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Preparedness nudging for warning apps? A mixed-method study investigating popularity and effects of preparedness alerts in warning apps

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ABSTRACT

Warning apps are used by many to receive warnings about imminent disasters. However, their potential for increasing awareness about general hazards and for increasing preparedness is currently underused. With a mixed-method design that includes a representative survey of the German population, a design workshop and an app evaluation experiment, this study investigates users' preferences regarding non-acute preparedness alerts' inclusion in crisis apps and the effectiveness of Nudging in this context. The experiment shows that while the social influence nudge had no significant effect compared to the control group without a nudging condition, the confrontational nudge increased the number of taken recommended preparedness measures. The evaluation indicates that the preparedness alerts increased users' knowledge and their motivation to use a warning app. This motivation is, in contrast, decreased when the messages are perceived as a disruption. While many oppose push notifications, favor finding persuasively designed preparedness advice in a separate menu or as an optional notification.

1. Introduction

Individual preparedness can be crucial to limit or even prevent the damage caused by emergencies. Nowadays, warning and emergency apps are available in many countries and offer a mobile warning system. They are able to reach many app users quickly, providing reliable and targeted information and multi-media content to people. Most emergency apps are geared towards the response phase, focusing on spreading information fast and wide and distributing concise localized warnings and recommendations (Tan et al., 2017, 2018). For the preparedness phase, recommendations are typically only found in a menu that needs to be proactively sought out (Hauri et al., 2022). However, human judgement of the need to comply with response and preparedness recommendations is influenced by cognitive biases (Meyer, 2006), previous experiences (Diekman et al., 2007) and a country's risk culture (Appleby-Arnold et al., 2020; Cornia et al., 2016; Reuter et al., 2019). Even when citizens are warned and have the knowledge to take preventive actions, they thus routinely underestimate the risks, rely on agencies, or perceive that nothing much can be done (Cornia et al., 2016; Meyer, 2006; Paton, 2019), leading to milling and a lack of preparedness.

Therefore, notifications with general preparedness advice, in addition to acute warnings, could increase safety and emergency apps' utility (Tan et al., 2018). However, notifications with general preparedness advice may also lead users to abandon the app, particularly those who use the app only to receive alerts, because they perceive that non-acute notifications misrepresent the emergency situation (Bonaretti and Fischer-Preßler, 2021). Therefore, it is an open and important question whether notifications with preparedness advice increase the utility of warning apps. Persuasively designed preparedness advice might further motivate users to implement preparedness measures by engaging with psychological patterns, such as risk aversion or social norms (Mirsch et al., 2017; Oinas-Kukkonen and Harjumaa, 2009). Nudges, which are easy to integrate in a simple design, "alter people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives" (Thaler and Sunstein, 2008). While nudging has been applied to different contexts, including safe and secure behavior (Hartwig and Reuter, 2021; Renaud and Zimmerman, 2019; Zetterholm et al., 2021), its usefulness in the context of warning apps and preparedness has hardly been studied so far. However, designing nudges that are accepted by (potential) users of warning apps is a challenge.

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We therefore explore the research question: **How should preparedness alerts be designed and integrated into warning apps to increase hazard preparedness?** We explore this question with a mixed-methods design. First, we review related work on emergency preparedness and persuasive design (Section 2), after which we outline our mixed-method research approach (Section 3). We then follow the digital nudge design process (Mirsch et al., 2018) that consist of four steps: (1) context, (2) ideation and design, (3) implementation, (4) evaluation. In the first step, we discuss the study *context* in Section 4 through a representative survey in Germany ($N = 1090$), looking at user acceptance of nudging in the context of preparedness information and warning apps. This is followed by the second step *ideation and design* (Section 5), in which we investigate the design of persuasive preparedness alerts and nudges for emergency preparedness in warning apps, first, by testing different nudge types in the same representative survey (Step 2a), then, through collaborative design workshops (Step 2b, $N = 5$). Section 6 describes the *implementation* (Step 3) of three prototypes based on the findings: One serves as a baseline prototype that offers general preparedness advice without any nudges, whereas the other two prototypes include either a socially or confrontationally worded nudge for each hazard. Section 7 *evaluates* the nudges' effect on engagement with the prototype in a one-week experiment ($N = 76$), with the groups using the prototypes on their own smartphones (Step 4a). In addition, short questionnaires capture participants' impressions und behavioral intentions after engaging with the preparedness messages and nudges. As an alternative measure of nudge effectiveness, we captured the experiment participants' implemented preparedness measures in a post-study survey ($N = 76$). In addition, the post-study survey was used to evaluate the user acceptance of preparedness nudging and to qualitatively capture ideas for improving the nudges (Step 4b). We then discuss the findings, implications for design and the study's limitations (Section 8) and follow with a short conclusion (Section 9).

2. Related work

Crisis informatics examines the "intersecting trajectories of social, technical and information perspectives during the full life cycle of a crisis: preparation, response, and recovery" (Hagar, 2013). As an interdisciplinary field, it is rooted in Human-Computer Interactions and employs insights from Psychology to explain and improve how humans interact with information and communication technologies. Interactions surrounding emergencies are particularly important and interesting aspects of that field, because users' safety is at stake and because such non-routine situations are characterized by uncertainty, urgency and a high mental load (Tan et al., 2020). Therefore, in the following, we present Crisis Informatics findings on designing digital emergency prevention interventions and findings from Psychology and Human-Computer Interactions on cognitive biases and persuasive design, before pointing out existing research gaps.

2.1. Crisis informatics for emergency preparedness

The terms disaster, emergency and crisis are commonly used interchangeably to describe sudden and usually unforeseen events that "call for immediate measures to minimize [their] adverse consequences" (UNDHA, 1992: 34). Although certain hazards, e.g., natural disasters, cannot be prevented, their resulting negative *impact* can be prevented or mitigated through adequate preparedness. Preparedness and prevention are thus related and cannot always be fully separated. Preparedness means "the knowledge and capacities […] to effectively anticipate, respond to, and recover from, the impacts of […] hazard events or conditions" (UNISDR, 2009: 21). In the context of preparedness, crisis informatics investigates the use of ICT for public safety and security (Reuter, 2022) where they are used as early warning systems, which communicate alerts about non-imminent hazards or warnings about imminent hazards.

Legacy warning systems such as sirens and radio are now complemented by mobile warning components. These mainly include Cell Broadcast, which are text messages sent to all cellular devices by the cell towers in a warning region. Similarly, Location-Based Short Message Service (LB-SMS), can be used to send text-based alerts to mobile phones registered at a cell tower (Hauri et al., 2022). Since smartphones are widely used in many countries, can be customized based on personal preference and geolocation, can alert and store relevant information, and can present multi-media content, warning apps have great potential to support users before, during, and after emergencies. While some apps (such as news and social media apps) are used in day-to-day life and are adapted for emergency mitigation purposes during crises, others are built particularly for disaster purposes (Tan et al., 2017). Studies in several countries have shown that a major user demand exists for there to be only one national app that covers all important hazards (Dallo and Marti, 2021; Haunschild et al., 2022), including disruptions of daily routines such as bomb disposals, school closures or large traffic accidents (Kaufhold et al., 2020). This indicates that users are unwilling to have an app that only provides warnings and another that focuses only on preparedness. This could explain the relative insignificance of emergency apps that offer other emergency features such as checklists without also offering warnings (Kaufhold et al., 2020). However, most apps discussed in research are dedicated to disaster response and only about a quarter to disaster preparedness (Tan et al., 2017). When it comes to relevant information and features of emergency apps, Dallo and Martí (2021) found that participants included behavioral recommendations as desired relevant information.

In Germany, 60% rate warning apps as useful in general and over 50% even support the idea that a government emergency app could be preinstalled on smartphones (Kaufhold et al., 2020). In addition, warning app usage has been increasing (Kaufhold et al., 2020), ranging between 16% and 33% in different European countries (Reuter et al., 2019). These previous findings indicate that warning apps are the main crisis tools used to increase safety and security (Kaufhold et al., 2020). They are used in many countries (Reuter et al., 2019) but rarely include extensive preparedness information (Hauri et al., 2022; Verrucci et al., 2016). In addition, due to the wish to integrate all relevant safety and security features into one app, preparedness advice should be easy to integrate into existing, widely-used apps, rather than introducing a new preparedness app. However, a preparedness feature should not deter users from downloading or continuing to use a warning app, as such apps have important safety and security functions for acute emergencies. Therefore, it is central to design a feature than can be easily integrated without decreasing the usability of warning apps. For emergency apps to be useful to users, they have to "provide users with faithful representations of an emergency […] [in order] to respond" (Bonaretti and Fischer-Preßler, 2021). This entails the three dimensions of transparent interaction (activation through alerting, saliency that allows judging the severity and type of emergency, and usability allowing easy interaction with the app), representational fidelity (being relevant, current, exact, complete, consistent, and trustworthy), and situational awareness (supporting prompt and actionable protective actions). One study has found that the perceived risk, perceived trust in the relevance and accuracy, as well as social expectations influence the intention to use a warning app and to comply with its recommendations (Fischer et al., 2019). This is, however, decreased by data security concerns, whereas the intention to use a warning app correlates with the intention to comply with its recommendations (Fischer et al., 2019).

Other usability requirements that may be important not only for the warning app, but also for the design of additional features are, phone resource usage, and minimal external links (Tan et al., 2020). A study revealed that primarily app utility, app dependability, and output positively influence the intention to continue using a disaster app (Tan et al., 2018). App dependability means that the app needs to be error-free and output means that critical information must be easy to grasp (Tan et al., 2018). In contrast, user input and interface graphics

have a negative influence (Tan et al., 2018), which indicates that disaster apps should not require user input and should have a simple design. App utility means that "the more users perceive that the app delivers its intended function, the more likely the users will continue using the app. […] [Users must] perceive that the app does not deviate from its main function" (Tan et al., 2018). This indicates that if the intended function of an emergency app is to increase safety and security, added preparedness advice could increase app utility and thus emergency app usage.

2.2. Emergency preparedness and nudging

A large body of research exists that provides recommendations and guidelines for designing effective warnings for imminent dangers, that include recipients' risk perception, social norms and experiences as important elements to spark a prompt reaction (Bean et al., 2016; Kim et al., 2019; Laughery and Wogalter, 2006; Schroeder et al., 2017). As risk perception is a core factor concerning people's reaction to a warning (Wachinger et al., 2013; Wood et al., 2018), a common strategy is to provide reliable information about a hazards' risks and consequences. However, risk perception and the perceived need to prepare for emergencies are prone to a host of biases (Paton, 2019). To name only a few, the risk compensation bias means that when people perceive that other actors, e.g. agencies, are taking precautions, they perceive their environment as less threatening and may not take necessary precautions (Etkin, 1999). This bias may be particularly prevalent in Germany, where a state-oriented risk culture prevails, in which citizens tend to rely on agencies (Cornia et al., 2016). Due to the unrealistic optimism bias, individuals tend to think that they are less likely to be affected by negative future events than others (Weinstein, 1980). In addition, people are attached to the status quo and tend to prefer immediate benefits, even if they incur costs in the future (Paton, 2019; Thaler and Sunstein, 2008). Due to these biases, information about risks does not always lead to preventive actions (Eiser et al., 2012). Dual Process Theory is often used to explain systematic deviations from rational judgement, including the systematic underestimation and inertia regarding risks and their prevention (Kahneman, 2011). It stipulates that humans frequently use their automatic system (System 1), which, being fast, reflexive, and unconscious, needs fewer cognitive resources, but also relies on flawed heuristics derived from readily available information (Kahneman, 2011).

To engage with and confront unhelpful biases, persuasive technology design has been explored to support behavior change and to serve as triggers in a digital environment (Fogg, 2003; Lockton et al., 2010; Oinas-Kukkonen and Harjumaa, 2009). Persuasive system principles are aimed at supporting different elements: users' primary tasks, the computer-human dialog, the system's credibility, and social elements. Each of these categories consist of further sub-categories, such as reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal for supporting primary tasks (Oinas-Kukkonen and Harjumaa, 2009). These support principles can be implemented through different features. For example, gamification typically includes elements of human-computer dialog (rewards) and social support (competition and social comparison). However, this example shows that many persuasive design interventions require user input and data collection, significantly influence the functioning of an app and cannot easily be integrated into existing apps without changing their nature.

In contrast, as a simple design intervention, nudging uses human's predisposition to cognitive biases to support them in making better choices (Thaler and Sunstein, 2008). Nudges that engage reflective thinking (System 2 nudges) are perceived as more acceptable because they are regarded as more transparent and as respecting of free choice (Jung and Mellers, 2016; Reisch and Sunstein, 2016). Harrison and Patel (2020) order the amount of influence exerted by nudges in health care from *framing information*, to *prompting an implementation intention,* to *enabling a choice* to *guiding a choice through defaults*. While the latter should be used at the time that a decision is made, the former are to be employed in cases in which the decision cannot be influenced at the time of the decision (Harrison and Patel, 2020: 797). This is the case with many emergency preparedness measures, which often need to be implemented before the emergency. Many measures even need to be taken before an acute emergency warning, because they require time, infrastructure and a purchase to be implemented. Framing information and prompting an implementation intention are, therefore, the main nudge elements that can be leveraged in emergency preparedness nudging.

When applying reflective text-based nudges aimed at framing information, language and wording are important. Text-based nudges, often delivered via SMS, are popular, because they are low-cost interventions that can reach many people and that simultaneously serve as a reminder prompt. So far, research has investigated wording of text-message nudges primarily in finance and health (Avery et al., 2020; Dai et al., 2021; Page et al., 2020). A study of text-based vaccination reminders showed a significant effect of ownership prompts in the texts, whereas added video information did not have a significant effect (Dai et al., 2021). Interestingly, this effect observed in an experiment was unlike the self-assessment made by study participants in an online survey, supporting the value of testing intervention in the wild (Dai et al., 2021). A similar study of text-based interventions confirmed the findings and additionally found that interventions performed better when they were "congruent with the sort of communications patients expected to receive from their healthcare provider (i.e., not surprising, casual, or interactive)" (Milkman et al., 2021: 1). While this shows that framing and communication style are important, a study on flood preparedness found that the way that a descriptive nudge was worded and whether concrete percentages were given, did not influence the outcome (Mol et al., 2021). Similarly, a study investigating application for financial college support found that differently worded SMS-based nudges (including social comparison and commitment) did not have an effect (Page et al., 2022). However, since a similar text-based reminder had increased timely application by 3% (Page et al., 2020), the authors attribute this to the lack of a trusted relationship between SMS recipient and senders. This is in line with a study on SMS text-based emergency warnings which found that unfamiliarity with the sender lead participants to dismiss warnings (Kim et al., 2019). These insights suggest that when it comes to text-based nudges, communication must rely on a trusted relationship and should be congruent with styles expected from trusted agencies, such as emergency management agencies.

In a review on nudging in Human-Computer Interaction (HCI), Caraban et al. (2019) show that nudges are used as a facilitator, motivator, or trigger for behavioral change by using the mechanisms of facilitating, confronting, deceiving, socially influencing, creating fear, and reinforcing. Fields that commonly employ nudges are sustainability and health (Coskun et al., 2015; Orji and Moffatt, 2018), in which a large number of apps use digital nudging or persuasive technology design to educate about, remind of and help manage healthy and sustainable behaviors (Johnston et al., 2018; Nkwo et al., 2021; Vo et al., 2019). Concerning safety, recent research on COVID-19 apps discusses the use of nudges to increase behavior that reduces the spread of the virus (Michalek and Schwarze, 2020; Zetterholm et al., 2021). Nudging has recently also been explored with regard to online safety and security by nudging towards better password creation (Hartwig and Reuter, 2021; Renaud and Zimmerman, 2019) and software updates (Frik et al., 2019). Mirbabaie et al. (2020) investigate Twitter posts that communicate emergency-related content with regard to which contain nudging elements and whether these lead users to share the post. Other studies have explored persuasive design and risk, using Virtual Reality to try to change users' attitude towards risks (Chittaro and Zangrando, 2010) or helping emergency management practitioners, e.g. in overcoming cognitive biases through a series of questions when responding to oil spills (Brooks et al., 2020).

Only one recent study investigates nudging in relation to preparedness (Mol et al., 2021). The researchers use an online laboratory experiment to investigate social norm nudges to increase flood preparedness among homeowners. They test two descriptive social norm nudges, in which they either state the exact statistic of other homeowners' investment decision or that 70% of previous participants had made an investment, before asking participants to decide about making an investment. The study finds no significant effects of the social norm nudge on flood preparedness. Similarly, they found no effect when eliciting participants' beliefs about the percentage of other participants that would invest (norm-focusing). However, both in the norm-focusing group and in the control group, the believe that many other participants would invest correlated positively with participants' own investment decision. Exploring other factors that predict positive flood preparedness, the authors found previous flood investments, personal norm (the degree to which one finds oneself morally obliged to perform an activity), immediate gratification bias (a preference for immediate benefits that incur higher later costs), response efficacy and expected effects of flooding (Mol et al., 2021). Developing nudges that target these aspects could thus be promising for increasing preparedness.

The only study looking at warning apps with a persuasive design lens is an analysis of app store user comments concerning widely-used warning apps in Germany, which identifies persuasive design elements which were praised or desired by users (Kotthaus et al., 2016). Studies looking at the effect of usability on the intention to comply with warnings in warning apps to some degree address aspects related to persuasiveness. Fischer-Preßler et al. (2021) suggest that due to the role of social influence for warning app use, social responsibility should be used to promote the adoption of warning apps. Perceived response efficacy, and to a lesser degree perceived severity and vulnerability, are also relevant for usage adoption and should thus be leveraged.

2.3. Research gap

With their use of push notifications for acute warnings and advice about imminent hazards, warning apps have to some degree already been functioning as persuasive technology that aim to trigger the taking of precautions. However, these are so far only used to persuade citizens to react to imminent dangers. In contrast, persuasive design targeting the increase of preparedness has so far only been implemented in selected online games and is absent in warning apps (Verrucci et al., 2016). This is problematic since research shows that cultural norms in countries like Germany lead to preparedness measures being neglected (Cornia et al., 2016) and cognitive biases influence risk assessment and lead to unsafe behavior (Eiser et al., 2012). A study analyzing web-based and mobile preparedness ICT found that "none of the resources analyzed has implemented any means to remind users about their need to remain prepared over time nor do any monitor progress towards enhanced preparedness. The lack of these dynamic interactive features reduces the chances of users returning to the websites or applications for more continuous and sustained learning" (Verrucci et al., 2016: 1598).

While an analysis of user reviews has shown users' interest in persuasive design elements in warning apps (Kotthaus et al., 2016), there is no research dedicated to persuasiveness in warning apps. Social norms, risk perception and social support have been suggested to increase compliance with recommendations of warning apps (Fischer et al., 2019), but they have not been tested empirically. In addition, one study suggests that personal norms and a belief that others are implementing preparedness measures can increase flood preparedness (Mol et al., 2021). However, whether these elements could be used as nudges to enhance preparedness notifications has not been explored yet.

Another research gap concerns the user acceptance of preparedness notifications. While studies of user expectations and warning app usability requirements exist, they focus on warnings about acute emergencies (Appleby et al., 2019; Dallo and Marti, 2021; Fischer-Preßler et al., 2020; Tan et al., 2020). So far, whether preparedness notifications could be integrated into these apps to increase their usefulness or whether preparedness notifications may be perceived as distracting from the main function of alerting about acute emergencies has not been explored. If the nudges are perceived negatively, this could lead to reactance (Lukoff et al., 2022; Ward et al., 2021) and a decreased interest in warning apps, which could negatively affect public safety. While preparedness features could increase warning apps' utility and public safety, preparedness information is currently neglected and not proactively delivered within warning apps. We investigate whether nudges can convince users of the relevance of preparedness and which nudges effectively increase the taking of preventive measures.

3. Research approach

We design a study that tests the effect of nudges on implemented preparedness measures. Building on Fogg's (2009b) guidelines for designing persuasive technology, the Digital Nudge Design method (Mirsch et al., 2018) offers a four-phased process to guide the design. The phases are (1) defining the *context*, (2) *ideation and design*, (3) *implementation*, and (4) *evaluation* of the digital nudge.

When it comes to the *context*, we chose official multi-hazard warning apps as a technology channel (Fogg, 2009b) that users are familiar with. This is the case because warning apps are the mobile component of the German warning system (Hauri et al., 2022) and regarded as important channels by citizens in crisis situations (Kaufhold et al., 2020). Since users strongly prefer a single app for emergency-related functions (Kaufhold et al., 2020), the preparedness feature and nudges should be easy to integrate into warning apps and adhere to warning app design requirements, which include a simple design and elements, such as naming reliable sources that increase trust (Tan et al., 2020).

According to Fogg (2009a), behavioral change requires users to be *motivated* and *able* to change their behavior. In addition, they require a *trigger* that reminds them to act accordingly. Concerning the trigger function of warning apps, a warning needs to include a distinct, strong notification (e.g. sound or vibration pattern) that disrupts users' routine and draws attention to the imminent hazard (Tan et al., 2020). When the hazard is non-imminent, an alert can be subtler and less attention-grabbing. Applied to smartphone alerts, we chose silent push-notifications, which present a preview of the information on the home screen, as a trigger.

To gain further insights into users' general motivation to prepare, their preferred modus of receiving preparedness advice and their acceptance of nudging in this context, we conducted a representative survey ($N = 1090$). In selecting the scenarios, we considered which hazards might be relevant to our user group at the time of our experimental study. We decided on the emergency categories cybersecurity, traffic safety, and fire protection, as all participants own digital devices, are road users, and live in an apartment or house. This ensures that all users have a basic motivation to implement the measures. For the preparedness advice, we reviewed behaviors recommended by official agencies and chose simple and relatively cheap measures, e.g., downloading an anti-software virus app, checking bicycle lights, or buying a fire extinguisher (see Appendix A3 for all recommended measures) to ensure that all respondents were able to perform the tasks.

The representative study also contributes to the *ideation and design* of the preparedness feature and nudges, as we use it to gain first insights into users' preferences for different types of nudges. We use nudges because they are persuasive design elements that can be easily integrated into warning apps while adhering to the warning app design requirement of simplicity, which allows users to interact with the app even under mental load in stressful situations. Based on findings from the survey, we conducted design workshops with potential warning app users ($N = 5$) until saturation had been reached concerning ideas for implementing the preparedness nudges. The workshops encompassed discussing design strategies that facilitate the processing of preparedness alerts, the effectiveness of the nudges, and suitable push notifications.

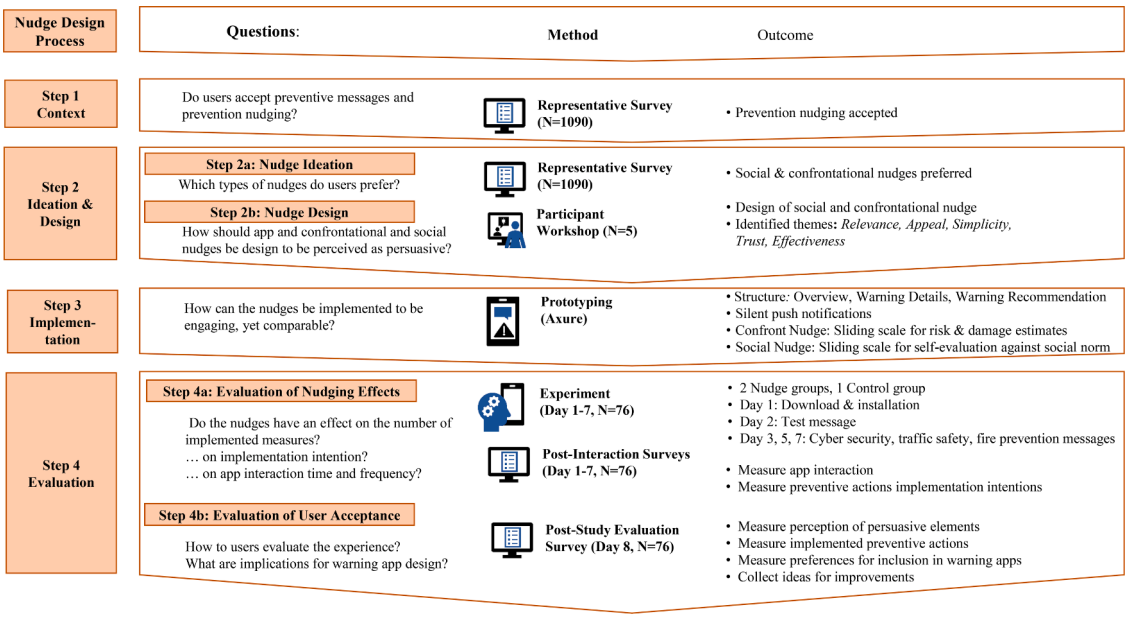

Fig. 1. Mixed-method study design following the Digital Nudge Design Process (Mirsch et al., 2018) and key outcomes. Own depiction.

The results were used to *implement* a warning app prototype, similar to official warning apps, but with persuasive preparedness advice and preparedness alerts. This prototype was *evaluated* in an experimental study ($N = 76$), focusing on the effect of a confrontational nudge and a social influence nudge. The experiment compared user perceptions, behavior intentions, implemented preparedness measures, and app interactions of a control group without any nudging condition with those of two experimental groups that interacted with nudges. Finally, to explore users' perceptions of the preparedness messages and the nudges, we conducted a post-study survey ($N = 76$). Fig. 1 shows the study's mixed-method research.

4. Step 1: preparedness nudge context: representative survey

Defining the context of the preparedness nudges, we chose the explore their integration into warning apps, as this is the ICT that is predominantly used to convey crisis information. To gain first insights into users' preferences and nudges in this context, we conducted a survey in October 2021, which is presented in the following.

4.1. Context survey design, sample and analysis

The commercial and ISO-certificated panel provider Gap Fish implemented the survey, ensuring a sample that is representative of the German population in age, gender, geography, and education. The questionnaire included two quality checks that had to be passed, which resulted in $N = 1090$ responses. The survey contained two questions about: whether one feels that precautionary measures can reduce harm (Q1), whether one feels sufficiently informed about precautionary measures (Q2) and four questions about the relevance (Q3) and modus for presenting precautionary measures in warning apps (Q4–Q7). Furthermore, we asked whether participants feel that others (Q8) or they themselves (Q9) could benefit from being nudged towards taking precautionary measures. We also inquired whether they could be prepared to submit information that allows to personalize nudges (Q10) or preventive messages (Q11) (see Appendix A1 for the questionnaire).

As some items do not fulfill the criterion of normal distribution, we use the non-parametric Mann Whitney U test to investigate group differences between current users and non-users of warning apps, between men and women, and participants who are older or younger than 55 years. We use the Pearson correlation coefficient r to evaluate the effect size (Cohen, 1988) and correct it using Bonferroni-Holm, to avoid spurious results from multiple comparisons (Holm, 1979).

4.2. Survey results

The representative survey of the German population indicates that people feel that information about preparedness measures should be integrated in a warning app ($M = 3.83$, $SD = .96$) rather than conveyed through a different channel ($M = 3.32$, $SD = 1.02$). Preventive measures should be event-related and sent along with acute warnings ($M = 3.93$, $SD = .93$), rather than unprompted by an imminent hazard ($M = 3.24$, $SD = 1.18$). Citizens are largely open towards nudging, with 52% regarding it as generally helpful (12% opposed, $M = 3.57$, $SD = 1.01$) and 47% stating that they would appreciate being nudged themselves (17% opposed, $M = 3.41$, $SD = 1.11$). More opposition (around 30%) is encountered when it comes to providing personal information to improve the preparedness messages, however around 35% of respondents were open to this ($M = 3.11$, $SD = 1.25$). Looking at group differences, most significant differences exist between current users and non-users of warning apps, while women and older people also judge some items differently (see Fig. 2). With $|\ r\ | \approx 0.1$ the effects are weak or very weak.

When comparing the survey participants who reported to be currently using a warning app with those who were not, current app users agree more that precaution advice should be delivered along with acute warnings ($M = 4.10$; $SD = 0.89$, non-users: $M = 3.87$; $SD = 0.93$) or for them to appear only as a menu item ($M = 3.93$; $SD = 0.88$, non-users: $M = 3.64$; $SD = 0.99$). In addition, they are significantly more willing to provide information in order to improve the preparedness warnings ($M = 3.36$; $SD = 1.28$, non-users: $M = 3.03$; $SD = 1.23$) and the preparedness nudges ($M = 3.31$; $SD = 1.28$, non-users: $M = 2.99$; $SD = 1.24$). Supporting previous findings (Kaufhold et al., 2020), we find that socio-demographic factors impact few items and only marginally. Women are less willing to submit information for personalizing nudges ($M = 2.94$; $SD = 1.21$, men: $M = 3.22$; $SD = 1.29$). Participants older than 55 years are similarly less willing to offer information for personalization of precaution advice ($M = 2.93$; $SD = 1.25$, younger people: $M = 3.29$; $SD = 1.21$) or of nudges ($M = 2.89$; $SD = 1.25$, younger people: $M = 3.24$; $SD = 1.24$). They are also less of the opinion that

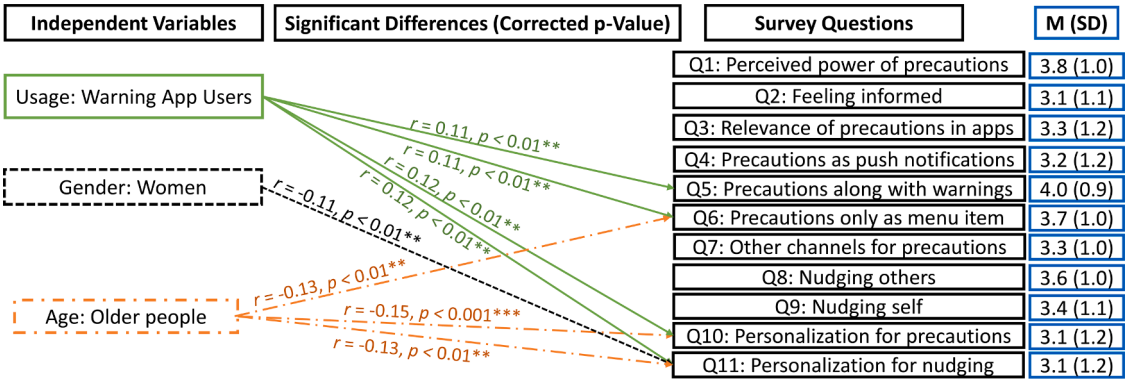

Fig. 2. Significant correlations, *p* value corrected with Bonferroni-Holm.

precautionary information should only be available as a menu item that needs to be proactively sought out ($M = 3.61$; $SD = 0.98$, younger people: $M = 3.83$; $SD = 0.96$). With the correlation coefficient r close to 0.1, the differences are small (Cohen, 1988).

5. Step 2: preparedness nudge ideation and design through a representative survey and qualitative design workshops

To get first insights into which types of nudges are deemed effective and appropriate, we explored first ideas for nudges in the representative survey. The results of the survey lead to a pre-selection of promising nudges. Following this, we conducted participant workshops to explore the concrete design of the nudges and their integration into a preparedness feature of a warning app. The following section describes the survey and the workshops.

5.1. Step 2a: representative survey for preparedness nudge ideation

The first ideas for nudges that could be effective as preparedness nudges, we considered psychological processes that are relevant for risk evaluation and combined them with insight on persuasive system design. This lead to a first set of differently framed nudges that were assessed by participants in the representative survey, which is presented in the following.

5.1.1. Ideation survey procedure, sample and analysis

To get first insights into which nudges are perceived as motivating and appropriate, we asked respondents in the same representative survey (see Section 4.1.) to evaluate different nudges according to these two dimensions and asked participants about the reasoning for their choices. As we strive to identify accepted nudges that can easily be integrated into warning apps, we focus on text-based nudges combined with a simple interactive nudge (see Table 1).

We include different nudges from different categories based on Caraban et al.'s review (2019) of nudging in HCI, who identify the categories *facilitate, confront, deceive, social influence, fear, and reinforce,* which each include further subcategories. We design three diverse nudges that target fear, by "evok[ing] feelings of fear, loss and uncertainty to make the user pursue an activity" (Caraban et al., 2019: 8), in particular we use the mechanism *reducing the distance,* which is used when the beneficial outcomes are distant in time. We use two emotional nudges to do this: One shows a picture of a burning apartment, the other shows a quotation from someone who has lost their home due to a fire. A third fear-nudge is more informational and shows the number of people that die daily due to a fire. Within the *confronting* nudges, the mechanism *reminding of the consequences* fits well with the aim of increasing preparedness, as it targets the regret aversion bias. These nudges are similar to the fear nudges that use loss aversion. We survey one such nudge which confronts users with a possible regret resulting from not having implemented a simple measure to avert losses. Finally, we design a social influence nudge that uses "people's desire to conform and comply with what is believed to be expected from them" (Caraban et al., 2019: 7) (see Table 1). We do not further explore nudges that deceive because they are not transparent, less accepted (Reisch and Sunstein, 2016) and thus likely to diminish trust. In addition, facilitation nudges target the decision at the moment when it is made (Caraban et al., 2019: 4). This is difficult to implement when it comes to preparedness, because the natural decision-making moment is typically an imminent hazard warning – when it is too late to implement many measures. Similarly, *reinforcement* nudges do not lend themselves to text-based interventions. However, as warning apps are already making use of push-notifications as prompts, we will use these in the study, too, albeit in all groups, including the control group, to ensure that all participants are exposed to the preparedness alerts.

A study of secure online behavior shows that warnings are more effective when they include a coping message that delivers advice about how to avoid a cyber attack, rather than only a threat appeal message that describes the negative consequences (van Bavel et al., 2019). We

Table 1
Participant evaluation of appropriateness and motivation of different nudges, sorted by preference. (The order in which the nudges appeared in the survey was randomized.).

Nudge Characteristics	Nudge Wording	Appropriateness *M* (*SD*)	Motivation *M* (*SD*)
Personal social norm, emotional	**N1:** When you buy a fire extinguisher, you protect your family and neighbors in case of fire. Responsible tenants and owners have a fire extinguisher.	3.74 (1.12)	3.66 (1.15)
Confront, information (response efficacy)	**N2:** A high-quality fire extinguisher costs less than €50. In 2019, a house fire caused an average building damage of 6639€ and a household damage of 2159€. (Source: GDV)	3.51 (1.20)	3.53 (1.24)
Fear, information (responsibility)	**N3:** In 2020, 20% of all fires that caused significant damage in buildings were caused by human error. (Source: IFS)	3.38 (1.15)	3.25 (1.18)
Fear, information (risk)	**N4:** In 2018, an average of one person died per day in Germany due to smoke, fire, or flames. (https://www.feuerwehrverband.de/presse/statistik/)	3.31 (1.17)	3.31 (1.22)
Fear, graphic	**N5:** [Picture of a three-story house with balconies in flames]	3.10 (1.32)	3.20 (1.33)
Fear, quotation	**N6:** "You just don't realize that this has happened to you. That the house is gone, from one day to the next."	3.06 (1.27)	3.07 (1.28)

therefore couple each nudge with the recommendation to buy a fire extinguisher. The nudges were presented in randomized order. Answers were given on a 5-point Likert scale from fully agree to fully disagree.

5.1.2. Design survey results

The survey shows that the preferred nudges were the social-normative nudge (N1, 34% rated this as the best nudge) and the confrontational nudge (N2, 24% rated this as the best nudge). Both nudges were worded in a constructive manner, highlighting the positive outcomes of a precaution. They are followed in their ratings by two text-based fear nudges (N3-4) and the picture and quotation-based fear nudges (N5-N6).

Qualitative statements showed that the favored nudges were perceived as neutral and non-paternalistic. Support for N1 was based on the perception that the statement was unemotional, did not incur negative emotions, but instead shifted the focus to social relations, which are perceived by many as "what is truly important in life". Participants liked that the message sounded caring and responsible, and it conveyed that they could take a simple measure to save lives. N2 was perceived as informative, factual, and convincing by showing a stark benefit in relation to the costs. Some also argued that money was the best way to convince others.

5.2. Step 2b: workshops for preparedness nudge design

While the survey showed some general preferences for the preparedness nudge framing, it was unclear show the nudges should be implemented as a preparedness feature in an app. Therefore, we conducted design workshops which are presented in the following.

5.2.1. Design workshops procedure, sample and analysis

We conducted individual remote online design workshops ($N = 5$, convenience sample of students with a background in Human-Computer Interaction and Media Communication, each lasting around 75 min) to design social and confrontational nudges that might increase users' motivation to comply with prevention recommendations. To introduce nudging and to provide a reference point for the different types of nudges, we used the Nudge Deck (Caraban et al., 2020), a design support tool consisting of cards which introduces the nudge categories that were also used to devise the nudges used for the survey (Caraban et al., 2019). In semi-structured interviews and with the collaborative online platform MIRO (miro.com), we iteratively designed a warning message for non-acute hazards and nudges based on participants' qualitative feedback (see Appendix A2 for the workshop guideline). After transcribing the audio of each workshop session, relevant text sections were iteratively coded using thematic analysis and building the coding scheme inductively (Braun and Clarke, 2006).

Due to the results of the representative survey, the social-normative

Table 2
Participant suggestions for persuasively designed nudges and warning apps and reasoning for implementation in this study (✓ indicates aspects that were implemented, x indicates aspects that were not).

Participant Suggestions	Design Implementation
Relevance	
Personal experiences: "I think everyone, at least as a kid, has been in this situation with their bike [lying on the road], everyone has certainly had a bike crash and that you show this again [through a photo]". "When it says, 'When was the last time you had a bike accident?'. Then I might think about it for a moment" (P4).	✓ Use examples of issues and incidents that users are familiar with -> selection of fire protection, traffic safety, cybersecurity
Personalized data: "[while seeing a map, you] think 'Yes, I live there in this environment'" (P2).	✓ Display of a map based on user location (similar to many warning apps, including NINA and KATWARN used in Germany) X No other personalization due to limited agreement with personalization in pre-study
Social norms: "When the Müller family says, 'We need to call the fire department, and they should bring our family a new fire extinguisher'. But that [the app] does this for the whole neighborhood. So that the feeling of togetherness arises. That everything is organized together and then carried out together" (P5).	X In conflict with the requirement of *trust – concern about pressure* and *trust - no data collection*
Relevant comparison group: "[The comparison should be] maybe not only with friends but also with the neighborhood and maybe all the people in the city who have this app" (P2).	X In conflict with the requirement of *trust – concern about pressure* and *trust - no data collection*
Appeal	
Positive framing: "I would rather say something like 'You are on a good track" (P4), "Those people [who have taken preparedness measures] should be portrayed as neighborhood heroes" (P5). "I don't know whether showing a sad video of a paraplegic after a bike accident would cause defensiveness. I think that quickly becomes too much" (P1).	✓ Encouraging wording, geared towards gains rather than losses ✓ Neutral rather than emotional
Additional appealing information: "a current statistic that includes bicycle and traffic accidents. […] Just interesting information that stays in your head a little bit" (P1), "include some funny icons that make it a little bit more appealing and not so dry. [...] So that not everything looks like an official agency website, but that it is also fun" (P5).	✓ Interesting information ✓ Appealing icons, modern design
Simplicity	
Use of tabs to give an overview: "I like the idea to divide the message [into] different sub-tabs for general information and countermeasures, links and so on" (P5).	✓ Different tabs are implemented to describe the risk and the preventive measures
Trust	
Statistics: "So basically, you can convince me with good statistics of a lot of things" (P1).	✓ Inclusion of statistics
No data collection: "When you set up a point system like that, […] it sounds a bit like the system in China" (P2).	✓ limited data collection: app uses only location (anonymized) ✓ clarify privacy or non-transmission of data in case of data input
Concern about pressure: "[Official agencies] can't force people to do something" (P5).	✓ Low pressure reflective nudges
Effectiveness	
Gamification rewards: "If I could reach some sort of level with points, that would give me a good feeling. Maybe then, I'd like to do something like that […] I would like to see a bar system or a score next to your status or level, but you also get an overview of the level of others" (P4).	X In conflict with the requirement of *trust – concern about pressure* and *trust - no data collection*
Social influence: "Reciprocity is always the highest" (P3), "'The average user has checked their bike within the last nine months'. You can do it with an indirect comparison" (P1).	X In conflict with the requirement of *trust – concern about pressure* and *trust - no data collection*
Commitment: "That you can set an appointment to be reminded to inspect your bike" (P1).	X Not feasible for the study design where triggers are controlled for
Pointing out consequences: "[…], statistics would actually be quite cool, or remind people of past accidents. So that you get the feeling you could change something if you inform yourself" (P2).	✓ Statistics of consequences included in reflective nudges

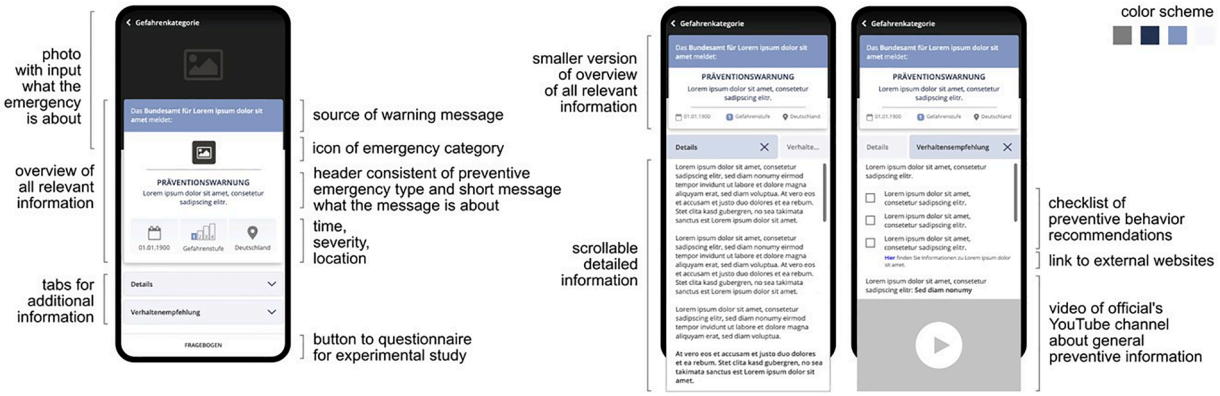

Fig. 3. Schematic design of the warning (left: opening screen, right: tabs "Details" and "Prevention Recommendations").

and informative-confrontational nudges were chosen for further exploration regarding their concrete implementation. In addition to creating persuasive nudges, we also wanted the technology to be persuasive, to avoid a scenario in which users might stop using the app because of its lack of important persuasive design elements, for example with regard to primary task support, dialog support or system credibility support (Oinas-Kukkonen and Harjumaa, 2009). Asking users about persuasive design elements for both the app and the nudges, helped us create an app that, on the level of the design, motivates both the treatment group and the control group to engage with it.

5.2.2. *Design workshops results*

The design of social and confrontational nudges, as well as persuasive warnings for warning apps, were therefore elaborated in design workshops with new participants who had not participated in the survey. From the workshops, 60 codes emerged, which could be grouped into the five themes (1) relevance, (2) simplicity, (3) appeal, (4) effectiveness, and (5) trust. Each theme includes, to varying degrees, aspects about general design proposals and specific details of the nudges. Table 2 shows users' design ideas for integrating nudges into warning apps. Participants suggested that nudges can increase reflection about the personal relevance of a hazard. On the one hand, photos or questions could activate the availability heuristic, bringing instances and reports of accidents to mind. On the other hand, personalized data could make clear what role the hazard plays in one's own geographical and social environment. Another approach was for users to enable neighborhood collaboration and show positive examples from a relevant social group. The need for simplicity could be met by creating a separate sub-tab for the nudge. Nudging aspects that participants said would be appealing were positive framing, interesting information, and elements that make interaction more fun. Since nudges aim to increase the effectiveness of the information in terms of implementing recommended actions, this was a central aspect. Suggested strategies were gamification and rewards for implemented measures, reciprocity, and social comparison, making commitments for preparedness measures, and pointing out the consequences of the hazard. Finally, trust was an important theme. In addition to the app originating from a trusted agency, participants suggested that statistics could increase trust in the importance of the information and the measures. Furthermore, participants were concerned about data collection by a state-run warning app and about nudges creating excessive pressure.

Because we want to design a preparedness feature that can be implemented in warning apps, we need to consider warning apps' design requirements as meta-requirements. While some of the requirements are specific to acute warnings, such as timeliness, others are relevant for the emergency ICT as a whole, because they influence its perception or its usability. With regard to usability, we strive for a simple design that allows for saliency, meaning the ability to easily identify critical from less relevant information and to navigate the tool effectively. In addition, because we must ensure that warnings are being taken seriously, trustworthiness is a key meta-requirement (Bonaretti and Fischer-Preßler, 2021). Therefore, we evaluate participant's comments in light of these requirements (see Table 2).

6. Step 3: preparedness nudge implementation in app prototypes

We consolidated the findings of the survey and design workshop into a web-based warning app prototype for Android called "PreWARN", which was built using Axure RP 10. By following warning app design guidelines (Tan et al., 2020) and the design workshop outcomes, we designed a persuasive preparedness alert that serves as the baseline alert for the control group. A neutral blue color scheme reflects the preventive, non-acute character of the warning. To give an overview upon opening the alert, we designed a window in the middle of the screen displaying all relevant information, including source, date, severity, and location (see Fig. 3, left). Below the window, two tabs with "Details" and "Behavior Recommendations" indicate additional available information (see Fig. 3, right). The recommendation section includes a checkbox list, links to external websites for further information about one of the recommended behaviors, and an embedded video of a state agency's YouTube channel with general preparedness information (see Appendix A3).

We implemented two types of nudges as persuasive elements, a social influence and confrontational nudge (see Fig. 4 and Appendix Table A3 for all nudges), which emerged from the survey as the preferred and appropriate ones. While participants in the design study also mentioned other persuasive elements, such as gamification, we decided on nudges because they are more in line with the usability criteria of warning apps, such as simplicity, minimalism, and minimal user input (Tan et al., 2020). Therefore, they are less likely to conflict with warning app users' expectations and they have a better chance of being adapted in the official warning apps. This is important since users strongly wish for only one warning app (Kaufhold et al., 2020). In addition to working with the space constraints in an app, the nudges should increase the motivation for all preparedness recommendations in each hazard category. The alerts in the nudging condition consisted of the improved persuasive design with an additional nudge. For both nudges, we asked users to provide estimates with a slider. To increase trust and elicit realistic estimates, we pointed out that the input of the slider was only collected anonymously.

For the implementation of the nudges, we designed a slider (see Fig. 4). Through interaction with which the slider, participants reflect about a hazard and are confronted with a gap between their estimate and the real consequences or preparedness. By then providing preparedness measures that are easy to implement, we seek to enhance self-

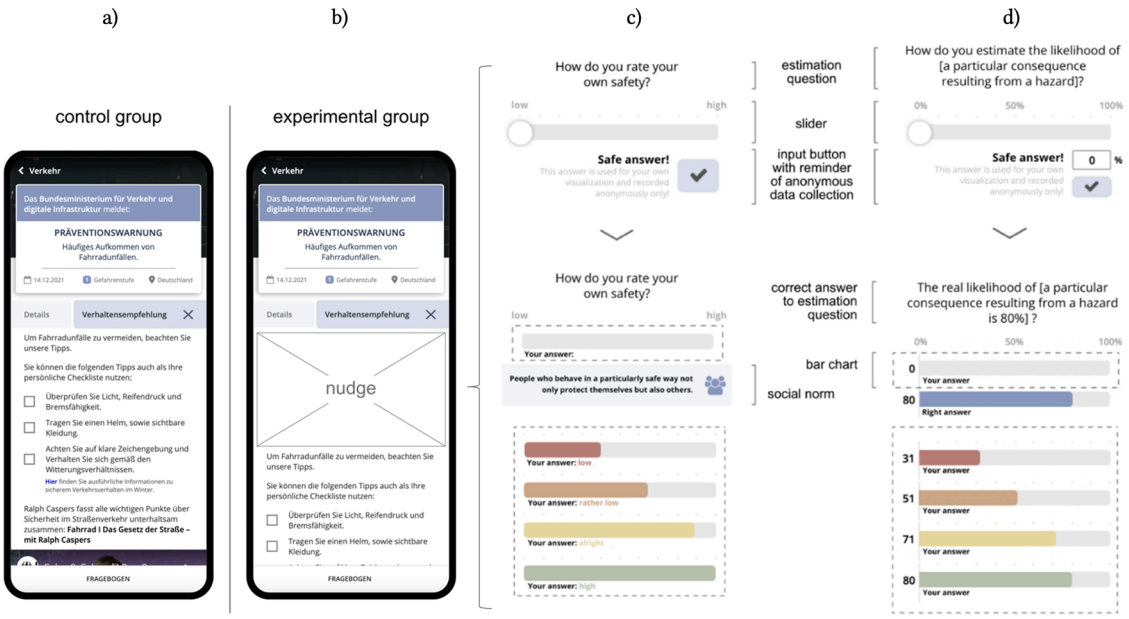

Fig. 4. Differences of the (a) control group without a nudge and (b) experimental group, including a schematic visualization of the (c) social influence nudges and (d) confrontational nudges.

efficacy and preparedness-efficacy, i.e., a sense that the participants and the measures can increase their safety and the safety of the people who are close to them.

For the *social influence nudge*, we lead users to compare themselves with a social norm (see Fig. 4, middle and Appendix A4 for the nudges). Participants assessed their own safety regarding the specific hazard from low to high on the slider, with low ratings resulting in a red and high ratings in a green bar. The classification was calculated conservatively to convey that more could still be done to be fully prepared. The result was followed by a statement about a social norm and social consequences, along the lines of: "People who behave in a particularly safe way not only protect themselves but also others". This aims to trigger a personal social norm, meaning a feeling of responsibility for the people who are close to the users. We designed the confrontational nudge in a similar way but with a wording that reminds of the negative consequences of poor prevention by asking participants to quantitatively estimate a hazard's damage or the role that personal activities play for the negative outcome with the slider. The users' answer was shown as a red bar when they underestimated the danger (see Fig. 4, right).

7. Step 4: experiment and post-study survey evaluating preparedness nudge effectiveness and user acceptance

In the final step of the nudge design process, we evaluated the effectiveness of the nudges regarding the reported intention to implement preparedness measures and the reported number of implemented preparedness measures after the study. In addition, we analyzed the interactions with the app, participants' reactions after receiving the alters and their attitudes after the one week of receiving recommendations to assess user acceptance of the nudges and the preparedness feature.

7.1. Step 4a: evaluating preparedness nudge effectiveness: a one-week experiment interacting with a preparedness app

To compare whether adding a social or a confrontational nudge to the persuasively designed preparedness alerts increases users' preparedness, we conducted an experiment with another new sample of participants. In the experiment, a control group and two nudge groups interacted with three preparedness alerts in the prototype on their own smartphones in the course of several days.

7.1.1. Experiment procedure, sample and analysis

Participants were randomly assigned to a control group (CG) without a nudging condition, or to one of two experimental groups, which get a warning with a confrontational nudge (EG Confront) or a warning with a social influence nudge (EG Social). Chi^2 tests confirmed that the randomized assignment of participants was successful, which ensures that potential group differences stem from the experimental setting instead of socio-demographic factors or personal experiences. The experiment was conducted between 10 and 17 December 2021. On day 1, participants received instructions for the installation of the prototype, followed by a welcome and silent test push notification on day 2. On day 3, they received the first preparedness notification concerning the topic of cybersecurity. Two days later, preparedness advice on traffic safety was sent, which was followed by a notification on fire prevention on day 7 (see Table A3 in the Appendix for the warnings' and push notifications' content and Fig. 1 for the timeline). On day 8, participants received instructions for deinstalling the prototype and a post-study questionnaire.

Because it is difficult to measure whether the nudges had an effect on the outcome, we used several approaches. As a measure of general interest in the issue, we tracked participants' interactions with the app, operationalized as number of interactions with the warnings and time spent interacting with the warning. These measures were tracked using Matomo (matomo.org). To capture participants' impressions of the interactions directly after the warning, we administered short post-interaction surveys after participants had interacted with each preparedness alert. These included a measure of whether the warning had been perceived as helpful, whether participants planned to implement the measures and two questions controlling for any technical issues with the prototype. Another two questions controlled for whether the hazards chosen were relevant to the users and whether they had any own previous experience with them (see Appendix Table A4 for the post-interaction questionnaire).

Due to the large number of required participants, we used convenience sampling for the study, with participants mainly originating from the student body of the universities involved. In addition, we used mailing lists and Facebook and Twitter to circulate the study invitation. Participants who did not give answers about the dependent variables had to be excluded from the analyses. The analyses are thus based on data from $N = 76$ participants, 35 females (46.1%) and 40 males

Table 3
Mean values and standard deviation for compliance intention for each hazard type (7-point Likert scale).

Experimental condition	*N*	Cybersecurity *M* (*SD*)	Traffic safety *M* (*SD*)	Fire protection *M* (*SD*)
CG no nudge	31	4.32 (1.30)	5.03 (1.33)	3.60 (1.11)
EG confront	13	5.02 (1.32)	5.42 (0.94)	3.99 (1.01)
EG social	15	4.16 (1.39)	5.06 (.87)	4.57 (1.16)

(52.6%). The participants' age ranged from 18 to 71 years ($M = 29.71$, $SD = 12.10$). 31 participants have a high school diploma or lower (41%), while 44 hold a university degree (58%). Around a third of the participants has experience using a warning app, with 22 participants currently using one (28.9%) and seven participants having used one in the past (9.2%). Another third (35.5%, 27 people) indicated that they did not use a warning app but planned to do so.

We analyzed differences between the nudging conditions (between-subject factor). Even though we could not assume normality of the model's residuals, we used a one-way ANOVA as it is relatively robust to minor violations of the normality assumption (Schminder et al., 2010). We therefore generated a QQ plot, which confirmed that deviations were only minor. When the prerequisites of normal distribution of residuals, homogeneity of the error variances or covariances were violated, we computed a robust mixed ANOVA, which is robust against violations by using location and dispersion measures (Mair and Wilcox, 2020) but can be interpreted analogously. As studies suggest that men and women react differently to loss and gain framing (Chittaro, 2016), we analyze the influence of gender, as well as of other socio-demographic factors.

7.1.2. Experiment results

No Nudging Effect on Preparedness Behavior Intention but on Reported Behaviors: Participants who were shown the confrontational nudge underestimated the likelihood of the occurrence and consequences across all emergency categories according to their slider input. Similarly, participants with the social influence nudge condition estimated their safety to be quite high across all emergency categories but somewhat lower for that of cybersecurity. Participants rated all emergency categories as rather relevant (cybersecurity $M = 4.09$, $SD = .98$; traffic safety $M = 4.39$, $SD = .59$; fire protection $M = 3.69$, $SD = 1.01$).

To examine the effect of different nudging conditions on the intention to take preventive measures across different emergency situations (see Table 3), we calculated a robust mixed ANOVA ($N = 59$, $n = 31$ CG, $n = 13$ EG confront, $n = 15$ EG social). There was neither a statistically significant interaction between the nudging conditions and the emergency categories ($F(4, 15.72) = 2.37$, $p = .096$) nor a statistically significant main effect of the between-subject factor ($F(2, 15.44) = 1.26$, $p = .310$). This means that the different nudging conditions have no effect on the compliance intention across the emergency categories.

A one-way ANOVA was conducted to determine the effects of different nudging conditions on the number of taken preparedness measures, as reported on the final day of the experiment, five (cyber), three (traffic), and one day (fire) after the alerts ($N = 72$, $n = 39$ CG, $n = 15$ EG confront, $n = 18$ EG social). That analysis showed a statistically significant effect with a medium effect size of the nudge condition on reported preparedness measures ($F(2, 69) = 3.26$, $p < .05$, $\eta^2 = .08$). Tukey post-hoc analysis revealed a significant difference ($p < .05$) in post-reported preparedness behavior between the control group ($M = 1.51$, $SD = 1.47$) and the experimental group with confrontational nudges ($M = 2.73$, $SD = . 1.22$) but no difference compared to the social influence nudges ($M = 1.56$, $SD = 1.58$). Tukey analysis was calculated with a 95% confidence interval of the difference between means from 0.03 to 2.41 points on a 0 to 12 scale. We can conclude that participants with a confrontational nudge reported significantly more implemented recommendations than participants without a nudge (see Fig. 5).

In a multiple regression, we tested exploratively whether gender, age, experiences with the warning app, experiences with the emergency category, and relevance of the emergency category predict post-study reported implemented measures, controlling for our experimental conditions no nudge and confrontational nudge. The analysis showed no statistical significance ($F(9, 44) = 1.25$, $p = .289$), which indicates that the effect is not influenced by any of these variables.

No Nudging Effect on Time Spent and Interactions with the Prototype App: We calculated a robust mixed ANOVA to examine the effect of different nudging conditions on the time spent with the preparedness alerts for the different hazards ($N = 76$, $n = 43$ CG, $n = 15$ EG Confront, $n = 18$ EG Social, see Table 4). This revealed no statistically significant effects, neither for the within-between interaction ($F(4, 14.18) = .56$, $p = .689$) nor for the main effect of the between factor ($F(2, 14.05) = .57$, $p = .578$) or the within factor ($F(2, 10.91) = 3.36$, $p = .072$).

In the same manner, we examined the effect of different nudging conditions on interactions with each preparedness alert (see Table 5). Any clicks on links or tabs are counted as an interaction. The robust mixed ANOVA showed no statistically significant interaction effect ($F(4, 14.30) = .81$, $p = .536$) or main effect of the between factor ($F(2, 14.22)$

Table 4
Mean values and standard deviation of time spent (in minutes) with each warning message.

Experimental condition	*N*	Cybersecurity *M* (*SD*)	Traffic safety *M* (*SD*)	Fire protection *M* (*SD*)
CG no nudge	43	2.23 (1.78)	2.82 (3.58)	2.58 (4.21)
EG confront	15	4.84 (6.13)	5.21 (6.69)	3.24 (3.65)
EG social	18	2.78 (2.28)	3.63 (7.30)	2.65 (4.37)

Table 5
Mean values and standard deviation of the number of interactions within the warning messages.

Experimental condition	*N*	Cybersecurity *M* (*SD*)	Traffic safety *M* (*SD*)	Fire protection *M* (*SD*)
CG no nudge	43	5.40 (2.83)	3.53 (2.42)	3.23 (2.34)
EG confront	15	5.93 (3.12)	5.27 (3.24)	4.13 (2.29)
EG social	18	4.61 (2.22)	3.94 (2.10)	4.17 3.14)

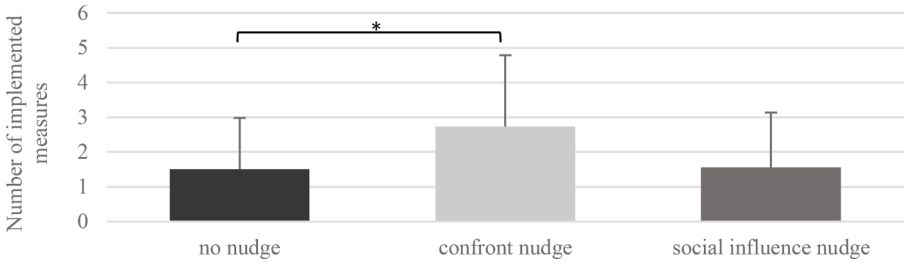

Fig. 5. Number of reported implemented preparedness measures (out of twelve measures maximum) after one week of warning app use. (M, SD, * significant group differences).

Table 6
Reflection of security behavior and app experience after the study (5-point Likert scale).

		Rethought behavior	Increased behavior	Learned something new	Felt disturbed	Motivation warning app use	Motivation prevention app use
Experimental condition	*N*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
CG no nudge	39	3.28 (1.15)	2.33 (1.25)	3.31 (1.13)	2.33 (1.20)	2.85 (1.16)	2.54 (1.27)
EG confront	14	3.43 (1.23)	2.86 (1.17)	3.71 (1.20)	2.14 (1.03)	3.20 (1.15)	3.01 (1.16)
EG social	17	3.71 (.70)	2.82 (.88)	3.35 (1.06)	1.82 (.88)	3.12 (.99)	2.53 (1.07)

= .49, p = .691), which indicates that nudging did not influence the interaction with the app.

7.2. Step 4b: post-study survey results investigating user perceptions

In the fourth phase of the nudge design process, the nudges are evaluation regarding the desired outcome. We evaluate a) the nudges' effectiveness measures by the intention to implement preparedness measures and number of self-reported implemented measures and b) users' acceptance of the nudges and the way they were implemented.

7.2.1. Post-Study survey procedure, sample and analysis

Intentions often do not predict behavior (although this is more likely for a *single action* such as a concrete preparedness measure than a for *goal*, which requires multiple actions) (Sheeran, 2002). Therefore, we also administered a survey one day after the last preparedness alert, which included questions about which of the recommended behaviors had been implemented concerning each hazard (see Table A5 for the post-study questionnaire and all percentages). In addition to the planned implementation of preparedness measures, this provided us with a measure of realized activities. The post-study questionnaire also served to reveal participants' perceptions of the preparedness feature and the nudges. Therefore, it also enquired about the feature's usability and utility, participants' evaluations of their own security behavior and a reflection about the effects of receiving preparedness alerts. Besides exploring the overall utility of the preparedness warnings, we also asked concrete questions concerning external links and push notifications, as these features, while enhancing the warnings' effectiveness, contradict warning app usability recommendations (Bonaretti and Fischer-Preßler, 2021; Tan et al., 2020). The questionnaires were administered online with SoSci Survey. Data collecting services were self-hosted, and data was stored only on university servers.

The post-study survey was conducted with the experiment participants. For the analysis of user acceptance and interaction experience, we included only those participants who had interacted with all three alters and answered the post-study survey (N = 76). Since these answers are not dependent on the experimental condition, we included all participant comments made relating to open feedback for improving the nudges and the preparedness feature.

Answers were typically on a 5-point Likert scale from "fully disagree" to "fully agree" and for behavior intentions on a 7-point Likert scale. First, we analyzed whether preventive warnings increased warning apps' utility. We use Kendall's tau-b (τ_b) as a non-parametric measure of correlations, because the Shapiro-Wilk test and the histograms show that the data are not normally distributed. Secondly, we qualitatively investigated participants' suggestions for improving the preparedness feature and the nudges. The open questions were analyzed qualitatively with thematic coding along deductively derived categories (Braun and Clarke, 2006), using MAXQDA. The categories were deduced from the Effective Use Theory for Emergency Warning Systems (Burton-Jones and Grange, 2013; Fischer-Preßler et al., 2020), allowing comparison of the requirements for preparedness alert with those for emergency warnings.

7.2.2. Post-Study survey results

Interesting New Information Increases Warning App Usage Motivation: The results show that respondents largely appreciated the preparedness advice, but did not welcome the use of silent push-notifications. This is reflected by the findings that forty-four percent of the study participants would be somewhat more motivated to use a warning app if it included preventive information, while a similar number of people (36%) disagreed (M = 3.00, SD = 1.12). This motivation significantly correlates with having learned something new through the warnings (τ_b = .29; p < .01), rethinking one's behavior (τ_b = .49; p < .01), and reporting to have implemented more measures than without the app (τ_b = .27, p < .01). However, having felt disturbed (15%, M = 2.17, SD = 1.14) is associated with being less motivated to use a warning app (τ_b = −0.34, p < .01). Interestingly, having felt pushed towards a behavior (11%, M = 2.04, SD = 1.03) has no significant effect, even though the two correlate strongly (τ_b = .42, p < .01). A third of respondents also felt motivated by the experiment to use an app dedicated to preparedness advice, whereas 52% disagreed (M = 2.65, SD = 1.21). This motivation does not correlate with any of the variables, except for the motivation to use a warning app (τ_b = .20, p < .05). Because warning app users might be more motivated to increase their safety, we tested whether current users of warning apps differed with regard to their preferences. Surprisingly, the only significant effect that we identified is that they agree *less* that preparedness information should be sent in a similar fashion as regular warnings in warning apps (τ_b = −0.24, p < .05). However, since 77% of the people who are currently using a warning app in our sample were male, this may also be due to gender differences, as women are more open to the use of push notifications (τ_b = .24, p < .05) and to the integration of preparedness information into warning apps (τ_b = .21, p < .05).

Sixty percent of participants stated that they had learned something new and the majority (61%, M = 3.48, SD = .97) agreed that they should do more for their safety and security and had started to rethink their behavior (see Table 6). Over a quarter (27%) claimed that due to the app, they had done more for their safety or security. Analyzing the group differences by using *eta* for a nominal and metric variable, we find that hardly any variation in this question can be attributed to the experimental groups, meaning that the nudging warnings were perceived similarly as the plain warnings. The nudging conditions had no significant effect on these evaluations. Despite these positive evaluations of the preparedness information, the results confirm that integrating preparedness prompts into warning apps is a challenge: While 87% of the respondents would welcome the preparedness information in a menu item in a warning app, a majority (57%) disapproved of the use of silent push notification for the warnings. However, 35% were open to these preparedness prompts in warning apps. When specifying that these push notifications would have fewer permissions than acute warning alerts (e.g., a less forceful tone), agreement rose to 64% (29% opposed, M = 3.47, SD = 1.26).

Since ethical nudges require including information to target reflection, and since increasing trust requires adding sources to this information, we included external links with further information, which should usually be minimized in warning apps (Tan et al., 2020). A great majority (80%) found the extent of external links acceptable (M = 3.00, SD = .49), which supports the initial argument that preparedness alerts have different usability requirements than acute warnings and thus merit separate design interventions.

Table 7
Most frequently mentioned topics (% of all respondents) for increasing the motivation of preparedness notifications and nudges, based on Effective Use Theory for Emergency Warning Systems (Burton-Jones and Grange, 2013; Fischer-Preßler et al., 2020) (left and middle columns).

Situational Awareness	**Promptness** (immediate actions)	Simplicity of proposed measures/increasing difficulty (11%)
	Actionability (coping countermeasures)	More tips and measures for preventing hazards (12%)
		(Links to) recommended programs, links to relevant settings (for cyber fraud) (6%)
		Providing checklists (10%)
Transparent interaction	**Activation** (alert)	No notification, but included in a separate menu item (22%)
		(Optional) push notifications (5%)
		Reminder (in combination with checklist) (5%)
	Saliency (severity and type)	Brief information (11%)
		Examples and indicators (for cyber fraud) (8%)
	Usability (easy interaction)	(Not) including graphics, images, or videos (8%)
		Should not require a separate app (6%)
Representational Fidelity	**Relevance** (matters to user)	Preventive warnings irrelevant or not requiring an app (10%)
		Different channel (news, local information, web app, social media) (7%)
		Personalization (personally relevant topics, locations) (6%)
		More informative content (5%)
	Trust (reliability)	Providing statistics (8%)
	Exactitude (correct, precise)	*Not mentioned*
	Consistency (with other channels)	*Not mentioned*
	Currency (up-to-date)	*Not mentioned*

Participants' Suggestions for Improvement: To look at where the requirements are similar or differ and at how preparedness alerts and nudging could be designed to increase users' personal motivation to implement the recommendations, we asked participants to describe how the messages might be improved to be more motivating. Participants mentioned some aspects similar to those relevant for warning systems (see Table 7). Most comments concerned ideas for improving the ability to take prompt and actionable measures, e.g., by suggesting simple measures and measures increasing in difficulty, or by providing checklists. Another dimension concerns transparent interaction, which includes adequate alerts, which for many participants means no or only optional push notifications.

Many also mentioned that the message should be brief and allow to judge the severity. Another main aspect concerned representational fidelity, which indicates that those users were unconvinced that the hazards represented a cause for warnings. Some said they generally were not interested in warnings and in using a warning app. Others found that different channels were more adequate. Suggestions for increasing the relevance of preventive alerts included personalization and generally more informative information. Statistics were mentioned both to prove the relevance of a hazard, as well as to increase trust in the suggested measures.

8. Discussion

In the following, we discuss the results with regard to user preferences and the effectiveness of nudging towards hazard preparedness and with regard to user acceptance of nudging and preparedness feature in warning apps. We further discuss implications for design, the limitations of the study and future work.

8.1. Informing the design of persuasive preparedness nudges

We assessed two different nudge framings that both used a slider to engage users and made them reflect on their own preparedness. The experiment shows that the confrontational nudges, which confront users with the negative consequences of a hazards and their contribution to it (and thus, in reverse, also their own role in decreasing the chances of a negative outcome), had a small significant effect on increasing preparedness. This is in line with another experimental study that investigated nudging to increase flood preparedness in homeowners (Mol et al., 2021). This study found that nudges would be effective, if they influence factors that are related to positive investments. These include the absence of bias that favors immediate benefits that incur higher later costs, response efficacy and expected effects of a hazard. Due to the limited number of experimental groups that we could explore with our sample size, we were unable to further differentiate these effects and nudges in this study, which should be done in future studies.

The social nudge that made users reflect on their own preparedness and its consequences for family, friends and neighbors, and then triggered a personal norm, i. e., a moral obligation to those close to the user, did not have a significant effect. While other social nudges were also ineffective in the previous flood preparedness study (Mol et al., 2021), that study found personal norms to be relevant for preparedness. We therefore sought to trigger such a personal norm in the way we designed our social nudge, by appealing to the general responsibility that one has for one's social environment in the message that followed the slider interaction. However, it is possible that because it was not interactive, that personal norm message had less weight for the users than the slider interaction, in which users compared their preparedness to that of others. While previous studies suggest that under specific circumstances, men and women are differently affected by loss- and gain-framed nudges (Chittaro, 2016), we did not identify any gender differences with regard to the effectiveness of the nudges.

In addition to the effectiveness of the nudge, another relevant aspect is user acceptance. With regard to the social nudge, we find a gap between what participants suggested would be a motivating nudge and a lack of effect of the social nudge. Such a perception-effectiveness gap has also been identified in previous studies (Dai et al., 2021) and might thus support the need for pilot-testing nudges instead of relying on user prediction of their effectiveness. The confrontational nudge, which included a positive wording by emphasizing the low costs of an easy measures, as compared to the large costs of a house fire, was also perceived as highly appropriate and motivating in the survey. Particularly the emotional nudges, which presented a personal quote of a victim and a picture of a burning building, were perceived as less motivating and acceptable. This is in line with previous research that shows reflective nudges to be more acceptable than less transparent ones (Reisch and Sunstein, 2016).

The representative survey and the design workshops generated first insights for how to design persuasive preparedness messages. These are in some regards similar, in others different from the persuasive elements that are proposed by Kotthaus et al. (2016) in the only other study of persuasive elements for warning apps. That study used online reviews by warning app users to deduce relevant persuasive elements for warning apps, based on the ones suggested by Oinas-Kukkonen and Harjumaa (2009). They identified the persuasive strategies *reduction, tailoring, personalization, liking* and *trustworthiness*. The evaluation also suggested that rather than reducing content, users wanted more interesting information, likely because they already had basic knowledge about the

general hazards. Instead of reduction, our design workshops rather pointed towards simplicity for persuasive preparedness warnings. In the implementation, simplicity was achieved by implementing different tabs that offer details and behavioral recommendations, and by using nudges as a simple design element instead of, e.g., gamification or more complex social facilitation elements. While the previous study suggested that tailoring and personalization may be good persuasive strategies, the survey, in line with previous research (Tan et al., 2018), shows that not everybody is willing to share information. The representative survey suggests that participants generally, and older people and women in particular, are not very open to sharing information in order to receive personalized preparedness advice or personalized nudges. However, the results also suggest that it is feasible to differentiate between people who are currently using a warning app and those who are not (Fischer et al., 2019). While the effect is small, we find that warning app users are significantly more open to sharing such information for personalization.

In the design workshops, participants expressed privacy concern about entering information while interacting with the nudges. Integrating personalization or user input should thus be done with caution and without or only with anonymous data collection and making this evident to users. Appeal (i.e. *liking*) is also identified by Kotthaus et al. (2016) and is achieved through a positive framing of the suggested safety measures in the social nudge. Interesting information, especially in the form of statistics, were mentioned as increasing appeal. Trust was also found to influence the persuasiveness (Kotthaus et al., 2016), while mistrust regards the collection of data about users' behavior, further stressing the importance of data privacy.

In addition to creating a message that is persuasive, our design study participants suggested that social influence, commitment, and confrontation with negative consequences can increase the effectiveness of the preparedness alerts. In line with this, we used checkboxes, social comparison, and a confrontation with the causes and consequences of the hazards. Gamification elements were also suggested but engaging gamification elements conflicts with other requirements, such as little user input, privacy concerns, and simplicity (Chittaro and Buttussi, 2019). While many participants opposed the use of push-notifications as prompts, others suggested occasional optional reminders to remind of the checklists and their completion. Overall, the evaluation indicates that preparedness information should be implemented as a menu and any further emphasis of preventive measures should be an optional feature. Future work should consider alternatives to push notifications as triggers and reminders of preparedness measures. Statistics were deemed helpful, possibly because they increase trust and perceived relevance, which may explain the confrontational nudge's success. While the information's source was not questioned, the mentioning of statistics may point towards a mistrust in the relevance of the hazards, which needs to be further proven to the users. Statements from our participants implied that the assessment of relevance depends on their perception of risk. Many participants considered their own preparedness behavior to be sufficient and therefore did not see themselves as at risk. However, the survey participants perceived other people as more endangered than themselves, which corroborates the optimistic bias and systematic underestimation of own risks (Weinstein, 1980). This underlines our initial argument that overcoming barriers to taking preparedness measures can be an important aspect of warning apps (Fischer et al., 2019).

The fact that users routinely underestimate the risk and damage of hazards leads to users' evaluation that preparedness advice reduces salience and thus makes it more difficult to identify acute warnings. This poses the challenge that, to be interacted with, the messages need to immediately establish the relevance of the general hazard to users, while also being immediately differentiated from acute warnings. Whereas push notifications suggest unwarranted urgency, a neutral color scheme and the inclusion of the preparedness alerts in a separate optional menu can be used to differentiate preventive content. On the other hand, participants particularly suggested that general hazards could be made relevant through statistics. This further supports the relevance of hybrid nudges, which combine the persuasive element with information and thus target reflective reasoning while making use of automated cognitive processes (Renaud and Zimmermann, 2018). Due to their transparency, they are deemed an ethical type of nudge (Renaud and Zimmermann, 2018), and due to their high informational content, they fit well with warning apps. Similarly, providing sources for the information that the nudge uses (e.g., the risk, the effect on others) increases trust and is important both for the nudged preventive content and regular warnings (Meyer, 2006).

While we opted for a simple design that could be seamlessly integrated into existing warning apps, other types of persuasive elements are possible and were mentioned by users in this study, including gamification elements and scenarios. Indeed, one study has shown that the use of emotional scenarios in Virtual Reality triggers an attitudinal change in risk evaluation (Chittaro and Zangrando, 2010). However, the most effective strategy also increased users' anxiety (Chittaro and Zangrando, 2010). This is a strong reminder that when it comes to safety and security, precaution is not everything. Instead, other factors like anxiety and trust in reliable warning apps need to be considered when planning the inclusion of preparedness measures and persuasive elements.

8.2. Acceptance of paredness features in warning apps

The second aspect that this study addresses is the question whether persuasive preparedness information should be integrated into warning apps. The evaluation indicated that while preparedness information makes warning apps more attractive, particularly for those who state they learned something new, those who felt disturbed by the warnings were deterred from using a warning app. This can be explained by Effective Use Theory and its element *representational fidelity*, which is "the extent to which notifications provide users with faithful representations of an emergency" (Bonaretti and Fischer-Preßler, 2021). One element of that dimension is *relevance,* which appears to be violated by notifications about non-immediate threats (Bonaretti and Fischer-Preßler, 2021). The analysis of users' comments about how to improve the preventive warnings and nudging elements revealed that compared with the criteria for warning systems, some aspects, particularly exactitude, consistency, and currency, appear less relevant. By contrast, major issues consist in proving the relevance of preparedness measures and finding an appropriate activation method to trigger the reflection of preparedness. While the use of push notifications was criticized, as preparedness information is often perceived as not warranting alerts, a majority would be open to occasional notifications. Agencies seeking to increase awareness and emergency preparation could consider occasional or seasonal notifications, or a themed month for preparedness measures. These should be easy to opt out of. Many users also appeared open to creating self-commitment through checklists and occasional reminders.

The fact that relevance of preventive alerts appears to be contested may to some extend be explained by the German state-centric risk culture (Cornia et al., 2016). Since people who use a warning app are interested in improving their safety and intend to follow the app's recommendations (Fischer et al., 2019), it could be argued that nudging could be a good avenue for overcoming aspects of risk culture that increase the risk of emergencies. The evaluation indicates that providing

interesting new information is the factor that most strongly correlates with participants rethinking their behavior and also being open towards receiving prompts, such as push-notifications and using a separate preparedness app. In general, however, participants rather wanted the preparedness information to be included as a menu item, that needs to be proactively sought out. To some degree, this is already offered by some warning apps (Hauri et al., 2022). Most did not prefer a separate app dedicated to preparedness, which is in line with previous findings that integration in one app is a major user demand (Dallo and Marti, 2021; Kaufhold et al., 2020).

Nudges and warnings can also lead to reactance (Dillard et al., 2021; Lukoff et al., 2022). We find that this might be the case in a subset of participants. While we cannot determine any causal relations, those who felt more disturbed by the preparedness warnings supported the use of push-notifications less, thought less that they should do more for their safety and had not started to rethink their preparedness behavior. However, we did not find a connection between having felt disturbed by the notifications and a reduction of implemented preparedness measures. In addition, the nudges, as chosen in this study, did not lead to a feeling of having been pushed towards a behavior, and even that feeling did not decrease the self-reported motivation to use a warning app. These findings encourage further exploration of preparedness messages in warning apps, because even when the messages are perceived as unhelpful, they do not lead to a reduction of preparedness activities.

8.3. Limitations and future work

While this study's insights offer important first insights into exploring persuasive preparedness measures and their integration into warning apps, it is subject to several limitations. Because we could only compare participants who had engaged with all scenarios and answered all questionnaires for the scenarios, the individual groups were relatively small. To avoid even smaller groups, we could not further differentiate the nudges into more fine-grained categories. As a result, we cannot determine which aspects in the confrontational nudges are the ones that had the biggest impact on users. For future research, we suggest that the confrontational nudges we used are further differentiated and tested. At the same time, such a study should measure the effect of the nudges on other aspects that have been found to increase preparedness, such as response efficacy and the immediate gratification bias (Mol et al., 2021). As the study indicates that the inclusion of non-imminent warnings can have positive effects on preparedness and largely does not demotivate the use of warning apps, further and larger studies are feasible and could be done without jeopardizing the perception of warning apps.

With regard to the social nudge, we identified a divergence between participants' prediction of the effectiveness and the true effectiveness of the nudge. While such a divergence has also been found in other studies (Dai et al., 2021), it could be due to the particular design and wording of the nudge as implemented in this study. By asking participants to rate their own safety, our participants on average reported a relatively high state of safety for the various emergency categories. This may have reinforced the optimistic bias, potentially mitigating the effect that the social reminder would otherwise have had (Rahn et al., 2020). This would be in line with research that shows that people who (falsely) feel that they perform better than average when it comes to ecological behaviors, also feel less threatened by climate change (Leviston and Uren, 2020). Since participants in the survey and design workshops emphasized that social influence would have a greater effect on them, other designs of social influence nudges should be explored. While we included an appeal to a personal norm with regard to taking responsibility vis-à-vis one's family, friends and neighbors, the text-based nudge might have been too weak in comparison to the slider interaction. Future social nudges might thus be designed to more strongly target reflection of why preparedness helps others (Knowles et al., 2014). The representative study suggests that positive wording might be preferred to loss-focused frames. Since we focused on testing nudges in the wild and on designing an appropriate tool, future research should also focus more on varying the wording in the text-based nudges, e.g. by testing more nudges in a survey with regard to their acceptability.

Another limitation might result from the measurement of the dependent variable, the implemented preventive actions, which was based on participants' expressed plan to implement actions directly after interacting with the nudges, their own statement about whether or not they had implemented more measures than they would otherwise have done, and a check of whether they had implemented a list of measures in the post-study survey. While this adds a measure of (self-reported) implemented measures to the planned measures, participants may overstate the number of implemented measures to meet perceived expectations. This effect may be stronger in participants who have been nudged, because they have been presented with further reasons and norms. Even though we asked respondents to report about specific measures, likely increasing the reliability of the answers, the study was unable to verify participants real activities. In addition, the questionnaire was administered only one day after the survey, which gave participants little time to implement some of the measures. However, the measures were designed to be able to be implemented quickly and it can also be assumed that the likelihood of participants implementing measures in reaction to the preparedness advice decreases as time passes.

While we involved participants in the design of the preparedness warnings and in the choice and design of the nudges, we chose the safety and security scenarios top-down. Instead, users might already have identified preparedness measures that they have been putting off. Another option would be to further involve emergency managers in the choice of recommendations that are most relevant from their perspective. In addition, while it made the nudges more acceptable to users, participants may not have chosen the most effective nudges. In a previous study, participants overestimated the effect of an informational video and underestimated the effect of a text-based commitment nudge (Dai et al., 2021), possibly believing themselves to be less prone to the effect of less transparent System 1 nudges than to reflective System 2 nudges.

In addition, future work could explore further persuasive design mechanisms. To do justice to the wish for integration into one app and to thus facilitate the integration of persuasive preparedness alerts into mainstream warning apps, we only considered persuasive elements that fit to the user requirements for warning apps (Tan et al., 2020). However, other persuasive elements to increase preparedness, such as gamification, are feasible and may be adequately included in other apps, such as motivational apps or news apps, which could benefit from insights of this study concerning the design and nudging effects. In addition, optional reminders were mentioned that could serve as additional triggers of the planned measures. Along with checklists, which were also mentioned, they can serve to increase users' commitment (Münscher et al., 2016). In addition, rather than activating individual preparedness as a value in a top-down manner, future research could explore the effect of users' reflecting on the *reasons* for improving individual preparedness (Knowles et al., 2014; Maio et al., 2001). For example, asking users who perceive that they are overusing their smartphones to write down a more valuable way of spending their time has been found to decrease screen time (Xu et al., 2022).

Despite these limitations, the study succeeds in exploring warning apps as a new technology in which nudging might be feasible. It shows that preparedness alerts increase warning app users' knowledge about

general hazards, that a confrontational nudge can moderately increase users' general preparedness, and that users are open towards receiving preparedness alerts as an optional feature, thereby increasing warning apps' utility.

9. Conclusion

In this study, we have investigated whether and how warning apps can be used to motivate users to preventively prepare for emergencies. Based on insights from a representative survey and design workshops, persuasive preparedness warnings and warning app prototypes with a confrontational and social influence nudge were developed. The prototypes were employed for a one-week experiment, during which participants were sent three preparedness alerts. The control group received the persuasively designed message, while two groups received either a confrontational nudge or a social influence nudge in addition to the persuasively designed message.

The study shows that while both confrontational and social nudges are deemed motivating and appropriate, only the confrontational nudge significantly increases the compliance with preparedness advice. The nudges did not affect the perception of the warnings, the interaction with the app, the intention to increase preparedness behavior, or the motivation to use a warning app, thus encouraging further exploration of nudging in this context. However, the qualitative analysis of users' perceptions indicates that while users want preparedness information to be integrated in warning apps, non-acute notifications appear to reduce the representational fidelity of warning apps. The motivation to use a warning app positively correlated with the perception of having learned something new and negatively correlated with having felt disturbed by the preparedness alerts. This indicates that interesting non-acute information can increase warning apps' utility, while over-use of alerts that are perceived as unimportant could lead users to abandon warning apps.

Concerning how persuasive prevention messages should be designed, positively framed rational-confrontational and social responsibility nudges were preferred to other nudges. Ensuing workshops, which explored how the ICT for preventive advice and the nudes should be designed in order to be perceived as persuasive, indicated that *relevance, simplicity, appeal, effectiveness,* and *trust* are relevant themes. The evaluation indicates that similar to warning messages generally, trust can be enhanced by pointing out the sources of the information. In addition, statistics can be used to underline relevance while increasing trust. The study indicates that particularly checklists and reminders should be explored as persuasive elements in future studies. The high acceptance of nudging both in the representative survey and the experiment, and fact that many participants indicated that they learned something new and have begun reevaluating their preparedness encourages further exploration of preparedness nudging in warning apps.

CRediT authorship contribution statement

Jasmin Haunschild: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Data curation, Visualization. **Selina Pauli:** Conceptualization, Methodology, Data curation, Writing – original draft, Visualization. **Christian Reuter:** Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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A. APPENDICES

A.1. Questionnaire following the app interactions

Table A1
Questions and items of the representative pre-study survey questionnaire.

Prevention and Warning Apps: In the following, we would like to know more about your attitude towards using an emergency information and warning app to avoid danger. [5-point Likert Scale *fully disagree (1) - fully agree (5)*].

- Q1: I think that by taking my own precautionary measures (such as buying a fire extinguisher, securing garden furniture or similar) I can reduce dangers to myself, my property, or my family.
- Q2: I feel sufficiently informed about precautionary measures against crises and emergencies such as natural disasters, burglaries, or attacks.
- Q3: Information on how to avoid crises and emergencies should be included in a good emergency information and warning app.
- Q4: Information on precautionary measures, for example on water conservation and water storage due to possible droughts, should be sent to the smartphone as an unprompted push message.
- Q5: Information on precautionary measures should be sent along with imminent warnings, for example stockpiling of food along with a warning of a storm or flooding.
- Q6: Information on preparedness measures should be available under a menu item, e.g. "Prevention/How can I prepare myself?", without the necessity of a separate notification.
- Q7: Information on precautionary measures should rather not be disseminated primarily via an information and warning app for emergencies but via other channels.

Appropriateness and Motivation of Nudging towards Prevention: Imagine you are advised in an information or warning app to take the following precautionary measure to prevent a fire: "Buy a fire extinguisher and keep it easily accessible. By using a fire extinguisher, the source of a fire can be extinguished before the fire spreads." – Please judge whether the following added message is (a) appropriate and (b) motivating [5-point Likert Scale from *not at all (1) - very (5)*].

- A high-quality fire extinguisher costs less than €50. In 2019, a house fire caused an average building damage of 6639€ and a household damage of 2159€. (Source: GDV)
- [P*icture of a three-story house with balconies in flames*]
- In 2018, an average of one person died per day in Germany due to smoke, fire, or flames. (https://www.feuerwehrverband.de/presse/statistik/)
- "You just don't realize that this has happened to you. That the house is gone, from one day to the next."
- In 2020, 20% of all fires that caused significant damage in and to buildings were caused by human error. (Source: IFS)
- When you buy a fire extinguisher, you protect your family and neighbors in case of fire. Responsible tenants and owners have a fire extinguisher.

[Of the above,] please select the message you find best in the context of a prevention warning app. You can only select one option.
Please explain why. [Open text field]

A.2. Structure of the design workshop sessions

Table A2
Structure of the workshop session.

- Opening: What Experiences have you already made with warning apps?
- Introduction of non-interactive mock-up: Imagine this was a warning app on your smartphone… [four screens]
- Introduction and choice of a warning hazard [cybersecurity, traffic safety, fire protection]: Which scenario would you prefer to discuss?
- Discussion of the design of a warning message for the chosen hazard: How would a persuasive warning message look like including the content of the chosen warning hazard?
- Discussion of a Social Influence Nudge according to the Nudge Desk and its dimensions (social comparison, responsibility, reciprocity, visibility of actions): How would a social influence nudge look, which could be included in the warning message we just designed and motivating for the behavioral recommendations of this warning?
- Discussion of a Confrontational Nudge according to the Nudge Desk and its dimensions (different standpoints, reminding of consequences, suppression of digressing): What would a confrontational nudge look which is included in the warning message we just designed and motivating for the behavioral recommendations of this warning?
- Discussion of the final designs and push notifications: What are additional important aspects concerning the designed preparedness alerts in the warning app mock-up? How should a push notification look like that alerts to the warning message?

A.3. Warning messages sent to participants during the experimental study

Table A3
Warning messages sent to participants during the experimental study (Translated from German).

WM 1: Cybersecurity

Push notification:
A new warning! There is a security notice for cybersecurity: Increased cyberattacks on smartphones.

Tab Detailed information*:*
In the period leading up to Christmas, many people expect parcels from online stores. Cyber criminals take advantage of this! They send links via SMS in which, for example, the arrival of a package is falsely announced. Such links hide malware that cyber criminals want to smuggle onto your smartphone. Malware can get onto your smartphone in various ways. Hidden apps in particular prove to be very dangerous. If such apps remain undetected, they can not only steal user data, but also render the smartphone unusable. Therefore, be extra vigilant. Check private information only on official websites, for example, of your parcel service provider and delete a suspicious SMS as soon as you receive one.

Tab Behavior recommendations:
Nudge (only experimental groups):
Confrontational nudge:
Screen 1: Personal behavior enables cyber attacks. In how many percent of cases do you think this is true.
Screen 2: In 95% of cases, cyber attacks succeed only through a mistake of the victim.
Social influence nudge:
Screen 1: How do you judge the security of your smartphone?
Screen 2: People whose smartphone is secure, don't only protect their own data, but also that of their contacts.
Below, simple tips are listed on how you can protect your smartphone before a cyber attack happen.
You can also use the following tips as your personal checklist:
☐ Download a suitable antivirus app.
E.g., the free apps from Avira, McAfee, BullGuard, Panda Dome or Kaspersky.
☐ Set up a third-party lock for yourself.
Here [external link: https://praxistipps.chip.de/drittanbietersperre-einrichten-anleitung-fuer-alle-mobilfunkanbieter_29732] you can find information on how to set up a third-party block.
☐ Update software regularly.
Learn why software updates are important on all digital devices here: Security updates | BSI [embedded YouTube video: https://www.youtube.com/watch?v=2AbOiCkbKiM&t=1s]

WM 2: Traffic Safety

Push notification:
A new warning! There is a safety notice for traffic safety: Frequent occurrence of bicycle accidents.

Tab Detailed information:
The trend towards cycling has been on the rise for several years now. Due to the COVID-19 pandemic, the use of bicycles in Germany has increased even more. Although the German Federal Ministry of Transport Safety and Digital Infrastructure advocates the use of bicycles, the number of accidents involving cyclists is also increasing with the growing bicycle traffic. Particularly the weather conditions and the early onset of darkness in winter pose a threat to the safety of cyclists. Nevertheless, you should not have to give up your bike even on cold days. Attention on the roads is especially important in winter. This applies to all road users! If you witness a traffic accident, contact the emergency services immediately and provide first aid.

Tab Behavior recommendations:
Nudge (only experimental groups):
Confrontational nudge:
Screen 1: Often, cycling accidents are caused by cars. But in how many percent of cases do you think cyclists cause the accident?
Screen 2: Cyclists, who are involved in an accident in which persons are hurt, are responsible in 45% of cases.
Social influence nudge:
Screen 1: How safe do you feel when you are cycling?
Screen 2: People who take care of their own traffic safety don't only protect themselves but also other road participants.
To avoid bicycle accidents, follow our tips. You can also use the following tips as your personal checklist:
☐ Check lights, tire pressure and braking ability.
☐ Wear a helmet and visible clothing.
☐ Pay attention to clear hand signals and behave according to the weather conditions.
Here [external link: https://www.bussgeld-info.de/ebook-fahrrad-im-winter.pdf] you will find detailed information on safe traffic behavior in winter.

(*continued on next page*)

Table A3 (*continued*)

Ralph Caspers summarizes all important points about road safety in an entertaining way: Bicycle I The Law of the Road - with Ralph Caspers [embedded YouTube video: https://www.youtube.com/watch?v=p5HPe27GqSY&t=37s]

WM3: Fire Protection

Push notification:

A new warning! There is a safety notice for fire protection: Frequent fire occurrence in private households.

Tab Detailed information:

Candles create a cozy and Christmassy atmosphere in winter. But every year the local fire department operations pile up in the period of Christmas, also this year. Frequent cause for the increased fire employments are carelessness and improper handling of candles or open fireplaces. Especially when several candles are placed at a close distance from each other or in the immediate vicinity of easily flammable material, such as Christmas decorations, they become major sources of fire. Nevertheless, you do not have to give up the use of candles. By being mindful with fire, you can easily avoid fire outbreaks. Never leave open light such as candles or fire unattended and place candles at a safe distance from other fireplaces or easily flammable material!

Tab Behavior recommendations:

Nudge (only experimental groups):

Confrontational nudge:

Screen 1: What do you guess: How expensive is the damage after a house fire on average.

Screen 2: The average damage after a house fire is 8789€. A good fire extinguisher costs less than 50€.

Social influence nudge:

Screen 1: How well protected is your home against a house fire?

Screen 2: People who prepare their house against a fire, protect their family and neighbors in case of a fire.

Our tips are easy to implement and show great effect to protect your home from fires.

You can also use the following tips as your personal checklist:

☐ Get a fire extinguisher and have it serviced regularly.

Here [external link: https://brandschutz-zentrale.de/wissen/einsatz/loeschen-aber-richtig/] you will find information on the correct operation of fire extinguishers.

☐ Remove easily combustible material from attics, basements, or hallways.

☐ Important documents and papers should be packed in a quick carry bag.

As original or certified copies: Family certificate, savings accounts and other securities, pension and income statements, certificates of qualification, contracts, living wills, and powers of attorney.

As a simple copy: identity card, extract from the land register, notices of change, proof of payment for insurance, proof of registration, bills, membership, or contribution books.

Here is more information about common causes of fire and how to prevent them: Fire - How to protect buildings from it [embedded YouTube video: https://www.youtube.com/watch?v=CHC3TByMxO4&t=5s]

A.4. Questionnaire of the experimental study

Table A4

Survey questionnaire of the experimental study.

Did you receive this warning as a push notification to your smartphone? [*Yes; No*]

Have there been any issues with the app's display or functionality so far that have interfered with your interaction with the alert? [*No; Yes, namely…*]

How do you perceive the warning's information [5-point scale *very helpful – very superfluous*]

What would make the warning more helpful to you? [Open question]

How much do you agree with the following statements? Please answer the questions according to how you feel at the moment. There are no right or wrong answers. [7-point Likert Scale *fully agree - fully disagree*]

Only for the topic cybersecurity:

- I will probably set up a third-party lock on my smartphone.
- I am sure that I will set up a third-party lock on my smartphone.
- I will probably download an appropriate antivirus app to my smartphone.
- I am sure that I will download an appropriate antivirus app to my smartphone.
- I will probably install a software update on my smartphone.
- I am sure that I will install a software update on my smartphone.

Only for the topic traffic safety:

- I will probably wear a helmet, as well as visible clothing, when riding my bike.
- I am sure that I will wear a helmet, as well as visible clothing, when riding my bike.
- I will probably check my bike's lights, tire pressure, and brake capacity.
- I am sure that I will check my bike's lights, tire pressure, and brake capacity.
- I will probably pay attention to use clear hand signals when riding a bike and to adapt my behavior to the respective weather conditions.
- I am sure that I will pay attention to use clear hand signals when riding a bike and to adapt my behavior to the respective weather conditions.

Only for the topic fire protection:

- I will probably buy a fire extinguisher and maintain it regularly.
- I am sure that I will buy a fire extinguisher and maintain it regularly.
- I will probably remove highly combustible material from attics, cellars, or hallways.
- I am sure that I will remove highly combustible material from attics, cellars, or hallways.
- I will probably pack important documents and papers in a bag to quickly take them with me.
- I am sure that I will pack important documents and papers in a bag to quickly take them with me.

Have you or someone close to you (e.g., family or friends) ever experienced a cyber attack/a bike accident/a home fire? [*Yes, me myself; Yes, someone close to me; No*]

How relevant is the topic of cybersecurity/traffic safety/fire protection for you? [*Very relevant - not relevant at all*]

A.5. Questionnaire of the post-study survey

Table A5
Questions and items of the post-study survey questionnaire.

	Fully disagree (1)				*Fully agree (5)*
Q1 Security Behavior: How would you describe your overall security and safety behavior?					
• I think I should actually do more for my own safety/security.	1%	20%	18%	51%	10%
• One shouldn't let safety/security considerations drive oneself crazy.	1%	7%	14%	52%	25%
• In the area of cybersecurity, I have already taken sufficient precautions before the notice in the app.	7%	30%	11%	41%	11%
• In the area of fire protection…	3%	38%	27%	31%	1%
• In the area of traffic safety…	0%	16%	13%	53%	18%
Q2 Agreement with App Usability Statements:					
• Typically, warning apps like NINA or KATWARN only send push notifications when it comes to acute warnings. I would find it appropriate to receive the preparedness alerts sent during the study in a warning app as a push notification?	13%	44%	9%	24%	11%
• Let's assume that you did not receive the sent notices as a push notification: I would find it helpful to be able to view the information sent during the study in a menu item (e.g., "Precautionary Measures Against Hazards") in a warning app.	0%	10%	3%	41%	46%
Q3 Agreement with App Utility Statements: There are different ways in which preparedness information, such as you have received over the past week, could be transmitted. In the following, we are interested in your preferences.					
• Preparedness notifications should be sent as push notifications via warning apps such as NINA or KATWARN, just like current warnings.	27%	40%	7%	17%	10%
• Preparedness notifications should be sent as occasional push notifications, but with fewer permissions than acute alerts (e.g., less forceful tone).	9%	20%	7%	44%	20%
• Preparedness warnings should be sent via special prevention apps, but not via warning apps such as NINA or KATWARN.	11%	36%	20%	24%	9%
• Integrating such preparedness notifications would motivate me to use a warning app.	11%	25%	20%	41%	3%
• I would be motivated to use a prevention app that does not send acute warnings but encourages the implementation of safety recommendations or precautionary measures.	20%	32%	16%	28%	4%
Q4 External Content: How do you rate the linking to further information within the preparedness hints you received during the study? (*too little additional - too much information*)	1%	7%	80%	11%	2%
Q5 Reflection: Due to the notifications I …					
• have learned something new.	6%	21%	11%	40%	11%
• have started thinking more intensively about my safety/security.	7%	14%	17%	52%	9%
• did more for my own security than I would have done without the messages.	19%	39%	16%	23%	4%
• felt too much pushed towards a behavior.	36%	37%	16%	10%	1%
• felt disturbed.	33%	37%	14%	11%	4%
Q6 Measures: Since I received the warning, I have been preparing for…	*yes*				*no*
… a cyber attack by...					
• downloading an antivirus app on my smartphone.	7%				93%
• setting up a third-party lock on my smartphone.	13%				87%
• updating software on my smartphone.	30%				70%
• doing something else, and that was [open text].	10%				90%
… cycling by…					
• paying attention to clear signaling and adapting my behavior to the respective weather conditions.	31%				69%
• checking lights, tire pressure, and brakes on my bike.	26%				74%
• wearing a helmet and visible clothing.	17%				83%
• doing something else, and that was [open text].	11%				89%
… a fire by…					
• packing important documents and papers for quick access.	12%				88%
• getting a fire extinguisher or serviced it.	7%				93%
• removing easily combustible material from attics, basements, or hallways.	6%				94%
• doing something else, and that was [open text].	6%				94%
Q7 App Improvement: We all probably sometimes have difficulties in taking measures that we actually find important and sensible to increase our safety or to take precautions. What should an app look like and how could app messages be designed so that they would motivate you to take meaningful precautionary measures? [open text]					

A.6. Results of the Kendall tau-b analysis of the post-study survey

Table A6
Report of post-study survey correlations (**. Correlation is significant at the 0.01 level (2-tailed), *. ... at the 0.05 level (2-tailed), $N = 67–75$ for each test).

		G	WA	Q1.1	Q1.2	Q1.3	Q1.4	Q1.5	Q2.1	Q2.2	Q4	Q3.1	Q3.2	Q3.3	Q3.4	Q3.5	Q5.1	Q5.2	Q5.3	Q5.4	Q5.5
G: Gender = female (binary)	Corr. coeff.	1																			
	Sig.																				
WA: Current warning app users (binary)	Corr. coeff.	-,309**	1																		
	Sig.	0,008																			
Q1.1: I think I should actually do more for my own safety/security.	Corr. coeff.	,275*	−0,028	1																	
	Sig.	0,013	0,801																		
Q1.2: One should not let safety/*sec* considerations drive one crazy	Corr. coeff.	−0,117	−0,036	−0,005	1																
	Sig.	0,293	0,747	0,962																	
Q1.3: In the area of cybersecurity, I had taken suffic. precautions […]	Corr. coeff.	,380**	-,309**	0,133	−0,166	1															
	Sig.	0,001	0,005	0,193	0,106																
Q1.4:In the area of traffic…	Corr. coeff.	0,049	−0,118	0,157	−0,029	0,044	1														
	Sig.	0,663	0,288	0,130	0,784	0,667															
Q1.5.: In the area of fire protection…	Corr. coeff.	,236*	−0,210	0,183	0,026	0,080	0,190	1													
	Sig.	0,034	0,060	0,078	0,805	0,432	0,068														
Q2.1: Appropriateness of push notifications	Corr. coeff.	,225*	−0,131	,414**	0,004	0,131	0,162	0,145	1												
	Sig.	0,040	0,232	0,000	0,973	0,192	0,113	0,156													
Q2.2: Helpfulness of presenting preventative information in a menu item […].	Corr. coeff.	0,036	0,107	0,146	0,133	−0,091	−0,104	−0,071	−0,105	1											
	Sig.	0,752	0,351	0,174	0,216	0,389	0,333	0,510	0,319												
Q4: Amount of external content.	Corr. coeff.	−0,080	0,000	0,039	−0,121	−0,016	−0,049	−0,076	−0,035	0,130	1										
	Sig.	0,504	1000	0,728	0,281	0,885	0,660	0,494	0,749	0,258											
Q3.1: Preparedness notifications should come …as push notifications via warning apps […]	Corr. coeff.	,214*	-,235*	,250*	0,019	0,167	0,082	0,136	,665**	−0,089	−0,008	1									
	Sig.	0,050	0,032	0,014	0,856	0,096	0,418	0,183	0,000	0,400	0,942										
Q3.2: … as occasional push notifications, but with fewer permissions than acute alerts […]	Corr. coeff.	0,169	−0,145	,238*	0,001	0,163	0,137	0,052	,352**	0,140	−0,030	,392**	1								
	Sig.	0,126	0,189	0,020	0,995	0,107	0,183	0,613	0,000	0,187	0,785	0,000									
Q3.3: via special prevention apps, but not via warning apps such as NINA or KATWARN.	Corr. coeff.	−0,093	0,045	−0,128	−0,042	−0,031	−0,005	−0,115	-,272**	−0,160	−0,135	-,382**	-,231*	1							
	Sig.	0,393	0,681	0,209	0,684	0,756	0,963	0,261	0,007	0,129	0,216	0,000	0,022								
Q3.4: Integrating such preparedness notifications would motivate me to use a warning app.	Corr. coeff.	0,180	−0,028	,300**	−0,107	0,153	0,080	0,141	,513**	0,181	0,135	,467**	,298**	-,346**	1						

(*continued on next page*)

Table A6 (*continued*)

		G	WA	Q1.1	Q1.2	Q1.3	Q1.4	Q1.5	Q2.1	Q2.2	Q4	Q3.1	Q3.2	Q3.3	Q3.4	Q3.5	Q5.1	Q5.2	Q5.3	Q5.4	Q5.5
	Sig.	0,101	0,802	0,003	0,296	0,129	0,436	0,169	0,000	0,088	0,218	0,000	0,003	0,001							
Q3.5: …motivated to use a prevention app [only for] precautionary measures.	Corr. coeff.	−0,021	−0,150	0,185	−0,040	0,041	0,193	0,046	,233*	0,075	0,065	0,189	0,052	0,104	,203*	1					
	Sig.	0,844	0,167	0,067	0,694	0,684	0,057	0,647	0,019	0,475	0,550	0,058	0,605	0,297	0,042						
Q5.1: Due to the notifications I … have learned something new.	Corr. coeff.	,240*	0,024	,439**	−0,019	0,109	0,078	0,110	,265**	0,172	−0,157	,240*	,221*	−0,099	,287**	0,165	1				
	Sig.	0,031	0,831	0,000	0,857	0,285	0,452	0,290	0,009	0,107	0,156	0,018	0,031	0,331	0,005	0,103					
Q5.2: … started thinking more intensively about my safety/security.	Corr. coeff.	0,187	−0,030	,320**	−0,066	0,090	0,122	0,067	,446**	−0,029	−0,089	,418**	0,140	−0,133	,493**	0,192	,509**	1			
	Sig.	0,092	0,786	0,002	0,525	0,378	0,241	0,516	0,000	0,789	0,424	0,000	0,173	0,192	0,000	0,058	0,000				
Q5.3: … did more for my own security than I would have [otherwise] done.	Corr. coeff.	0,086	−0,014	,262*	−0,080	0,097	0,066	0,006	,219*	0,130	−0,131	,278**	,266**	−0,148	,265**	0,070	,654**	,451**	1		
	Sig.	0,433	0,899	0,010	0,434	0,336	0,517	0,951	0,029	0,219	0,234	0,006	0,009	0,140	0,009	0,486	0,000	0,000			
Q5.4: … felt too much pushed towards a behavior.	Corr. coeff.	−0,080	0,020	−0,076	−0,163	−0,024	0,042	,223*	−0,160	−0,050	0,100	−0,131	−0,062	0,178	−0,027	−0,019	−0,065	−0,153	−0,023	1	
	Sig.	0,472	0,855	0,464	0,117	0,817	0,686	0,032	0,115	0,640	0,366	0,197	0,550	0,080	0,791	0,854	0,529	0,138	0,819		
Q5.5: … felt disturbed.	Corr. coeff.	−0,187	0,000	-,363**	−0,050	−0,018	0,038	0,127	-,448**	−0,080	−0,044	-,310**	-,378**	,324**	-,342**	0,024	−0,162	-,285**	−0,155	,424**	1
	Sig.	0,091	1000	0,000	0,628	0,857	0,710	0,219	0,000	0,452	0,692	0,002	0,000	0,001	0,001	0,812	0,113	0,005	0,124	0,000	

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