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Do Publics Share Experts' Concerns about Brain–Computer Interfaces? A Trinational Survey on the Ethics of Neural Technology

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Abstract

Since the 1960s, scientists, engineers, and healthcare professionals have developed brain–computer interface (BCI) technologies, connecting the user's brain activity to communication or motor devices. This new technology has also captured the imagination of publics, industry, and ethicists. Academic ethics has highlighted the ethical challenges of BCIs, although these conclusions often rely on speculative or conceptual methods rather than empirical evidence or public engagement. From a social science or empirical ethics perspective, this tendency could be considered problematic and even technocratic because of its disconnect from publics. In response, our trinational survey (Germany, Canada, and Spain) reports public attitudes toward BCIs ($N = 1{,}403$) on ethical issues that were carefully derived from academic ethics literature. The results show moderately high levels of concern toward agent-related issues (e.g., changing the user's self) and consequence-related issues (e.g., new forms of hacking). Both facets of concern were higher among respondents who reported as female or as religious, while education, age, own and peer disability, and country of residence were associated with either agent-related or consequence-related concerns. These findings provide a first look at BCI attitudes across three national contexts, suggesting that the language and content of academic BCI ethics may resonate with some publics and their values.

Keywords

brain–computer interfaces, public attitudes, neural technology, ethical expertise, survey

Background

Brain–computer interfaces (BCIs), as a general category, refer to a range of technologies that connect brain activity to computer-mediated outputs. The underlying mechanism for these devices, that neurons can be retrained to interact with artificial systems, is often traced back to a frequently cited study from the 1960s; in that case, the device was justified as a tool for causal scientific investigation of brain structure (Fetz 1969). This predominantly epistemic rationale did not last long. As Forman (2007) describes, research conducted in post–World War II democratic societies was marked by destabilization in cultural understandings of the boundaries between science and technology. BCI research of the time was no exception. In the following decades, Fetz and other researchers expanded their stated rationale for neural device research to include human applications in healthcare and other contexts.

BCI researchers have since devised a variety of applications in which the human user purposefully generates outputs including moving paralyzed limbs, controlling a computer cursor, and spelling out words, as well as other applications that rely on passive monitoring of the user (Brunner et al. 2011; Shih, Krusienski, and Wolpaw 2012). One recent research publication and its associated press releases include shareable videos, depicting persons with tetraplegia using an experimental device that has been implanted at the top of their head; one video depicts the user laying in a bed, ostensibly motionless, but nevertheless typing Google chat messages on a tablet computer (Nuyujukian et al. 2018). For this and other BCI devices, neural activity is collected either indirectly, using a wearable sensor cap, or directly by implanting electrodes in brain tissue. The resulting signal is then translated into usable information or commands.

A focus on BCI technology can also be found outside the laboratory in various institutional and mediated forms. The US BRAIN initiative and comparable international projects direct millions of dollars in funding to technology-driven neuroscience, while do-it-yourself communities have emerged around open-source platforms like OpenBCI and promise of increased well-being through self-administered brain stimulation (Wexler 2016). These practices have amplified existing brain-centered discourses in society, including popular media depicting neural imagery and even sociological and ethical research on neuroscience (Pickersgill 2013). University press releases and commercial advertisements have already started to introduce the idea of BCI to various publics, and evocative human–computer imagery has come to represent “post-humanity” or beyond the human (Purcell-Davis 2013; Jasanoff 2016). Media coverage of related neurotechnologies (such as deep brain stimulation) in the United Kingdom, the United States, Canada, and Spain has been found to be enthusiastic, with limited explicit attention to potential ethical issues (Racine et al. 2007; Cabrera et al. 2018). Meanwhile, researchers in biomedical ethics and in the relatively new field of “neuroethics” (Illes et al. 2011; Marcus 2002) investigate BCIs as an object of concern.

Ethics researchers worry, in particular, that the use of these devices might be dangerous to the user, threaten mental privacy, challenge the user’s self-understanding, exacerbate inequality, and bring about other negative outcomes (Klein et al. 2015). A subset of authors is specifically concerned that the technology is framed as a healthcare device, which implicitly defines the ideal human and may further the stigmatization of disabled people (Aas and Wasserman 2016; Wolbring and Diep 2016). The sophistication and scope of this ethics literature, however, does not imply that it responds to the actual understandings and significance of BCI technology in nonacademic contexts. Some scholars have noticed this, calling for a two-way dialogue with diverse affected publics, including potential BCI users (Doucet 2005). This hope for a more inclusive mode of neuroethics has not yet been realized in the BCI ethics literature and may warrant skepticism about the claims made therein. A recent literature review of BCI ethics found many concerns based on ethical theory and relatively few quantitative and qualitative studies on public attitudes (Burwell, Sample, and Racine 2017).

Unfortunately, existing empirical evidence provides limited insight into the relationship between academic ethics and diverse publics. Many empirical studies focus on aspects of BCI users' and researchers' perspectives such as expectations around technical performance (e.g., speed and accuracy; Nijboer et al. 2013) but do not clearly address ethical issues associated with BCI use in society. Furthermore, these studies often provide participants with limited explanation of what a BCI is, with no consideration of the various tradeoffs or consequences of various aspects of BCI design (Huggins et al. 2015; Huggins, Wren, and Gruis 2011). Lastly, there is little research on the role of socio-economic background, experience with disability, and values in determining how these technologies are appraised, even though people may vary in their needs and outlooks depending on their personal and cultural setting (Yuste et al. 2017). As such, only a few studies explored public understandings of BCI ethics.

A Pew Center poll (Funk, Kennedy, and Sciupac 2016) on human enhancement reports that only 34 percent of US adults are "very" or "somewhat" enthusiastic about brain implants compared to 68 percent who are worried. They also report that the majority of people find cognitive enhancement morally unacceptable, especially women and white evangelicals. A series of focus group studies conducted in the United States and Europe identify some shared qualitative themes; participants responded positively to health applications (as opposed to military and consumer applications) and express ambivalence about the idea of government regulation of neural technology (Jebari and Hansson 2013; Funk, Kennedy, and Sciupac 2016). These relatively sparse empirical findings may justify the existence of preliminary speculative or conceptual BCI ethics research, but stronger empirical evidence is needed to identify and close the gap (if any) between academic BCI ethics and the emerging publics of neural technology.

We can understand the urgency of this task in at least two ways, depending on perspective. For some, the methods of speculation and reflection common in BCI ethics prevent adequate understanding. Researchers in "empirical ethics," "critical bioethics," and "responsible innovation" maintain that public beliefs and attitudes toward new biomedical interventions are absolutely necessary to inform debates about how biotechnologies should be developed and regulated. These forms of research are deeply committed to contextual understandings of ethical issues and the experiences that ground them (Hedgecoe 2004; Borry, Schotsmans, and Dierickx 2005; van der Scheer and Widdershoven 2004; Racine and Sample 2018; Demers-Payette, Lehoux, and Daudelin 2016). For other researchers, the methods of academic ethics prevent not just understanding but also political legitimacy. An analogous tension between democracy and expertise has already been noted in scholarship on the societal role of expert bioethics (Evans 2002; Engelhardt 2002; Kelly 2003). Hurlbut (2017), most recently, observes that bioethicists in the United States have come to stand in for the reasonable citizen, a paradoxical effect of Rawlsian public reason. Yet, it is not clear whether and to what extent these dual critiques invalidate the speculative and conceptual claims made in academic BCI ethics literature.

In response, the present study addresses two gaps in the literature: (1) a lack of empirical evidence about public attitudes and (2) a comparison between academic and lay perspectives on BCI ethics. We report the results of a quantitative survey that gauged 1,403 participants' level of concern for not only potential applications of BCIs but also toward the dominant ethical issues identified in the academic ethics literature. By mapping these onto basic demographic information about respondents across three countries (Canada, Spain, and Germany), we provide a first look at the national dimensions of attitudes toward BCI technology, revealing characteristics of the potential publics of neural technology.[1] Additionally, by carefully presenting ethical issues in a way that mirrors the academic ethics literature, we assess public receptiveness to the language and content of expert BCI ethics. As a result, these findings contribute to less speculative BCI ethics as well as broader discussions in philosophy and science and technology studies (STS) about the relationship between academic and lay ethics.

Method

Participants and Study Design

Participants from Canada, Germany, and Spain were recruited for a web-based survey via a commercial Internet panel provider. Beyond

Table 1. Descriptive Information on the Sample.

	M/proportion	*SD*	Minimum	Maximum
Female	0.51		0	1
Age	43.40	14.82	18	89
Education (in years)	13.49	2.86	6	22
Religiosity	4.08	2.73	1	10
No own disability	0.89		0	1
Own disability, no paralysis	0.10		0	1
Own disability, yes paralysis	0.01		0	1
No peer disability	0.64		0	1
Peer disability, no paralysis	0.23		0	1
Peer disability, yes paralysis	0.13		0	1
BCI knowledge	3.49	2.11	1	10
Canada	0.34		0	1
Germany	0.32		0	1
Spain	0.34		0	1

Note: number of observations = 1,403, weighted data. *M* = mean, *SD* = standard deviation; BCI = brain–computer interface.

simply providing a comparative perspective, these countries were selected because they corresponded to expertise among study team members (see Strengths, Limitations, and Directions for Future Research section). Participation was voluntary and anonymous. In total, 4,977 respondents started with the survey, of which 4,744 (95.32 percent) consented to participate, of which 1,643 passed the attention check (34.44 percent)[2]; 1,403 respondents remained after excluding respondents who met other various exclusion criteria. Specifically, we removed responses from those who were ineligible because they dropped out or reported an age of less than eighteen. We also excluded those who exhibited behavior that may lead to poor data quality, as follows: showed a pattern of straight-lining answers, had response times below 360 seconds, selected a survey language that was not localized for their country (i.e., French or English had to be selected in Canada, German in Germany, and Spanish in Spain), or had missing responses for the analyzed variables. Upon completion, respondents received a cash incentive (no more than US$4, as determined by the panel provider) to increase their motivation to participation and to compensate for their time (Lavrakas 2008; van Veen, Göritz, and Sattler 2016; Göritz 2014; see Table 1 for descriptive information on the sample).

Ethics Statement

Ethics approval was received from the Institut de recherches cliniques de Montréal (approval number: 2018-904).

Instrument

Preparatory works. A recent scoping literature review found forty-two articles about BCI ethics (Burwell, Sample, and Racine 2017) and analyzed them to identify key themes in academic ethics literature. We used this review to develop thirty-six items that capture some of the most frequently discussed ethics concerns. A first draft of this list was presented at a two-hour public-facing consultation event in Granada, Spain, as an early assessment of intelligibility and comprehensiveness for both academic specialists and attendees from the local community.

To increase the validity of survey items, we sought feedback from experts ($N = 6$) with backgrounds in neuroethics, medicine, and engineering in exchange for modest compensation. The experts assessed whether each item was consistent in tone, concrete, and clear, ensuring that the presentation of each ethical issue was faithful to the source material and interpretively valid (Maxwell 1992). Based on this feedback, we revised and clarified the language of survey items. Ten ethical issues were identified as either redundant or as not clearly "concerning" (e.g., ethically neutral or potentially positive in character) and were removed.

Subsequently, we conducted cognitive think-aloud pretests ($N = 15$) including probing questions with researchers, college students, and people we know without research expertise to evaluate survey clarity and comprehensibility for nonexperts. Pretest results suggested that respondents, while uncertain about the meaning of some concern labels, understood the examples and could follow the instructions. Based on these results, the items were again revised to increase comprehensibility of the language; some respondents indicated that they misunderstood the technology as solely medical, and briefing information was refined to highlight nonmedical examples.

Briefing. To create a basic shared understanding of BCIs, we briefed respondents with examples for the use of BCIs including pictures of a wearable and an implantable BCI (see Figure S1 in Online Appendix). After at a minimum of 45 seconds had elapsed, respondents were asked to confirm that they carefully read the briefing information.

BCI knowledge. Respondents were asked to self-report their knowledge about BCI technology before starting this survey. Responses were assessed on a scale ranging from 1 “nonexistent (I’ve never heard of it)” to 10 “very high.”[3]

Worries and enthusiasm about domains of BCI applications. Respondents were asked about their worries (assessed on a scale from 1 = “not worried” to 10 = “extremely worried”) and enthusiasm (1 = “not enthusiastic” to 10 = “extremely enthusiastic”) about the possibility of applying BCI technology to six areas of life including two examples for each area: (A) military, police, and security, (B) marketing and commerce, (C) work, (D) entertainment and recreational use, (E) education and learning, and (F) healthcare and assistive technology (see item text in Table S3 in Online Appendix).

Concerns about BCI use. We used twenty-six items to assess respondents’ concerns about BCIs (see item text in Table S4 in Online Appendix). Responses were assessed on a scale from 1 = “not concerning” to 10 = “extremely concerning.” We provided the respondents with a brief definition of each potential item of concern, accompanied by two short examples. To reduce the number of variables to be analyzed and to investigate whether groups of concerns form certain factors, an exploratory factor analysis (principal components factor analysis with Varimax rotation) was used (see Table S5 in Online Appendix). The analysis was repeated until only factors with loadings above .32 and no double loadings above .32 occurred. This iterative process resulted in two factors and a factor analysis with a Kaiser–Meyer–Olkin measure of .89, which indicates a very good suitability of the data for structure detection. The first factor (internal consistency: $\alpha = .86$) centered on six items (i.e., *becoming cyborgs*, *redefining humanity*, *changing the self*, *doubting authenticity*, *defining normality*, and *enabling unfair enhancement*), which we named *Concern for Agent-related Issues* because items mainly relate to how the human agent is affected by BCIs. The second factor (internal consistency: $\alpha = .70$) centered on five other items (i.e., *enabling new forms of hacking*, *limited availability*, *risking surgical complications*, *seriousness of device failure*, and *media hype and inaccuracy*), which we named *Concern for Consequence-related Issues* because they mainly refer to the concrete societal or practical implications of BCIs. We recognize that this distinction is not necessarily a strict dichotomy and that the terminology we used should not be overinterpreted as referring to well-defined, clear-cut concepts. Regression factor scores for each factor were used to account for a potentially different impact of each item on the scales (DiStefano, Zhu, and Mindrila 2009). Thereby, a score of 0 indicates an average concern and 1 is the standard deviation.

Own and peer disability. Because disability and associated societal challenges are currently a dominant justification of BCI development, respondents were asked whether they have no disability (coded 0), or if yes, whether they have (1) or do not have (2) a partial or complete paralysis (due to stroke, spinal cord injury, or other reasons); and whether a friend or family member has no disability (0) or a disability without (1) or with paralysis (2).

Sex, age, and education. As socio-demographics, we assessed respondents' sex and age as well as their number of years of education by considering country-specific education levels.

Statistical Analyses

We used ordinary least squares regression models to explore how the respondent characteristics were associated with respondents' concerns toward BCIs. We report standardized regression coefficients and confidence intervals. For all analyses, we used sampling weights (Winship and Radbill 1994) based on information regarding the gender and education distribution from the general populations of each country[4] to decrease potential biases due to selective study participation. Weighting has been suggested to reduce biases in nonprobability online samples (Sakshaug et al. 2018).

Results

Worries and Enthusiasm about Domains of BCI Applications

Respondents are especially worried about the use of BCIs in the context of military, police, and security as well as marketing and commerce. In contrast, they reported much less worry regarding applications in healthcare and assistive technology as well as education and learning (see panel 1 in Figure 1). For all of these domains, enthusiasm is almost the inverse of worries (see panel 2).

Concerns about BCI Use

Generally, the level of concern is moderately high (see Figure 2). All items have mean values above the midpoint of the scale. The highest level of

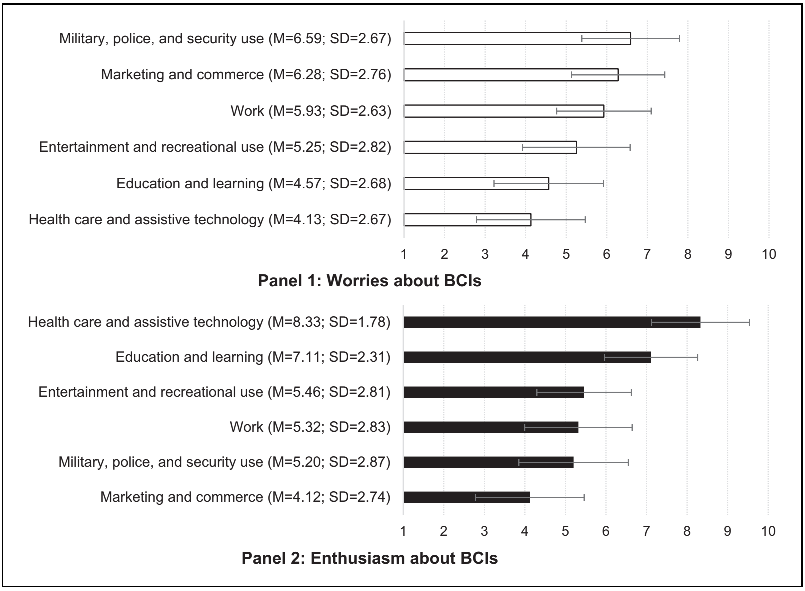

Figure 1. Worries (panel 1, white bars) and enthusiasm (panel 2, black bars) about the domains of application of brain–computer interfaces (number of observations = 1,403, weighted data). Scale for worry: items ranging from 1 = "not worried" to 10 = "extremely worried." Scale for enthusiasm ranging from 1 = "not enthusiastic" to 10 = "extremely enthusiastic"; empirically values ranged from 1 to 10 (see full wording for domains of application in Table S3 in Online Appendix). *M* = mean, *SD* = standard deviation (indicated by error bars).

concern was that new forms of hacking might occur, followed by concern about serious device failure. The least concerning were the promotion of a medical model of disability and the possibility of unfair enhancement.

Concern about Agent-related Issues

Agent-related concern was especially pronounced in respondents who reported as "female" in comparison to "male" ($p = .004$; see Figure 3 and Online Resource S6). Such concern is higher for respondents with higher levels of religiosity ($p < .001$). Respondents without a disability are more concerned than respondents who have a disability but no paralysis ($p < .010$), but they are similarly concerned as respondents with a disability related to paralysis ($p = .171$). A Wald postestimation shows no difference

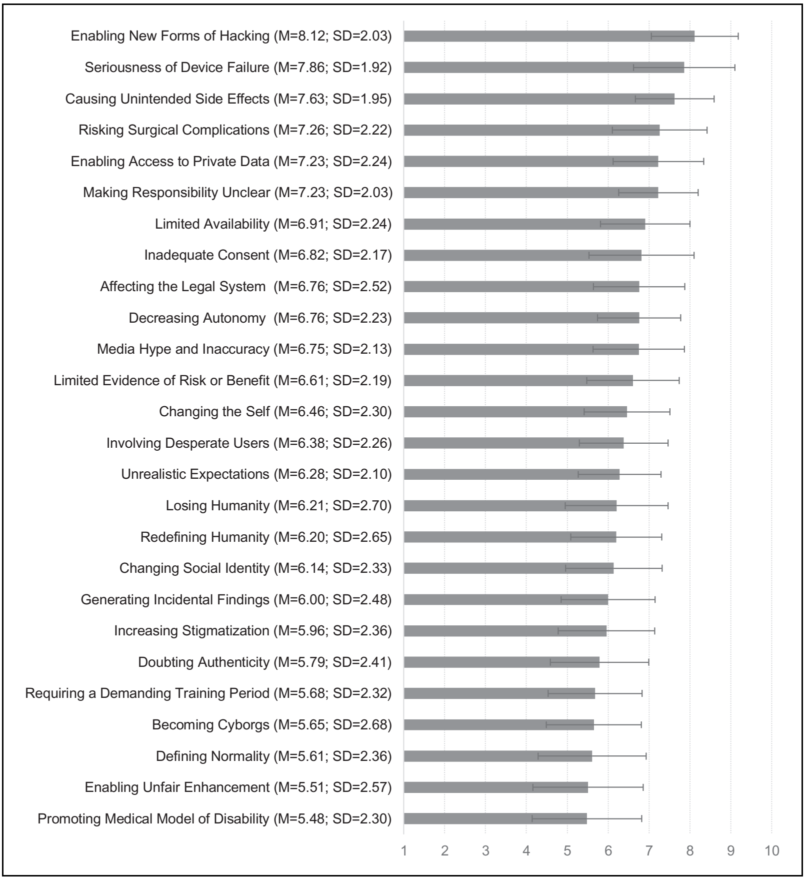

Figure 2. Concerns toward brain–computer interfaces (number of observations = 1,403, weighted data). Scale ranging from 1 = "not concerning" to 10 = "extremely concerning"; empirically values ranged from 1 to 10; for items, see full wording in Table S4 in Online Appendix. *M* = Mean, *SD* = standard deviation (indicated by error bars).

between both groups with a disability, that is, with or without paralysis ($p = .615$). Those having friends or family members with a disability without a paralysis reported a similar level of concern as those who do not have peers with a disability ($p = .984$), while respondents with peers with a disability and a paralysis report a lower level of concern than those who do not have peers with a disability ($p = .016$). A Wald postestimation shows that the

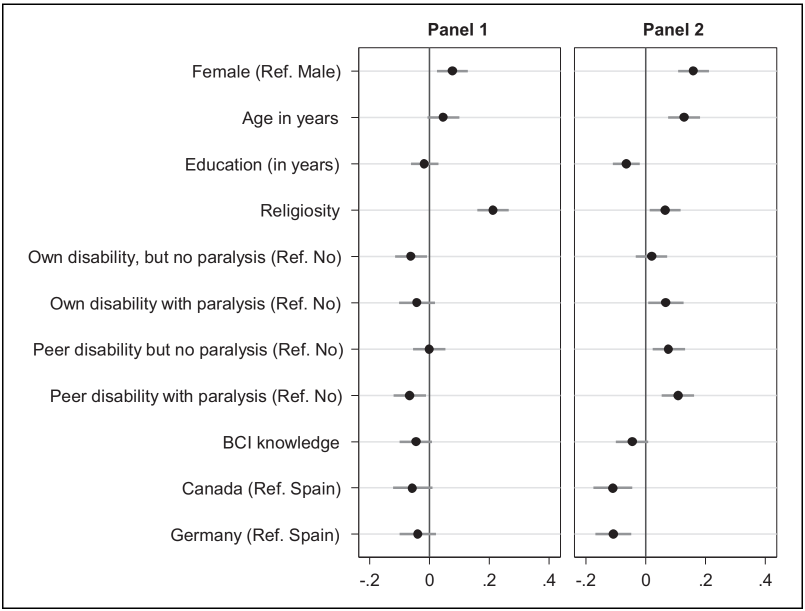

Figure 3. Standardized regression coefficients (β) and confidence intervals of associations with "agent-related" concern (see panel 1, based on the model 1 in Table S6) and "consequence-related" concern (see panel 2, based on the model 2; number of observations = 1,403, weighted data). Coefficients right from the value zero indicate a positive association; those left a negative association. Confidence intervals that overlap with the value zero indicate statistically insignificant associations.

difference between both groups with a disability (i.e., with or without paralysis) fails conventional levels of significance (p = .054). Age (p = .085), education (p = .488), self-reported higher BCI knowledge (p = .098), and living in Canada (p = .095) or Germany (p = .206) in comparison to Spain but also living in Canada in comparison to Germany (p = .590, based on a Wald postestimation) are not significantly associated with this concern.

Concern about Consequence-related Issues

Consequence-related concern is especially high in respondents who reported as "female" ($p < .001$). This concern increases with age ($p < .001$) and religiosity (p = .014) but decreases with education (p = .005). This concern is higher for respondents with paralysis in comparison to those without disability ($p = .026$) but not for those with a disability and no paralysis in comparison to those without disability ($p = .470$). A Wald postestimation shows no difference between both groups with a disability (i.e., without or with paralysis, $p = .222$). Respondents who have friends or family members with a disability, paralysis related ($p < .001$) or not ($p = .005$), report higher levels of concern than those without such peers. A Wald postestimation shows no difference between both groups with a disability (i.e., without or with a paralysis, $p = .369$). Moreover, respondents in Canada ($p = .001$) and Germany ($p < .001$) report lower concern than those from Spain, but they do not differ from each other ($p = .955$, based on a Wald postestimation).

Discussion

Relationships between Academic Ethics Discourse and Public Attitudes

Despite the speculative character of the academic literature on the ethics of BCIs, our study substantiates, broadly speaking, this literature's salience for nonresearchers. The issues highlighted in the ethics literature seem to resonate with lay publics in three different countries. Both agent-related and consequence-related concern regarding BCIs were on average moderately high, as were the worries about the application of BCIs in the context of military, police, and security (taken as a group) as well as marketing and commerce. Perhaps this result should be expected, given that the brain has long been a culturally significant symbol in many Western cultures (Vidal 2009), making neural technologies and the prospect of their misuse especially meaningful. We might also consider other cultural dynamics that are related not to the brain but instead to the role of significant institutions. Building on Forman (2007), we may interpret our results as an instance of the increasing weight of technology *and* science—the dichotomy should not be overemphasized—in public understandings of desirable societal futures (Jasanoff and Kim 2015). But, regardless of how we explain it, the common concern between experts and publics also has implications for the political function of academic ethical reasoning about emerging technologies.

Various social theorists have suggested that citizens in Western democracies are increasingly wary of experts, referring to this phenomenon as "reflexive modernity" and as a "constitutional moment" (Beck 1992; Jasanoff 2011). Despite this observation of cultural tension, our study suggests that the lack of empirical research and public engagement in BCI ethics, while problematic in several respects, may not imply incongruence of opinion with all publics. This finding may justify new investigations into the fundamental connections between academic and lay attitudes, keeping in mind limitations of the survey method (see below). Regardless of the precise explanation of *why* respondents in each of the three countries are concerned, the fact that they find the content of the BCI ethics literature to be salient complicates academic critiques of "technocratic" ethical practice. To the extent that the public is indeed receptive to scholarly discourse, it becomes more difficult to argue for the existence of a representation gap that impedes more inclusive modes of ethics of technology. Why, for instance, should ethicists actively consult publics if the ethics literature already approximates public concerns? Is it possible that experts and publics share an implicit agreement on the cultural significance of the brain? We leave these questions for future work to explore.

The Structure of Public Opinion about Ethical Issues and Domains of Application

Beyond a moderately high level of concern among respondents, we noted some additional complexity in their attitudes toward the twenty-six ethical issues presented. Some issues are seen as more concerning than others, on average. It could be that respondents have justifications for their attitudes. But high concern might also be attributable to the popular salience of an issue (e.g., discussions about hacking and data security in various spheres of life—even beyond BCIs) or the relatively high understandability of an issue (e.g., *device failure*). Items with lower levels of concern may indicate a lack of either or both of those features (e.g., *promoting a medical model of disability*). Further qualitative and quantitative studies would help to better understand the causes of the level of concern for each item. In either case, we follow Davison, Barns, and Schibeci (1997) in resisting the assumption that publics lack the cognitive or deliberative resources to reason carefully about emerging technology.

We also found that respondent attitudes toward the twenty-six items depicting ethical issues could be clustered into two factors, which we interpret as broadly "agent-related" and "consequence-related." This split is consistent with social psychology literature suggesting a distinction in kinds of ethical concerns based on "components" in human morality such as the agent–deed–consequence (ADC) model of moral judgment[5] (Dubljević and Racine 2014a) as well as literature on ethical predispositions (or moral preferences) toward different components (Reynolds 2006, Brady and Wheeler 1996). Obviously the factors we found do not perfectly align with the agent, deed, and consequence components of moral judgments predicted by the ADC model, and further examination of this relationship would be required, maybe by examining the interrelation of the two sets of concerns with moral preferences by using an instrument such as the new Preferences for Precepts Implied in Moral Theories Scale (Dubljević, Sattler, and Racine 2018). Nevertheless, a two-factor structure is consistent with normative ethical theories that highlight differences between these components (Dewey 1966). As proposed previously, this congruence is perhaps due to the fact that ethical theories reflect more basic families of intuitive heuristics that are rooted in these components (Dubljević and Racine 2014a, 2014b; Cimpian and Salomon 2014; Sunstein 2005).

Taking a different framing, respondent attitudes toward particular *domains* of BCI application are in keeping with previous research. As reported in some recent studies (Jebari and Hansson 2013; Wolbring and Diep 2016), healthcare and assistive technology are commonly associated with beneficial uses BCIs, while military, police, and security (taken as a group) as well as marketing and commerce uses are not. In this way, BCIs are likely part of what Joly (2010) has called an "economy of technoscientific promises," in which scientists and technology creators have to justify their work in terms of benefits (e.g., health, education) that are desirable among publics. While not necessarily surprising, this finding presents ethical challenges for the responsible development and media coverage of BCIs. If publics are excited about BCIs as a form of health intervention or as an assistive technology, then the promotion of BCIs may worsen stigmatization of the intended beneficiaries of BCIs (e.g., as needing to be fixed via BCI; Aas and Wasserman 2016). This potential for harm has been discussed extensively in reference to other biomedical devices, such as cochlear implants, and to medicine in general (Rose 2009; Sparrow 2010). Even if some disabled persons wish to use a BCI-based device, they may reject the association with being "ill" or physically deficient. Meanwhile, concerns about violent or coercive uses of nonmedical BCI devices may foreshadow future controversies, analogous to current media discourses on artificial intelligence being used for immigration control and drone warfare (Russell et al. 2015; Shane and Wakabayashi 2018; Soper 2018).

Interpretation of Associations of Respondent Characteristics with Levels of Concern about BCIs

The associations found for the respondent characteristics with the two factors of concern mainly fit the pattern that has already been established for other technologies. Age, reporting as female, lower formal education, and religiosity, among other characteristics, have been demonstrated to correlate positively with higher perceptions of risk regarding nanotechnology (Cobb and Macoubrie 2004), biotechnology (Sparks, Shepherd, and Frewer 1994; Siegrist 2000; Akin et al. 2017), and a range of environmental and industrial hazards (Pilisuk and Acredolo 1988; Stallen and Tomas 1988; Flynn, Slovic, and Mertz 1994). Thus, it is not surprising that we found positive associations between the level of religiosity with concern about both factors. Older respondents and those with less formal education also expressed higher levels of concern but only toward consequence-related issues. Much scholarship has been dedicated to statistically modeling the link (or lack thereof) between these particular demographic characteristics and level of scientific knowledge (Simon 2010; Allum et al. 2008) and trust in experts (Gauchat 2012), as potential explanations of public opinion. Such models, while partially explanatory, often leave uninterrogated the details of how these various causes of opinion are grounded in lived experiences of the individual.

Our demographic findings should also be informed by holistic understandings of persons situated in their cultural and social setting. Related (though indirectly) to our findings about respondents who report as female, it has been argued that higher concern among women is not explained by a lack of knowledge or by assigned biological sex but rather by shared experiences of marginalization and oppression. Finucane et al. (2000) conclude that women and people of color report similar levels of risk perception primarily because of shared sociopolitical realities, which white men are less likely to experience. These and other researchers have suggested that more research should be conducted on how experiences of being a man and individualist worldviews come together to produce an insensitivity to risk among men (Davidson and Freudenburg 1996). In general, explaining our results would require a more nuanced approach to studying respondents' self-understanding with respect to gender and associated categories.

An understanding of worldview and lived experience is equally important for interpreting the relevance of religiosity, education, and age in our study. In an analysis of public attitudes toward biotechnology, De Witt, Osseweijer, and Pierce (2017) propose that such demographic information can be productively synthesized in terms of "integrative" worldviews. They hypothesize that lower levels of formal education and higher religiosity, for instance, may indicate a "traditional" worldview in which metaphysics and science are not separated; as a result, biotechnological interventions may be rejected as "unnatural" or as "playing God." Nisbet and Goidel (2007) conclude, along similar lines, that biotechnological skeptics may be socialized to have particular values (e.g., the human form is valuable because it is "created in God's image") and to use cognitive schema (e.g., "We depend too much on science and not enough on faith"). Further ethnographic or multivariate studies could lend clarity on how these dynamics affect public attitudes toward BCIs and neural technology.

The story is less straightforward for the effects of country of residence and disability status, which do not clearly fit a previously identified pattern from previous survey research. We found that respondents in Spain are more concerned about the ethical issues that we label as "consequence-related" than their counterparts in Germany and Canada. At face value, this seems to contradict other findings in the Eurobarometer survey on biotechnology on a similar topic; here, a smaller proportion of the Spanish population (3 percent) was worried about "brain and cognitive enhancement" than the German population (12 percent; Gaskell et al. 2010), with Spanish respondents generally less likely to report pessimism toward emerging technologies than respondents from Germany. Similarly, a recent media analysis of deep brain stimulation coverage found that the technology was typically described in a positive tone, with Spain substantially more positive than Germany and Canada since 2011 (Cabrera et al. 2018). Nevertheless, these previous studies differ substantially from the present survey, focusing on brain enhancement and stimulation. These varying findings point to the need for more in-depth comparative study of international public opinion about ethics and technology as well as the value of doing so.

Finally, the attitudes of persons who report having a disability or a peer with a disability are especially relevant for BCI technology; as mentioned above, they are the most commonly envisioned beneficiaries of BCI technology in both the literature and among nonresearchers but are not always given a role in BCI design (Sullivan et al. 2018). Although individuals who have first- or second-person experience with disability comprised a very small fraction of respondents in the present survey, significant statistical associations with disability were detected. Specifically, among the four groups of respondents with disability experiences (i.e., own disability, own disability with paralysis, peer disability, peer disability with paralysis), two were less concerned than the reference groups (i.e., no own or peer disability) regarding agent-related issues. Furthermore, three of the four groups were more concerned about consequence-related issues than the respective reference groups. Together, these two findings seem consistent with some existing research on the experiences and values of disabled people and their close peers. Everyday challenges of disability seem to be more pressing than philosophical questions about humanity and the self.

One previous study reports that some mothers are motivated to use BCIs for their disabled children as a way to expand the child's social participation, worrying primarily about potential need for invasive implant surgery (Diep and Wolbring 2015). More generally, disabled people internationally face serious everyday problems of limited access to healthcare, employment, and technology (McColl, Jarzynowska, and Shortt 2010; World Health Organization and World Bank 2011), which has been understood by many disability rights activists, policy makers, and academic researchers as a failure of society rather than the disabled individual (Shakespeare and Watson 1997; Jongbloed 2003; Priestley 2005). Simultaneously, others have documented the ways in which users of commonplace "assistive" technologies, like wheelchairs, are already implicated in a re-envisioning of the self, the environment, and their respective boundaries (Winance 2006; Papadimitriou 2008; Gibson, Carnevale, and King 2012). These existing discourses could help to explain why respondents with disability experiences are less concerned about agent-centered issues, while also underlining an unresolved tension; disabled persons are at once targeted and excluded in technological contexts, reflecting broader tensions between inclusion and stigma, the medical and the functional, in disability-focused research and services (Wolbring and Diep 2016; Silvers 2011; Wolbring 2016).

Strengths, Limitations, and Directions for Future Research

It can be seen as a strength that this study, one of the first of its kind on public attitudes toward BCIs, uses systematically derived items on concerns from the BCI ethics literature; this approach narrows the possible meanings of concern (discussed as a limitation below) in order to allow for a comparison of attitudes among academic and other publics. Moreover, this study contributes to a limited body of knowledge about the role of socioeconomic background, experience with disability, and values in determining how BCI technologies are viewed.

One potential limitation is that respondents may have been influenced to agree with the predetermined list of twenty-six ethical issues, rating them as "concerning" out of deference to a university-affiliated research team. However, responding to the survey was anonymous, which is known to reduce such socially desired responding (Ong and Weiss 2000), and web-based, which may result in higher accuracy of responses and a higher likelihood of reporting sensitive information (Kreuter, Presser, and Tourangeau 2008; Crutzen and Goüritz 2010). While some respondents left comments thanking the team for a chance to learn about an "interesting" and "thought-provoking" topic, others expressed appreciation for a chance to voice their opinion.

Participants were also required to express their thoughts on a complex topic via short closed-ended questions, which did not allow them to propose new concerns or revise the wording of any particular item. In evaluating methods of public participation in technology policy, Rowe and Frewer (2000) note that this method can be cost-effective and statistically representative of a population. Nevertheless, our study may have missed some salient concerns. And because respondents in our study reported little prior knowledge of BCIs, they may not have fully understood the language of some ethical concerns (e.g., *increasing stigmatization*) or have had preexisting attitudes toward them. Although we provided a briefing on BCI technology (see Table S1 in Online Appendix) to increase understanding and conducted cognitive pretests to increase item comprehensibility, the meaning of "concern" or "worry" in our results should be interpreted according to these limitations. Our findings should also be complemented with methods that facilitate an open-ended dialogue between citizens such as focus groups and participatory strategies (Rowe and Frewer 2000).

Finally, participants for this trinational study were recruited by a commercial panel provider rather than through a random selection of the population. To address this limitation, we used sampling weights (Sakshaug et al 2018; Winship and Radbill 1994) with information about gender and education from the populations of each country to decrease selectivity biases. Yet, even with these adjustments, the results are limited to three Western countries with particular cultures. Future research should use representative samples from a more diversified and broader set of countries to validate or challenge our results and to be better able to investigate attitudes about BCI technology and how they might be influenced by the social and cultural background of participants.

Conclusion

Ethicists claim that BCIs present serious ethical challenges, leaving open the question of whether their concerns correspond to those of publics. This knowledge gap is problematic because it may involve a disconnect from everyday experience and a lack of political legitimacy. In our study, we found that respondents were both enthusiastic and worried about BCI technology, depending on the domain of application. They reported moderately high concern regarding a range of ethical issues that center on agent-related and consequence-related issues, with higher concern reported among respondents who report as "female" and among more religious individuals. Agent-related concern was lower if respondents had a disability (without paralysis) in comparison to no disability and if they knew others with a disability (with paralysis) in comparison to not knowing someone with a disability. Consequence-related concern was associated with higher age and lower education. Such concern was also higher for respondents with paralysis in comparison to no disability, among respondents who knew others with a disability in comparison to those who did not and also for respondents from Spain in comparison to those from Canada or Germany. In this way, several of our findings are in keeping with previous empirical studies on the public attitudes toward science and technology, but they suggest the need for further investigation.

These data are more provocative from the perspective of disciplinary ethics and critical STS, as each projects particular assumptions about the proper role of ethical expertise in society. Since the ethical issues presented to respondents were carefully designed based on the academic ethics literature, respondents' moderately high level of concern toward the expert-identified issues indicates that there is something persuasive about the language or content of academic BCI ethics for nonresearchers. Researchers in BCI ethics may see this as a legitimation of their methods and claims, but such a conclusion requires additional premises beyond the results we present here. Simultaneously, critical STS scholars may see these results as a complication of social theory that presents public trust in expertise (including expert ethics) as waning or as inappropriately technocratic. This too can be addressed, perhaps in terms of lingering deference to academic authority. In either case, our study and its survey methods cannot settle these issues definitively but suggest important directions in exploring the relationship between academic ethics and the publics, current and future, of neural technology.

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Supplemental Material

The supplemental material for this article is available online.

Notes

1. Publics, according to Dewey (1927), are not preexisting aggregates of individuals but rather dynamic communities that emerge in response to particular shared problems.
2. An attention check was used to improve data quality (e.g., to remove bots and hasty responders; Berinsky, Margolis, and Sances 2014). We ostensibly asked about whether participants were using a desktop computer, and in the adjacent instructions, we told participants to ignore that question. Instead, participants were instructed to type the word "serious" (translated for each country) in a text field if they were taking the survey seriously.
3. Results show that the knowledge about brain–computer interfaces is relatively low (see Table 1), especially among respondents who report as "female," have lower formal education, report lower levels of religiosity, have peers with paralysis in comparison to those who have no such peers or peers with a disability but no paralysis; those in Canada and Germany in comparison to Spain; and Canadians in comparison to Germans (see Table S2 in Online Appendix).
4. Data used from Statistics Canada 2017 (Table 051-0001: Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual), accessed March 2018 at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pi

d=1710000501; The German Microcensus, accessed March 2018 at https://www-genesis.destatis.de/genesis/online/data;jsessionid=AE5897126D228AEFB34DC10A6C9E8D79.tomcat_GO_1_3?operation=begriffsRecherche&suchanweisung_language=en&suchanweisung=population+by+age&x=3&y=7; and the Instituto Nacional de Estadistica (Population Figures. Provisional 2017), accessed March 2018 at https://www.ine.es/dyngs/INEbase/en/categoria.htm?c=Estadistica_P&cid=1254735572981.

5. According to this model, moral reasoning includes a consequence-oriented component, a deed-oriented component, and an agent-oriented component.

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