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Citizen views on genome editing: effects of species and purpose

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Abstract

Public opinion can affect the adoption of genome editing technologies. In food production, genome editing can be applied to a wide range of applications, in different species and with different purposes. This study analyzed how the public responds to five different applications of genome editing, varying the species involved and the proposed purpose of the modification. Three of the applications described the introduction of disease resistance within different species (human, plant, animal), and two targeted product quality and quantity in cattle. Online surveys in Canada, the US, Austria, Germany and Italy were carried out with a total sample size of 3698 participants. Using a between-subject design, participants were confronted with one of the five applications and asked to decide whether they considered it right or wrong. Perceived risks, benefits, and the perception of the technology as tampering with nature were surveyed and were complemented with socio-demographics and a measure of the participants' moral foundations. In all countries, participants evaluated the application of disease resistance in humans as most right to do, followed by disease resistance in plants, and then in animals, and considered changes in product quality and quantity in cattle as least right to do. However, US and Italian participants were generally more positive toward all scenarios, and German and Austrian participants more negative. Cluster analyses identified four groups of participants: '*strong supporters*' who saw only benefits and little risks, '*slight supporters*' who perceived risks and valued benefits, '*neutrals*' who showed no pronounced opinion, and '*opponents*' who perceived higher risks and lower benefits. This research contributes to understanding public response to applications of genome editing, revealing differences that can help guide decisions related to adoption of these technologies.

Keywords Public attitudes · Biotechnology · Food and agriculture · Genetic modification · Genome editing

Abbreviations

GE Genome editing
GM Genetic modification

Introduction

The genetic modification (GM) of plants and animals is one of the most contentious topics in food production (Lusk et al. 2005; Klümper and Qaim 2014). Adoption of food production technologies that involve GM, including products from genetically modified plants and animals, will depend on how the public responds to these technologies (Siegrist and Hartmann 2020; Frewer et al. 2004). To date, acceptance of GM in food production has been low (Special Eurobarometer 2010; Scott et al. 2016). Nevertheless, GM technologies continue to be developed at a rapid rate, aided by the development of new technologies including genome editing (GE) techniques such as CRISPR (Baltes et al. 2017). Public input can help determine societal legitimacy of these technologies.

Previous studies have assessed factors thought to influence public acceptance of GM, and the results of these studies suggest that attitudes and underlying reasons are diverse (e.g. Hudson et al. 2015). In particular, the *purpose* of the GM matters. People care why a technology is used and this

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influences how they respond. In the case of GM, this means that acceptance tends to be higher for medicines and genetic testing (thought to benefit human health) compared to GM crops and food (thought to benefit actors in the food system) (Gaskell et al. 1999). The *species of organism modified* also affects attitudes; in food production, people are usually more positive towards GM plants than animals (Frewer et al. 2013; Frewer 2017).

Bredahl (2001) showed that attitudes towards the use of GM in food are related to perceived *risks and benefits* of the applications. These perceptions may differ between experts and lay people due to different sources of information available, as well as to different mental models applied (e.g. mental shortcuts and heuristics are more frequently used by lay people; Bearth and Siegrist 2016). People perceive risks that are either related to the expression of the gene that has been modified, or are directly related to the technique itself (Weaver and Morris 2005). People's beliefs about risks and benefits are embedded in more general attitudes towards nature (Grunert et al. 2003). The theme of *tampering with nature* has been shown to be important and related to risk perception towards technology (Sjöberg 2000; Ronteltalp et al. 2016). For the majority of consumers, naturalness of foods is of high importance, leading to positive associations between natural foods and the environment (Siegrist and Hartmann 2020). Many people feel that GM is unnatural or interferes with nature (Myskja 2006; Scott et al. 2018). Different lines of arguments about naturalness with regard to GM could be observed showing that human interference, the mix of species, perceptions of unnaturalness, imbalances in nature and the unknown in modifications, all play a role (Mielby et al. 2013). The perception that GM is unnatural has increased over time (Frewer 2017). Naturalness is used as a normative argument with nature being a positive frame of reference to judge actions (Bartkowski et al. 2018). For GE, where, in its simplest form, the results are not distinguishable from naturally occurring mechanisms in the cells (Jones 2015), one might argue that the results are natural—an argument that Siipi (2008) terms the property-based approach. In contrast, using a history-based approach that looks at the process, the technology might be judged as unnatural because it involves human interference (Siipi 2008), sometimes framed as 'playing God' (Pirscher et al. 2018). Cisgenic modifications are often considered as more natural compared to transgenic modifications (Mielby, et al. 2013; Myskja 2006; Rommens et al. 2007). Such considerations reflect the view that naturalness is a continuum (something can be more natural) rather than a dichotomy (something is either natural or unnatural), but this view is not shared by all (Mielby et al. 2013; Siipi 2008). In these ways, GE blurs the boundary between nature and technology (Bartkowski et al. 2018), leading to uncertainty about how the public will respond. The concept of tampering with nature involves morally important aspects of naturalness such as human interference with nature, displaying human arrogance and acting against the natural order of things (Sjöberg 2000); all are points that arise in debates around the ethics of GM and GE (Pirscher et al. 2018).

People with concerns about GM think in terms of *moral acceptability* of a technology, which might be more important than perceived risks (Gaskell et al. 1999). Moral judgements can be interpreted as the evaluation of an action with respect to a set of virtues (Haidt 2001). In many models, moral judgments are the result of a moral reasoning process, understood as a conscious and therefore intentional mental activity that uses information to reach a moral judgment (Haidt 2001). The moral intuitionist model doubts that moral judgments are always a consequence of moral reasoning and instead posits that they are primarily shaped by moral intuitions. Moral intuition is the "sudden appearance in consciousness of a moral judgment, including an affective valence (good–bad, like–dislike) without any conscious awareness of having gone through steps of searching, weighing evidence, or inferring a conclusion" (Haidt 2001). In this model, the reasoning process starts after a moral judgement is already made, in effect, to justify the conclusion already made by moral intuition (Haidt 2001). The social intuitionist model includes a social dimension, meaning that reasoning by others and interacting with other people and their reasoned arguments influences peoples' judgements. The model therefore does not doubt that information and reasoning matter for moral progress and change, but rather asserts that more typically people rely on intuition and that reasoning is often applied post-hoc to support our initial intuitions (Haidt 2013). There is evidence that moral intuitions play an important role in accepting or rejecting GM application in food production and products (Scott et al. 2018) and that individuals refer to their feelings and use affect as information when assessing a situation, also in risk-related decisions (Zahry and Besley 2019). Certainly, the set of virtues that people hold, act as an intuitive measure to determine a moral judgment. Haidt proposes five general *moral foundations* that influence moral judgments: care/harm, fairness/cheating, sanctity/degradation, loyalty/betrayal, authority/subversion (Haidt and Graham 2007; Haidt 2012). Although Haidt's moral intuitionist approach is debated (e.g. Saltzstein and Kasachkoff 2004), we consider it a valuable and tested approach for assessing peoples' moral judgements. In addition to other cultural factors, *religious affiliation* might influence the virtues that people use to evaluate GM in food production. Muslims and Catholics, for example, are more skeptical towards cisgenesis (i.e. artificially introducing genes from species that are sexually compatible), compared to non-religiously affiliated people (Hudson et al. 2015). Other *socio-demographic characteristics* can also play a role in how GM are judged. Men are more likely to approve of GM technologies compared to women, as are those who are more educated, younger, and more urban (Hudson et al. 2015).

This study aimed to assess the impromptu responses of participants to specific applications of GE. As we expected opinions to be heterogenous, we investigated opinions of the benefits and risks of gene editing, as well as the extent that this technology is considered to be tampering with nature. We also investigated the effects of differences in individual moral foundations, as well as religiosity and other socio-demographic characteristics. Specifically, we assessed five applications of GE: three of these inducing resistance towards a disease (in three different species), and two others varying the reason for the application within the same species (cattle). Participants from three European (Austria, Germany, and Italy) and two North American (Canada and the United States) countries were included to account for possible differences between countries. To the best of our knowledge, our study is among the first to analyze citizen attitudes towards specific applications of GE in agriculture (see GeneInnovate et al. 2020 as one of the few existing works), accounting for the aforementioned aspects.

Method

We conducted an online survey with citizens from Austria, Canada, Germany, Italy, and the US. Ethics Commission of the Free University of Bozen-Bolzano, Italy, approved the study. Participants were informed that all data would be treated confidentially and that data would be used anonymously, and then provided their online consent. Participants were informed that they could withdraw at any time during the survey by closing their internet browser.

Survey design

The questionnaire viewed by participants is included in the supplementary material section of this manuscript. The survey began with questions about gender identity, age and education that were set as quotas according to the population of each country. People were asked what type of diet they followed and about their awareness and knowledge of GM and GE. Following these questions, participants read a short text describing GE technology (Table 1) and were asked two questions to determine their understanding of the

Table 1 Text describing GE and six GE applications that were used as treatments in the survey (N = 3928)

Text describing genome editing to survey participants: "Genome editing is a type of genetic modification that involves changing specific types of genes (DNA) in an organism. It is possible, in theory, to use the technique of genome editing to change any aspect of genetic information such as appearance, performance or morbidity in a living organism, including plants, animals and humans. The genetic changes brought about with genome editing cannot be detected as artificial introductions to the genome, even by experts."	
Disease resistance…	
…within humans. (wording a) n = 189 (Canada only)	(a) "Resistance within humans to HIV: HI-Virus (HIV) is an infection leading to AIDS that humans can contract. Using GE, it is possible to generate resistance to this disease in humans**.** The resistance is generated in the human embryo."
… within humans. (wording b) n = 732	(b) "Resistance within humans to HIV: HI-Virus (HIV) is an infection leading to AIDS that humans can contract. Using genome editing, it is possible to generate resistance to this disease in humans."
… within plants n = 794	"Resistance within wheat plants to mildew: Mildew is an infection that wheat plants, cultivated for human consumption, can contract. Using genome editing, it is possible to generate resistance to this disease in wheat plants."
… within non-human mammals n = 806	"Resistance within pigs to the Porcine reproductive and respiratory syndrome (PRRSV): The porcine reproductive and respiratory syndrome is an infection that pigs, raised for human consumption, can contract. Using genome editing, it is possible to generate resistance to this disease in pigs."
Changing animal food product…	
… quality n = 718	"Allergen-free milk**:** Some people have an allergic reaction to dairy cow's milk. Using genome editing, it is possible to generate cows that produce allergen-free milk."
…quantity n = 764	"Increased muscle growth in cattle: Beef cattle are raised for human consumption. Using genome-editing, it is possible to generate cattle with more muscle, resulting in more beef from one animal."

Each participant saw the describing text about GE and one of the examples text. All participants, other than those in Canada, were randomly assigned to one of five treatments that each described one example of an application of GE (i.e. a completely randomized between-subject design) (Table 1). Three of the treatments described introducing disease resistance (within a human, a non-human animal, or a plant) and the two other treatments described changes in product attributes (quality and quantity). The texts introducing the applications to participants were kept brief by design and worded so as similar as possible to each other. By doing so, we aimed to focus the participant's attention on the effects of species and the effect of purpose within species.

The decision was taken to include a disease resistance application in humans, along with the four applications from agriculture, to provide comparison with a different species, namely human, and to include a case that we thought would not be acceptable for many people. We based this assumption on the results of the 2018 clinical trial conducted by a Chinese team of scientists who edited gene CCR5 associated with resistance to HIV in the human germline, garnering public criticism (e.g. Allyse et al. 2019; Wang and Yang 2019; Zhang et al. 2019). By doing so we included an application from which we can get a relative comparison for the other species, non-human animals and plants. The positive evaluation of the HIV scenario that we initially found upon preliminary analyses was surprising. On the basis of the positive evaluations of the HIV application, we decided for the Canadian sample (which was tested later) to introduce a sixth treatment designed to determine the effect of a slight change in wording to this scenario; the alternative wording clarified that the modification of the genome was done in the human embryo and was not a modification to an adult human. In this way we were more clear about the procedure of genome editing and were able to test for differences in evaluations due to wording within the Canadian sample.

After reading the assigned text, participants were asked if it was right or wrong to use genome editing for this purpose. Answers were given on a 7-point scale from "very right to do" to "neutral" to "very wrong to do". Participants were also asked how sure they were about their judgement and if their response was based on reasoning or on gut feeling, again on 7-point Likert scales (based on Haidt et al. (2000). This question was included in order to see whether the question of GE is more an intuitionist or reasoning question for people (Haidt et al. 2000) and whether we find heterogeneity in the answers among participants. Following this, a set of seven moral judgments about the application were presented, based on the personal theories for morality questionnaire (Gamez-Djokic 2019). Participants were asked to indicate their level of agreement to these moral judgment statements on a 7-point scale, followed by a question about the perceived purposes of the application of GE. The purposes to choose from were "increasing profits for companies", "improving human health", "controlling nature", "protecting the environment", and "improving wealth of the world population". Answers were non-exclusive (i.e. participants could select more than one purpose). Participants could also choose "other" or "I do not know".

The next section in the survey was dedicated to risk evaluation. Questions about perceived risks and benefits associated with the application of GE were included, inspired by Weber et al. (2002) and Scott et al. (2016). Participants' perception about how much they thought the application of GE was tampering with nature was evaluated using six statements adapted from Sjöberg (2000). We conducted a factor analysis on all questions relating to perceived risks and benefits and extracted two factors (KMO = 0.89, Bartlett test of sphericity = 0.000, explained variance = 63.4): one bundling risk perceptions (Cronbach's Alpha = 0.90) and the other bundling benefit perceptions (Cronbach's Alpha = 0.63). A second factor analysis was conducted using the statements about tampering with nature and exhibited one factor (KMO = 0.76, Bartlett test of sphericity = 0.000, explained variance = 55.8, Cronbach's Alpha = 0.80). The individual moral foundations of participants' personality were collected using parts of the moral foundations-questionnaire (Graham et al. 2009). The dimensions of care/harm, fairness/reciprocity and purity/sanctity were tested and scores were calculated on the individual level. Religiosity was measured using the Centrality of Religiosity scale by Huber and Huber (2012) consisting of seven statements. The questionnaire closed with demographic questions about place of residence, having children, and religious affiliation.

To ensure that participants read all questions carefully, two quality check questions were included. Within these questions, participants were asked to simply tick a specified answer. If participants failed to answer these two questions correctly, they were excluded from further participation and from the final data set.

Data collection

Participants in the European countries and the United States were recruited online in May and June 2019 using the crowdworking platform Clickworker. The remuneration given to participants that completed the survey was 1.26€. Data in Canada was collected online in November 2019, recruiting via Dynata and paying participants around 1$, depending on the reward offerings that participants had selected. A total of 4003 participants completed the survey. The average response time was about 12 min. Participants that answered the survey in less than 4 min (one third of average response time) were excluded from dataset, as were those who incorrectly answered the question designed to determine if they had read and understood the introductory text on GE. After applying these exclusion criteria, a total of 3698 respondents remained in the data set for further analyses (Canada = 1042, USA = 805, Austria = 430, Germany = 903, Italy = 518).

Sample description

Table 2 shows the distribution of age, gender and education in the samples and the populations of the five countries.

Results

Knowledge and awareness about genetic modifications and GE

Table 3 shows how many respondents had heard about genetic modification and GE and how those who had heard about this, rated their knowledge of the topic. Nearly all participants had heard about genetic modification; however, less than half of the sample was aware of gene editing technology. For both technologies, about half of the participants rated their knowledge as very low, to below average.

Table 2 Description of demographics in the samples and populations in Canada, the US, Austria, Germany and Italy

	Canada		USA		Austria		Germany		Italy	
	n = 1042	N	n = 805	N	n = 430	N	n = 903	N	n = 518	N
Age										
18–29	18.6%	19.1%	25.1%	21.4%	36.7%	16.9%	18.5%	16.8%	27.2%	14.6%
30–44	23.8%	24.4%	30.7%	24.9%	47.2%	22.3%	24.6%	22.0%	39.6%	23.2%
45–59	37.7%	27.3%	36.1%	25.5%	11.9%	25.7%	41.4%	27.9%	29.3%	27.8%
Over 60	19.9%	29.3%	8.1%	28.1%	4.2%	35.2%	15.5%	33.3%	3.9%	34.4%
Gender										
Female	51.6%	50.3%	60.6%	49.2%	57.0%	50.8%	49.6%	50.7%	59.5%	52.2%
Male	47.9%	49.7%	37.9%	50.8%	43.0%	49.2%	50.3%	49.3%	40.4%	47.8%
Gender variant/non-conforming/not listed[1]	0.5%	–	1.5%	–	0.0%	–	0.1%		0.2%	–
Level of education[2]										
Education high	29.1%	28.5%	41.9%	32.5%	32.1%	30.0%	35.9%	26.6%	36.9%	16.8%
Education low	70.9%	71.5%	58.1%	67.5%	67.9%	70.0%	64.1%	74.4%	63.1%	83.2%

n sample, *N* population

Age population: Statistics Canada (2019), U.S. Census Bureau (2018a), Statistik Austria (2018), Statistisches Bundesamt (2018), Istituto nazionale di statistica (2018)

[1]No official data available. Gender population: Statistics Canada (2020), U.S. Census Bureau (2018b), Statistik Austria (2019), Statistisches Bundesamt (2018), Istituto provinciale di statistica (2018)

[2]Education high = University degree at bachelor level or above; education low = all other levels of education. Education population: Statistics Canada (2019). U.S. Census Bureau (2018a), Austria, Germany, Italy: Eurostat (2019)

Table 3 Self-indicated awareness and knowledge about genetic modifications and GE in the sample (n = 3697)

Have you ever heard of the following technologies?	Yes	No	I am not sure
Genetic modification	92.5%	3.7%	3.8%
Genome editing	45.1%	34.4%	20.5%
You told us that you have heard about genetic modification/genome editing. How would you rate your knowledge about the technology?*	Very low to below average	Average	Above average to very high
Genetic modification	41.3%	44.8%	13.9%
Genome editing	50.1%	35.1%	14.8%

*Scale from 1 = very low to 4 = average to 7 = very high

Evaluation of rightness of application

People's views about whether it was right or wrong to use GE for the purposes presented are shown in Fig. 1. In all countries, the rank order of acceptance was the same, with the HIV resistance in humans (HIV) considered the most right, followed by mildew resistance in wheat (Mildew), PRRSV resistance in pigs (PRRSV), and the production of allergen-free milk (Milk). The scenario considered least right was that describing increased muscle growth in cattle (Muscle). For the Canadian sample we were able to test whether the difference in wording in the HIV scenario influenced perceptions; no difference was detected (ANOVA; $p = 0.33$) therefore all results for the HIV scenario were combined.

German and Austrian participants did not differ in their responses to the scenarios. US and Canadian participants did not differ in their responses to the three disease scenarios but did differ with regard to the two production-oriented scenarios. For all but the double muscle scenario, Italian participants answered similarly to US participants, but for the double muscle scenario their responses were similar to those of Canadian, Austrian and German participants.

Most (76.8%) participants stated that they were somewhat sure to very sure about the judgment they had made, 11.5% were ambivalent, and 11.7% were somewhat unsure to very unsure. Participants were evenly split between those who felt their decision was mainly based on reasoning (40.4%) and those who decided partly on reasoning and partly on gut feeling (42.1%); fewer participants (17.5%) stated that their decision was mainly based on gut feeling. The scenarios that participants had seen did not affect whether the decision was based on reasoning or gut feeling (ANOVA, $p = 0.34$).

For the HIV scenario, 85.7% of participants agreed that improving human health was the purpose of the application, followed by 31.0% that selected increasing profits for companies as a purpose. The latter was the most selected purpose for the mildew (60.8%), the PRRSV (58.4%), and

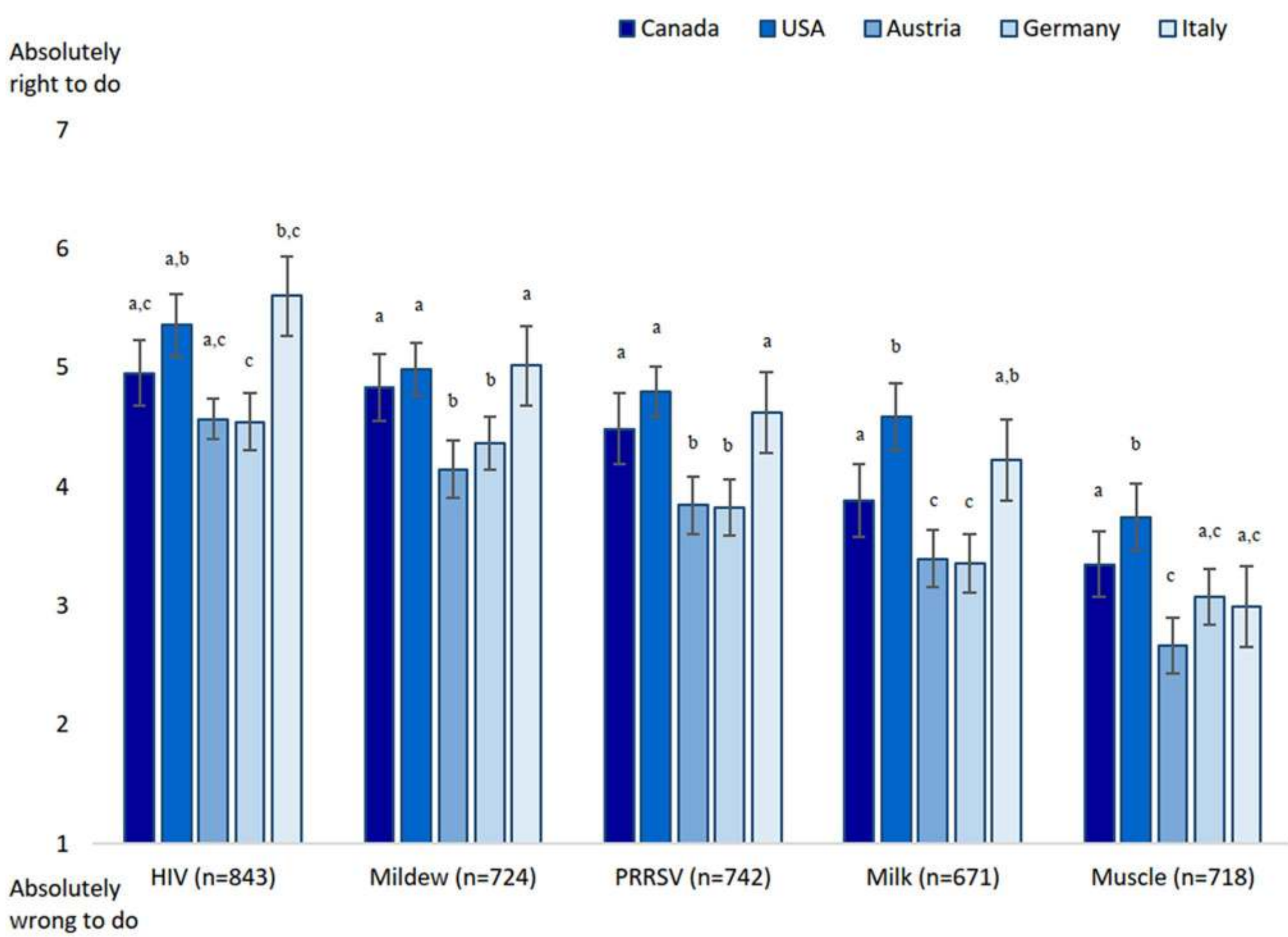

Fig. 1 Decision of whether GE is right or wrong to use in five applications by country. Displayed are the means and 95%-confidence intervals. Scale from: 1 = absolutely wrong to do to 7 = absolutely right to do. Letters indicate differences between the countries for each scenario tested with ANOVA (post-hoc tests LSD and Tamhane)

the double muscle application (78.0%). For the creation of allergen-free milk, 65.4% selected improving human health as purpose driving this application.

Clusters of participants regarding attitudes towards GE applications

We identified four clusters of participants, derived from answers to whether it is right or wrong to use GE for the presented application (single statement), their risk and benefit perceptions (one factor for each) and if the participants believed that GE was tampering with nature (one factor). The mean values of the four clusters are displayed in Fig. 2.

The results show that '*strong supporters*' perceived gene editing as right to do; they also had the lowest risk perceptions, highest benefit perceptions and did not think that gene editing was tampering with nature. *'slight supporters'* still perceived the applications as right to do, although to a lesser extent; they perceived some risks but also some benefits and did not think that GE was tampering with nature. *'Neutrals'* were indecisive on all four cluster building variables. Finally, '*opponents'* thought it was wrong to use GE, perceived high risk and low benefits, and perceived the technology as tampering with nature.

Figure 3 illustrates how the different clusters judged the application of GE. '*Strong supporters*' indicated that they had no moral concerns, did not feel the application disrespects the dignity of life, thought that God would approve of this application, did not think it was disgusting, perceived the intention to be good, thought that most of society would approve of the application and did not experience negative feelings about the application. The '*slight supporters*' answered similarly but tended to be more towards the middle point of the scale, indicating more ambivalent attitudes. '*Neutrals*' were similar to the slight supporters. '*Opponents*' expressed stronger objections to gene editing in all aspects, indicating that they had moral concerns, that the dignity of life was disrespected, that God would not approve, that the application was disgusting, that the intention was not good, that it would not be approved by the majority of society and that they experienced negative feelings when reading about the application.

Among '*opponents*', 83.5% agreed to the statement "this application of genome editing should be prohibited, no matter how much the benefits outweigh the risks.". Among the '*neutrals*' this number decreased to 29.7% of respondents, and further declined to 14.5% of '*Slight supporters'* and 2.1% of '*strong supporters'*.

Figure 4 shows that the application that participants were exposed to affected the cluster they were assigned to. Within the HIV and the mildew group respectively, there was a higher share of supporters (standardized residuals ≥ 2), whereas the share of '*neutrals*' and '*opponents*' was lower than would be expected by chance (standardized

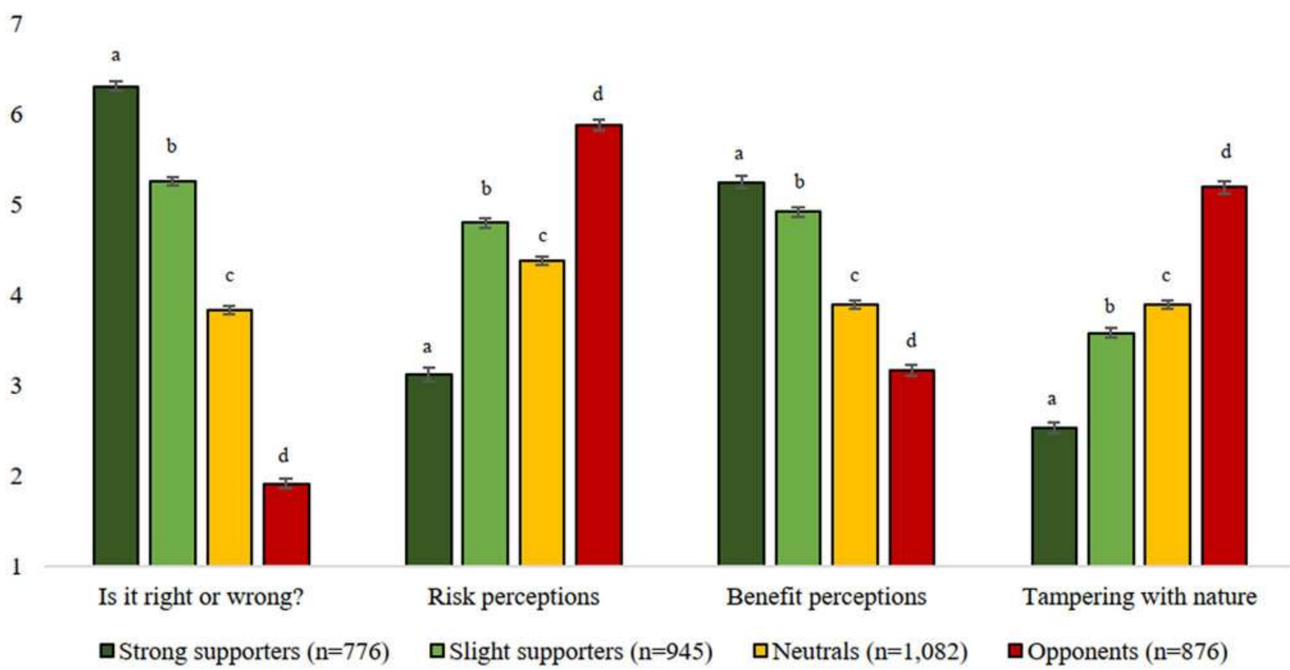

Fig. 2 Mean values and 95%-confidence intervals of the four cluster building variables by clusters (N = 3679). Scale: Is it right or wrong?: 1 = absolutely wrong to do to 7 = absolutely right to do; Risk perceptions: 1 = very unlikely to 7 = very likely; Benefit perceptions: 1 = not beneficial at all to 7 = very beneficial; Tampering with nature: 1 = strongly disagree to 7 = strongly agree. Letters indicate differences between the clusters tested with ANOVA (post-hoc tests LSD and Tamhane)

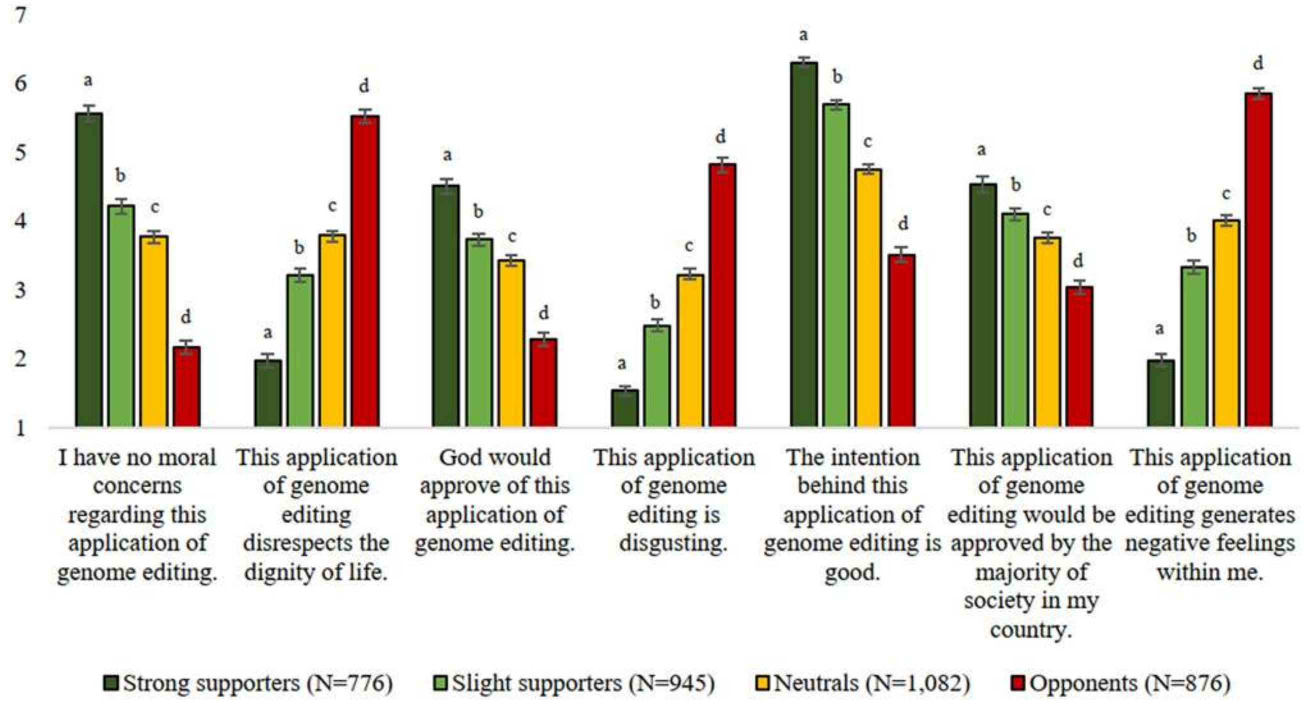

Fig. 3 Mean values of moral evaluation of applications by clusters. Displayed are means and 95%-confidence intervals. Scale from 1 = I strongly disagree to 7 = I strongly agree. Letters indicate differences between the clusters tested with ANOVA (post-hoc tests LSD and Tamhane)

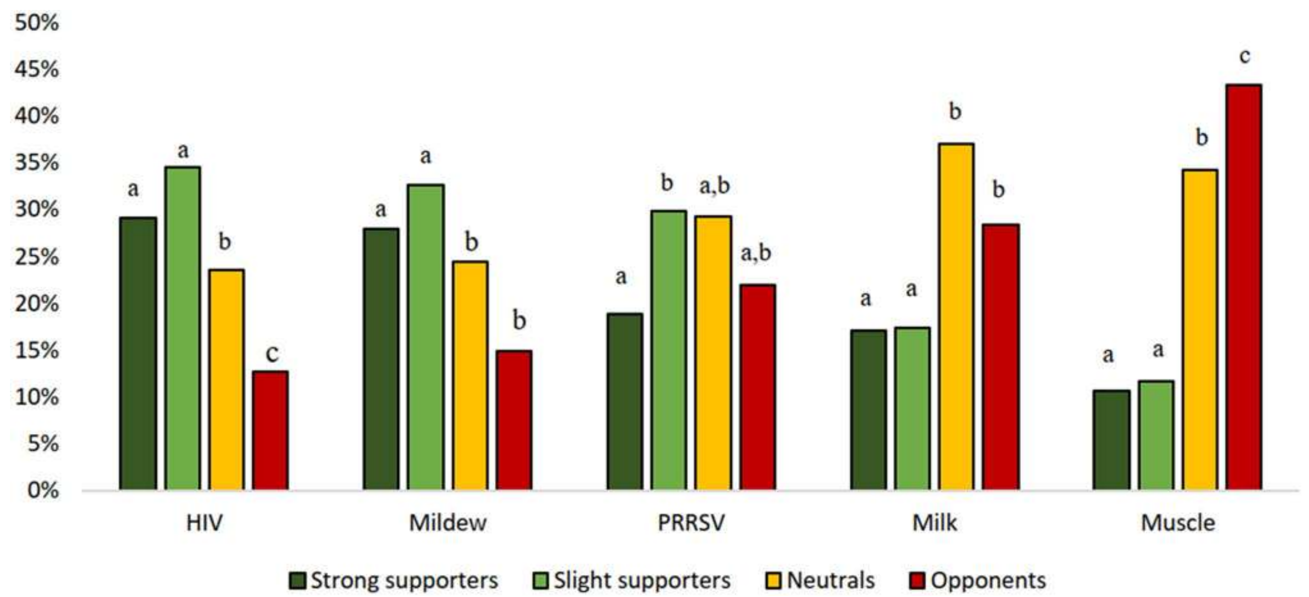

Fig. 4 Distribution of clusters within the five applications. Differences of distribution have been tested using cross-tabulation and Z-test

residuals ≤ -2). Within the group of participants that read about the PRRSV application, 'Slight supporters' were overrepresented (standardized residuals ≥ 2); whereas, the distribution of the other clusters was similar to what was expected by chance. Looking at those participants that were exposed to the milk and muscle scenario, the two supporting clusters were underrepresented (standardized residuals ≤ -2), and the '*neutrals*' and '*opponents*' were overrepresented (standardized residuals ≥ 2).

Table 4 Differences between the clusters according to cluster describing variables

	Strong supporters	Slight supporters	Neutrals	Opponents	Total sample
Country shares [1,2]					
Canada	20.2%[a,b] SR = − 0.5	25.4%[a,b] SR = 0.0	34.9%[a] SR = 3.0	19.6%[b] SR = − 2.8	100.0%
USA	26.6%[a] SR = 3.5	32.5%[a] SR = 4.0	27.2%[b] SR = − 1.2	13.7%[c] SR = − 6.1	100.0%
Austria	16.7%[a] SR = − 1.9	22.1%[a] SR = − 1.4	25.6%[a] SR = − 1.4	35.5%[b] SR = 4.7	100.0%
Germany	15.4%[a] SR = − 3.6	21.2%[a] SR = − 2.5	30.8%[b] SR = 0.8	32.5%[c] SR = 5.0	100.0%
Italy	26.6.6%[a] SR = 2.8	24.5%[a,b] SR = − 0.4	24.1%[b] SR = − 2.2	24.9%[a,b] SR = 0.3	100.0%
Gender shares					
Distribution of female participants[2]	17.1%[a] SR = − 3.6	26.0%[b] SR = 0.2	28.8%[b] SR = − 0.5	27.9%[c] SR = 3.7	100.0%
Distribution of male participants[2]	25.6%[a] SR = 4.0	25.1%[b] SR = − 0.5	30.3%[b] SR = 0.7	19.0%[c] SR = − 4.0	100.0%
Religiosity[2]					
Highly religious	20.2%[a,b,c] SR = − 0.4	27.9%[b] SR = 0.8	20.2%[c] SR = − 3.2	31.8%[a,b] SR = 3.1	100.0%
Religious	19.3%[a] SR = − 1.7	25.7%[a,b] SR = 0.0	30.5%[b] SR = 0.9	24.4%[a,b] SR = 0.5	100.0%
Not religious	23.7%[a] SR = 2.1	25.1%[a,b] SR = − 0.5	30.2%[a,b] SR = 0.6	21.0%[b] SR = − 2.2	100.0%
Age (means)[3]	42.0[a,b]	40.1[a]	43.0[b]	43.6[b]	42.2
Moral foundation (means)[3]					
Harm/care	22.0[a,b]	22.2[a]	21.6[b]	23.5[c]	22.3
Sanctity/degradation	13.9[a]	16.4[b]	16.0[b]	18.3[c]	16.2
Fairness/cheating	21.8[a]	22.1[a]	21.1[b]	23.1[c]	22.0
Evaluation based on reasoning or gut feeling (Means and standard deviation in brackets)[3, 4]	2.76[a] (1.60)	3.60[b] (1.63)	3.94[c] (1.46)	3.57[b] (1.71)	3.51 (1.65)
Share of participants that have heard about GE[2]	25.0%[a]	28.5%[a]	27.5%[b]	19.0%[c]	100.0%
Knowledge about GE (Means and standard deviation in brackets)[3,5]	3.69[a] (1.36)	3.23[b] (1.41)	3.07[b] (1.27)	3.06[b] (1.26)	3.27 (1.35)

[1]Those Canadians that received HIV wording a were excluded from the country comparison to make data comparable between the clusters

[2]Differences between the clusters were tested using cross tabulation with Chi-square and Z-tests. SR = Standardized residuals

[3]Differences between clusters were tested using ANOVA and post-hoc tests (LSD and Tamhane)

[4]Scale: 1 = completely on reasoning to 4 = partly, partly to 7 = completely on gut feeling

[5]Scale from 1 = very low to 4 = average to 7 = very high

Table 4 shows how the clusters differ from each other with regard to other descriptive variables. '*Strong supporters*' were more common among US and Italian participants and less so among German and Austrian participants. The share of female participants in this cluster was lower and there were more non-religious people compared to chance expectations. Participants in this cluster showed the lowest scores on the sanctity dimension of moral foundations. The *'strong supporters'* had the highest share of participants who had heard of GE, and participants in this cluster rated their knowledge about GE higher compared to other participants.

'Slight supporters' were similar to '*strong supporters'* in their distribution among countries. The share of female participants in this cluster was somewhat higher than among '*strong supporters'*, as was their score in the sanctity dimension of moral foundations. This cluster was most likely to answer that they based their decision about the application on reasoning.

More Canadians and fewer Italians were "*neutrals*". There were fewer highly religious participants in this cluster and the average age is a little higher compared to the two supporting clusters. These participants scored lower on harm/care and fairness/reciprocity dimensions of moral foundations, and they reported more gut feeling evaluations of the applications compared to the other clusters.

There were fewer Canadian and US participants, and more than expected German and Austrian participants, in the '*opponents'* cluster, as well as more female participants than expected by chance. The portion of non-religious people was lower, and the share of highly religious people was higher; participants in this cluster had the highest scores on all moral foundations tested. Few participants in this cluster had heard about GE, and they rated their knowledge about GE lower compared to 'strong supporters'.

Discussion and conclusions

The results of this study show that, in the countries included in this survey, the concept of GM is understood by the majority of people but the specific concept of GE is less well understood. In Japan, 67.2% of people from the general public had never heard of GE and 25% of the people who indicated an understanding of what GE means (6.6% of sample), answered a question about CRISPR/Cas9 incorrectly (Uchiyama et al. 2018). These numbers indicate a relatively low awareness of comparably new GM technologies, such as GE. The rapid development of these technologies likely outstrips informed debates about how far society wants these technologies to go, and leads people to rely instead on heuristics to judge risks and benefits of the technology (Siegrist and Hartmann 2020). One such heuristic might be to oppose a food production system (e.g. conventional food production) that use GM/GE, and therefore oppose GM/GE as well (Bartkowski and Baum 2019). The current study illustrates the complexity of concerns involved in evaluating these technologies.

Attitudes regarding the use of GE were diverse. Most notably, the specific application that people were confronted with influenced their attitudes. This finding demonstrates that the specific context matters, and suggests that the debate on GE should not be whether it is right to use this technology in general, but rather about where it is appropriate to apply it. This result supports the call made by the European Academies Science Advisor Council (EASAC 2020) that regulators in plant breeding should focus on specific applications rather than attempting to regulate GE as a technology per se.

A high number of participants across all applications indicated that their decision was based on both reasoning and gut feeling, suggesting that both moral reasoning and moral intuition influenced decisions. Among the five countries we studied, differences in the average responses to the right or wrong question were visible, although the relative ranking of the applications was the same in all countries. Others have found that Americans have more positive attitudes compared to Europeans with regard to GM in foods (Frewer et al. 2013), which may be attributable to a higher degree of media coverage of GMO in Europe compared to the US (high coverage on controversial topics is associatd with decreased public support; Marques et al. 2015; Galata et al. 2014; Gaskell et al. 1999).

The three applications that targeted modification of animals were considered less positively compared to the application on plants or humans. Other work has shown that modifications of plants are viewed as more acceptable compared to animals (Frewer 2017; Frewer et al. 2013), and that applications in human medicine are generally more acceptable than food applications (Gaskell et al. 2000). The use of GE to cure diseases has been shown to be widely accepted (Gaskell et al. 2017). That said, the relatively high degree of support for the HIV scenario was surprising given wide public criticism of Chinese scientists who edited gene CCR5 associated with resistance to HIV in the human germline (e.g. Allyse et al. 2019; Wang and Yang 2019; Zhang et al. 2019). Part of the difference in support between our study and the case involving Chinese scientists might be the context in which this case came to light, including a lack of regulatory approval and oversight for the intervention. Framing GE in positive terms has been found to reduce negative feelings such as dread in consumers (Costa-Font and Mossialos 2005). In addition, public trust in institutions, including governments, influences trust in applications of new technologies including GE technologies (Siegrist 2000); specifically, that benefits are perceived to be greater and risks lower when there is trust in institutions (Siegrist et al. 2000). The media focused on the negative aspects of the application in an unsanctioned study by Chinese scientists, while our study emphasized the positive aspect of conferring resistance to HIV, without the additional context related to regulation or jurisdiction. In addition, we did not prime participants to consider changes to the germline, possible off-target mutations, or other societal and ethical considerations surrounding GE in humans (Lander et al. 2019).

The four clusters of participants illustrate how attitudes towards GE are diverse; referring generically to "public opinion" on GE underestimates this heterogeneity. Our results show that being critical of GE in terms of risks, naturalness and moral scruples holds true for '*opponents*', but not for '*strong supporters'* who did not perceive these as obstacles. Gaskell et al. (2000) also found heterogenous attitudes towards applications of biotechnology. In combination, these results suggest that in addition to the case-by-case decisions on applications of GE, policy makers should account for the heterogeneous public perspectives. One approach to accommodating this diversity is to provide 'exit and voice' options, following Albert Hirschmann's exit-voice framework (Bartkowski and Baum 2019). Exit strategies could be provided, for example through mandatory labelling of products, and institutionalized voice could be improved, for example through deliberative mini-publics in which diverse, randomly chosen people from the population are provided the opportunity to engage deeper with the topic and deliberate about GE.

The clusters further differentiated with respect to perceptions of how much GE was tampering with nature, with 'Opponents' viewing this as an important concern. The natural-is-better heuristic that people can use to form an opinion on novel food technologies (Siegrist and Hartmann 2020) seems to influence perceptions of GE applications. As others have found that GE is perceived as more natural compared to other GM, especially compared to transgenic modifications (Muringai et al. 2020; Yang and Hobbs 2020), we might expect more positive evaluations of GE. The differences in perception of GE as tampering with nature might also be due to different concepts of nature and naturalness people hold (Siipi 2008; Pirscher et al. 2018; Mielby et al. 2013). In one previous study, GE in plants was described by stakeholders as being more natural than GM and equivalent to traditional breeding methods (Bain et al. 2020); this may provide a starting point for future discussions with the public, at least with '*slight supporters*' and '*neutrals'* who were less likely to perceive GE as tampering with nature but who also felt that they lacked information about this technology. Technologies viewed as more natural are also perceived as less risky and more beneficial, resulting in a more positive evaluation (Siegrist and Hartmann 2020; Ronteltalp et al. 2016).

Scott et al. (2016, 2018) argued that many who oppose GM food can be characterized as moral absolutists, meaning that moral values are upheld by these people independent of consequentialist considerations (Scott et al. 2016). Consistent with this idea, the '*opponents'* in our cluster largely agreed with the statement that the application of GE should be prohibited regardless of the benefits (in contrast to the other three clusters). This result indicates that participants in this cluster were less open for debate and compromise compared to the others.

The stronger perception of reasoning among '*strong supporters*' indicates that these participants reflected on judging the application as a weighting of pros and cons. Among 'strong supporters', more people had heard about GE and their knowledge was perceived to be higher compared to the other clusters. According to Haidt's (2013) social intuitionist model, intuition typically comes first and is followed by strategic reasoning; higher involvement in the topic may lead to adjusting moral judgments and intuitions and therefore perceiving more reasoning than gut feeling.

We observed differences in the responses of participants to different applications of GE, suggesting that acceptance may relate to both the species involved and the intention of the application. Our results indicate that disease curing applications in food production (especially in plants) may be acceptable, but that changing animal food product quality and particularly quantity will have lower acceptance—results that have also been found for other applications of GM (Frewer et al. 2013; Frewer 2017; Gaskell et al. 1999). Individuals opposing GE applications were likely basing their opposition on strong moral convictions of it being wrong, making it unlikely to change these opinions. Providing exit strategies, such as labeling of food products, might be one way to give these individuals the opportunity to act according to their convictions (Bartkowski and Baum 2019).

Attitudes towards the use of GE are diverse; with the rapid development of GE technologies (and applications) there is urgent need for public debate on how this technology should be used. Our results suggest that applications in plants are more favorable compared to applications in animals and that preventing diseases is a more acceptable purpose for many compared to production related applications. Clear and transparent labelling of food products that have been altered are needed in the market if technologies come into practice, allowing people to behave according to their attitudes. Framing of applications affects perceptions, as shown in the positive perception of the HIV example. Public deliberation is needed to come to an informed consensus on what application are acceptable for many and which are not. We hypothesize that perceptions and openness to dialogue are influenced by peoples' virtues making some more open than others to engaging in the topic.

Limitations, strengths, and future research

Data used in this study was collected online and the final samples analyzed were not fully representative of the populations in the countries surveyed, both in the sociodemographics measures we assessed and likely also in others that were not assessed (e.g. internet users differing from non-internet users; Paolacci and Chandler 2014). However, the study used large and diverse samples from five different countries and therefore allows for comparison between these on a quantitative scale.

We used five diverse but realistic applications of GE. In doing so, differences in attitudes with regard to species and purposes of applications were elicited, informing the debates surrounding the legitimate use of GE. We did not distinguish between GE and GM by intention in this study in order to get peoples' impromptu responses. The surprisingly positive evaluation of the HIV application contrasts with how the case was debated in the media suggesting important effects of the way applications are framed. Future studies may wish to distinguish between GM and GE and explain the differences more clearly to respondents.

Gene editing technology is rapidly developing, outpacing ethical discussions in society and resulting in an urgent need to understand public attitudes towards a range of issues related to GE use (e.g., risk, trust, acceptability of the purpose of applications) (Schultz-Bergin 2018). For many in society, deep engagement on this issue (including consideration of pros and cons, expert opinion, and social deliberation) in every-day life is unlikely due to competing demands for time and attention. In this context, we suggest that the relatively impromptu responses elicited in the current study are important to understand. At a minimum, these responses can identify areas where scientific and commercial practice are out of step with widely held social attitudes, as seems to be the case with the animal scenarios investigated in the current study. We did not control for how participants understood the applications presented. The texts were kept short which might have led to some respondents to give quite uninformed answers. Future work could provide more context, for example, by explaining that GE is able to induce small, precise changes at relatively low cost or explicitly describing that changes are to the germline. Such work should examine the attitudes of people more deeply engaged in the topic, ideally in a social context, for example using a deliberative mini-publics methodology as described above.

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Data availability All data are available on request.

Code availability The codes of the analyses are available on request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Ethics Commission of the Free University of Bozen-Bolzano (Italy) approved the study before data collection. Participants were informed that all data would be treated confidentially and that data would be used anonymously, and then provided their online consent. Participants were informed that they could withdraw at any time during the survey by closing their internet browser.

Consent to participate Participants were informed that all data would be treated confidentially and that data would be used anonymously, and then provided their online consent. Participants were informed that they could withdraw at any time during the survey by closing their internet browser.

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