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Fostering safe food handling among consumers: Causal evidence on game- and video-based online interventions

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ABSTRACT

We design a game-based online intervention to foster awareness of food safety and risk-reducing behavior among consumers. 1087 participants, aged 20–50 years, and additional 886 participants, aged up to 89 years, from the UK and Norway were assigned to (i) a control condition with pre- and post-survey measures of food safety beliefs and behaviors with a one-week spacing, or (ii) in addition exposed to a brief information video, or (iii) in addition played an online game. Both intervention types improved food safety beliefs to a similar extent relative to control. But only the game interventions significantly improved self-reported food safety behavior, suggesting that providing information to consumers often is not sufficient to change routinized behavior. The novel insight of our study is that repeatedly applying correct behavior in the virtual environment of the online game spills over to real-world behavior. Importantly, treatment effects are not concentrated on young people, but are consistent across age groups.

1. Introduction

According to the WHO, 1 in 10 people in the world suffer from food-borne disease each year (WHO, 2015). While food-borne disease is in particular a problem in developing countries, it also causes high costs in developed countries in terms of sick days, hospitalizations and even death. In the US, for example, each year an estimated 9.4 million cases of food-borne disease result in more than 55,000 hospitalizations and more than 1300 deaths (Scallan et al., 2011). For Europe, the estimates are 23 million cases of food-borne disease and 4700 deaths each year (WHO, 2019). The actual numbers might be much higher because many cases go unreported (e.g., WHO, 2002; Langsrud et al., 2020).

Around 10–30 percent of the cases of food-borne disease can be attributed to food preparation at home (for the US and Europe respectively, see Dewey-Mattia et al., 2018; EFSA and ECDC, 2018). For example, private households are the most common place where food is consumed that leads to salmonellosis outbreaks (EFSA and ECDC, 2018). Improper handling and storage of food at home – such as inadequate cooking, consumption of risky foods, cross contamination, inadequate hand washing routines, and lack of time-temperature control – are frequent (Skuland, 2020; Evans & Redmond, 2019; Young et al., 2017a, b; Byrd-Bredbenner et al., 2013). Such mishandling facilitates bacterial contamination of food, which increases the likelihood of consumers contracting food-borne diseases.

Since consumers play an important role in the prevention of food-borne diseases, promoting awareness and fostering correct risk-reducing behavior has become an important objective for organizations dealing with the protection of citizens' health (Ravarotto et al., 2016). For example, one of the main topics of the WHO food safety day in 2021 was "Know what's safe – Consumers need to learn about safe and healthy food" (WHO, 2021); and numerous national and international health authorities provide information about food safety to consumers (e.g., CDC, 2021; NHS, 2020; WHO, 2006).

Yet, despite these hazards and information materials distributed, many people are not aware of food-borne disease and its prevention at home (e.g., Thaivalappil et al., 2019; Lange and Marklinder, 2016). But even people who are aware of the risks, do not necessarily follow the authorities' guidelines. That is, food safety information does not always

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result in proper food handling behavior or in consumers refraining from eating risky food (Brennan et al., 2007). For example, despite numerous campaigns by national food safety authorities and widespread news coverage of past outbreaks, many consumers prefer to eat hamburgers that are rare or not well done.

A reason for such behavior is that, in addition to scientific facts, people are influenced by preferences, ethical, political, and religious beliefs as well as culture, history, and personal experiences when making their decisions. The pleasure of eating is arguably one of the strongest predictors of food choice (see Steptoe et al., 1995) and sensory preferences may distract from food risk information (Olsen et al., 2014). Further, in the area of domestic food safety, both demographic factors (such as age, gender, and health), as well as psychological factors (such as habits, biased beliefs, overconfidence, trait worry, and internal locus of control) influence behavior (Fischer & Frewer, 2008; Young et al., 2017b,a). Specifically, individuals often adopt food safety beliefs and behaviors from their parents and apply them without much reflection (see Lange, 2017). Further, since food preparation involves repetitive behavior that is performed on a daily basis year in, year out, behaviors become habitual and under the control of automatic processes (see Aarts & Dijksterhuis, 2000). Consequently, routinized food safety behaviors and beliefs might be difficult to change with information alone.

To break such routines, we design an online game that does not only inform consumers about correct food safety behaviors, but also trains consumers to apply them. In their review of the E-bug project – a food safety project designed for young people by Public Health England's Primary Care Unit, which includes interactive, computerized components – Young et al. (2019) argue that effective risk communication on food hygiene will need to rely on the use of relevant and accessible methods in the digital era, such as online games. Yet, a survey by the SafeConsume consortium (Kasza et al., 2019) reveals that most authorities rely on "passive" information, such as webpages and only 10–20 percent rely on "active" information over, e.g., social media or an app.

Our study aims to demonstrate the potential for well-designed online games to contribute to the prevention of food-borne disease. We do not only test whether the game is successful in improving food safety beliefs and behaviors compared to a control condition, but also whether it is more successful than a more traditional intervention with video-based information only. Further, we include an additional condition in which we frame the information video in a disgust eliciting way to test whether such a frame further increases the impact of the game on food safety beliefs and behavior.

1.1. Related literature

The game at the heart of our intervention is an example of a serious game – a game that has an educational purpose and is not just intended to be played for amusement (Abt, 1970). The broad idea of gamification[2] and serious games as tools to induce behavioral change is that the engaging nature of certain game elements helps consumers to change their behavior by influencing psychosocial constructs such as attitudes, intentions, motivations, cognitive skills and affective states. The engagement felt when playing a video game has been found to increase blood pressure and heart rate, and to change facial expressions (Ravaja et al., 2008). People get emotionally aroused by gaming, and both enjoyment and fear can be felt. This engagement and the intrinsic motivation it triggers, provide opportunities for learning. Games have been found to increase both descriptive and conceptual knowledge, problem solving, skills in spatial representation and higher-order thinking when compared with traditional lecturing methods (Ke, 2009; Boyle et al., 2011).

Serious games and gamification are increasingly being used as a behavior change technique, for example, to influence energy saving behavior (Iweka et al., 2019; Wemyss et al., 2019), transportation choice (Lieberoth et al., 2018), exercising (Höchsmann et al., 2019; Patel et al., 2017), or other health related behaviors (for reviews and meta-analyses see, e.g., Johnson et al., 2016; DeSmet et al., 2014; Koivisto & Hamari, 2019). Specifically, serious games, have been applied as educational tools in a variety of settings such as, for example, training of police, firefighters, safety training, well-being at the workplace, and healthcare (e.g., Backlund et al., 2007; BinSubaih et al., 2009; Lowensteyn et al., 2019; Martínez-Durá et al., 2011).

Food safety related educational interventions (for reviews see, e.g., Sivaramalingam et al., 2015; Young et al., 2015) primarily take the form of training (e.g., Harrison, 2012, developed a hand washing education initiative using a university mascot) or workshops (e.g., Ravarotto et al., 2016, found application of the consensus conference model as a communication process to be an effective opportunity to engage young consumers and experts on the topic of food safety). Yet, training or workshops can be impractical when it comes to educating large parts of the population about food-borne disease. Studies targeting larger audiences often rely on text messages (Trifiletti et al., 2012; Townsend et al., 2006) or videos (Quick et al., 2015). Only few studies consider the effects of serious games on food safety behavior of children and adolescents (Mac Namee et al., 2006; Quick et al., 2013; Clark et al., 2020).

2. Methods

2.1. Experimental procedures and sample

The study design and hypotheses were pre-registered (for the pre-analysis plan see Koch et al., 2020). A total of 1087 participants (499 from the UK and 588 from Norway) completed our two-part, online experiment through the survey company Kantar Gallup from January to March 2021. Because the enjoyment of computer games tends to be higher for younger people, we expected that the game might have less of an impact for older people. This motivated our pre-registered restriction to participants aged 20–50 years. Data on an additional 886 participants outside the pre-registered age range that became available are analyzed separately (see Section 5.2). As several of the targeted hygiene behaviors relate to the preparation of meat, we screened participants to prepare at least two warm lunches/dinners with meat or poultry per week on average. The sample was stratified to ensure equal distribution of gender across treatments.

Tables S.1 and S.2 provide more details on the sample (number of participants by country, condition and gender) and Supplementary Section S.1.1 gives further details on sampling. Table S.3 shows that compared to those who drop out, the final sample has individuals who are slightly older, have a somewhat higher income, and live in smaller households. Further, there are differences in what type of meat was consumed in the week prior to the study. We control for these variables in our analyses.

2.2. Experimental design

The study consisted of three main parts: A pre-survey, the intervention part, and a post survey. The intervention relied on information videos and a computerized home cooking game (see Figs. 1 and 2 for screenshots; the game can be played at https://safeconsume.eu/tools/safeconsume-game). Participants were assigned to one of four conditions in a between-subjects design, as summarized in Table 1.

In all conditions, participants answered a pre-survey and seven days later a post-survey. In the survey, next to collecting some information on sociodemographic background and certain preferences, participants reported some recent food safety behaviors and we elicited beliefs in the efficacy of certain food safety actions, as well as beliefs in myths. The

[2] Gamification is defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011, p. 9). Examples are the use of rewards or avatars.

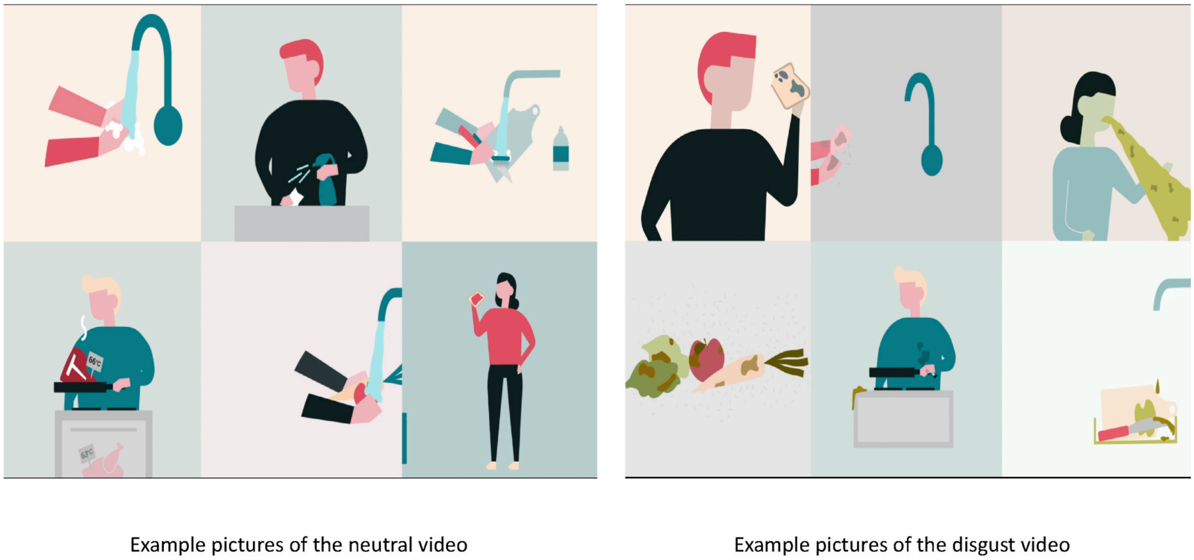

Fig. 1. Screenshots from the information videos.

questions were either directly taken from or inspired by previous work of the SafeConsume EU consortium (https://safeconsume.eu/). The survey was developed by finding relevant established scales of food safety behaviors and beliefs. These were discussed and modified within the research team, and then tested on food safety experts within the SafeConsume consortium. During further iterations, the survey was discussed with experts from the survey company and pilot tested with members of the target group. To facilitate recall of behaviors, we asked participants to think of a specific dish they prepared within the last week (see Schwarz & Oyserman, 2001).

No further intervention took place in the *Control* condition. In the *Info* condition, after the pre-survey, participants watched a 2 minute information video about food safety. It addressed five broad categories: personal hygiene (hand washing), kitchen hygiene (cleaning utensils and surfaces), washing fresh vegetables and fruits, *not* rinsing meat or poultry, as well as cooking foods thoroughly. These categories align with core elements of the WHO's five keys for safer food (WHO, 2006). Pictures were accompanied by simple (spoken and written) messages such as: "Washing poultry or meat can spread harmful bacteria through water droplets. So do not wash raw poultry or meat." In the *Game* condition, after answering the pre-survey and watching the information video, participants played a home cooking computer game where they had to prepare four recipes with meat. After completion of a recipe, participants received feedback on how well they handled important food safety actions related to the categories addressed in the information video. The *DisgustGame* condition was identical to *Game*, except that we replaced the information video with a version were the pictures were visually framed to trigger a disgust reaction (see Fig. 1; Supplementary Figs. S13-S14 provide further examples). The messages accompanying these pictures were identical to those in the neutral video.

We based the content of the information video on a thorough analysis of food safety issues and food safety advice given by authorities, which were collected and reviewed by the SafeConsume EU consortium. The design of the video drew on the evidence that information can be effectively communicated if it is factual, brief, easy to understand (Jacob et al., 2010) and supported by pictures (Alter & Oppenheimer, 2009). Because messages with argumentative power are more likely to have an effect (Byrne & Hart, 2009), we paired advice on behavior with an argument or fact that supports it (see Supplementary Fig. S13).

Through the video, we also addressed several food myths that were a subsample of food myths collected by the SafeConsume EU consortium: Fruit and vegetables that will be peeled do not have to be washed; it is safe to eat a piece of bread that has fallen to the ground if picked up within 5 seconds; and only poultry meat needs to be well done to be safe to eat. To avoid reinforcing the myths, we did not explicitly mention them in the video.

In the game (see Fig. 2 for screenshots), participants had to prepare dishes consisting of chicken, raw vegetables, and bread. The kitchen included a worktop, a sink, hand soap, dish liquid, surface cleaner and paper towels, a rubbish bin, a cutting board and a knife, a pan on the stove, and a food thermometer. Participants had to take meat and fruit/vegetables from a refrigerator and bread from a basket. They had to cut each food item on a cutting board and to heat the meat in the pan before serving the food on a plate. Sometimes, a miaowing cat disturbed the cooking process. If the participant did not remove the cat, it kept walking over the worktop, leaving a trail of cat hair behind (see Fig. 2).

The game involved a number of critical handling points, to which we henceforth refer as *important food safety actions*, or IFSAs. These were: (1) Washing hands with soap before starting to cook and after preparing a food item. (2) Cleaning food preparation tools with water and dish liquid after preparing a food item. (3) Cleaning kitchen surfaces after preparing a food item. (4) Checking with a food thermometer that the chicken has an internal temperature of 74 °C before removing it from the pan. (5) Rinsing fruit/vegetables (even if later peeled) before preparing them. (6) Not rinsing raw meat. (7) Not consuming dropped food items.

Before the game, participants watched a video explaining how to play the game. They then completed four recipes. Recipes differed in the raw vegetable or fruit to be prepared and we included both fruit/vegetables that had to be peeled and some that did not. After each recipe, participants received feedback on whether they met the time limit and how well they performed in terms of the IFSAs.

Depending on treatment, the median duration for part 1 was 15 min for *Control*, 18 min for *Info*, 65 min for *Game*, and 61 min for *DisgustGame*. The median duration for part 2 (the post-survey) was 9 min.

3. Theoretical background and hypotheses

Our primary hypotheses are that the game in combination with the information video in *Game* improves food safety related beliefs (**Hypothesis 1**) and behavior (**Hypothesis 2**) compared to the *Control* condition.

The foundation for Hypothesis 1 is that serious games foster active and problem-based learning and thus affect beliefs. Boyle et al. (2011) link the success of serious games to a number of psychological factors and emphasize that active learning is encouraged through two possible channels. First, the players get repeated feedback that is linked to their

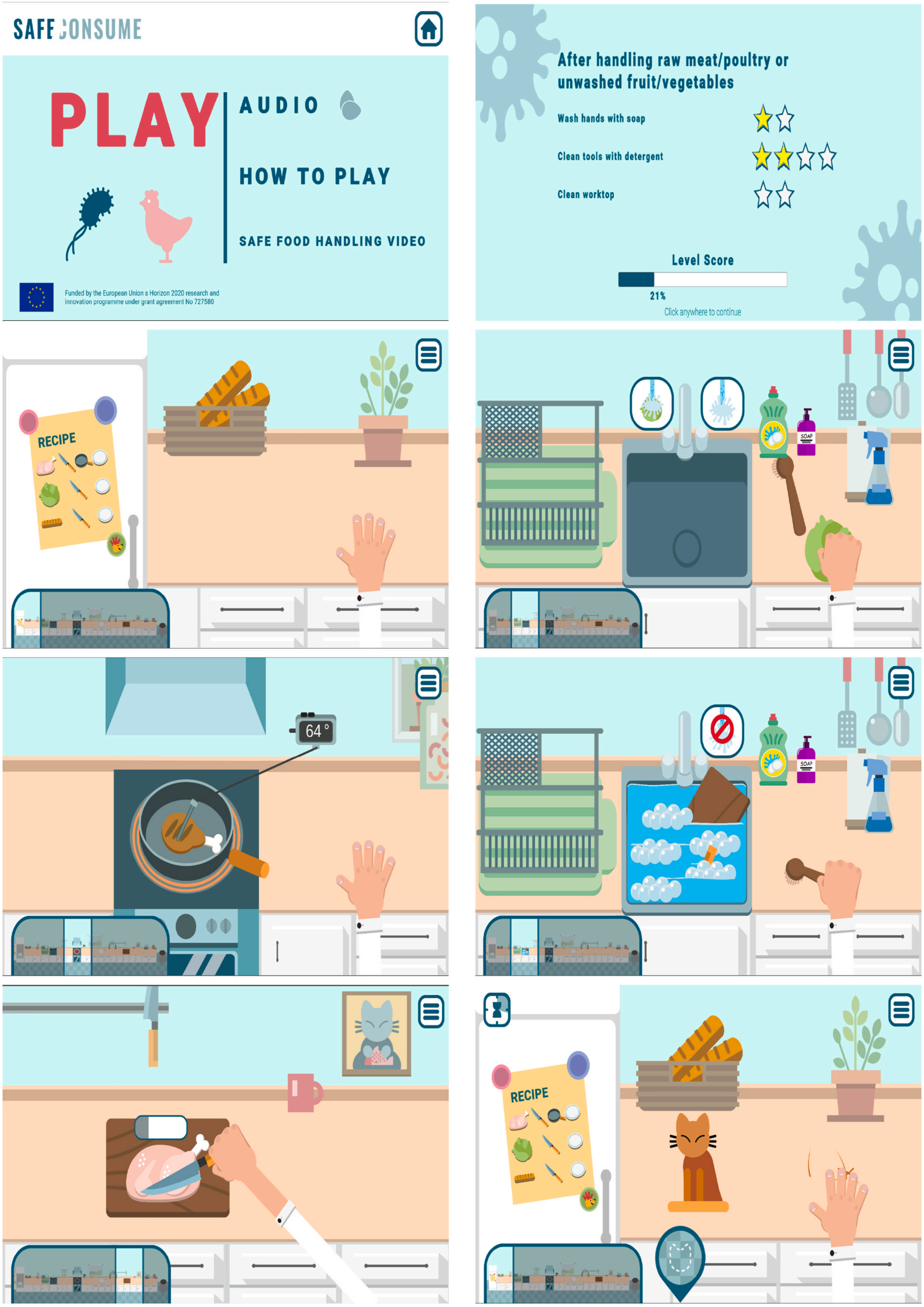

Fig. 2. Screenshots of the game.

own past behavior. Such feedback reinforces knowledge because repeated exposure to a message makes it faster and more effortless to retrieve from memory; and processing fluency makes people more likely to perceive a message to be true (Hasher et al., 1977; Reber & Schwarz, 1999; Alter & Oppenheimer, 2009). Second, the online game requires players to become actively engaged. This engagement is likely to increase attention to the messages that target behavioral change, compared to passively consuming information materials (Deater-Deckard et al., 2013).

The foundation for Hypothesis 2 is the evidence that gamification

Table 1
Overview of treatments and time line.

Treatment	Date 1			Date 1 + 7 days
	Pre-Survey	Information Video	Game	Post Survey
Control	✓			✓
Info	✓	Neutral frame		✓
Game	✓	Neutral frame	✓	✓
DisgustGame	✓	Disgust frame	✓	✓

can foster behavioral change. That is, we expect the game not only to change behavior indirectly over beliefs, but also directly. For example, Cugelman (2013) discusses elements such as committing to achieve a goal, capacity to overcome challenges, feedback on performance, reinforcement through rewards, monitoring progress, social connectivity, and fun and playfulness. Our game challenges participants because they need to keep the time and plan their actions. By connecting the desired behaviors with positive feedback through the scoring system and rewarding correct behavior, the game leverages the underlying psychology of goal setting, rewards, mastery, autonomy, and pursuit of meaning – thereby increasing intrinsic motivation to pursue desired behaviors (see Boyle et al., 2011). Further, the game gets participants to repeatedly practice behavior in the virtual environment, which can support forming new habits. The psychology literature emphasizes that in order to create habits it is important to repeatedly apply an action (e.g., washing hands in our context) in response to a cue (touching raw meat) and to receive immediate rewards for taking the action (e.g., Wood & Neal, 2007, 2009). In our game, the reward comes in the form of getting a higher feedback score.

In addition to the two primary Hypotheses 1 and 2, we test a range of secondary hypotheses to better understand the mechanisms behind our results. First, we test whether the game is more effective than a pure information intervention. The game, as well as the information condition affect beliefs and beliefs affect behavior. Yet, because of the active learning process outlined above, we expect the game to have a stronger effect on beliefs than the information condition. In addition, we expect that the game has a direct effect on behavior that is not mediated by beliefs.

To test whether the game is more successful than the information condition, as a first step, we test whether and in which dimensions the information intervention (condition *Info*) is successful. Based on past research that showed, for example, that corrective messages have a moderate positive influence on beliefs in the health domain (Walter & Murphy, 2018), we hypothesize that the pre-post change in food safety related beliefs and behavior, respectively, is larger in the *Info* than in the *Control* condition (**Secondary hypotheses 1 and 2**, respectively). Then, in a next step, we test the hypothesis that the game is more successful in changing beliefs and behavior, respectively, than just providing information. For this we compare the pre-post change in food safety related beliefs and behavior in *Game* with *Info* (**Secondary hypotheses 3 and 4**, respectively).

We consider a second set of mechanisms related to disgust, which is an emotional reaction triggered by aversion towards potentially contaminated objects. Triggers of disgust are bodily products as feces, vomit, urine, mucus, and blood. Disgust is thought to be an evolutionary adaption to prevent exposure to pathogens (e.g., Curtis et al., 2004). It thus seems particularly relevant in the context of food safety.

Indeed, health campaigns often rely on images or words that evoke disgust (see Gagnon et al., 2010; Lupton, 2015) to persuade target audiences by linking health risks with the negative affective reaction that disgust triggers. Drawing on the research related to the "pedagogy of disgust" in public health communication (Lupton, 2015), eliciting a disgust reaction in participants may make our game intervention more effective. It has been shown that decisions can be influenced by presenting information in a way that triggers disgust (Rozin and Fallon, 1987; Haidt et al., 1997). Specifically, in the context of food safety, Nauta et al. (2008) observe that disgust formulated information is effective in changing beliefs and behavior.

What are the potential reasons for disgust being effective in changing behavior? It is well established that information presented in an emotionally evocative way is more memorable (e.g., Bradley et al., 1992), which is, at least in part, because emotionally arousing stimuli increase attention (Talmi & McGarry, 2012). Arousing stimuli have been shown to have an automatic memory enhancement effect, whereas high valence, low arousal stimuli rely on controlled encoding (Kensinger & Corkin, 2004). There is ample evidence that disgust enhances attention (Morales et al., 2012; Van Hooff, van Buuringen, El M'rabet, de Gier, & van Zalingen, 2014) and memory consolidation (Croucher et al., 2011; Chapman et al., 2013; Van Hooff et al., 2014) – an effect that increases with time (Chapman et al., 2013; Moeck et al., 2021). Fear is another negative emotion with similar valence and arousal, but disgusting stimuli lead to greater immediate attention (Chapman, 2018).

In our setting, the more people pay attention to the video, the more information they retain in short-term memory. An additional effect is that disgust acts to enhance recall and recognition of episodic memory on both short (minutes) and longer (days – weeks) time scales (Chapman et al., 2013). Both of these effects serve to increase information retention, recall and recognition and therefore can result in a larger effect on beliefs. Further, exposing participants to the disgust formulated version of the information video may bolster the claim about the severity of the risk (Dillard & Shen, 2018). All of these factors would suggest that the subsequent play of the online game has a larger impact on beliefs and behavior than for those participants exposed to the neutral frame of the video. Hence, we test with the *DisgustGame* condition whether disgust formulated information creates more attention than merely factual presentation of information and in doing so leads to a larger pre-post change in beliefs and behavior than *Game* (**Secondary hypotheses 5 and 6**).

Lastly, even though disgust is thought to be a universal and basic emotion (e.g., Rozin et al., 2008), individual differences in disgust sensitivity exist (Haidt et al., 1994) that could potentially explain heterogeneity in the response to health messages like in our intervention. As disgust sensitive individuals may generally be more receptive to information about food safety, the disgust frame of information may be particularly effective for disgust sensitive individuals. That is, we expect the change in beliefs and behavior investigated under Secondary hypotheses 5 and 6 to be larger for more disgust sensitive individuals (**Secondary hypothesis 7**) and that in *Game* there is a positive moderation effect by disgust sensitivity (**Secondary hypothesis 8**). We capture disgust sensitivity using the 7-item food disgust picture scale (Ammann et al., 2018).

4. Empirical analysis

The empirical analysis was carried out using Stata 17 (see Koch, Mønster, Nafziger, and Veflen (2021) for the data and replication code).

4.1. Outcome variables

As the main outcome variables we use reported beliefs and behavior in the areas that are targeted in the game and the videos (*targeted behavior* and *targeted food safety efficacy beliefs*). For beliefs, we further use *beliefs in myths*.

Efficacy beliefs refer to an individual's belief that a particular action will affect the likelihood of contracting food-borne disease. We designed the game and video interventions to make people aware that certain actions, such as, for example, rinsing chicken, increase the likelihood of getting food-borne disease. We measured efficacy beliefs targeted by our interventions using 13 questions in the pre- and post-surveys (see Supplementary Table S17).

Beliefs in myths refer to commonly held 'true-or-false' beliefs with no base in scientific facts. We measured them using 8 questions in the preand post-surveys (see Supplementary Table S16). These myths were collected across Europe and assessed by the SafeConsume EU consortium.

Target behavior refers to self-reported food safety behaviors that were targeted in the intervention. We measured them with 21 questions in the pre- and post-surveys, such as, whether and how a participant checked the temperature of the meat when preparing a dish in the week before the survey or whether a participant rinsed certain fruits and vegetables (see Supplementary Table S18).

If increased information about food safety triggers greater reflection and an increased general understanding of the causes of food-borne disease, the interventions may make people revise their beliefs or question myths also in areas that are not directly targeted in the intervention. Thus, further outcome variables used in some of the pre-registered exploratory analyses are beliefs and behavior in relevant food safety areas that were not targeted in the interventions (see Supplementary Tables S16-S18). For the beliefs, we consider a measure based on seven non-targeted beliefs. For behavior, we consider actions such as seeking information on how to safely handle food, checking the temperature of the fridge, and checking use-by dates of food items.

We standardize all individual items based on the mean and standard deviation of the respective pre-survey measure (see Supplementary Fig. S1). That is, comparison with the standardized post-survey measure captures by how many standard deviations the measure changed relative to the pre-survey and thus has the interpretation of an effect size. Whenever relevant, items are recoded so that a positive change between pre- and post-survey responses indicates an improvement in beliefs or behavior (see Supplementary Tables S17- S19). We then aggregate items for the respective groups of outcome measures by taking the average over the individual standardized measures.

4.2. Empirical strategy

To test our hypotheses, we estimate average treatment effects using difference-in-differences regressions (e.g., Imbens and Wooldridge, 2009) that take the average pre-post difference in the outcome variable in each condition and compare the difference in these differences across two conditions[3]:

$$y_{it} = \beta_0 + \delta_0 P_{it} + \beta_1 T_i + \delta_1 P_{it} \cdot T_i + \gamma X_i + \epsilon_{it},$$

where y_{it} is the outcome variable of interest for a person at date t (we have two observations per person), T_i is a treatment dummy, and P_{it} is a dummy equal to zero for the pre-survey observation and equal to one for the post-survey observation. P_{it} captures any time-related changes that occur across treatments. The interaction between T_i and P_{it} is the difference-in-difference estimate of interest. It captures how the treatment affects changes in the outcome variable between pre- and post-survey observations. We add a set of control variables X_i that include individual and socioeconomic characteristics and further account for experience with cooking and food safety (the list of control variables is given in Supplementary Section S.2.1).

Specifically, to test the main hypotheses (Hypothesis 1 and 2), the treatment dummy is set equal to one for *Game* and 0 for *Control*. To test secondary hypotheses 1 and 2, the treatment dummy is set equal to one for *Info* and 0 for *Control*. Similarly, to test secondary hypotheses 3 and 4, the treatment dummy is equal to one if the participant participated in *Info* and 0 if s/he participated in *Game*. Finally, to test secondary hypotheses 5 and 6, the treatment dummy is equal to one if the participant participated in *DisgustGame* and 0 if s/he participated in *Game*. The treatments not mentioned are not included in the respective regressions.

The *p*-values and effect sizes in the results that we report in the next section refer to our main specifications that estimate the treatment effects without controls, but we also report estimates with a basic and extended set of control variables (see Supplementary Section S.2.1) and run a number of robustness checks (see Supplementary Section S.1.2).

5. Results

Table S.4 shows the descriptive statistics for the main outcome measures for the pre- and post surveys. Outcome measures at baseline are not perfectly balanced against the control treatment (see Table S.5) and there are some imbalances between the treatments for some control variables (see Table S.6). The difference-in-differences estimation approach accounts for such imbalances.

The data support Hypotheses 1 and 2, as illustrated in Fig. 3 and summarized in the following result:

Result 1. *Relative to Control, Game improves targeted efficacy beliefs by 0.16 standard deviations* ($p < 0.001$)*, beliefs in myths by 0.13 standard deviations* ($p = 0.013$)*, and targeted behavior by 0.20 standard deviations* ($p < 0.001$).

We next turn to our first set of secondary hypotheses (Secondary hypotheses 1–4). While the information video improves food safety related beliefs compared to the control condition, a knowledge-behavior gap (Hornik, 1989) emerges in that information changes beliefs, but not behavior. Given that *Info* and *Game* are both effective in changing food safety related beliefs, it is not surprising that we find no treatment difference in beliefs between these two conditions. Yet, unlike the information video, the game improves behavior and thus bridges the knowledge-behavior gap. We summarize in the following result (see Fig. 3):

Result 2.
1. *Relative to Control, Info improves targeted efficacy beliefs by 0.14 standard deviations* ($p < 0.001$)*, but has no significant impact on beliefs in myths* ($p = 0.279$) *or targeted behavior* ($p = 0.242$).
2. *Relative to Info, Game has no significant impact on targeted efficacy beliefs* ($p = 0.771$) *or beliefs in myths* ($p = 0.374$)*, but it improves targeted behavior by 0.13 standard deviations* ($p = 0.013$).

We next turn to our secondary hypotheses related to disgust (Secondary hypotheses 5–8). We hypothesized that disgust formulated information would lead to a stronger learning effect, but expected the effect to be small. In line with this, the estimated treatment effects

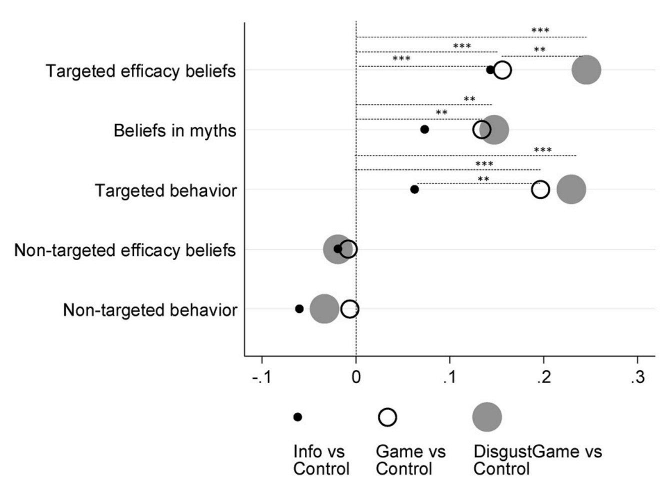

Fig. 3. Average treatment effects for the main outcomes.
Note: Difference-in-differences estimates. *p<.1, **p<.05, ***p<.01. Based on Supplementary Table S7.

[3] In principle, we could include an individual specific intercept, or so-called fixed effect. While this typically reduces standard errors by controlling for certain types of omitted variables, the downside is that inference is "notoriously susceptible to attenuation bias from measurement error" (Angrist & Pischke, 2008, p.225). For this reason, we implement the model without individual fixed effects.

relative to *Control* for efficacy beliefs, beliefs in myths, and targeted behavior are all higher for *DisgustGame* compared to *Game*, but for the latter two outcomes the differences are not of sufficient magnitude to be statistically significant (0.09 standard deviations and $p = 0.045$ for targeted efficacy beliefs; $p = 0.848$ for beliefs in myths, and $p = 0.542$ for targeted behavior).

Further, the evidence contradicts the hypothesized mechanism of a disgust reaction increasing attention to food safety. We do not find treatment effects being moderated by disgust sensitivity (see Supplementary Table S7 and Supplementary Section S.1.2.2). Only for one outcome do we find a significant effect, yet it goes against our hypothesis: for participants with disgust sensitivity above the median compared to those below the median, there is a lower treatment effect of *DisgustGame* on beliefs in myths relative to *Game* (−0.299 standard deviations, $p = 0.003$).

5.1. Mechanisms

We next test the potential mechanism behind our observed result that the game affects behavior (this analysis is not pre-registered). From a theoretical point of view, the game may either change behavior directly or affect behavior by changing beliefs. Fig. 4 illustrates how we can decompose the total treatment effect on behavior (panel A) into a direct effect of being exposed to the treatment and an indirect effect that operates through the mediator efficacy beliefs (panel B). The classic approach to mediation analysis outlined in Baron and Kenny (1986) requires four conditions to be met. First and second, that the overall treatment effect (TE in panel A) and the treatment effect on the mediator (path a in panel B) are significant. We already saw that both conditions hold for *Game* and *DisgustGame* treatments, as illustrated in Fig. 3. Third, controlling for the treatment, the effect of the mediator on the outcome (path b in panel B) is significant (for *Game* $\beta = 0.17$, $p < 0.001$; for *DisgustGame* $\beta = 0.19$, $p < 0.001$). Interaction terms between treatments and mediator are insignificant, indicating that treatments do not moderate the mediator-outcome effect (for *Game* $\beta = 0.08$, $p = 0.33$; for *DisgustGame* $\beta = 0.08$, $p = 0.25$). Fourth, a significant indirect effect, or mediated effect (panel B), which we establish by estimating the effects using the procedure of Imai et al. (2010).

We find that most of the total treatment effect of *Game* operates as a direct effect on behavior and only around 1/6th of it is mediated through efficacy beliefs (see Table 2). The picture is similar for *DisgustGame*, for which the higher total treatment effect on behavior (we find no statistically significant difference, as shown in Fig. 3) is distributed proportionally across higher direct and indirect effects. Above we discussed a number of theoretical mechanisms through which serious games can affect behavior directly rather than through beliefs. Our results support the importance of these mechanisms.

5.2. Exploratory analysis

We conduct additional pre-registered exploratory analyses. First, given that the game exhibits promising effects on targeted beliefs and behavior, we test whether these lead to spillover effects on food safety related behavior and beliefs in areas that are not targeted in the game. We observe no significant spillover effects on non-targeted behavior and beliefs (see Fig. 3 and Supplementary Table S7). This indicates that the game increases attention to specific food safety actions, not food safety knowledge in general.

Second, we analyze treatment effects on individual items (see Supplementary Section S.1.2.1). In line with the analysis of aggregate beliefs, we also do not find treatment differences for individual belief items. Yet, for the targeted behaviors there is a pattern of *Game* and *DisgustGame* having larger treatment effects compared to *Info* – in particular, for the individual items related to handling meat, and rinsing fruits and vegetables even if they are to be peeled.

Third, we explore heterogeneous treatment effects (UK vs. Norway and Men vs. Women). We do not find any significant effects (available upon request).

Finally, we report exploratory results based on an additional 886 participants: The survey company also collected data outside of our pre-registered age range of 20–50 years because they omitted screening on age and this was only noticed after data collection had run for a while. Using the extended sample with 1973 participants aged 18–89, our main findings are robust, with the exception that we find for the extended sample that *Game* also significantly improves efficacy beliefs relative to *Info* (see Supplementary Fig. S8). This result stems from heterogeneous treatment effects by age. We observe that *Game* relative to *Info* has little impact on beliefs for individuals aged 20–30, but has an effect for the older age groups; for targeted behavior the treatment effect is constant across age groups (see Supplementary Figs. S9-S11).

While positive news, the result is surprising. Our motivation for recruiting only 20–50 year old individuals was that we expected older individuals to enjoy less or even have difficulty playing computer games. Indeed, we find that both enjoyment and frequency of computer gaming generally tend to decrease with age (see Supplementary Fig. S12). Yet, we find no correlation between age and the rating of how much fun our game was (Spearman $\rho = 0.03$, $p = 0.359$).

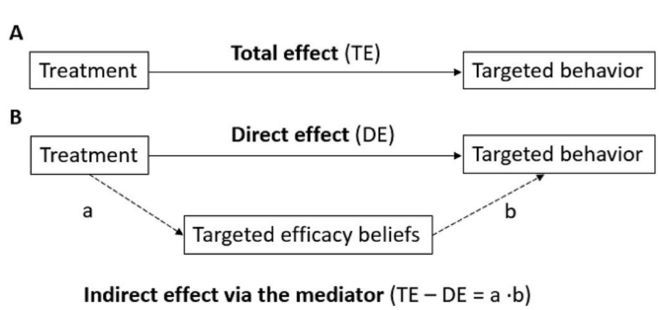

Fig. 4. Mediation.

Table 2
Mediation of the Game treatment effects on behavior through efficacy beliefs.

	Total effect[a]	Direct effect	Indirect effect[b]	Percentage mediated[c]
Game	0.20***	0.17***	0.03***	15.51***
DisgustGame	0.23***	0.19***	0.04***	17.58***

*p<.1, **p<.05, ***p<.01 based on bootstrapped confidence intervals using the `medeff` package for STATA (Hicks & Tingley, 2011). Controls (not reported): targeted efficacy beliefs and behavior at baseline and the basic and extended control variables listed in Supplementary Section S.2.1.
[a] Total effect of treatment on targeted behavior.
[b] Effect mediated through targeted efficacy beliefs.
[c] Indirect effect as percentage of the total effect.

6. Discussion

We provide causal evidence from a randomized experiment with a large number of observations on the ability of an online serious game to change beliefs and behavior in the area of domestic food safety. The previous literature on serious games and game-based interventions often does not, involve experimental designs or quasi experimental methods, relies on small samples, or has other methodological issues (see Hamari et al., 2014; Koivisto & Hamari, 2019; Sailer & Homner, 2020).

Our study goes beyond a simple treatment-control comparison by also comparing a game-based intervention with a pure information-based intervention. Specifically, by comparing the game-based with the video-based condition, we provide insights into the comparative advantage of a game-based intervention relative to a pure information intervention. Existing studies on promoting health related behavior using serious games (see above) tend to focus on the impact of a game and do not include the comparison of game-based and non-game-based approaches (e.g., Chow et al., 2020). Yet, such comparisons are important because there would be no need to impose the extra costs for a game intervention on society and participants (e.g., in terms of programming costs and participants' time) if simple information material was equally effective as the game in inducing behavioral change.

We observe that both interventions successfully communicate information. Yet, despite its impact on beliefs, the video-based intervention has no significant effect on changing food safety behavior. In contrast, the game-based intervention significantly improves behavior. Importantly, these results arise not only for young people. Previous studies on the effects of serious games on food safety (Mac Namee et al., 2006; Quick et al., 2013; Clark et al., 2020), as well as many food safety interventions in general, focus on children, teenagers, or professionals in the food service sector. Much less is known about how such interventions work among the general adult population, especially when it comes to game-based interventions. For older individuals, habits and non-scientific beliefs might be more persistent and more difficult to change. By targeting adults, our study shows the potential for serious games to educate the general population about food safety and to promote safe food handling behavior.

While the knowledge-behavior gap that arises in the video-based intervention is well known in other areas, such as vaccinations and health screenings, the result may appear surprising in the context of food safety. In contrast to vaccinations or screenings, the planning costs of conducting food safety actions are rather low and people have little incentive to procrastinate. This suggests that other forces, such as bad habits, are at play for the observed knowledge-behavior gap in the area of food safety. Our results suggest that the reason why the game is able to alleviate the knowledge-behavior gap, is that it provides an engaging environment in which individuals repeatedly apply correct behavior (In our study, 50 percent of the participants agreed with the statement "The game is fun", with the mean on the 5-point Likert scale being significantly higher than the neutral mid-point rating; t-test, $p < 0.001$, $N = 545$). By doing so, the game trains correct behavior and facilitates the creation of appropriate food preparation habits. What is interesting about our findings is that exposing consumers to repeated targeted behavior in a virtual environment for a limited time is able to change reported real-life behavior in the right direction. That is, not only repetition in real life, but also repetition in a game has the power to change behavior.

Our study further sheds light on whether framing information in a disgusting way can enhance the effects of the game-based intervention. While a disgust frame, improves targeted efficacy beliefs relative to the neutral frame, it does not additionally change behavior and beliefs in myths. Further, we find no evidence of individual differences in disgust sensitivity being a moderator. Thus, the results contradict the hypothesized mechanism of disgust triggering heightened attention to food safety – a result that might appear surprising given the previous literature. A plausible ex post rationalization of the findings is that the disgust frame perhaps made the video more amusing and memorable. Future studies should look further into such mechanisms.

7. Limitations and future research

A limitation of our study is that we rely on self reported behavior. To observe real behavior in a large, representative, two-country study as ours would be very expensive and time consuming. For example, a study by the SafeConsume EU consortium that observed and interviewed households in six European countries during shopping and preparation of a meal with chicken and vegetables reached only 87 households and paid EUR 60–170 per visited household (Møretrø et al., 2021).

While self-reported and observed food safety behaviors have been found to have low correlation in a study of 183 professional food handlers in Brazil (da Cunha et al., 2019), another recent study of 38 individuals from low-income families in four U.S. states showed a high agreement between self-reported and observed behavior (Moore et al., 2019). The latter study included actions such as time-temperature control, personal hygiene, cross-contamination, and adequate cooking in a real-life setting very similar to our game setting: one meal consisted of chicken breast and apple, while the other consisted of ground beef and tomato (Moore et al., 2019, p. 451). Whether the difference between these two studies are due to the different study populations (professional food handlers vs. home cooking), methodologies or other factors is hard to say, and further research is clearly needed both to test how well self-reported and observed behavior correlate, but also whether it is possible to affect real-life behavior with a game intervention, as our results indicate.

8. Conclusion

Our study aims to demonstrate the potential for well-designed online games to contribute to the prevention of food-borne disease. Overall, our study demonstrates that a relatively short duration of game play is enough to change beliefs and behavior in the short run and that it can be an effective tool not only for targeting young people but for reaching the general population. Next to being engaging, a game has the advantage that, once developed, it is cheap to roll-out on a large scale and thus has the potential to create a large impact on preventing food-borne disease by reaching many consumers.

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Data availability

Data and the replication code are accessible at Koch et al. (2021).

Ethics

As a low risk study on human behavior, the study was exempted from review by the Health Research Authority in the UK, by the Norwegian Centre for Research Data, and Nofima's ethical board in Norway. Participants gave informed consent.

CRediT authorship contribution statement

Alexander K. Koch: Project administration, Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Dan Mønster:** Project administration, Conceptualization, Writing – review & editing. **Julia Nafziger:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Nina Veflen:** Funding acquisition, Conceptualization, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2022.108825.

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