses, we expected the moral acceptability of specific uses to be associated with subjects' willingness to endorse them.

Methods: We administered two surveys to the public in which subjects were asked to report how willing they would be to enhance or repair specific cognitive abilities using a hypothetical brain stimulation device called "Ceremode".

Results: Among 894 subjects, we found that subjects were more willing to use technologies to repair other people than themselves. They were most inclined to repair core functions in others. Subjects' ratings of the moral acceptability of specific uses was related to their reported willingness to use brain stimulation.

Conclusion: Moral acceptability is related to the public's willingness to use brain stimulation. These findings suggest that the public endorses a generous approach to applying brain stimulation for cognitive gains in others. Further, this study establishes a basis to guide moral psychological studies of cognitive modification and social processes that guide attitudes toward and uses of brain stimulation.

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Introduction

Humans enhance cognitive functions through physical and cognitive training [1], pharmaceuticals [2], and invasive and noninvasive neuromodulation [3]. With increasing public access to potentially effective tools to modify cognition has emerged a "do-it-

yourself" (DIY) noninvasive brain stimulation movement [4]. Within the DIY movement, people use technologies such as transcranial direct current stimulation to treat depression and other psychological problems and to enhance cognition [5]. Beyond this movement, we can reasonably expect that the combination of easy access to home manufacturing technologies [6] and open-source information will allow laypersons to build ever-more effective tools for neuromodulation at home. In addition, technologies such as deep-brain stimulation provide powerful invasive means to influence human cognition [7]. In this context, researchers and ethicists have debated how we should study public

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use of brain stimulation [4,8,9], provide information to consumers [10], prioritize who receives interventions [11], and regulate available technologies [4,12].

Experiments suggest that the public has sophisticated perspectives and sensitivity to major debates in cognitive enhancement research [13]. However, while the (DIY) culture is rapidly growing with unique opportunities for scientific discovery [4,8,9], and more invasive techniques are being applied for a variety of disorders, we know little about public perspectives and moral attitudes toward human enhancement techniques more broadly. Several major variables could affect human willingness to use certain technologies to influence cognition. Here, we focus on whether people are willing to use a hypothetical brain stimulation technology to influence cognitive functions that are more or less fundamental to the “authentic self” [14]. Henceforth, we call these “core” and “peripheral” functions, respectively [15]. We additionally examined whether subjects are more willing to repair or enhance functions, and more willing to influence others *versus* themselves. Finally, we considered the extent to which judgments of moral acceptability were associated with the willingness to apply certain uses. Examining these variables could begin to identify what guides intuitive judgments about brain stimulation for cognition and could further establish the moral foundations of public attitudes about brain stimulation.

Some previous research points to the potential relevance of these variables. Research investigating consumers’ willingness to take pharmaceuticals found that young, healthy adults were reluctant to enhance core functions [15,16]. However, it is unknown whether those preferences generalize to non-pharmaceutical interventions such as brain stimulation. In addition, individuals may view interventions used to repair (i.e., therapeutically) rather than enhance performance more as acceptable than others [17] when moving individuals toward normative functioning. Further, individuals sometimes seek to gain performance advantages for themselves rather than for others in well-controlled experimental contexts [18]. However, the extent to which this tendency applies to brain stimulation has not been examined. Moreover, moral acceptability – whether engaging in an action is thought to be the right thing to do – was strongly related to the desire to legalize enhancement as opposed to personally taking the enhancement [15]. This suggests that individuals may engage in moral reasoning when considering institutional action about enhancements, but not for limited uses on an individual basis. However, whether moral evaluations contribute to willingness to apply cognitive enhancement and repair more generally has not been thoroughly evaluated.

In a within-between subjects design, we examined individuals’ willingness to apply a limited supply of a hypothetical brain stimulation device called “Ceremode” to enhance or repair cognitive functions in themselves or others. We hypothesized that subjects would be less willing to enhance or repair core functions [15]. We further predicted that in limited supply vignettes, subjects would prefer to enhance or repair cognitive functions in themselves rather than others. We anticipated that subjects would be more willing to repair than enhance cognitive functions, and similarly willing to enhance peripheral functions in themselves and others, but more willing to enhance core functions in others. We expected moral acceptability to be positively related to subjects’ likelihood ratings across conditions. Finally, we anticipated that demographic variables associated with particular ideological positions could be associated with willingness to apply certain uses. Specifically, we speculated that politically more conservative individuals would be less willing to enhance or repair individuals, and that this effect would be partially mediated by Openness to Experience [19].

Open science framework pre-registration

We are sensitive to increasing concerns about scientific transparency, academic honesty, the influence of “perverse” incentives on researchers [20,21], and the complexity of the interactions between variables that influence psychological research [22]. We considered it important to constrain the focus of our work to test hypotheses that were discussed among the coauthors ahead of time and only to test the predictions that we made before looking at any data. Thus, prior to any data analysis, we pre-registered the current confirmatory hypotheses for this study *a priori* in the Open Science Framework (www.osf.io). Thus, the primary results in the current manuscript presents only the procedures and results proposed in our initially intended research as protection against implicit or explicit researcher biases during data analysis.

Subjects

In two separate survey administrations (one each for the “self” and “other” conditions, between subjects), 500 subjects for each condition were solicited via Amazon Mechanical Turk (M-Turk). M-Turk allows researchers to collect high-quality data rapidly among demographically diverse individuals [23]. The participants were required to have completed at least 100 tasks previously and maintain at least a 95% approval rating on M-Turk. The study was approved by the Institutional Review Board at the University of Pennsylvania and all participants provided informed consent prior to participating in the study.

Survey design

We administered two surveys (“self” and “other”): one to assess using technology on one’s self (“self survey”) and another to assess using technologies on others (“other survey”). For the between-subjects study, the full 32 description within-subjects survey was presented to one group with Ceremode being applied to themselves, while a separate group of respondents received the identical 32 descriptions but the Ceremode was to be applied to others. In each of these between-subjects surveys, we included within-subjects conditions for enhancement or repair and evaluating items more “core” or “peripheral” to authentic human self-identity. Specifically, we presented 32 descriptions of the hypothetical brain stimulation device Ceremode in randomized order. Sixteen of these described Ceremode as enhancing cognitive functions while healthy, and the other 16 described Ceremode as repairing functions following a brain injury. The 16 descriptors referred to specific cognitive functions from a prior study that established them as more core or peripheral to human self-identity [15].

Specifically, we selected the eight most “core” functions (Kindness, Empathy, Self-confidence, Mood, Motivation, Social Comfort, Relaxation, and Emotional Recovery) and the eight most “peripheral” functions (Reflexes, Rote Memory, Wakefulness, Foreign language ability, Math ability, Episodic memory, Concentration, and Music ability). For each item, subjects responded on a Likert scale from among the responses (1) Extremely Unlikely; (2) Somewhat Unlikely; (3) Neutral; (4) Somewhat Likely; and (5) Extremely Likely. This allowed us to determine how subjects valued each of the functions in both the enhancement and repair conditions. Thus, the self/other condition was between subjects, whereas the enhance/repair and core/peripheral factors were within subjects.

Then, we asked subjects to consider how they would distribute Ceremode to affect specific cognitive functions in a zero-sum scenario. Next, we asked subjects to rate the moral acceptability of specific uses of Ceremode. Afterwards, we asked subjects to respond

to items measuring demographic variables, personality, and political ideologies.

Specific procedures for each section are described below. Please see the Supplementary Information for the text of the surveys exported from Qualtrics.

Self survey design: giving Ceremode to the self

This survey began with definitions of each of 16 terms referring to specific cognitive functions from a prior study that established them as more core or peripheral to human self-identity [15]. Specifically, we selected the eight most “core” functions (Kindness, Empathy, Self-confidence, Mood, Motivation, Social Comfort, Relaxation, and Emotional Recovery) and the eight most “peripheral” functions (Reflexes, Rote Memory, Wakefulness, Foreign language ability, Math ability, Episodic memory, Concentration, and Music ability).

Subjects were instructed to respond as follows:

“In a breakthrough discovery, scientists have created a brain stimulation device called Ceremode that can be used on individuals to change cognitive abilities. There are several different versions of Ceremode. Each version can affect only one type of cognitive ability at a time without side effects. In addition, each version of Ceremode can be used in either healthy individuals or individuals with brain injuries to change cognitive abilities.

Imagine that you are responsible for deciding whether to use Ceremode on yourself to affect your cognitive functions. With this in mind, your task is to read sentences describing the effects of each version of Ceremode. Then, decide how likely you would be to give that version to yourself. Some versions of Ceremode will be used to enhance cognitive functions while you are healthy. Other versions of Ceremode will be used to repair cognitive functions if you suffer a brain injury. You will rate each item from 1 (Extremely Unlikely) to 5 (Extremely Likely). Importantly, you cannot receive every version of Ceremode because only so many versions of each type of Ceremode exist. Considering that Ceremode comes in a limited supply, please use the entire range from 1 to 5 when making your decisions.”

Then, we presented 32 items. Half of the items asked whether subjects would be likely to enhance their functions while they are healthy, and half of the items asked whether subjects would be likely to repair functions if they had brain injuries:

“This version of Ceremode can be used on you < *while you are healthy/if you have brain injuries* > to < *enhance/repair* > cognitive abilities. If you are stimulated by this Ceremode you will receive improved < *cognitive function* > with no side effects.

I would be ——— to give this version of Ceremode.”

If the prompt included “while you are healthy”, then it was always followed by “enhance”. If the prompt included “if you have brain injuries”, then it was always followed by “repair”.

We included two attention checks in this portion of the survey. Each attention check stated:

“This is an attention check. If you are paying attention please select Extremely Likely.”

For each item, subjects responded on a Likert scale from among the responses (1) Extremely Unlikely; (2) Somewhat Unlikely; (3)

Neutral; (4) Somewhat Likely; and (5) Extremely Likely. The item order was presented uniformly at random for each participant.

Distributing ceremode to the self with a zero-sum constraint

In the willingness condition, Ceremode was said to be in “limited supply” because we wanted to assess subjects’ willingness to use the hypothetical device to influence certain specific functions with somewhat vague knowledge about the exact scope of available resources. This is more analogous to the case where subjects are “consumers” of the devices and know that the supply is not infinite, but the extent to which they are limited is not necessarily known. We used these items to test our primary hypotheses as surrogates for a potentially representative decision-making circumstance.

As a complement to the willingness items, after assessing subjects’ estimated likelihood of administering Ceremode to enhance or repair specific functions, we asked individuals to distribute a limited number of Ceremode versions to enhance or repair various cognitive functions (within subjects). The “zero-sum” condition was included as an exploratory aim because we wanted to obtain data to describe how subjects would be willing to distribute resources to improve cognition when they were confronted with a finite supply and where the total supply could be distributed to any number of cognitive abilities. Here, subjects were shown a list of various cognitive functions and asked to distribute a limited number of units to the functions that they would most want enhanced or repaired.

In the “enhance” condition, subjects were asked:

“Now imagine that you receive a special version of Ceremode. This version can enhance your functions right now. It can enhance many functions. However, it has a limited amount of energy, which affects how much you can enhance each cognitive function. For example, you could set it to enhance all functions a little bit, or a single function completely, or anywhere in between.

Please read the whole list carefully before making your choices and please use 16 total units of energy (that is, the total of energy across all items should equal 16).”

In the “repair” condition, subjects were asked:

“Now imagine that you receive a different special version of Ceremode. This version can repair lost functions if you suffer a brain injury. It can repair many functions. However, it also has a limited amount of energy, which affects how much you can repair each cognitive function. For example, you could set it to repair all functions a little bit, or a single function completely, or anywhere in between.

Please read the whole list carefully before making your choices and please use 16 total units of energy (that is, the total of energy across all items should equal 16).”

Underneath the prompt for each condition, the subjects typed the number of units they would allocate to each of the 16 cognitive functions into a box next to the name of each cognitive function. Responses were fixed so that subjects had to allocate exactly 16 total units (i.e., the sum of allocated units across all functions equaled 16) before proceeding. Please see the Supplementary Information for a descriptive report of the responses to the “zero-sum” condition. The original survey response data are available on the Open Science Framework.

Moral acceptability of using Ceremode on the self

After assessing subjects' distribution of *Ceremode* to various cognitive functions, we asked the extent to which they thought specific uses of this hypothetical technology on the self were morally acceptable.

For the *enhance* condition, we asked subjects:

"Now consider that there is no limit to how many versions of *Ceremode* you can use to enhance your cognitive abilities. How morally acceptable are each of the following uses of *Ceremode* to enhance your cognitive abilities right now?"

For the *repair* condition, we asked subjects:

"Now consider that there is no limit to how many versions of *Ceremode* you can use to repair your cognitive abilities. How morally acceptable are each of the following uses of *Ceremode* to repair your abilities if you suffer a brain injury?"

Then, for each of the two conditions, for each of the sixteen cognitive functions, subjects were prompted with a series of items in a randomized order with the format:

"It is morally acceptable to < enhance/repair > your < cognitive function>."

For each item, subjects responded on a Likert scale from among the responses (1) Strongly disagree; (2) Somewhat disagree; (3) Neutral; (4) Somewhat agree, and (5) Strongly agree. The item order was presented uniformly at random for each participant.

Other survey design: giving Ceremode to others

The survey measuring attitudes toward other-enhancement was structured identically to the self survey, except that the instructions and prompts were changed to ask a different sample of individuals to think about using *Ceremode* on others instead of themselves. Please see the Supplementary Information for a full version of the survey exported from Qualtrics.

Moral acceptability of using Ceremode on others

After assessing subjects' distribution of *Ceremode*, we asked the extent to which they thought specific uses of this hypothetical technology on others were morally acceptable.

For the *enhance* condition, we asked subjects:

"Now consider that there is no limit to how many versions of *Ceremode* you can use to enhance cognitive abilities. How morally acceptable are each of the following uses of *Ceremode* to enhance cognitive abilities in healthy individuals?"

For the *repair* condition, we asked subjects:

"Now consider that there is no limit to how many versions of *Ceremode* you can use to repair cognitive abilities. How morally acceptable are each of the following uses of *Ceremode* to repair abilities after individuals have suffered brain injuries?"

Then, for each of the two conditions, for each of the sixteen cognitive functions, subjects were prompted with a series of items in a randomized order with the format:

"It is morally acceptable to < enhance/repair > your < cognitive function>."

For each item, subjects responded on a Likert scale from among the responses (1) Strongly disagree; (2) Somewhat disagree; (3) Neutral; (4) Somewhat agree, and (5) Strongly agree. The item order was presented uniformly at random for each participant.

Big five inventory-10 (BFI-10)

Following the Moral Acceptability section in each of the *enhance* and *repair* conditions, subjects completed the BFI-10 to provide validated and time-efficient measurements of the Big Five personality traits [24].

Neoliberal beliefs inventory (NBI)

Subjects then completed the NBI [25], which is a reliable and valid 25-item measure of neoliberal beliefs. The NBI contains four factors that entail beliefs about system inequality, competition, personal wherewithal, and government interference.

Demographics

Subjects reported their gender, age, race/ethnicity, education, income, field of study, employment status, and political party. In addition, subjects reported their religious upbringing, current religious tradition, degree of religiosity, degree of spirituality, church or other religious meeting attendance, time spent in religious/spiritual activities, relationship status, and a reporting whether they thought human minds are more like computer or souls.

Statistical analyses

Analyses were conducted using multilevel modeling with maximum-likelihood estimation [26] implemented in the lme4 v.1.1–9 [27] package of R version 3.2.1 [28]. This technique allows for a classical regression analysis to be performed on repeated measures data by accounting for the non-independence of observations collected from each participant in a within-subjects design, without resorting to computing separate regression equations for each subject [26,29,30]. Multilevel modeling also accounts for violations of the sphericity assumption by modeling heteroscedasticity in the data when necessary, improving statistical power over other methods commonly employed for analyzing repeated-measures data. Specifically, we examined the Self/Other, Enhance/Repair, and Core/Peripheral variables as discrete sum coded independent variables, age, education, and gender (sum coded) as covariates, and included random effects for subjects. Self, core, enhance, and male were encoded as 1 and other, peripheral, repair and female were encoded as –1 for all analyses. We examined political affiliation and moral acceptability as independent variables in separate main effects models to isolate these effects.

Survey factor structure replication

In the current study, we adapted the cognitive functions found to be more "core" and "peripheral" to authentic identity from Ref. [15] for use in our items assessing subjects' willingness and moral evaluations. To test whether the findings in the current survey conform to a similar factor structure, we performed a confirmatory factor analysis (CFA) assuming a two-factor solution with the items from the Core and Peripheral factors in Ref. [15]

assigned to two separate factors. We computed the CFA across all individuals' responses for the Willingness to enhance and repair specific cognitive abilities. The two-factor solution demonstrated an acceptable fit: we found a comparative fit index (CFI) = 0.912 and Root Mean Square Error of Approximation (RMSEA) = 0.076. These values surpass widely used benchmarks of CFI greater than 0.9 and RMSEA less than 0.08, and just below more stringent margins recommended following large scale simulation studies [31]. Thus, the 2-factor solution found in the previous study in pharmaceuticals is reasonably replicated in this dataset and suggests that our items are sensitive to similar latent dimensions in the current study. There may be some deviations from the prior study due to sampling characteristics and method variance in the current survey.

Data availability

The data from this study are available for download on the Open Science Framework on the pre-registration page for this study: <https://osf.io/dtw2g/>

Results

Final sample

A total of 1000 subjects enrolled to take the surveys, half for the “self survey” and half for the “other survey”. In the self survey, we excluded 30 subjects who did not provide complete data and an additional 21 subjects failed at least one attention check item and were excluded. In the “other” survey, we excluded 31 subjects who did not provide complete data and an additional 17 subjects who failed at least one attention check item. The final sample included 894 subjects, with 449 to the “self” survey and 445 to the “other” survey. The total sample consisted of 443 females, a mean age of 37.4 years of age (SD = 11.55), and the modal education level was a Bachelor’s degree. The included subjects completed the self survey in an average of 17.7 min (St.D. = 10.5 min) and the other survey in an average of 17.2 min (St.D. = 9.7 min).

Main effects

The results of the main effects model can be observed in Table 1. Across the sample, older individuals reported a lower willingness to use any kind of brain stimulation. Two of the three primary independent variables (enhancement versus repair, and self versus other) were significant. The fundamentalness of the cognitive functions (“core” versus “peripheral”) was not. Subjects were more willing to repair than enhance functions overall (Fig. 1) and to use brain stimulation on others rather than on themselves (Fig. 2).

The results of the mixed effects model including two-way interactions can be viewed in Table 2. As anticipated, the self-/other factor interacted with the cognitive fundamentalness factor and enhance/repair factor.

Table 1
Main effects model.

	Estimate	Std. Error	df	t-value	p
Intercept	3.954	0.126	894	31.479	<0.001
Age	-1.137	0.002	894	-5.421	<0.001
Education	-0.036	0.034	894	-1.056	0.291
Gender	0.020	0.048	894	0.414	0.680
Self/Other	-0.064	0.024	894	-2.673	0.008
Core/Peripheral	0.003	0.007	2771	0.478	0.633
Enhance/Repair	-0.198	0.007	2771	-30.388	<0.001

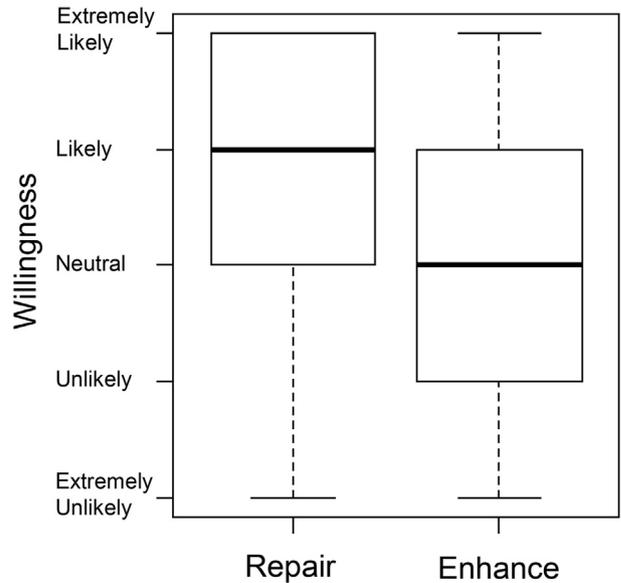


Fig. 1. People are more willing to repair than enhance. Overall, subjects expressed relatively increased willingness to use Ceremode to repair rather than enhance cognitive functions. The top and bottom horizontal hash marks represent the maximum and minimum values, respectively. The top and bottom of the box represent the third and first quartiles, respectively. The thick horizontal line represents the median value in each condition.

Specifically, Fig. 3 shows that subjects were especially more likely to report willingness to use Ceremode to repair others than any other condition. In addition, they were more likely to report willingness to repair rather than enhance themselves.

Fig. 4 shows that while subjects were willing to influence others more than themselves, this effect was driven by more willingness to influence Core functions in others relative to themselves.

Lastly, we performed a full model with a three-way interaction between the Core/Peripheral, Self/Other, and Enhance/Repair

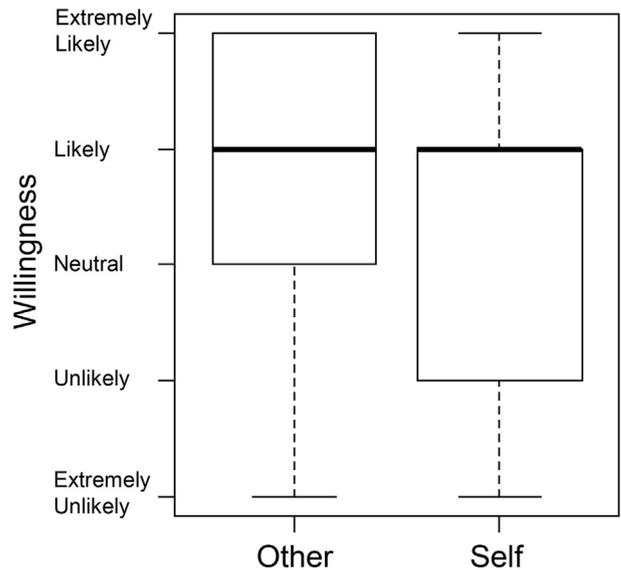


Fig. 2. People are more willing to influence others than themselves. Across all items, subjects reported a tendency to use Ceremode on others rather than themselves. The top and bottom horizontal hash marks represent the maximum and minimum values, respectively. The top and bottom of the box represent the third and first quartiles, respectively. The thick horizontal line represents the median value in each condition.

Table 2
Interaction model.

	Estimate	Std. Error	df	t-value	p
Intercept	3.954	0.126	894	31.479	<0.001
Age	-0.137	0.002	894	-5.421	<0.001
Education	-0.036	0.034	894	-1.056	0.291
Gender	0.020	0.048	894	0.414	0.679
Self/Other	-0.064	0.024	894	-2.673	0.008
Core/Peripheral	0.003	0.006	2771	0.542	<0.588
Enhance/Repair	-0.199	0.006	2771	-30.753	<0.001
Self/Other*Core/Peripheral	-0.086	0.006	2771	-13.340	<0.001
Self/Other*Enhance/Repair	0.117	0.006	2771	18.186	<0.001

factors (Table 3). Fig. 5 illustrates that among all of the conditions, subjects were most willing to repair core functions in others.

Across all items, moral acceptability was positively related to the willingness to use Ceremode (See Table 4 and Fig. 6). Post hoc t-tests at the item level indicate that subjects viewed repair to be more morally acceptable than enhancement overall ($t(2771) = -13.14$), affecting core functions to be more morally acceptable than peripheral functions ($t(2771) = -28.91$), and affecting themselves to be more morally acceptable than others ($t(2771) = 3.762$, $p < 0.001$). Importantly, the median response for each condition was to “Agree” that uses were morally acceptable, suggesting that differences between condition involve relative acceptability instead of acceptable versus unacceptable uses.

There was no significant relationship between political affiliation and the willingness of individuals to enhance or repair cognitive functions (See Table 5). Additionally, there was no significant relationship between neoliberalism and willingness to use Ceremode (See Table 6). In addition, there was no significant interaction between openness to experience and core or peripheral functions (See Table 7).

Discussion

In self-report surveys measuring moral assessments of applications of brain stimulation on various cognitive functions, we found partial support for our hypotheses. Subjects were more willing to repair than enhance cognitive functions overall. Moreover, the reported moral acceptability of specific uses of Ceremode

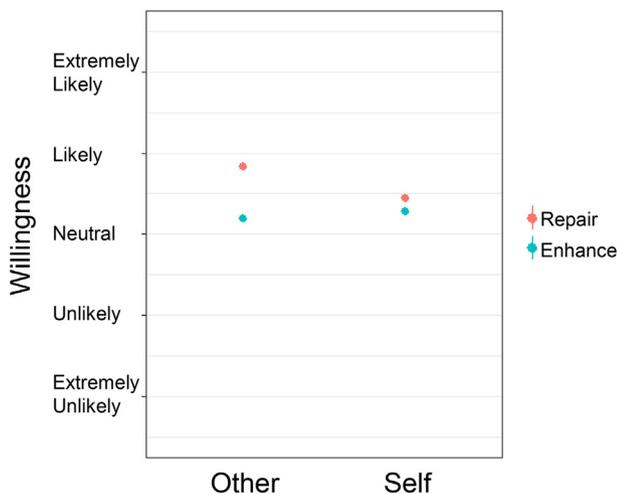


Fig. 3. The significant interaction between the Self/Other and Enhance/Repair factors. We observed that repair was favored over enhancement overall, and that this is especially the case when considering to use Ceremode on others. Circles represent the condition means; standard errors of the mean too small to observe at this scale.

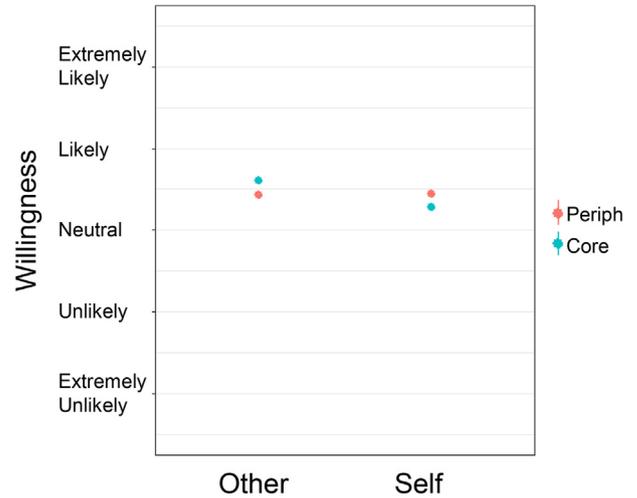


Fig. 4. A significant interaction between Self/Other and Core/Peripheral factors. We observed that subjects were similarly willing to use Ceremode to enhance or repair peripheral functions in themselves and others. However, subjects were much more willing to use Ceremode to influence core functions in others. Circles represent the condition means; standard errors of the mean too small to observe at this scale.

was positively associated with willingness to use Ceremode for that purpose. In addition, subjects were similarly willing to use Ceremode to influence peripheral functions on themselves and others, but demonstrated willingness to influence the core functions in others but *not* in themselves. However, some results differed from our predictions. Contrary to our hypothesis, subjects were more willing to use Ceremode on others than themselves overall.

Our findings suggest that moral evaluation contributes to willingness to use brain stimulation when resources are limited. In vignettes describing a hypothetical brain stimulation technology that comes in a limited supply, subjects prioritized repair over enhancement in alignment with their moral judgments. However, subjects' overall willingness to use brain stimulation on core or peripheral functions and on themselves rather than others was in the opposite direction of ratings of moral acceptability. This suggests that moral evaluation may contribute to judgments to repair over enhancing functions, but that subjects override their moral dispositions in the other survey conditions. In the case of self versus other brain stimulation uses, significant main effects were observed in opposite directions: subjects may believe it is somewhat more appropriate to modify themselves, but report more willingness to apply brain stimulation to others. Subjects' high willingness to repair core functions in others may suggest that additional social attitudes override certain moral intuitions. Research shows that moral commitments can dissociate from moral judgments [32], and our current study suggests that it will be important to clarify the links between moral commitments and values, discrete moral judgments, hypothetical willingness, and real-world behavior in brain stimulation uses. Another possibility is that subjects may be reluctant to use brain stimulation on others if they believe it is an infringement on others' rights to self-control (i.e., a form of autonomy [33]), leading it to be a less morally acceptable prospect. Because similar dissociations at the person- and policy-level have been observed in attitudes toward pharmaceuticals for enhancement, systematic research should assess specific moral attitudes and their relationships to hypothetical willingness and actual behavior.

The most surprising finding – that individuals were more willing to influence others, and specifically for core functions –

Table 3
3-way interaction model.

	Estimate	Std. Error	df	t-value	p
Intercept	3.954	0.126	894	32.439	<0.001
Age	-0.114	0.002	894	-5.430	<0.001
Education	-0.036	0.034	894	-1.052	0.291
Gender	0.009	0.024	894	0.362	0.717
Self/Other	-0.191	0.052	1160	-3.705	<0.001
Core/Peripheral	0.003	0.006	2771	0.542	<0.588
Enhance/Repair	-0.199	0.006	2771	-30.753	<0.001
Self/Other*Core/Peripheral	-0.086	0.006	2771	-13.342	<0.001
Self/Other*Enhance/Repair	0.117	0.006	2771	18.190	<0.001
Core/Peripheral*Enhance/Repair	-0.006	0.006	2771	-0.955	<0.339
Core/Peripheral*Enhance/Repair*Self/Other	-0.021	0.006	2771	-3.197	0.001

bears special consideration. In general, we know little about how the public views the potential to distribute cognitive enhancement. It is possible that individuals in the current study were generously inclined to repair others' "true" selves when the self has been lost due to brain injury. Curiously, individuals were less inclined to endorse repair of core functions in themselves. Speculatively, this could be due to the difficulty in imagining what it is like to lose one's own authentic, holistic sense of self (the "Mind's I" [34]), and the relatively easier task of being able to observe how others change due to injuries in the public imagination or by experiences with friends and family. The potential link between imaginability and willingness could be explicitly tested in future studies. An additional nuance is worth noting: we did find some partial support for our prediction that individuals would favor self-enhancement for performance gains over others. Specifically, individuals were more likely to enhance and repair peripheral functions in themselves relative to others. Since some of these "peripheral" functions include those that are valuable in a performance-based economy (e.g., memory, concentration), it is possible that individuals may prioritize these uses for personal gains over others. Examining individuals' beliefs about the links between specific functions and real-world outcomes could clarify this finding. Further, examining the relationships between moral commitments and moral judgments [32] could help explain why some individuals favor specific uses in themselves or others. Finally, another important variable may be the extent to which subjects are generally more cautious when considering to use brain stimulation on themselves given that such technologies have only recently entered the public market. Examining subjects' familiarity with brain stimulation as a moderating variable could test this possibility.

Interestingly, contrary to prior work in pharmaceuticals [15,17], we did not find that individuals were less willing to influence traits more "core" to authentic identity with hypothetical brain stimulation. This indicates that consumer intuitions may differ due to the hypothetical mechanism of delivery. Brain stimulation and pharmaceuticals can both be "neuromodulatory" and influence cognition. However, brain stimulation is often administered with devices that use electromagnetism, whereas pharmaceuticals are administered intra-orally and chemically modulate metabolic, neural, and other cerebrovascular effects. To examine broad intuitions among subjects, we gave them very few details about the hypothetical technology, meaning that subjects may have had different assumptions about the nature of Ceremod, such as how it might work and whether it was invasive or noninvasive. Moreover, brain stimulation predominantly emerged in the 1980s, whereas pharmaceutical manufacturing began in the late 1890s. This means that public awareness, acceptance, and reasoning about pharmaceuticals has developed for many decades longer than for brain stimulation (but see Ref. [35] concerning an exception during the 1920s). How sociocultural processes shape evaluation of the specific mechanisms of interventions and their public or professional acceptance could inform an important new area of study for research pertinent to reasoning and public policy.

In this vein, our research contributes an important empirical basis from which research informing public education, outreach, and policy could develop. Several groups have opined that growing trends toward in brain stimulation could lead to issues with ethical and equitable distribution of clinical and enhancing or "neuro-aesthetic" [36] uses of brain stimulation [11,37]. Moreover, the public is more worried than enthusiastic about enhancement using invasive forms of brain stimulation to enhance themselves [38].

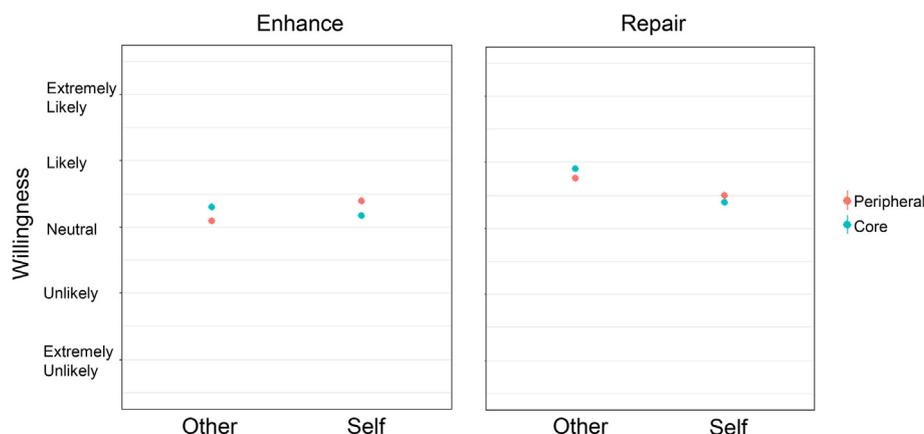


Fig. 5. A significant three-way interaction between the Core/Peripheral, Self/Other and Enhance/Repair factors. We observed that subjects were willing to use Ceremod to repair especially core functions in others overall, followed by willingness to repair peripheral functions in others.

Table 4
Moral acceptability associations with willingness to use Ceremode.

	Estimate	Std. Error	df	t-value	p
Intercept	3.317	0.128	1037	25.838	<0.001
Age	-0.120	0.002	889	-5.812	<0.001
Education	-0.048	0.034	890	-1.418	0.156
Gender	0.001	0.047	890	0.021	0.983
Moral Acceptability	0.160	0.009	2737	18.297	<0.001

There have also been efforts to educate and caution at home brain stimulation users about unknown or harmful effects [10]. Thus, there are several stakes that can be studied. The first concerns the effects of specific uses of brain stimulation, where investigators must determine what functions are affected, to what degree, and in what circumstances [39]. The second, depending on the first, concerns whether and how ethical and equitable distribution are feasible [11]. The third, motivated by the current work, concerns how objective facts about brain stimulation and the ethical and equitable distribution of brain stimulation are viewed by the public and professional brain stimulation practitioners. This latter issue has heretofore largely been subject to intensive conceptual discussions and opinions, despite the fact that the public is demonstrably sensitive to many of the key debates and stakes [16]. More pressingly, we should objectively study public and professional attitudes and behaviors toward brain stimulation to inform decisions about how these phenomena affect brain stimulation practices in the real world, and how we might seek to positively influence these processes [4,5,9,40].

Concerning potential ways to change public or professional attitudes toward brain stimulation, our findings suggest at least two directions worth immediate inquiry. First, studying how judgments are influenced by an intervention's mechanism of action, individuals' understanding of the mechanisms, and the intervention's objective effects is important. Second, we should examine judgments about brain stimulation interventions drawing from research in human decision making [41], neuroeconomics [42], well-being [49] and moral reasoning [43]. Each of these fields are clarifying how specific neurocognitive traits, biases, and adaptive processes produce more or less rational and emotional responses and shape beliefs. While we focus on survey responses to vignettes,

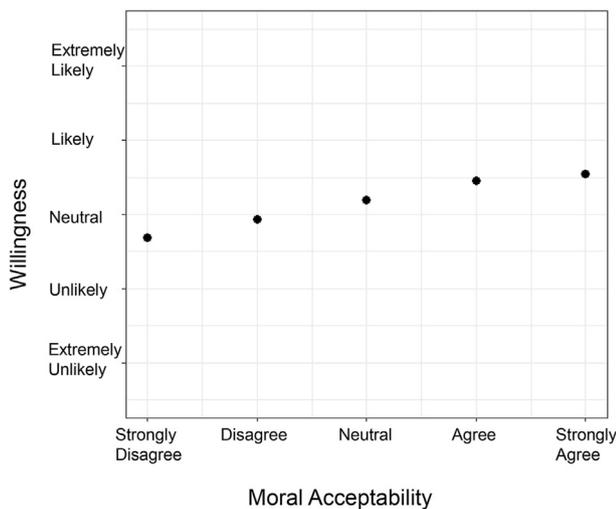


Fig. 6. Moral acceptability is related to willingness to use Ceremode. We observed a positive association between the moral acceptability of specific uses of Ceremode and willingness to use Ceremode for each purpose. Circles represent means at each value of moral acceptability, standard errors of the mean too small to observe at this scale.

Table 5
Main effects of political affiliation (Democrats as reference group).

	Estimate	Std. Error	df	t-value	p
Intercept	3.997	0.129	887	30.891	<0.001
Age	-0.012	0.002	887	-5.515	<0.001
Education	-0.040	0.034	887	-1.165	0.244
Gender	0.024	0.048	887	0.497	0.619
Republican	-0.034	0.062	887	-0.537	0.591
Independent	-0.062	0.058	887	-1.070	0.285
Other	0.054	0.135	887	0.400	0.690

we can also begin to study judgments about self enhancement and repair using cognitive models, identify variables that influence specific judgments, and explore moral and willingness judgments in nonzero sum scenarios. This would let us test how moral attitudes could be informed to change judgments about brain stimulation. Would could also examine how cognitive-emotional processes contribute and could be modified to promote best practices. Indeed, we found that individuals viewed affecting themselves with brain stimulation to be more morally acceptable, but were overall more willing to use brain stimulation on others to repair core functions essential to empathic functioning. One important study could be to more closely examine zero-sum vignettes. Given our exploratory data, it would be interesting to test how subjects evaluate trade-offs when asked to modify cognition in the context of finite resources (See [Supplementary Figure 1](#)). This could include studies that examine whether subjects would express altruistic attitudes when deciding whether to optimize themselves or others.

Limitations

Several limitations to the current study can and should be addressed with future research. The current study is subject to the limitations inherent in self-report survey research. We cannot identify causal influences with the current study. It will be important to examine whether the main effects of interest differ in within- and between-subjects administrations. In addition, the structure of the survey did not allow us to test for possible order effects between the willingness and moral acceptability conditions since the latter always followed the former. Future studies could manipulate moral framing to test whether moral primacy influences willingness to use brain stimulation for specific purposes. In addition, it is well established that reverse coding and item-level issues can influence ratings [44]. Moreover, while we

Table 6
Main effect of the neoliberalism summary score.

	Estimate	Std. Error	df	t-value	p
Intercept	3.842	0.152	889	25.215	<0.001
Age	-0.012	0.002	889	-5.620	<0.001
Education	-0.039	0.034	889	-1.125	0.261
Gender	0.016	0.048	889	0.335	0.738
Neoliberalism	0.044	0.028	889	-0.598	0.110

Table 7
Interaction model between openness to experience and trait fundamentalness.

	Estimate	Std. Error	df	t-value	p
Intercept	3.913	0.151	894	25.972	<0.001
Age	-0.119	0.002	894	-5.649	<0.001
Education	-0.040	0.034	894	-1.173	0.241
Gender	0.009	0.024	894	0.369	0.712
Core/Peripheral	0.003	0.007	2771	0.470	0.638
Openness	0.022	0.025	894	0.878	0.380

uncovered several significant main effects and interactions, there was notable variation in responses that was not accounted for by the variables we examined. An interesting future direction would be to examine item-level accuracy in assessing attitudes and potential ways to influence judgments. In addition, while we included a specific mechanism of injury in our repair condition, other mechanisms of injury could be investigated as a dimension of interest. Throughout the survey, subjects were told to assume that the brain stimulation has no side effects. However, this is not realistic [45–47] and subjects might have assumed that side effects were still a possibility.

Another salient variable is the religious identity of individuals; in a public survey about invasive technologies, religious individuals were more reluctant than atheists and agnostics to receive enhancements [5,38]. Religious affiliation may interact with the variables explored here, including underlying moral evaluations. Some exploratory data for subject religiosity are available as part of the full dataset are available on the Open Science Framework (see “Data availability” in the Methods). In addition, while we included only subjects who passed our attention checks and subjects generally completed the surveys in less than 30 min, the length of the survey may have influenced reporting over time. The order of the survey administration could be examined in replications studies. The exploratory ideological and demographic data were collected at the end of the survey, raising the possibility that they were more susceptible to order, distractibility, and fatigue effects. Finally, while prior research suggests that survey data collected via Mechanical Turk can be representative of data acquired in person [23,48], it is unknown whether this generalizes to the current context.

Conclusion

Brain stimulation is increasingly available, but empirical studies of public attitudes and judgments have lagged behind opinions and policy. The current study is the beginning of an effort to understand judgments and moral dispositions toward cognitive enhancement and repair. Our results suggest that while uses of brain stimulation tend to be morally acceptable, the degree of acceptability is commensurate with the willingness to repair functions core to identity in others, but is at odds with the willingness to endorse enhance the self. Future efforts can begin to apply these findings to contexts beyond brain stimulation to inform human judgment and reasoning in brain stimulation more generally. We can begin to develop a mature understanding of moral judgments about these technologies with the aim of informing public and professional policy, education, and biomedical interventions.

Conflicts of interest

We confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Author contributions

JDM conceptualized the study, analyzed the data, and wrote the manuscript. DY helped to conceptualize the study and contributed to manuscript writing. CH helped to conceptualize the study, edit manuscript drafts, and interpret findings. MH contributed to the study design, item creation, and survey creation and administration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.brs.2018.09.014>.

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