“I can feel the risks by looking at the robot face”: Communicating Risk through a Physical Agent

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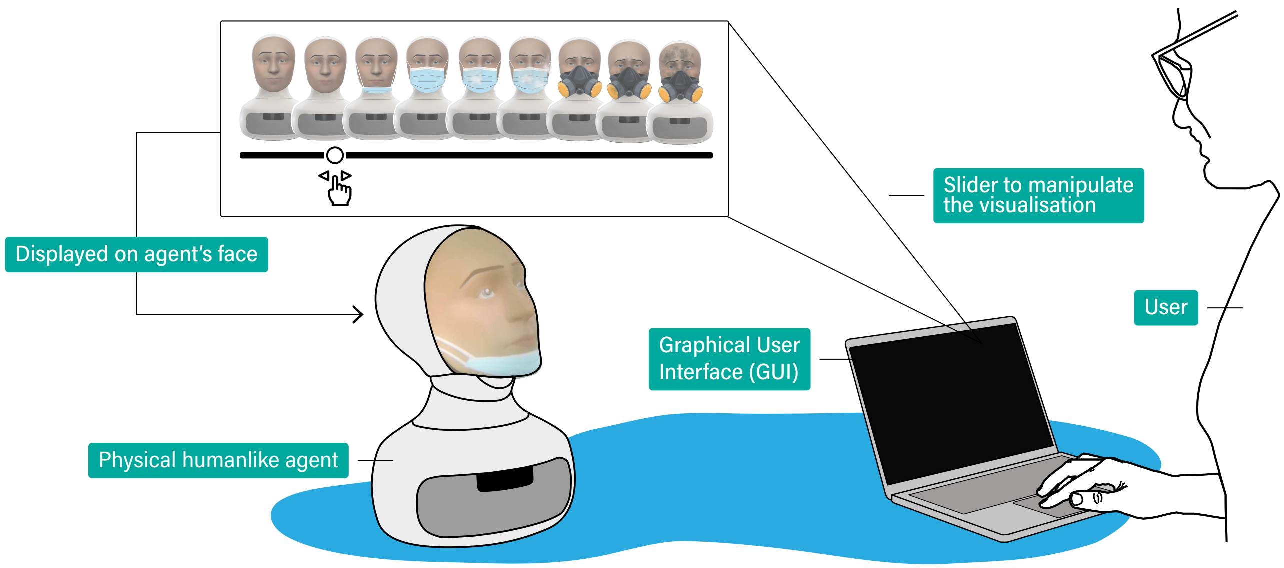

Figure 1: Exemplified experimental setting for air pollution: participants were given a GUI to manipulate the different levels of particulate matter by moving a slider. The respective information was conveyed through the physical humanlike agent placed next to them.

Abstract

Risk communication is essential for shaping public understanding and encouraging action in response to hazards. We investigate the potential of physical humanlike agents as a novel visualisation interface for risk communication, given their ability to communicate emotion and visually convey information. We first conducted a design workshop with 9 HCI experts to identify challenges, opportunities, and design strategies for using an agent's face as a visualisation canvas. We then conducted a lab study with 28 participants to assess the effectiveness of this interface to visualise the consequences of health risks. Our findings reveal that it facilitates data comprehension, heightens risk perception, elicits empathy, and motivates behavioural change by making the risk relatable and emotionally resonant. We discuss the potential of using these interfaces for risk communication in public spaces, health campaigns, education, and beyond. We provide design considerations, takeaways and future directions for an important pathway of human-centered risk communication.

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CCS Concepts

• **Human-centered computing → User studies**.

Keywords

embodied agents, affective visualisation design, health, risk communication, information visualisation, social robots

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1 Introduction

Rapid industrial growth and population expansion have led to widespread environmental and health risks, such as air pollution and respiratory diseases [22, 76]. As millions of people already face the consequences of these developments, or are likely to in the near future, it becomes increasingly critical to explore innovative approaches and to include state-of-the-art technology to effectively communicate these risks, to inform the public about their negative consequences and to motivate protective actions.

A common inhibitor to combat today's societal challenges is that it is extremely difficult to envision the consequences of these often abstract risks for oneself, and *how they would feel* once experienced, since "how a person comes to experience the consequences associated with the hazard may be unclear" [70]. In the context of risks associated with climate change, Leiserowitz [39] showed that people "lack **vivid**, concrete, and **personally relevant affective images** of climate change." Surprisingly, people do not associate climate change with human health, e.g. health effects due to air pollution, but rather with abstract and generic concepts such as melting glaciers or a raising temperature [39]. So **how can we make risks more relatable and risk communication more human-centered?** Research suggests that emotions play a critical role in effective risk communication, acknowledging "risk as feelings" [62]. In addition, Roeser [52] proposes emotions as a key driver to support behavioural changes.

The future of risk communication has to (a) support people's understanding of the consequences of risks, but (b) also *make them feel*. In addition, it has to shed light on (c) the impact of such risks on humans to make people envision themselves experiencing the consequence. However, such "self-referencing" will only happen if the viewer reflects upon their own life and body [12]. To do so, we can leverage new technologies to move beyond traditional risk messages and interfaces. Research on virtual avatars shows the positive impact on people's risk perception and personal risk relevance when visualising negative consequences through virtual human agents [29] and doppelgängers [1, 20] in VR environments. Notably, compared to on-screen robots or virtual agents, *physical agents* show a greater positive effect on persuasion, attention, trust, and affect due to their physicality, social presence and anthropomorphism [40, 53, 61]; factors that are particularly important for risk communication. However, the investigation of risk communication through *physical humanlike agents* remains scarce. This represents a critical research gap, emphasised by the expected in-situ deployment of social robots in health and public spaces [10, 18, 19], where social robots directly interact with humans and handle vast amounts of data, which offers a multitude of opportunities to communicate risks in a meaningful way. Therefore, the investigation of physical agents as a complementary and impactful form of risk communication is both timely and promising.

We investigate the use of a co-located, physical humanlike agent as a visualisation interface for risk communication. In specific, we explore an agent's face to communicate emotion as a foundation of effective risk communication *and* to inform about the negative consequences of risks, to make risks not just easy to understand, but deeply felt. The human face has long been a focus of attention in affective computing [41, 45], HCI [31] and Human-Robot Interaction (HRI) [15, 67] due to its expressiveness and association with emotions. A human face tells stories and can communicate without the need for spoken language. Human faces offer a variety of attributes and features that can be manipulated and used to render data. From the skin as its surface, with all its wrinkles, shadows and colours, to eyes — the windows to the soul, which can convey emotions that words struggle to articulate. Yet, the investigation of an agent's face for risk communication remains underexplored. With social robots now featuring highly advanced and expressive humanlike faces [51], there is significant potential to investigate how physical humanlike agents can effectively communicate risks "face-to-face". This work is guided by the questions of **how the anthropomorphic nature of a physical agent's face as a visualisation canvas for risk communication necessitates adapting visualisation methods to accurately represent and convey information** and **to understand how such risk communication influences people's risk perception and affective responses.**

To tackle this important and novel avenue of risk communication, we conducted two studies. First, we carried out a design workshop with 9 HCI experts to gain an initial understanding in how we can leverage an agent's face as a canvas for risk communication. From the workshop, we collected 23 design outcomes, three overarching design strategies for mapping information to an agent's face, and challenges and opportunities for employing an agent's face as an interface for risk communication. Second, we conducted a mixed-method user study with 28 participants to investigate participants' risk perception, self-reflection, empathy, and motivation to act when exploring health risks through an agent's face. The visualisation designs in Study 2 were informed by the design workshop and deployed on a popular social agent [51]. We focused this study on health risks related to air pollution and cholesterol, as pressing global health challenges [22]. Our results show that using the face of a physical humanlike agent for risk communication increases participants' risk perception, including perceived severity and affect. It fosters deep self-reflection related to the health risks conveyed, supports self-projection, evokes empathetic concern for populations facing such health risks, and encourages participants to act on the conveyed risk.

Our contributions are as follows:

- Our work presents an important and novel approach for risk communication in HCI, i.e. to leverage physical humanlike agents as visualisation interfaces to communicate negative consequences of risks, expanding the landscape of risk communication and HRI.
- Based on findings from a design workshop and mixed-method user study, we demonstrate the effectiveness of our approach in increasing risk perception, self-reflection, and affective engagement with health risks, making it a valuable tool for public health and environmental risk communication in the light of global health challenges.
- Our findings provide empirical insights on the potential of an agent as a visualisation interface to foster behavioural change by making health risks relatable, personally relevant and actionable.
- We highlight design considerations and key takeaways for the design and deployment of effective risk communication interfaces using physical humanlike agents and provide informed directions for future research in HCI.

2 Related Work

We present the rationale behind our research and introduce key concepts which build the foundation of our design workshop and user study. We underscore the multidisciplinary and exploratory nature of our work by drawing insights from affective visualisation design, risk communication, psychology, and Human-Agent Interaction.

2.1 Risk Communication and the Role of Affect

The risk of a specific hazard can be decomposed into two essential determinants, the likelihood of a hazard and its (negative) consequence [12, 54]. Our work focuses on the second determinant, namely communicating risk consequences. The *perceived consequence* is a function of two separate factors denoting the perceived severity of a consequence and affect, i.e. feelings triggered by the hazard [75]. In fact, affect is often the cause why the *perceived* risk diverges from the objective risk at hand [72]. This means that the feelings associated with a hazard can lead individuals to perceive the risk as higher or lower than it objectively is [17]. Therefore, affect is recognised as a critical factor in research on risk perception, influencing how individuals assess and respond to potential hazards [62, 68]. Visschers et al. [68] discuss several affect-inducing cues, such as emotion induction, risk stories or images. Further, they distinguish between integral cues, which are explicit and deliberate, and incidental cues, which induce affect due to more indirect circumstances. One of the most well-known examples of affect-inducing risk communication is the use of images to convey the severe consequences of smoking [7].

2.2 Affective Visualisation Design

Risk information can be abstract and difficult to connect with. To address this, we draw on insights from affective visualisation design, which aims to "transform complex, cold data into vivid, affective representations" [36]. The design space goes beyond the purpose to objectively convey information, but (among others) to *educate*, *advocate*, to *provoke* [36], and to enhance user engagement [35] with the conveyed information. The communication of negative emotions, in particular, promotes thoughtful reflection and introspection, and can challenge individuals to think and focus their attention [37] — traits that are especially important when confronted with risk information. The use of anthropomorphism to convey the human behind the data [5, 23, 24], metaphorical representations [28, 46, 77], colour [3], and motion [35] has proven useful to design for emotions. In addition, physicality, leveraged in so-called data physicalisations [78], can be a powerful design choice to induce affect and to make visualisations more meaningful [46]. Both the investigation of state-of-the-art technologies, such as physical agents, and their empirical evaluation have been identified as critical avenues for future research in the affective visualisation design space [36].

2.3 Agents to Communicate Health Risk Consequences

2.3.1 Physical Embodiment and Anthropomorphism. Motivated by the need to make risk communication more impactful, virtual humanlike avatars have been explored as tools for visualising the negative consequences of risky behaviours [1]. Examples include VR simulations of car accidents experienced by an avatar to discourage drunk driving [30], visualising weight gain to emphasise the consequences of physical inactivity [20], and to demonstrate the health consequences of soft drink consumption, which was additionally depicted as piles of fat accumulating on a digital scale next to the avatar [1]. Notably, visualising weight gain through generic avatars or virtual doppelgängers compared to reading an info brochure increases the perceived health risk of soft drinks, with doppelgängers further enhancing the personal relevance of the risk [1]. Moreover, customising VR avatars fosters emotional closeness and perceived similarity compared to interacting with default avatars, which leads to positive behavioural intentions when confronted with the consequences of risky behaviour (drinking and driving) [30].

In HRI research, the role of robots as risk communicators remains underexplored. Prior research shows that robots may better attract attention during emergency evacuations than traditional exit signage [50], and that affective verbal persuasion through humanlike robots elicits a slightly higher, though not statistically significant, compliance rate than logical appeals in the context of cyber security and social engineering threats [49]. In prior research, Schömbs et al. [60] further investigated different modalities through which robots could convey probabilities in high-stakes settings, which directly informs how to communicate the likelihood of hazards.

In healthcare, robots have been predominantly investigated as companions for emotional support, aides in rehabilitation, or assistants in clinical tasks [10]. While there is growing interest in their role as communicators of health information, e.g. to mediate health information between parents and young adults [74], little research has examined their potential for health-related risk communication, particularly communicating risk consequences. This represents a critical gap, as robots are increasingly expected to inform and interact with users in healthcare settings. Beyond tasks like medication management, they could communicate health risks relevant to the user, such as the dangers of neglecting prescribed medication, not exercising, or exposure to poor air quality.

Interestingly, physical robots evoke stronger empathic responses than on-screen or mixed-reality counterparts due to their tangible and spatial presence [61]. A recent meta-analysis shows that anthropomorphic features of physical agents further support trust, likability, perceived intelligence, and affect activation, which makes them especially promising for emotionally engaging risk communication [53]. A comprehensive survey of 33 empirical studies involving physically present robots, robots depicted on-screen and virtual agents shows that physical robots are more persuasive, capture more attention, and foster more positive attitudes, e.g. greater trust and enjoyment, compared to their on-screen counterparts or virtual agents [40]. While virtual agents outperformed physical agents in a few areas like response speed [40], these findings support the potential of co-present physical humanlike agents as a complementary approach for effective health risk communication. However, we emphasise that our work does not aim to replace screen or virtual agents.

2.3.2 Face-to-Face Risk Communication. The face plays a crucial role in human-human interaction to infer information and to interpret emotional cues. Its role in risk communication is illustrated in Fox and Bailenson [20], who investigate the impact of linking real-world physical activity to changes in a "virtual self" created from photographs of the participant's face. When participants exercised, their avatars visibly lost weight, and when they were inactive, their avatars gained weight. This dynamic representation of behaviour-consequence displayed through the face motivated participants to change their behaviour positively. In HRI too, facial features are key to elicit empathy and emotional engagement [33]. While the impact of anthropomorphism and facial features on empathy remains underexplored and difficult to generalise [53, 58], Konijn and Hoorn [33] demonstrate that higher levels of facial articulacy elicits greater emotional responsiveness and empathy, particularly in scenarios involving negative affect. The authors argue that robots with more humanlike and expressive facial features can momentarily override the robot's artificial nature, which allows for better affective engagement. Recent advancements in projection-based faces of social robots [51] now allow more detailed, realistic, and high-fidelity facial expressions without limitations posed by mechanical actuators, which paves the way for physical humanlike agents to communicate health risks face-to-face.

Our work builds on multidisciplinary insights and addresses a critical gap: the investigation of physical humanlike agents to communicate the consequences of health risks. As robots are increasingly integrated into healthcare and public spaces, investigating their potential to communicate health risk through their face is both promising - given their physicality and humanlikeness - and timely. Throughout this paper, the term agent refers to a physical humanlike agent for improved readability, unless specified otherwise.

3 Study 1: Design Workshop

We conducted a design workshop with 9 HCI experts to gain an initial understanding of how we can use an agent's face as an interface to visualise risk information and communicate emotion [59], both essential for effective risk communication. The objectives are threefold: (i) to investigate strategies and techniques for mapping and encoding information to a humanlike face, (ii) to assess its potential to elicit emotion as a foundation for effective risk communication, and (iii) to unveil practical and conceptual challenges associated with using an agent's face for risk communication. A design workshop is a common practice in HCI and provides the opportunity to collaboratively generate a multitude of design ideas, to facilitate idea generation, and to unveil challenges and constraints [21], which aligns with the exploratory nature of our work.

3.1 Method

3.1.1 Participants. We recruited 9 (6F, 3M) experts as participants for the workshop. Prior to the workshop, participants filled out a survey to determine their eligibility, i.e. to ensure the relevant knowledge and diverse perspectives [27]. We recruited experts with work, research or teaching experience ($M = 4.3$ years) in HCI related fields, e.g. user experience, prototyping, data analysis or interface design to reflect diverse insights and to address the complex interplay between data interpretation, human emotions, and interface design. The design workshop received approval from our University's ethics committee.

3.1.2 Stimuli. We provided experts with three example stimuli to constrain the workshop as proposed by Kerzner et al. [27]. We carefully selected stimuli from the comprehensive corpus of affective visualisation design by Lan et al. [36], covering the three most common domains: *environmental science & ecology*, *social issues*, and *health & well-being*. The first example based on Kuznetsov et al. [34] visualises air pollution through sensor-based balloons that change colour depending on the pollutant type. The second stimulus shows "Harassment Plants" designed by Morais et al. [47] to convey data related to harassment cases against women, e.g. time of the day. The third example from Khot et al. [28] visualises heart rate data using 3D-printed chocolate treats that adapt their message depending on the level of physical exercise. The selected stimuli allowed us to explore potential risk communication related to environmental changes, violence, and health.

3.1.3 Procedure. The workshop consisted of four phases: 1.) introduction, 2.) demo, 3.) design activity, and 4.) a follow-up group discussion, targeting the experts' design experience, challenges and thoughts on leveraging an agent's face to communicate information and emotion. We allocated experts into groups of three, considering gender diversity and varied backgrounds [21]. The 10-minute introduction included an ice-breaker to encourage self-expression and to foster trust among the experts [27], the design task and relevant concepts to avoid misunderstandings and knowledge imbalance. Experts received a 5-minute demo of the Furhat robot [51], a humanlike robot head. The Furhat robot is a social agent known for its customisable appearance, facial movements and expressiveness, which makes it particularly suitable for our purposes. During the demo, we introduced the robot as the visualisation canvas participants would be working with, and showcased its built-in facial expressions along with a selection of character faces varying in gender and appearance. We deliberately refrained from showcasing speech, as this was not the focus of the study. Thus, experts were able to acquaint themselves with the agent and its facial features to become familiar with the concept of using an agent as a visualisation tool and to ignite inspiration.

The third phase of the workshop involved a 45-minute design activity. We asked experts to brainstorm designs that visualise the information from the stimuli introduced in Section 3.1.2 (e.g. air pollution), using the agent's face as their interface. We provided all groups with photocopies of the Furhat's various face options, differing in gender, ethnicity, age, and humanlikeness, and other crafting materials typically used for design activities. To guide the design process, we instructed each group to understand the stimuli, brainstorm individually for 3 minutes, and then collaboratively select, refine, and annotate their designs. After the design activity, each group was asked to explain their design outcomes. We closed the design workshop with a semi-structured group discussion led by the first author.

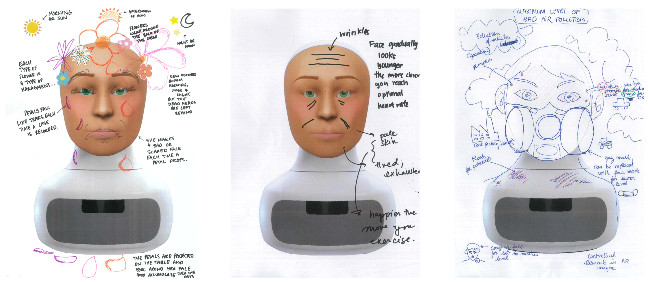
3.1.4 Data Collection and Analysis. We collected generated design outcomes from the design activity and qualitative data from our group discussion. Before the group discussion, the experts were asked to describe their designs, elaborate on specific elements, and explain their rationale. This ensured that the experts themselves interpreted their work to provide a foundation for analysing the design outcomes without imposing external interpretations. An outline of the semi-structured group discussion is included in the Appendix, Section A. The group discussion included an opening question based on Lan et al. [37] to initiate the discussion, an introductory question targeting the overall design experience and methodology, and three key questions to investigate the experts' thoughts on challenges, benefits and pitfalls for using an agent's face as a visualisation interface. The group discussion took 30 minutes and was audio-recorded. We analysed the transcriptions using a reflexive thematic analysis following the six phases outlined by Braun et al. [6], detailed in Terry and Hayfield [65], which acknowledges the researcher's role in constructing meaning. While the exploratory nature of our workshop led to a predominantly inductive approach, our research objectives and semi-structured format of the discussion informed an initial set of tentative themes [65]. The analysis primarily aimed to evaluate whether a physical agent's face could serve as an interface for mapping risk-related information and to elicit affective responses. We further sought to understand the benefits and challenges of using an agent to represent such information. We examined the generated designs to identify the metaphors used, selected features, distinct design elements, and how experts leveraged the agent to support information meaning. An internal and an external researcher independently familiarised themselves with the transcripts and recursively coded the full dataset. As new clusters of meaning were identified during coding, the tentative themes were iteratively revised to ensure they represent patterns of shared meaning rather than topic summaries. The researchers met to compare codes, discuss discrepancies, and collaboratively refine the final set of codes and themes.

3.2 Results

We collected qualitative data from our group discussion and 23 design outcomes generated from the design activity. Our analysis revealed three overarching design strategies for encoding information via the agent's face, alongside two main challenges and opportunities specific to using an agent's face as an interface for risk-related information.

3.2.1 Generated Design Outcomes. We present an extensive overview of all design outcomes including descriptions for each design in a dedicated website[1]. Experts used three strategies to encode information through the agent's face: metaphorical representations, expressive facial features, and dynamic elements, each contributing to how the agent visually conveys information and engages viewers affectively.

Metaphorical Representations. Experts designed representations with varying metaphorical distance to convey the stimuli. For example, air pollution was either visualised through the use of facial masks, which directly derives from known and learned associations, or visualised as an "*“artistic landscape”*" (E2), where *“growing leaves”* turned into *“cracks”* or took on a *“Terminator”*-like appearance. To convey harassment cases, one design featured flowers blooming around the face, *“each type of flower is a type of harassment”* and *“every time a case happens, a petal falls like a tear down her face”* (E6); see Figure 2a. Among various metaphors explored in the context of health data, the metaphor of battery levels was used (both colour-encoding and gradual filling of the face); *“If you don't exercise, you have low batteries, a red color”* (E8). E7 explains that they first identified a fitting metaphor, which they deconstructed to map the associated data attributes. *“It was more top-down. Getting inspiration from what we knew and then … translate it onto [the agent's face]”*. Similarly, a design inspired by the Tamagotchi concept represented heart rate data through growth, where the agent *“starts small and cute, and the more you exercise, the more you feed it, it gets bigger. If you don't exercise, it dies”* (E5).



(a) Flowers represent harassment types, with falling petals and facial expressions symbolising frequency.

(b) Less exercise ages the face, making it look tired, while more exercise keeps it youthful and vibrant.

(c) Projected smoke, skin rash, pimples and dynamically changing face masks used to convey air pollution.

Figure 2: Examples of designs using an agent's face to convey (a) harassment, (b) heart rate, and (c) air pollution.

Facial Features and Expressions. Experts explored a wide range of facial features (e.g. eyes, skin texture, mouth movements) and human facial expressions (e.g. happy, sad) to visualise the information and communicate the associated emotion; which was also reflected in experts' mapping logic. E1 and E2 started with a list of potential facial features that can be used to map data and convey its underlying meaning. For air pollution, experts proposed colour-coded skin reactions, such as “a rash and pimples” for pesticides or “red eyes” for industrial emissions (E7). To depict harassment cases, facial expressions and movements were utilised to reflect the type of assault, e.g. stalking through “eye movements', verbal assault through “mouth muttering” (E1), but also to evoke affective responses, e.g. *“watering eyes”* or the agent *“exploding into crying”* (E4). E6 emphasised that *“every time a petal falls, the face is sad”*. To convey information about people's heart rate, one group designed the agent's face to depict varying facial expressions based on activity levels, from “lethargic” to “happy and lively”(E8); see Figure 2b. Another group experimented with different smiles to convey *“faces for praising or motivating”* (E2).

Dynamic and Responsive Design Elements. In line with the definition of an agent [56], experts envisioned the agent as ‘someone’ reacting and responding to the changes in their environment. E3 first reflected on *“what is causing an effect, so the source of the data … and then how the human or robot face reacts to it … whether it's pollution, harassment or lack of exercise”*. Experts visualised this relationship through dynamic and responsive elements, including motion, changes in illumination intensity, colour shifts, dynamic facial decorations (e.g. different types of face masks), dynamic iconic

[1]https://sites.google.com/view/agent-risk-communication/home

or symbolic representations (e.g. spreading smoke, filling of battery inspired colour-coding), and responsive behaviour-consequence relationships (e.g. spreading rashes, pimples). For instance, several experts incorporated dynamically adjusting facial masks and variations in the degree of smoke scattering on the agent's face to convey different levels of air pollution (see Figure 2c). Another group envisioned that *"the head would shake"* (E2) in response to dangerous heart rate levels, conveying high risk.

3.2.2 Challenges. We identified two main challenges when using an agent to convey information and communicate emotion.

C1: Balancing Storytelling and Data Precision Data comprehension is a common concern in the affective visualisation space [37] and particularly important when conveying risks that are relevant to the viewer. Several experts experienced a trade-off between telling the overall message of the information versus being accurate and precise in their data mapping. They also found it challenging to map multiple variables onto the agent's face simultaneously without compromising comprehension and the impact of the visualisation. *"You can get some really elegant things that make you feel when it's just one thing, like the petals falling. It's so impactful. The more you pile on, ... the more complicated it gets and potentially the less impactful"* (E2).

C2: The Face Shapes Context Some experts observed *"conflicting effects"* (E4) when applying traditional data encodings or symbols to the agent's face, as human associations could lead to ambiguous or unintended interpretations. For example, *"I was especially noticing it with the battery idea... why is the face green? That doesn't look good, a green face is usually disgust"* (E4). Others noted that the agent's humanlike appearance strongly influences how its features are interpreted, which can limit its use or lead to misinterpretations, as *"you cannot project a line graph on there and hope for the best"* (E1). E2 raised ethical concerns about the agent being overly provocative or manipulative; *"I think there's ethical issues with demonstrating certain emotions in the face. It can be really triggering. You have to be really mindful ... to even begin to dictate who feels what"* (E2).

3.2.3 Benefits and Opportunities. We identified several benefits contributing to two overarching opportunities when using an agent to convey information and communicate emotion.

O1: Enhancing Impact and Engagement Experts emphasised the potential of using a physical agent as a visualisation tool to deliver information in a way that is both captivating and impactful. For instance, E2 described that the agent makes the information *"interesting to look at each time"*, while E1 reflected that the agent's face could *"amplify certain situations"* and *"leave a more lasting impact"* compared to traditional visualisation methods [37]. E7 described the agent's role to effectively illustrate future consequences, showing *"what it would look like if you'd have continued [polluting air]"* (E7). E4 explained that visualising a behaviour-consequence relationship through the physical agent might empower users to take on a more active role in managing their own health [77] while fostering self-reflection [36]. *"[The agent] could convey the expression that communicates how poor your heart rate is in relation to an activity. So if you just did a walk and [the agent] is super exhausted, that's not good."* (E4).

O2: Creating Connections to Foster Empathy Notably, experts expressed that the agent's humanlikeness encouraged empathetic concern with the underlying data and motivated them to put themselves in the agent's shoes. *"I think the idea of exploring that [the agent is] a human [is] compelling because it can help you as the viewer to empathise"* (E4). Mimicry is an important determinant in the human tendency to emphasise and prosocial behavior [63]. Some experts noted a tendency to mimic the agent's expressions, with E2 describing how they instinctively imitated the agent during the demo session. E1 attributed this to a *"Monkey See, Monkey Do effect"*, explaining that the agent's ability to convey specific facial expressions naturally prompts mimicry, often unconsciously. In line, E4 expressed to have experienced mutual gaze with the robot. *"It is also weird, it's a visualisation that's looking at you. Like I've caught mutual gaze with it"* (E4).

3.3 Lessons Learned

During the workshop, experts successfully generated a multitude of designs to represent different types of information through an agent's face, with the intention to communicate emotion and information, both essential for effective risk communication. Interestingly, our findings show that an agent's face is not restricted to visualise information solely related to the human, i.e. physiological data, but also environmental risks, i.e. air pollution. We identified three design approaches - metaphorical representations, facial features and expressions, and responsive design elements - and discuss design considerations for future research.

Experts used the agent's facial features and expressions to mainly achieve two goals: (i) to encode information, such as red eyes to represent high levels of air pollution, and (ii) to underpin data with emotional cues, such as sadness. Experts further envisioned the agent as an interactive entity responding to its environment [56], using its **face as a reflective canvas to visually communicate the impact of external or internal stimuli on the human body**. This approach often linked physiological states with facial cues intended to make the information more relatable, e.g. exposure to pollution causing skin irritation. Moreover, it emphasises the potential of **physical humanlike agents to communicate behaviour-consequence relationships**, similar to strategies shown to be effective with virtual agents [20]. Notably, experts used a varying degree of metaphorical distance to encode information [78] and to make information relatable and engaging. From facial masks to convey air pollution to falling flower petals to convey harassment frequencies. However, **designers should carefully consider the metaphorical distance to strike a balance between accessibility and emotional impact.** While direct metaphors could be immediately understood, abstract ones may require explanation.

Between Ambiguity, Precision and Storytelling. Our findings highlight the difficulty of integrating complex information into a single visual medium, which suggests that trying to represent too much information at once can lead to confusion or a less effective design. In line with affective visualisation design [36], the use of a physical humanlike agent as an interface for risk communication should aim to inform and engage without causing distraction or compromising comprehension. Past research has shown that the expressiveness of affective visualisation designs does not hinder data comprehension

[37]. However, it remains to be evaluated if using a physical humanlike agent as a visualisation interface supports both expressiveness and comprehension to effectively communicate risk. We suggest **designers to carefully limit the number of variables visualised simultaneously and to consider layering information thoughtfully to balance expressiveness and comprehension.** Moreover, we identified concerns about ambiguous interpretations and conflicting effects when mapping conventional encodings onto a physical humanlike agent. While leveraging the agent's humanlikeness and physicality can make visualisations more relatable and impactful, it can also lead to misinterpretations caused by the context of a human face (e.g. green being interpreted as disgust rather than representing good or full energy). **Designers must carefully navigate ambiguities, as a humanlike face inherently shapes interpretations and activates human-related associations.**

Monkey See, Monkey Do. Interestingly, our findings show that using a physical humanlike agent as visualisation interface can enhance empathetic concern and make risk information more impactful. Several experts felt inclined to mirror the agent's expressions. In social interactions, mimicry is an influencing factor for building rapport and empathetic concern [63, 64]. These findings align with our vision that physical humanlike agents have the potential to bring data alive, as *"a visualisation that's looking at you"*. Notably, the high degree of humanlikeness can result in a triggering and provoking visualisation. Provocation [36] and the communication of negative emotions are considered powerful tools in both affective visualisation design [37] and risk communication [68]. However, **designers must find a balance between a provocative design that encourages reflection without causing an avoidance response and inducing stress or harm to the viewer** [7].

Our design workshop identified the utilisation of physical humanlike agents as a promising new approach for communicating risk. Building on these initial insights, we refined the designs (see Section 4.1.1) and conducted a follow-up mixed-methods user study to investigate the effectiveness of using an agent as a visualisation tool for risk communication, focusing on health.

4 Study 2: Lab Study Evaluation

Based on the findings from our workshop, we deployed refined designs on a real-world social agent, i.e. Furhat [51] to communicate the negative consequences of particulate matter (PM2.5) and LDL cholesterol on people's health. We conducted a mixed-method lab study to investigate (i) the effectiveness of using a physical humanlike agent to communicate negative consequences associated to different health risks; (ii) how using an agent as visualisation interface influences affective responses from viewers (incl. empathy and self-reflection); (iii) its application potential.

4.1 Method

4.1.1 Stimuli. We carefully selected two stimuli which served as hazard scenarios in this second study: LDL cholesterol and PM2.5 (as an indicator for poor air quality). We selected the scenarios based on their real-world significance as global health risks [22] and their conceptual proximity to the workshop stimuli. The selection further allowed us to narrow the scope for an in-depth investigation, focusing on direct and indirect hazards to human health, driven by the potential applications of social agents in healthcare. To design the stimuli for each scenario, we deployed the idea of the physical agent responding to changes and built upon design approaches identified beforehand (see Section 3.2); i.e. facial features and expressions, responsive design elements, while avoiding potential ambiguities or misinterpretation. We refrained from evaluating designs with a high metaphorical distance due to data comprehension concerns raised in the workshop. The final designs were deployed on the Furhat robot [51]. An example is shown in Figure 1, and the full interaction, including both implemented stimuli, can be seen in the accompanying video. We used the default built-in character as the design base. In addition, we implemented the built-in furhat.attend() method for the agent to attend the user via gaze to support the social interaction [32], which was also informed by the design workshop.

Design Details: Fine Particulate Matter (PM 2.5). Air pollution is a serious environmental factor that impacts public health and contributes to millions of deaths and cases of disease worldwide [57, 66]. PM2.5 is a critical air pollutant, which often serves as an indicator for air quality. It includes particles smaller than 2.5 μm, which can be inhaled and result in e.g. respiratory diseases or lung cancer [9, 66].

To visualise the risk of PM2.5, we build upon design ideas on air pollution from the previous workshop, exemplified in Figure 3. The design was refined to incorporate various face masks and smog elements, which dynamically change according to the PM2.5 levels. We used facial expressions —ranging from a smile for low PM2.5 to a frown and sad expression for higher levels— and modified facial features, such as the intensity of the blush on the agent's cheeks. To ensure an accurate representation, we mapped these design elements to PM2.5 levels following the official categorisation from IQAir[2], aligned with the latest WHO global air quality guidelines[3]. The air quality index chart corresponds PM2.5 [μg/m^3] levels with health recommendations, categorising them from "good" to "hazardous" for human health. The categories are asymmetric and do not increase in uniform steps. For example, 0-9 μg/m^3 represents "good," while 55-125 μg/m^3 indicates "unhealthy". The implemented design consisted of 10 frames to convey the scale from 0 μg/m^3 to 225 μg/m^3.

Figure 3: Left: design outcome from the workshop. Right: refined and implemented design illustrating hazardous PM2.5 levels through physical humanlike agent.

[2] https://www.iqair.com/au/newsroom/what-is-aqi
[3] https://www.who.int/publications/i/item/9789240034228

Design Details: LDL Cholesterol. LDL cholesterol is considered a key contributor to global health issues [79], as high levels of LDL cholesterol are strongly linked to an increased risk of strokes and other cardiovascular diseases. To convey the associated health risk, we drew inspiration from our workshop outcomes on visualising heart rate data, see Figure 2b. We implemented the metaphor of "sickness", and manipulated various facial features, e.g. the colour of the lips, skin, and cheeks, the facial contours, and the intensity of shadows to convey dark circles on the eyes. Besides, we applied facial expressions —ranging from mouth movements indicating happiness to sadness— and altered blinking duration to convey a sense of tiredness. Again, the design elements were carefully aligned with the respective LDL cholesterol levels, as outlined by official guidelines from Johns Hopkins Medicine[4]. Here too, the categories had varying intervals. The implemented design consisted of 10 frames to convey the scale from 89 mg/dL to 210 mg/dL.

Data Manipulation Interface. To enable participants to explore the risks through the physical agent, we developed a browser-based graphical user interface (GUI), which allows users to manipulate the data (e.g. mg/dL values) through a simple slider. As participants adjust the slider, each position triggers a corresponding design frame in the Furhat robot. The designs change in real-time and thus provide immediate visual feedback. The GUI also presented basic information on the respective topic, instructions for the study task, and three questions with input fields to capture participants' interpretation of the visualisation. Additionally, the GUI displayed a "Done" button that recorded the time spent on the interface and notified the researcher upon completion of the exploration task. The interface is designed to seamlessly integrate with the expressive capabilities of the Furhat robot, utilising JavaScript for the front-end interaction and Kotlin for the backend logic that drives the robot's facial animations.

4.1.2 Quantitative Measurements. The terminology of all measures was adapted to reflect the specific hazard scenario, i.e. PM2.5 or LDL cholesterol. We measured participants' disposition to trust technology [38] and tendency to anthropomorphise [58, 73] to account for individual differences. We also recorded the time participants spent on the GUI, not as a strict measure of user engagement but to gain an impression of their interaction duration.

Data Comprehension. We asked participants three questions to assess their interpretation of the visualisation and data comprehension, following Lan et al. [35]. Participants answered the questions using input fields on the GUI. The first two questions aimed for participants to interpret specific values of PM2.5 and LDL cholesterol, e.g. *"Looking at the visualisation, how do you interpret the level of 170 mg/dL LDL cholesterol? Please describe in your own words."*. We selected low and high values that represented neither extreme to obtain more nuanced insights on participants' comprehension. The third question targeted the participants' interpretation of the overall trend; asking *"What observations did you make as you moved the slider from left to right and how did you interpret them?"*.

Risk Perception. To gauge participants' holistic perception of risk and their change in risk perception after viewing the visualisation, we used a single-item measured before and after exposure, asking *"How risky is particulate matter (PM2.5)?"*) according to Walpole and Wilson [70]. Following the decomposition of risk consequence into its determinants severity and affect [75], we implemented the proposed items by Walpole and Wilson [71] for severity and affect, which can be applied across hazards. Severity was measured using the three recommended items, e.g. *"How severe would you expect the consequences of particulate matter (PM2.5) to be?"*, and rated on a 5-point Likert scale (1 = "Not at all severe", 5 = "Extremely severe"). Similarly, affect was measured using the recommended three items, e.g. *"How concerned are you, if at all, about particulate matter (PM2.5)?"*, rated on an 5-point Likert scale (1 = "Not at all concerned", 5 = "Extremely concerned"). Severity and affect were measured before and after exposure to the agent and for each hazard scenario to assess changes in risk perception.

4.1.3 Participants. Prior to the experiment, we conducted a power analysis to determine our sample size using *G*Power* [16]. The calculation was based on an alpha level of 0.05, and a power of 0.8, resulting in a targeted sample size of $N = 27$. To counterbalance the order in which participants viewed the hazard scenario, we recruited 28 participants (17*F*, 11*M*) for our mixed-method lab study using our university's notice board. The study took roughly 30 minutes and participants were compensated with a \$15 gift voucher. The user study received approval from our University's ethics committee.

4.1.4 Procedure. We conducted several pilot studies to finalise our measures, interview questions and the overall experimental flow of the lab study. We counterbalanced the order of the hazard scenarios to mitigate any order effects. The final procedure of the study consisted of four phases: 1.) briefing, 2.) pre-task survey, 3.) exploration task, and 4.) semi-structured interview (see full experimental flow in Figure 4).

Upon arrival, the participant was seated on a desk in our lab, facing the Furhat robot positioned next to them. The Furhat robot was introduced as an additional interface through which information can be communicated. To begin, the participant was asked to carefully read the task description, plain language statement and consent form to ensure the participant understands the study, its purpose, and their involvement. Secondly, participants were assigned a specific order (counterbalanced) in which they receive information and explore each hazard scenario (PM2.5 or cholesterol) through the agent. Before the exploration task, each participant received a survey and was asked to provide their demographic information, information on their tendency to anthropomorphise, and dispositional trust in technology. Moreover, participants were instructed to read general information about each hazard scenario (PM2.5; LDL cholesterol) and provide answers on the selected risk measures to assess their initial perception of risk. We standardised the description for each hazard scenario as much as possible to reduce noise.

Thirdly, the participant was handed a laptop which provided the interface to manipulate the data of the respective hazard scenario. On the GUI, participants were instructed to take 2-3 minutes to explore the different levels of the data using the slider and to observe the visualisation conveyed through the physical agent placed next to them, see Figure 1. Subsequently, the participant was

[4] https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/lipid-panel

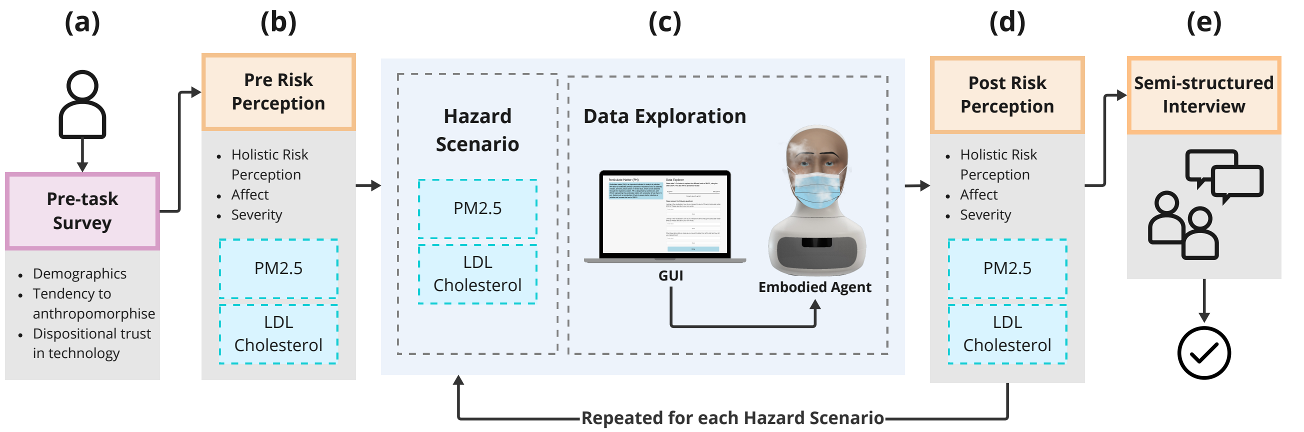


Figure 4: The experimental flow. Participants viewed hazard scenarios (PM2.5 and LDL cholesterol) in a counterbalanced order. (a) Pre-task survey: demographics, tendency to anthropomorphise, dispositional trust in technology. (b) Pre risk perception: measured before viewing the visualisation based on short description of each scenario. (c) Data exploration task: participants manipulated data via GUI, viewed data visualised through agent. (d) Post risk perception: measured after viewing the visualisation. (e) Semi-structured interview.

asked to provide answers about their observation and interpretation of the visualisation, using the input fields below the slider. After clicking the "Done" button, the researcher was notified upon the participant's completion and the participant was handed a survey assessing the participant's risk perception post visualisation. The exploration task was repeated for the second hazard scenario, following the same procedural sequence. Lastly, participants engaged in a semi-structured interview (~10-15 minutes).

4.1.5 Data Collection and Analysis.

Quantitative Analysis. We collected participants' self-report to the aforementioned items (4.1.2) through an online survey. We employed Cumulative Link Mixed Models (CLMM) given the quantitative ordinal data. In our CLMM we included individual differences, i.e. participants' tendency to anthropomorphise and dispositional trust in technology, as fixed effects. We included time (pre/post) to capture changes in perceptions after interacting with the physical agent to account for the pre-post nature of our study design. Pre-exposure measures served as a baseline to ensure that individual differences in participants' initial perceptions were controlled. We included participant IDs and the interaction of participant ID and hazard scenario as random effects to account for the repeated nature of the study and for variations across hazard topics. The latter is particularly important, as it controls for the possibility that a participant's response might vary depending on whether they are evaluating PM2.5 or LDL cholesterol. We performed a post-hoc analysis to obtain pairwise contrasts between participant's prior and post perception.

Qualitative Analysis. We collected qualitative data through free-text field responses on the GUI and semi-structured interviews (see Appendix Section B) with all 28 participants. Each interview was audio-recorded, transcribed, and, along with the free-text answers collected from the GUI, analysed using a reflexive thematic analysis following Braun et al. [6]. The research objectives presented in Section 4 and the semi-structured format of the interviews guided a set of tentative themes, shaped by prior research in affective visualisation design (e.g. self-reflection, empathy) and insights from our design workshop. The themes were iteratively refined by the research team through a thorough familiarisation with all data, recursive coding, and discussions within the research team to resolve discrepancies and to better construct shared-meaning. While the study remains exploratory, the analysis adopted a slightly more deductive approach than the design workshop. The qualitative data helped us gain a deeper understanding of the quantitative measures by delving into how participants experienced concepts such as risk severity [44]. Moreover, our analysis explored participants' experienced empathy, self-reflection, motivation to act, and views on potential application contexts.

4.2 Results

Unless specified otherwise, qualitative results are based on the data obtained from the semi-structured interviews.

4.2.1 Comprehension and User Engagement. GUI logs showed that participants spent an average of 7m 15s on the PM2.5 visualisation and 6m 52s on the LDL cholesterol visualisation. Data comprehension is a critical aspect of risk communication, a common concern in affective visualisation design [35] and was identified as a challenge in our design workshop (Section 3.2). During the interview, several participants described that the visualisations were *"clear"* (e.g. P10, P20, P09, P21), supported their understanding of the topic, and imbued meaning to each data value (e.g. *"those numbers didn't mean much, but when I saw the robot then it means a lot"* (P28)). Some participants highlighted the visualisation as *"representative"* (P23) and *"intuitive"* (P08), stating that *"it allows me to interpret the data easily"* (P12). We analysed responses from the free-text fields in the GUI, which targeted specific data values and overall trend (see Section 4.1.2). All participants correctly interpreted the data values, inferred the level of risk (e.g. *"safe to go outside"* (P21)) and recognised the decline/increase in air quality/cholesterol levels and their effects on human health (e.g. *"this level of LDL will result in illness if not treated immediately"* (P23)). Several participants demonstrated a nuanced understanding of the respective values instead of a binary categorisation of good or bad (e.g. *"it's slightly elevated, but the person should still be fine"* (P10)).

Between Interest and Provocation. Fear-appeal is a common design choice in risk communication [55, 68]. In line, provocation can be a crucial element for user engagement, as it stimulates thoughtful reflection and encourages new perspectives [28, 36]. Notably, some participants described the visualisations as *"shocking, but very interesting"* (P04), emphasising that they experienced shock, which ultimately improved their awareness and willingness to act upon the risk. One participant explained in detail, *"you hear a lot of diabetes kills people, smoking kills, but they don't really materialise that, that's just words, it's not that scary. But I think if you have this robot, it'll really struck people more and it will make them more health conscious"* (P25). In addition, the visualisations led participants to be confronted and engaged with uncomfortable truths (e.g. *"I was a bit uncomfortable ... it's forcing you to face things that you don't really want" (P01)*). Few participants also raised concerns about the visualisations being too fear-inducing (e.g. *"I wouldn't want it to fear monger too much" (P17)*).

4.2.2 Risk Perception. The results from the CLMM show that participants *Holistic Risk Perception* changes significantly after viewing the visualisations conveyed through the agent (β = -0.847, SE = 0.40, p = .033). Participants perceive the risk to be greater after viewing the visualisations (EMM = 2.29, SE = 0.48) compared to prior seeing the visualisations (EMM = 1.44, SE = 0.43); p = .033 (see Figure 5). Our analysis shows that participants whose risk perception did not increase after viewing the visualisations either had prior knowledge that already resulted in a high level of risk perception (e.g. *"with my background experience, I feel like I'm a bit desensitised to it" (P01)*) or perceived the consequences as preventable (e.g. *"there's medication for it to help you"* (P07)) and in their control (e.g. *"it's something that I can control"* (P14)). Although not the primary focus of this research, several participants compared the visualisation to other information sources, highlighting the potential effectiveness of physical humanlike agents for risk communication; *"It really visually speaks to me instead of just reading a textbook" (P04).*

Severity. We applied the CLMM to investigate how the visualisations conveyed through the agent influenced the perceived severity of the risk, as captured by our quantitative measure. Participants *Perceived Severity* changes significantly after viewing the visualisations (β = 1.44, SE = 0.24, $p < .0001$). Participants perceive the severity of the risk significantly greater after viewing the visualisations (EMM = 2.63, SE = 0.42) compared to prior seeing the visualisations (EMM = 1.19, SE = 0.40); $p < .0001$ (shown in Figure 5, detailed overview per item in Figure 6). The intensified perception of severity is reflected in participants' statements during the semi-structured interviews, highlighting the facial cues as indicators of severity. One participant emphasised, *"when I am looking at the robot's facial expressions, I could tell it is really very, very severe"* (P03). Several participants noted that the protective measures the agent took (i.e. different types of facial masks) served as an indicator of severity (e.g. *"to see the equipment that you need, it showed me the broader impact of the issue, the severity of the issue itself"* (P27)). The ease with which people can imagine the consequence of a risk is highly relevant in effective risk communication [25]. Several participants articulated that the visualisations supported their imagination (e.g. *"I can imagine how it would be if the air got more polluted"* (P05)). Few participants further explained that they felt as if the agent was showing them a potential future, which made them better understand the consequences and their severity (e.g. *"this is what's going to happen to you in this many years if you keep going the way you're going"* (P01)).

Affect. Negative emotions play an important role in risk communication [68] and affective visualisation design [37]. To examine how the visualisations influenced participants' affect, we applied the CLMM to responses from the corresponding quantitative measure. Participants' *Affect* changes significantly after viewing the visualisations (β = 1.63, SE = 0.43, $p < .000$). Participants affect is significantly greater after viewing the visualisations (EMM = 1.40, SE = 0.56) compared to prior seeing the visualisations (EMM = -0.24, SE = 0.56); $p < .0001$ (see Figure 5, detailed overview per item in Figure 6). The result is in line with the findings from our interviews, in which most participants expressed experiencing the risk as a feeling (e.g. *"I can feel the risks by looking at the robot face" (P26)*) and that facing the negative consequences when viewing the visualisations made them feel fear, concern and worry. Others described the feeling as *"uncomfortable"* (P01), *"intense"* (P20), or *"sadness"* (P20).

Motivation to Act. The increase in perceived severity and affect is reflected in participants' motivation to act upon the potential consequences. Facing the severity of LDL cholesterol incentivised participants to take better care of their health by improving their diet (e.g. *"starting to eat healthier"* (P10)) or taking other measures to realise a healthier lifestyle. Some participants derived their motivation from the fact that their personal action has a direct outcome, a determinant of risk perception that is termed perceived efficacy [8]. Only a few participants expressed little efficacy and ownership for the conveyed risk, which resulted in little motivation to act (e.g. *"I don't feel a lot of ownership for the issue, it's not on me, it's on the companies that are doing all the polluting"* (P17)). Other participants were motivated to take protective actions such as checking PM2.5 levels or wearing masks (e.g. *"this visualisation makes me want to wear masks [and] to protect our environment by using less vehicles"*(P26)).

4.2.3 Empathy and Self-reflection. The visualisation not only triggered negative affect, but also fostered a deeper sense of empathy and self-reflection. The face was seen as a crucial tool for establishing an emotional connection and sharing emotions.

Empathy. From our analysis, we identified two dimensions of empathy elicited by the visualisation: (i) self-projection and (ii) empathy for others. First, many participants reported projecting the agent's experience onto themselves (e.g. *"that's how I'm gonna be looking when the air quality is bad or if you have high cholesterol levels"* (P11)), essentially putting themselves in the agent's shoes (e.g.

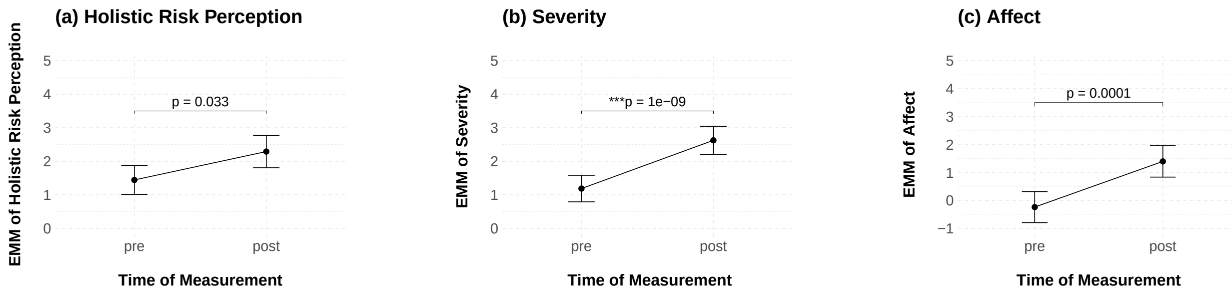


Figure 5: Plots illustrating the pre post evaluation of (a) Holistic Risk Perception; (b) Perceived Severity; (c) Affect. Error bars denote Standard Error (SE).

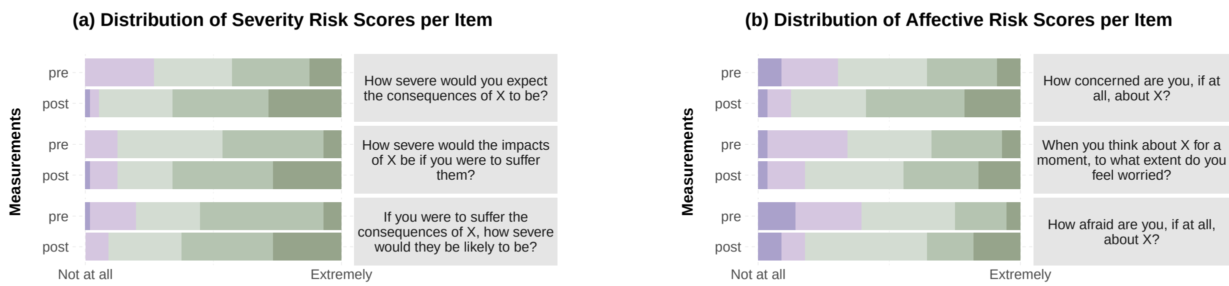


Figure 6: Plots illustrating the pre post distribution of each (a) Severity Item; (b) Affect Item.

"when I imagine myself in that situation. I think I would be the same with that face" (P05)), which heightened their personal connection to the consequences depicted (e.g. *"the visual impact is big for me. So oh my God, I will look like that"* (P20)). This mirroring effect was heightened by participants' tendency to ascribe emotional states to the agent, which allowed them to envision the risks as though they were personally experiencing them (e.g. *"you're actually feeling like the robot is suffering. So maybe I, in this situation, will be suffering too"* (P16)). One participant noted that the agent offers a more generalised face, not a specific person's face, which facilitates self-projection, *"[an image of a] real person might not have the same impact because this person is a specific person. I know that they may eat unhealthy, it's their own decision. But here, it is generalised so it could be me"* (P20). Secondly, several participants perceived the physical agent as a facilitator for feelings of concern and empathy towards others (e.g. *"I was able to empathise with family members or older groups of people who would experience this"* (P26)), and noted an increased awareness of potential people who might experience the consequence (*"people in really bad environmental conditions are really suffering"* (P10)).

Self-reflection. Previous research shows the relevance of negative emotions to foster contemplative thoughts and self-reflection [37]. Viewing the visualisations made most participants reflect upon past experiences related to the conveyed topic. Facing the visualised negative consequences of PM2.5 made several participants reflect upon their own up-bringing in areas with high air pollution or visits to areas impacted by air pollution. Interestingly, some participants reported that they were re-evaluating their past experiences, stating that *"I never, put on a mask or anything. But I feel like I really should"* (P04), now aware of the risk. Few participants reflected upon covid-19, triggered by viewing the facial masks (e.g. P20, P05, P27). A few others reported that it made them contemplate about the environment in general.

Facing the negative consequences of LDL cholesterol, several participants reflected upon the health of family members and friends (e.g. *"my parents looked very exhausted even after working for a short time because they have high cholesterol. Well, now I could relate to that"* (P02)). Other participants reflected upon their own health journey (e.g. *"I'm overweight. So I was thinking about myself"* (P28)). Moreover, several participants reflected on their current behaviour and its impact; e.g. *"it let me think about my consumption of junk food"* (P18).

4.2.4 Agent Perception. Agents can act upon their environment, based on their ability to perceive [56]. In line with the findings from our design workshop, participants experienced the physical agent as responding to either internal or external changes (e.g. *"as the environment changes, external environment or internal, the robot was reacting to that"* (P13)). Few participants indicated perceived intentional agency [26], describing the agent's intent to send a risk message (e.g. *"it was a direct message, ... I was feeling [as if] getting a message from the robot"* (P28)).

Humanlikeness, Realism and Vividness. We identified three qualities contributing to participants' experience: humanlikeness, realism, and vividness of the physical agent. Most participants highlighted the humanlikeness of the agent which helped them relate and build a connection with the agent and the conveyed information (e.g. *"it is behaving like a human. And I'm also human." (P13)*), going as far as to describe the agent as a human itself; e.g. *"it helps *me to empathise with the situation, seeing another kind of human go through it"* (P07). Solely few people were hesitant, describing the agent as somewhat humanlike, or expressing an uncanney valley effect that needed to be overcome (e.g. *"at first it was a bit weird, but when you get used to it, it feels pretty natural"* (P11)). Second, several participants highlighted the realism of the visualisation conveyed through the agent which increased the perceived authenticity (e.g. *"the authenticity is quite real to me"* (P14)). Besides its realism, several participants explained that the liveliness of the agent (e.g. *"it's quite vivid"* (P03)) brought the information and inherent risk to life (e.g. *"I guess it brings it to life. Like what if it was me? What if it was my family? ... it humanises the problem"* (P25)). Notably, eye contact with the agent was highlighted by few participants as a key element for vividness (e.g. *"the eyes they kept moving like real people"* (P26)) and to foster an emotional connection (e.g.*"the eye contact builds more of a connection"* (P25)).

While information acceptance was high across participants indicated by their increased risk perception, willingness to act-upon the risk and to take proactive measures, few participants indicated a certain degree of wariness towards the agent (e.g. *"I will be wary of the truth, whether they are actually representing the real information"* (P14)). Few participants raised the concern that they recognise the agent as a representation of others or as a conduit for presenting information about people, but not as having its own independent thoughts or intentions (e.g. *"It may represent other people in general, but the robot itself, I don't think it will have its own mind"* (P23)). Notably, several participants highlighted the potential to go beyond the agent's face, but to include e.g. sound (P23), dialogue features to tell a story about the hazard (P25) or the agent's body (e.g. P11, P22, P16) to enhance the visualisation experience.

4.2.5 Potential Future Applications. Our qualitative analysis shows that participants were eager to implement a physical humanlike agent to communicate risk in a multitude of contexts.

Public Spaces. The majority of participants mentioned the potential of the visualisation for education (e.g. *"in the classroom so we can have a better understanding of how it actually affects us, rather than reading a block of text"* (P03)) and healthcare (e.g. *"for the nutritionist or for the GP to demonstrate to their patients"* (P06)). Among the public spaces, participants emphasised parks, museums, grocery stores and transportation related applications, i.e. next to a bus stop, traffic light or in the metro station to inform and alert the community. Some participants envisioned such physical agents as tools for public health announcements and warnings, as an indicator for protective actions and for health crisis management (e.g. *"in the city, as warning, if you could combine that with an actual air quality measure and say this is the amount today and this is what you should be doing"* (P01)). Contrarily, one participant envisioned applications in the private space, such as the kitchen to support a healthy lifestyle or in the bedroom to convey the air quality in the morning (P23).

Accessibility. Participants often grounded their application ideas in the enhanced accessibility when using a physical humanlike agent as a visualisation interface for risk communication, which makes it particularly helpful for children, or lay people (e.g. *"they could read the facial expression much better than reading a complex science article"* (P19)) or people with literacy difficulties (e.g. *"in areas where not everyone can read or write"*(P28)). Conversely, few participants challenged the accessibility for the older generation (e.g. *"tech savvy people might find easier to use ... I wouldn't be sure about how people of the older generation would respond to it"* (P01)).

5 Discussion

5.1 Where Risk Communication meets Physical Agents

Our work introduces a novel and complementary approach for risk communication in HCI, which presents physical humanlike agents as effective risk communicators. While our design workshop offers important design considerations for how to leverage the face of a physical agent as a visualisation interface for risk communication (see Section 3.3), our user study demonstrates that a physical agent can bring health risks to life, supports self-projection and reflection, motivates protective actions, and captures interest not despite being provocative, but because of it. We discuss and contextualise our results to inform future research and provide takeaways for HCI. While findings from HRI, virtual avatars and conversational agents are difficult to compare, given differences in the degree of humanlikeness and fidelity between real-world robots, depicted robots on screens and virtual avatars, our aim is not to claim that physical humanlike agents are inherently superior to e.g. virtual agents for risk communication. Instead, our research unveils the unique potential that physical humanlike agents offer, especially with recent advancements in robot facial technology. We emphasise the timely relevance and importance of expanding risk communication research to include such agents to advance HCI research.

The agent brings risk to life. Effective risk communication hinges on the ability to convey potential consequences in a manner that resonates with individuals, to make risks personally relevant and to prompt action. On the topic of climate change, research has suggested that people often struggle to connect environmental risks with their implications for human health [39]. The results from our design workshop and user study show that the face of a physical humanlike agent can effectively convey risks directly tied to the human body, such as LDL cholesterol, and tied to external factors like air pollution. People's risk perception increases after engaging with the risk information conveyed through the agent, reflected in heightened perceptions of severity and affect. Leveraging **a physical humanlike agent as visualisation tool "humanises" the risk and brings information to life due to its high humanlikeness, realism and vividness.** It draws a direct connection from an abstract risk information to the human experience, by making abstract or invisible information more concrete and emotionally resonant through visual cues that mirror or link to human experiences. Our findings emphasise that a physical humanlike agent is more than a static display but perceived as an agent that actively reacts and responds to its environment and embodies information, which is e.g. highlighted by people's perception of mutual gaze in both the design workshop and user evaluation.

People envisioned the physical agent to be deployed in various contexts, from the classroom to the GP office to public parks and museums, which sheds light on the potential of physical agents to communicate risk in-situ, directly within relevant contexts. Interestingly, recent advancements in HCI research introduce agent re-embodiment and co-embodiment [43], both of which present exciting directions for the future of risk communication. Re-embodiment, where an agent’s social presence transfers across multiple physical forms, could enable a personal risk agent to “manifest” in various contexts. Co-embodiment, on the other hand, envisions multiple agent identities sharing a single physical body. This approach could allow a single physical agent to address diverse risks or tailor its communication to different audiences, an interesting avenue for future research.

This is how I would experience it. Alongside an increased risk perception, our results reveal that the visualisation supports self-projection, which **increases people’s personal connection with the consequence displayed**. The ease with which people are able to imagine themselves experiencing a certain risk (imaginability) is an important determinant for feelings of risk, i.e. how vulnerable or at risk participants feel [25]. Our findings show that, instead of trying to identify the messenger, participants put themselves in the agent’s shoes, and imagined how they would *look* and how it would *feel* when experiencing the same physical and emotional state as the agent. Notably, our work reveals a physical humanlike agent as a facilitator for self-projection, since it mimics human features but yet does not simulate a specific person. This balance creates a sense of familiarity and relatability while maintaining a neutral identity, which makes it a versatile tool for risk communication since it can resonate with a broad audience. It raises an intriguing question: How many shared features are necessary for viewers to successfully project themselves onto the agent? Understanding this ‘sweet spot’ could further enhance the ability to connect with diverse audiences, to ensure that risk communication is both impactful and inclusive.

Motivation to take action in response to risk. Several people expressed that the visualisation conveyed through the physical agent allowed them to picture the future, showing the consequences of (in)action. This idea of an agent acting as a bridge to the future-self served as an alarm bell, making participants more alert and aware of potential risks. In addition to people’s tendency to self-project, the visualisation made people reflect and contemplate about past experiences such as childhood events, their own health journey and the health of family members and friends. This so-called self-referencing increases people’s motivation to act upon risks [12, 14]. The finding is somewhat in contrast to findings by Ahn et al. [1] showing that virtual avatars and doppelgänger both increase perceived risk, but virtual doppelgängers were significantly more effective in promoting personal relevance to the health message, mediated by self-referent thought and self-presence.

People further expressed a high motivation to mitigate the risk, to take better care of their health (e.g. through diet or exercise) or to take actions to protect the environment as a means to protect their own health. The different types of facial masks were interpreted as protective actions and welcomed as a guide for better behaviour. The PM2.5 design thus not only conveyed the consequence of the risk, but also suggested what actions should be taken to mitigate these consequences. **This dual focus on consequence and mitigation made the risks relatable *and* actionable.**

Shocking, but interesting. Public health campaigns often use “threat appeals” to induce fear by implementing imagery and graphic displays of negative health consequences [8]. Common examples are smoking campaigns or campaigns to reduce driving speed on highways. When confronted with highly fear-inducing risk images, people’s self-rated probability of experiencing the risk drops significantly [7]. This inverse and defensive response is caused by the fact that it is simply too stressful to engage with the risk at hand [7]. Interestingly, our results show the opposite. Seeing the consequences of both PM2.5 and LDL cholesterol “materialised” on a humanlike face was perceived as provoking and significantly increased affect (i.e. worry, fear, concern). Yet, most people emphasised that **while provoking, the visualisations nevertheless sparked their interest, supported their understanding and increased awareness.** This is in line with critical design research in HCI, “aimed at leveraging designs to make consumers more critical about their everyday lives” [2]. We take into account concern around provocation and re-emphasise our consideration from the design workshop, i.e. that **designers have to identify the delicate balance between provoking —to foster reflection, increase attention and challenge viewers to think— while ensuring not to cause emotional stress and harm.**

5.2 Empathy with Others and Data about People

I feel for others. Our visualisations acted as a facilitator for empathetic concern *for others* — from family members to other groups of people who might be experiencing the consequences of the depicted risks. The physical humanlike agent serves as a conduit for human experiences, which makes it a great opportunity to explore as example driven charts, a currently understudied design approach [48]. Example driven charts are visualisations that use a single person as a representation of many [48]. It is particularly interesting in the light of the “compassion fade effect” — where people’s compassion and pro-social behaviour tend to decrease as the number of suffering individuals increases [69]. This approach has significant implications for risk communication, where statistics (X% people are suffering from ...) are often used to communicate risks. In addition, observing the experience of others who we feel close to, i.e. vicarious experiences, can be an important source of information and affect how we follow protective behaviour or perceive our vulnerability to a health threat [4, 13].

Our work also resonates with research on anthropographics, visualisations designed to evoke empathetic concern by representing people in the data [5]. While prior studies on anthropographics, such as human-shaped icons, resulted in mixed results regarding their impact on pro-social behaviour [5, 42, 47], our findings show the potential of physical humanlike agents as visualisation interfaces to convey data about people who may suffer health consequences or face risks. This opens a new avenue for exploring anthropographics, particularly in the context of physicality and realism, and supports calls for novel design strategies for anthropographics and their effects on prosocial outcomes [48].

5.3 Takeaways

We identified three key takeaways for the use of physical humanlike agents as visualisation interfaces to communicate risk consequences and emotion, which we summarise next. Our implications guide future research in this space, pushing the boundaries of how we design human-centred risk communication in HCI.

- **Making risk relevant to human experience:** Our results demonstrate that the use of a physical humanlike agent as a risk communicator effectively humanises the conveyed risk and makes the negative consequences experienceable and relatable. It can be particularly valuable in contexts where understanding the impact of a certain risk on humans is crucial (e.g. climate change).
- **Suitability to communicate risk in public spaces:** Agent visualisations enhance risk perception, awareness, and understanding. This makes physical humanlike agents particularly suitable for public health campaigns and public spaces such as museums, where the goal is to inform the public about risks, raise awareness, and promote behavioural change.
- **Facilitator for empathetic responses:** By acting as conduits for human experiences, physical agents foster empathetic concern for others who may be affected by the conveyed risks. This is a critical outcome for risk communication when addressing collective challenges like health crises or climate change.

Our work lays the groundwork for using physical agents in effective health risk communication, to inform diverse health applications and future studies in HCI.

5.4 Limitations and Future Work

In this study, we used simulated levels of PM2.5 and LDL cholesterol rather than a real dataset. This approach was intentional, as the primary focus of our work was to explore the use of an agent's face as an interface for risk communication. While this allowed us to thoroughly investigate the potential of this novel approach, we see future opportunities for physical humanlike agents to convey data about real people and real-time data.

We acknowledge that the slider interface may have implicitly conveyed the data range through its endpoints, which may introduce bias by allowing participants to infer values without fully understanding the visualisation. However, we purposefully selected non-extreme values and asked participants to justify their interpretations in their own words. Data comprehension served primarily as a robustness check to support our understanding of participants' interpretations. Future work could explore alternative manipulation interfaces.

Moreover, we used the default setting of Furhat as the visualisation base. Dhawka et al. [11] highlight the need to include diverse human characteristics to better represent demographic groups. We strongly emphasise the potential of this approach to accomplish the latter and for future research to expand this work by elevating the representation of diverse groups through the highly adaptable, humanlike features. Further, we recognise that our work focuses on an agent's face, a deliberate design choice. However, there are several other design opportunities beyond the face. Future research could potentially include multisensory extensions to enhance the visualisation experience, e.g. voice to narrate data stories, or sound effects to create more immersive experiences.

Finally, we quantitatively examined the viewer's risk perception (severity and affect) as we visualised risk consequences. However, we acknowledge that other determinants of risk perception, e.g. perceived efficacy, controllability, or susceptibility [8, 70] exist. Our approach may not capture the full landscape of risk perception affected by our visualisation, but it presents a starting point for future investigations. In line, Schömbs et al. [60] investigated how to communicate probabilities using a robot's embodiment. Future works should examine how to use a physical humanlike agent as an interface to communicate hazard likelihood as the second key component of risk.

6 Conclusion

In this work we explore the use of a physical humanlike agent as a visualisation interface for effective risk communication, i.e. to communicate risk information and emotion. Through a design workshop, we collected design outcomes and insights from experts on how we can use an agent's face as a visualisation canvas for risk. We identified design strategies, challenges and benefits. We deployed visualisation designs depicting health risks on a real-world agent and investigated their effects in a mixed-method user study with 28 participants. Our findings show that using a physical humanlike agent as a visualisation interface for risk communication increases risk perception, perceived severity and effect. Moreover, it facilitates self-reflection, empathy and viewer's motivation to act. Participants also highlighted that this approach would be well-suited for campaigns in public spaces and to educate people on the consequences of important health-related risks.

Our work offers an important and novel approach to leverage physical humanlike agents as effective risk communicators in HCI. By doing so, our goal is not only to communicate negative consequences more effectively, but also to reduce the long-term health, social, and economic burdens on society by making risks relatable, easy to understand, and actionable.

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A Semi-structured Interview: Design Workshop

- "Please pick and quickly present your favourite visualisations for each category."
- **Opening Question:**
  - "Which visualisation impressed you most and why?"
- **Design Process and Experience:**
  - "How did you proceed to map data onto a robot's face or encode data?"
- **Key Questions:**
  - "Please describe challenges you have faced during your design process, e.g. design constraints when using a robot to visualise affective data."
  - "Could you please elaborate on why you think a robot's face could be useful or not useful in conveying data affectively, and if you can think of potential pitfalls?"
  - "We gave you one specific robot—what did you miss to better convey data, and what else could the robot be doing to visualise data?"

B Semi-structured Interview: User Study Evaluation

- **Data Exploration:**
  - "Could you please walk me through your exploration?"
  - "What did you observe as you adjusted the slider to different values?"
- **Risk Perception:**
  - "Can you explain to me the risks associated with the data shown in the two scenarios?"
  - "Did viewing the visualisations change how you perceived the risk of each topic? If so, how?"
  - "In what ways did using a robot's face for the visualisation help or hinder your understanding and perception of the risk?"
- **Affective Responses:**
  - "What did you feel when viewing these visualisations?"
  - "Did the visualisations make you imagine yourself in the robot's position or the position of someone affected by the data presented? If so, how?"
  - "Can you describe that experience?"
- **Agency and Anthropomorphism:**
  - "How did the human-like features of the robot influence your emotional connection to the data and the topic?"
- **Self-Reflection and Introspection:**
  - "Did viewing the visualisation make you reflect on your own life and experiences? If so, how?"
- **Motivation to Act:**
  - "Do you think that the visualisation motivates you to take any action regarding particulate matter or cholesterol?"
  - "If so, what actions do you feel inspired to take?"
- **Application Context:**
  - "Can you think of potential applications or use cases for robot's visualising data?"
- **Ending Question:**
  - "What did you like or dislike about the visualisation?"
  - "Is there anything else you would like to add or mention?"