Office for Product Safety & Standards

UK Public's Tolerance of Risks from Products with Internet Connectivity in the Home (Smart Products)

Research

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Executive Summary

The aim of the present studies was to investigate the risk tolerance profile of consumer products with internet connectivity (CPIC) (e.g., voice assistants, smart TVs, smart doorbell, smart baby monitor, smart glasses). All three studies were nationally representative (Study 1 (2023), N =854, Study 2 (2025), N = 1500 Study 3 (2026), N = 460). Using Study 1 as a baseline it was possible to examine the dynamics of risk tolerances for the same products across 2025 and 2026.

The methods employed in all three studies were the same. The studies were conducted online, and participants were required to give their responses to a standard set of questions that involved making appraisals of 5 CPIC. The 5 CPIC were randomly selected from a total of 10 (smart: watch, pet feeder, speaker, doorbell, toothbrush, door lock, robot sweeper, teddy camera, connected children's toy and bluetooth tracker) in Study 1, and 15 (the same as Study 1 along with smart: glasses, oven, baby monitor, drill, smoke detector) in Study 2 and 3. There were 9 measures of risk in total (familiarity, frequency of use, benefits, worry, controllability of hazards, knowledge of risks, concern about data usage, vulnerable groups' interactions with the product, risk considerations at the point of purchase) for which responses were given on a 7-point Likert scale. The approach used was a typical psychometric method in risk analysis research to investigate public perceptions of risk. The novel adaption employed in the present project was to investigate risk tolerance which is based on previous academic research (Hunte et al., 2024; Jenkins, et al., 2024; Jenkins & Osman, 2026).

The statistical analysis used was a principal component analysis which revealed two components (consisting of concern and benefits) that were found to explain 89.3% of the variation in 9 risk ratings in Study 1, 87.4% of the variation in Study 2, and 86.8% of the variation in Study 3. Examining trends across time using Study 1 as a baseline, overall in Study 2 while benefits for the 10 smart products remained broadly at the same levels as Study 1, there was a general decrease in concerns. When comparing Study 3 with Study 1, there was a more pronounced increase in perceived benefits and further reduction in perceived concerns. We also observe the same general trend between Study 2 and 3 for the 5 additional products with the exception of smart glasses, with a marginal increase in perceived benefits, but also an increase in concerns.

Overall, the findings presented here show that over a short period of time (2 to 3 years) the public tend to show greater tolerance of risks that CPIC present. However, if anything this trend is largely with respect to perceiving greater benefits from them rather than dramatic reductions in concerns. The important aspect of this research is that, unlike many previous studies examining CPIC with respect to user perceived benefits and risks, adoption and general concerns, the work here explores tolerances of risk of specific CPIC, and also how they are perceived relative to each other. Crucially not all CPIC are perceived in the same way, which also means that any efforts to regulate them needs to careful develop taxonomies that group them (e.g. by functionality, by complexity, hybrid hazards, hybrid harms) for which there is emerging research to support this. By classifying them, this will help more efficiently determine and anticipate associated hazards and harms, along with the patterns of user behaviour as revealed through perceived tolerances of risk.

Introduction

Patterns of behaviour around early "smart products"

In the mid 1980s there were prototypes of industrial robotic vacuum cleaners, the commercial version was prototyped in the mid 1990s and on the market in 2001 (Juzovitski, 2011; Prassler et al., 2000). While the functions are the same, current designs are voice activated (e.g. Midhun et al., 2024) can map the layout of the home, and enable remote scheduling (e.g. Manasa et al., 2021; Nishad et al., 2025). As a case study, we can ask, what has changed in the 25 years of experience of this product and how has our understanding of the concerns and benefits of them apply to general views of consumer products with internet connection in the home (CPIC) (i.e. smart products).

Using established measures of perceived risks (Jacoby & Kaplan, 1972) the findings indicated that robotic vacuum cleaners, as with semi-automated washing machines, were attributed with risk across a number of dimensions (e.g. performance loss, inefficiency, financial risk, psychological risk, social risk) along with privacy and security (Rijsdijk & Hultink, 2009; Sung et al., 2009; Sung et al., 2010; Vaussard et at., 2014). Many of the concerns that emerged in early adoption user studies included damage to furnishings in the home (property damage), tripping over the appliance and injuring pets (physical harms), upfront costs and maintenance (financial harm), as well as security and privacy (Fink et al., 2011; Fink et al., 2013; Denning et al., 2009; Sung et al., 2009). Many of these concerns generalise across time to smart vacuum cleaners that are on the market, and the reason is that the same ongoing practical issues still apply. User experiences reported in recent studies converge on the same reported experiences, which is that smart vacuum cleaners are not reliably efficient at collecting different sized dust particles, they struggle to access narrow spaces, maintenance is a burden, there is a worry that they can room map, their battery life is limited, and they do not show high energy efficiency (e.g., Nicholls & Strengers, 2019; Megalingam et al., 2025; Said et al., 2024).

Along with perceptions of risks and general concerns, much of the early work investigated usage of automatic vacuum cleaners, several were longitudinal (1 month to 6 months) (e.g., Fink et al., 2011; Fink et al., 2013; Hertzum, 2024; Sung et al., 2009; Sung et al., 2010; Vaussard et at., 2014). Longitudinal studies were important because they were informative of the utility of the appliance past the initial novelty phase of ownership which could bias interpretations of adoption. The findings consistently showed that autonomous robotic vacuum cleaners were used as an adjunct rather than a substitute for manual house cleaning routines (Rijsdijk & Hultink, 2009; Sung et al., 2009; Sung et al., 2010; Vaussard et at., 2014). In fact, this pattern holds to date, as revealed through survey work, ethnographies and diary studies (Avci et al., 2024; Hertzum, 2024; Nicholls & Strengers, 2019; Shiokawa et al., 2025; Wilson et al., 2017; Yu et al., 2024).

Much of the qualitative and quantitative pattern of findings of appliances with some semi-automate functionality is that potential adopters and users make pragmatic evaluations by weighing up their concerns against the perceived range of benefits. Just as the market for CPIC has grown, so too has the intensity of studying many of the same questions that were considered 20 or so years earlier in the advent of devices in the home that operated semi-autonomously. Two areas of particular interest which are worth considering with respect to early work in this area are what continue to be barriers to adoption, and whether there are substantive changes in the perceived benefits of CPIC.

Barriers to adoption

Several factors were explored to understanding the adoption or barriers to adoption of robotic vacuum cleaners in the home. For instance, the impact on perceived risk when increasing levels of autonomy of the product, which was found to be positively correlated (Rijsdijk & Hultink, 2003, 2009). Similar patterns are found for smart vacuum cleaners (Franzmann, et al., 2018) and when directly compared to their non-smart counterparts (i.e. manual vacuum cleaner) (e.g. Hunte et al., 2024). Perceived risk was found to be inversely associated with utility at the time the products were first introduced (e.g., Rijsdijk & Hultink, 2003) and the same pattern is found for smart vacuum cleaners now (Hunte et al., 2024; Yang & Li, 2024).

In present research on CPIC, barriers to adoption of CPIC are used as a proxy for the types of concerns that the public have and the risks they associated with them. For instance, Koblas et al., (2019) presented a sample of 415 participants several CPIC (security cameras, door locks, light switches and bulbs, thermostats, air conditioners, washing machines, cookers, coffee machines, radios, and music players) for examination of perceived security risk, controllability, intention to use and attitudes towards usage. Koblas et al., (2019) presented analyses of the dependent variables collapsed across all of the products to present a general picture that suggested that while only 15% of the sample owned CPIC, attitudes towards them and perceived control played a direct role in negatively impacting interests in purchasing and using the CPIC, and that this was mediated by perceived security risks. Seymour et al., (2024) citizen's assembly study was designed to elicit the general attitudes and scepticism of smart home adoption, where they provided their sample of 20 respondents example of products that would constitute a smart home (heating, lighting, temperature, alarm, entertainment). Here also the focus was to ascertain overall attitudes and concerns towards a smart home rather than specific products per se, with the main concerns based around data control, privacy and trustworthiness specifically concerning how exposed they would be to security breaches, hacks, and data theft and fraud. In contrast, Mani and Chouk (2017) surveyed 402 respondents' perceived usefulness, control, price, privacy concerns of a smart watch. The findings indicated that several factors negatively impacted attitudes towards the smart watch, in particular perceived uselessness, its likely high cost, and intrusiveness which was strongly linked to privacy concerns. While this does provide valuable insights, they are specific to a single smart product, and so it is hard to determine how different the attitudes would be when contrasted with other CPIC.

Overall, we see some factors that preserve over time that influence decisions around adoption of semi-automated appliances in the home and current CPIC, the two most obvious being the level of self-initiated functions of the product (i.e. how smart/sophisticated its functions are), and the other is security and privacy (i.e. control over data collection and usage). While the capabilities of semi-autonomous and autonomous devices in the home have advanced to the connected networked, they are also evolving to include artificial intelligence assisted systems within them, at the core, at least two practical core concerns remained the same.

Perceived benefits

When it came to the benefits of automated vacuum cleaners, early work showed a considerable level of consensus. Users primarily referred to the importance of their ability (or potential) in saving time, at least for designated areas the devices were able to clean, reducing energy consumption (e.g., Rijsdijk & Hultink, 2003; Rijsdijk & Hultink, 2009; Sung

et al., 2009; Sung et al., 2010). As the technology evolved, then potential adopters as well as users attributed high utility to multi-attributes (e.g. variable adjustment of suction, surfaces, energy efficiency modes) automated vacuum cleaners (Rijsdijk & Hultink, 2009; Sung et al., 2009; Sung et al., 2010).

To understand the potential benefits of CPIC, Shank et al., (2021) first examined respondent's knowledge and familiarity with several fictitious descriptions of smart pet collar, smart pet cam, smart doorbell, smart security camera, smart door lock, smart house lights, smart thermostat, smart oven and smart refrigerator. The products were grouped into categories (e.g. pet care, outside doors, lights, security, food storage, temperature, cooking) or else the patterns of responses were collapsed across all products. Overall the findings showed that there was a positive relationship between familiarity and perceived benefits, where the benefits concerned overall cost reduction, having a technologically advanced home, safety, time saving and having remote monitoring and control functions. In addition, compared to smart product owners, non-smart product owners were likely to adopt products into their home if the perceived benefits spanned all dimensions studied (i.e. money, safety, fun, time, easy, controllability, advanced technological home).

In their qualitative study, Shank et al., (2021), 8 of the student participants were living in student accommodation that had 10 CPIC, and so for 12 months their experiences were measured. The overall benefits of using the products remained stable over the period, also products weren't judged as easier to use over time, or that they increased in reliability with more experience of using them. Over time there was a marginal drop in overall usage of the 10 products, though this was based on self-reported usage (i.e. 7-point scale from 1-I have never used it to 7-I use it all the time). Wang et al (2018) examined perceived benefits (i.e. Performance Expectancy – improve handling household chores, Effort Expectancy – ease of use, Compatibility – supporting the individual/household way of life, Image – enhancing personal reputation and image) against perceived risks (Privacy Risk – losing control over data and it being collected without consent, Security Risk – security breaches, Performance Risk – doesn't meet expectations, Time Risk – is too labour intensive to use, Financial Risk – too costly to buy and maintain). A general description of a smart home was provided, along with examples of CPIC (e.g. security cameras, door locks, light switches and bulbs, thermostats, air conditioners, washing machines, cookers, coffee machines, radios, and music players). However, participants were required to respond to the benefits and risks ratings for the overall description of the smart home imagining the products listed, rather than judge the risks and benefits of each. There were differential effects of benefits and risks on adoption, where benefits strongly effected intention to have a smart home, suggesting that while risks were perceived they were forgone because the overall benefits were perceived to be greater.

Consistent with this, Wilson et al (2017) provided a general description of a smart home to 1025 respondents in a national UK survey, and also found likelihood of adoption was based on familiarity, and the overall benefits were higher than the risks, which were still perceived but less influential on adoption. In addition, the survey found that the majority agreed that a smart home would make their lives convenient – energy saving, time saving and money saving (83% agree or strongly agree), provide security (71% agree or strongly agree), and increase their access to entertainment (60%). These were judged against risk which were increased dependency on the products leading to adverse changes in habits (77% agree or strongly agree) and increasing usage of energy (63% agree or strongly agree), while fewer indicated privacy (38% agreed or strongly agree) or intrusiveness (34% agreed or strongly agree) as risks.

Looking across the early work examining appraisals of automated vacuum cleaners, there are three common features that were attributed as benefits, time saving, energy saving, and having choice over functions. The first two continue to be the main perceived benefits that are attributed to CPIC to date. As the sophistication of their capabilities has increased, the perceived benefits of CPIC have also increased to include, cost saving, and that they can better fit around a household's daily routine.

Evidence gaps addressed by the present empirical project

The main focus of this review has been to highlight two patterns in the early studies on automated appliances and current work on CPIC. First, there appear to be fundamentals in the barriers to adoption which reflect the concerns surrounding these types of consumer products, and that there are some core perceived benefits that remain the same across time. Second, spanning 20 years of investigation, and across disciplines, studies show that potential adopters and users make pragmatic evaluations trading off their concerns, and the potential risks they attribute the "smart" appliances, against the benefits. However, it is only in the past 2 years that work has started to look at concerns and benefits to enable a profiling of CPIC to understand user behaviour. Recent work has explicitly examined this and has shown that for a range of consumer products risk perceptions alone are less predictive of choice behaviour than risk tolerance (a trade-off between risk/concern and utility) (e.g. Jenkins et al., 2024); modelling work was able to show how informative measures of risk tolerance were for evaluation of smart and non-smart equivalents (Hunte et al., 2024), and for a range of smart products (Jenkins & Osman, 2026).

Jenkins and Osman (2026) were the first to use the risk psychometric method to examine risk tolerances and causes of harms for 10 CPIC (Smart: pet feeder, speaker, teddy camera, connected children's toy, doorbell, toothbrush, bluetooth tracker, door lock, robot sweeper, watch). Participants gave 9 ratings which when analysed revealed two dimensions which were predicted based on prior work suggesting, as is the case in the present literature review, that people make trade-offs based on concerns/risks against benefits. Jenkins and Osman's (2026) risk map located the 10 products on two dimensions concern (e.g., worried about potential risks, controllability, concern around data handling) and benefits (e.g., familiarity, frequency of usage, personal benefits). Some of the products that were perceived as most beneficial were smart door lock, smart speaker, smart doorbell, and smart Bluetooth tracker. However, at the same time they were also perceived as the most concerning along with the smart teddy bear.

What the mini review of the literature reveals is that there are stable patterns in the concerns and benefits that people attribute to semi-automated/automated devices and CPIC. Jenkins and Osman's (2026) study was conducted in 2023, and so this is used as a baseline to examine risk tolerances of CPIC over time (Study 2 – 2025, Study 3 – 2026). The original study contained 10 CPIC which were used in Study 2 and 3, however, an additional 5 other CPIC were included in the latter two studies. The rationale here was that as new products come onto market they can be included, and can be examined with respect to potential stable patterns in public perceptions of CPIC that are more established. The present study is exploratory, and so no precise predictions were made. The overarching research questions were:

1. Are there stable trends in public tolerances of risk of a range of CPIC over a short span of time?
2. Do public tolerances of risk generally tend towards increasing over time for the same range of CPIC?

Methods

The details regarding the sampling method, design, procedure are the same for all three studies, so this section is organised in a way that reports on the details of the three studies together rather than separately.

Participants

Study 1

A nationally representative sample of 854 participants was recruited from the online participant platform Prolific Academic (www.prolific.ac). Participants were required to be over 18 (in order to meet ethical requirements), to have an approval rate of 95-100% and to be located in the UK. Participants were paid £1.70 for the study. Participants were excluded for completing the study unreasonably quickly (<5 minutes), had not fully completed the study, or if their responses for any of the ratings of products had a SD < 0.5, leaving a final sample of 791, for characteristics see **Table 1**. Informed consent was obtained from all participants. Ethical approval was granted from the University of Leeds Research Ethics Committee (AREA 17-055). All methods were carried out in accordance with relevant guidelines and regulations.

Study 2

The same conditions applied as above, but in this case a nationally representative sample of 1500 participants was recruited, and were paid £2.00 for the study. When applying criteria (e.g., incomplete response, unreasonably quick) the final sample of participants was 1454, for characteristics see **Table 1**. Informed consent was obtained from all participants. Ethical approval was granted from the Cambridge Judge Business School ethics board, University of Cambridge (CJBS- 25-34).

Study 3

The same conditions applied as above, but in this case a nationally representative sample of 460 participants was recruited, and were paid £6.00 for the study. When applying criteria (e.g., incomplete response, unreasonably quick) the final sample of participants was 457, for characteristics see **Table 1**. Informed consent was obtained from all participants. Ethical approval was granted from the Cambridge Judge Business School ethics board, University of Cambridge (CJBS- 25-34).

Table 1. Characteristics of Sample of Study 1, 2 and 3

Demographic	Category	Study 1 (%)	Study 2 (%)	Study 3 (%)
	Total sample post exclusions (n)	791	1464	457
Gender	Male	49.2	47.8	48.8

	Female	50.3	51.8	50.1
	Not specified, stated	0.3	0.3	0
	Prefer not to say	0.1	0.1	0.2
Age	18 - 24	8.3	8.3	11.6
	25 - 34	26.2	16.9	17.1
	35 - 44	29.6	17.5	16.2
	45 - 54	17.6	18.4	17.1
	55 - 64	11.5	26.5	29.8
	65+	6.8	12.1	8.3
	Prefer not to say	0	0.2	0
Children under the age of 18	None	63.0	70.8	66.3
	Prefer not to say	0.5	0	0.4
	Yes, aged between 0-10	0.3	12.5	16.4
	Yes, aged between 11-18	7.3	11	12
	Yes, aged between 0-10 & 11-18	9.0	5.1	4.8

Materials

Study 1

Included ten CPIC that were available on the market including their prevalence and topicality (Statista, 2023): (smart: pet feeder, speaker, teddy camera, connected children's toy, doorbell, toothbrush, Bluetooth tracker, door lock, robot sweeper and watch). Each product was presented with a short descriptive sentence to provide context, though no mention of associated risks or benefits was made. For the full list of products and their associated descriptions (see **Table 2**).

Study 2 and 3

Included the exact same ten CPIC as Study 1 but also included 5 additional CPIC (smart: glasses, oven, baby monitor, drill, smoke detector) that are available on the market with variation in their prevalence and topicality (see Osman, 2026)[1]. Because 10 of the CPIC were the same across all three studies, it was possible to conduct analyses to track trends in changes over time for the same dependent measures used to determine perceived risk tolerance.

Procedure

All three studies were run using the Qualtrics online survey platform (www.qualtrics.com). Before beginning the main study, participants were asked a series of demographic questions. They were asked to indicate: gender (male/female/other – please specify/prefer not to say); age; if they had children under the age of 18 (Yes – aged between 0-10/Yes – aged between 11-18/Both/No/Prefer not to say) and two questions on attitudes towards new technology and CPIC. They were also asked for their Prolific ID, used for payment.

Participants were randomly presented with five of the ten products to rate (in Study 1 this was the case, but in Study 2 and 3 it was five out of 15 products) and asked to assume that they owned the product if they did not already. Each product was rated on a series of

[1] Remember to cite the OPSS gov.uk paper.

nine characteristics (see **Table 3)**, using a 7-point Likert scale presented in a randomised order.

Risk characteristics were largely selected on the basis of their use in previous psychometric studies of consumer products (Jenkins et al., 2024; Vaubel & Young, 1992a; Wogalter et al., 1986, 1987; Young et al., 1992; Young & Laughery, 1994) and in relation to attributes of smart products (e.g., use of data).

The complete list of characteristics and response scales can be found in **Table 3**. Several other dependent measures were included in each of the three studies, and the full set of survey questions, and all raw data collected for each study can be found https://osf.io/cguj4/overview (Study 1, 2) and here https://osf.io/q9y6g/overview (Study 3). Once the study was completed participants were thanked, debriefed, and given a code to claim their payment.

Table 2. Products and Associated Descriptions.

Product	Description
Smart Pet Feeder	A device that automatically feeds pets food at regular intervals, often with metering and remote control options.
Smart Speaker	An audio device that connects to the Internet and features a voice assistant that can play music, answer questions, and control smart home devices through voice commands.
Children's Teddy Camera	Smart surveillance cameras in the shape of teddy bears, capable of video recording, real-time monitoring and remote access.
Connected Children's Robot Toy	A robot provides interactivity and educational features such as teaching language, maths, or programming skills, which is aimed at elementary school students (3-12 years old) age groups.
Smart Doorbell	A doorway-mounted device that provides real-time video surveillance, voice calls and remote access control via a mobile app or cloud connection.
Smart Toothbrush	An electric toothbrush equipped with sensors and connectivity to track brushing habits, provide real-time feedback and syncs with mobile apps.
Bluetooth Tracker	A small device that connects to a mobile phone via Bluetooth technology and is used to help locate and track the location of items.
Smart Door Lock	A door locking system equipped with electronic or wireless technology that allows for convenient and secure access control via password, fingerprint, mobile app or remote control.

Robot Sweeper	A robot that automatically cleans floors, using lasers, cameras or sensors to navigate and clean the floor.
Smart Watch	A smart wearable device, usually connected to a mobile phone, that provides functions such as time display, health monitoring, notification alerts and exercise tracking.
Smart Glasses	A smart wearable device that includes a microphone, speaker and camera for accessing features like a mobile internet browser, camera, maps, calendar, and other apps through voice commands
Smart Baby Monitor	A device that has built in video and audio monitoring, motion detection, to allow for remote health tracking of the breathing and heart rate of the baby
Smart Oven	An appliance that can be controlled remotely via a smart phone or other connected device for adjusting the temperature, accurately setting the cooking times of foods, and making energy saving recommendations.
Smart Drill	A smart power tool that has automated adjustments to enhance drilling accuracy, efficiency in drilling times, and energy efficiency.
Smart Smoke Detector	A smart device that automatically detects the presence of smoke and carbon monoxide and alerts occupants via an audible alarm and sending notifications to a smartphone or other connected device.

Table 3. Main dependent measures used to determine risk tolerance

Product Characteristics
Familiar How familiar are you with the above product? *(Not at all familiar to Extremely familiar)*
Frequency If you own (or were to own) the above product, how often would you use it? *(Never to Daily)*
Benefit Estimate what you think the level of benefit is associated with the above product to you personally? *(No benefit at all, Very great benefit)*
Worry How worried are you about the potential risks associated with the use of this product? *(Not worried at all, Extremely worried)*

Control If exposed to the product, to what extent can you, by personal skill, diligence or training, avoid the hazards associated with the above product? That is, how much control do you have over being harmed by the product? *(No control at all, Total)*
Knowledge of Risk To what extent are the risks associated with this product known precisely to the persons who are exposed to the risk? (*Completely unknown to Known Precisely)*
Concern about Data Usage When using this product, how much are you concerned by how the product stores and uses your personal data for its personalized operation? *(Not at all concerned to Extremely concerned)*
Vulnerable Groups Interaction To what extent do you agree that vulnerable groups (such as children or the elderly) use or interact with the above product more than other groups of people? *(Completely disagree to Completely agree)*
Consider Risk when Purchasing If you were to purchase/have purchased this product, how much would/did you consider the potential risks associated with its use? *(Would not consider at all to Would consider a lot)*

Results

The first pattern to consider overall is in the mean ratings that participants gave for the 9 dependent variables (see **Table 4**), which at gross levels indicates the degree to which there is consistency over time. To make the studies comparable, the patterns were examined with respect to the 10 CPIC that were presented in each study.

Table 4. Mean ratings (Standard Deviation) of each of the 9 dependent variables in Study 1, Study 2 and Study 3 across the 10 CPIC that were presented in all three studies.

Risk Dependent Variables	**Study 1, n = 791**	**Study 2, n = 1464**	**Study 3, n = 457**
Worry	***M* = 3.8** (SD = 1.9)	***M* = 3.6** (SD = 1.9)	***M* = 3.5** (SD = 1.8)
Control	***M* = 4.3** (SD = 2.3)	***M* = 4.5** (SD = 1.6)	***M* = 4.7** (SD = 1.7)
Concern about data Usage	***M* = 4.1** (SD = 2.5)	***M* = 3.9** (SD = 2.0)	***M* = 3.8** (SD = 2.0)
Consider risk when purchasing	***M* = 4.4** (SD = 2.9)	***M* = 4.1** (SD = 1.9)	***M* = 4.1** (SD = 2.0)
Familiarity	***M* = 4.1** (SD = 2.0)	***M* = 4.1** (SD = 2.1)	***M* = 4.6** (SD = 2.0)
Frequency	***M* = 4.7** (SD = 2.1)	***M* = 4.8** (SD = 2.1)	***M* = 5.3** (SD = 2.0)
Benefits	***M* = 4.1** (SD = 1.9)	***M* = 4.3** (SD = 1.9)	***M* = 4.8** (SD = 1.9)
Knowledge of Risk	***M* = 3.7** (SD = 2.3)	***M* = 3.6** (SD = 1.6)	***M* = 3.7** (SD = 1.7)
Vulnerable groups interactions	***M* = 3.7** (SD = 2.5)	***M* = 3.7** (SD = 1.8)	***M* = 3.7** (SD = 1.8)

Preliminary analyses using the F statistic were conducted on the mean ratings for each of the 9 dependent variables for each of the three studies to determine if there were differences in rates by the three study periods. Analyses are reported based on effect sizes, where any analysis that reached the level of low (partial eta squared = 0.01), medium (partial eta squared = 0.06) or large (partial eta squared = 0.14) are reported.

The first thing to highlight is that looking at main effects, we do not see a substantive effect of study, ($F(2, 10477) = 26.29$, $p < .001$, partial eta = .005), which means that overall, at a gross level the effect of Study (Study 1, 2, 3) on ratings for the 9 dependent variables is extremely weak. Instead, we do see a large effect of product, that is for the 9 dependent variables, ratings were impacted by the specific CPIC itself ($F(9, 10477) = 84.05$, $p < .001$, partial eta = .068). There is also no substantive interaction effect (Study x Product), that is the extent to which ratings were impacted by specific CPIC when presented in the three different studies ($F(18, 10477) = 1.07$, $p = .381$, partial eta = .002).

Looking at ratings for the 9 dependent variables, the only effect that was low was benefits ($F(2, 10477) = 71.2$, $p < .001$, partial eta = .013), in all other comparisons, even where the analyses were significantly past the alpha (0.05), the effect sizes were well below the low threshold of an effect size. To explore this in more detail, independent t-tests (2-tailed) were conducted comparing rating of benefits between Study 1 and Study 2 ($t(8957) = 3.35$, $p< .001$, d'[2] = 1.90), between Study 1 and Study 3 ($t(5602) = 11.91$, $p< .001$, d' = 1.88), and between Study 2 and Study 3 ($t(6397) = 9.70$, $p< .001$, d' = 1.90). What the findings suggest is that there are large effect sizes for each of the comparisons, where over time, from 2023 to 2025 overall ratings of benefits of the 10 CPIC increased, and between 2023 to 2026, they increased, and also between 2025 and 2026.

Even with such a large set of data, the only main impact for which time suggests that there is a change for benefits, which as **Table 4** indicates, increases over time, collapsed across all 10 CPIC. Put another way, what we see are highly stable responses to the 9 dependent variables across time, where there doesn't appear to be substantives effect over time on the ratings provided. What we do see are substantive differences in ratings based on the individual CPIC (see **Table 5**).

Applying the same thresholds here, analyses are reported where the effect sizes are large (i.e. partial eta squared = 0.14), especially because multiple comparisons risks there being an increased chance of finding effects. Using a multivariate analysis we find that for familiarity ($F(9, 10467) = 341.96$, $p < .001$, partial eta = .23), usage ($F(9, 10467) = 285.91$, $p < .001$, partial eta = .20), benefits ($F(9, 10467) = 155.61$, $p < .001$, partial eta = .12) and worry ($F(9, 10467) = 203.98$, $p < .001$, partial eta = .15). There were either low or moderate effects of products on ratings of controllability, known risks and considering risk when purchasing, data concern and vulnerable users.

For familiarity we see the lowest ratings of familiarity for the Children's robot toy and Children's Teddy Camera, and the greatest familiarity for Speakers and Watch (see **Table 5**). For usage, we see the lowest ratings for the Children's Teddy Camera and Children's robot toy, and the greatest usage for the Toothbrush and Watch. Regarding benefits we see the lowest ratings for the Children's Teddy Camera and Children's Robot Toy, and the greatest benefits for the Watch and the Doorbell. For worry, the greatest worry was for Children's Teddy Camera and Children's robot toy, and the lowest worry was for the Toothbrush and Vacuum Cleaner. There is a clear pattern emerging which suggests that for CPIC aimed at children familiarity, usage and benefits are low and with the greatest level of worry of all 10 CPIC.

[2] *d'* this refers to Cohen's d which is an indication of effect sizes, as a rough guide, low = 0.2, medium = 0.5, low = 0.8, very large = 1.3

Table 5. Mean ratings (Standard Deviation) of each of the 9 dependent variables in Study 1, Study 2 and Study 3 across the 10 CPIC that were presented in all three studies.

CPIC	Pet feeder	Speaker	Teddy Camera	Child's Toy	Door Bell	Tooth Brush	Bluetooth Tracker	Door Lock	Vacuum Cleaner	Watch
Risk Dependent Variables										
Worry	**3.01**	**3.75**	**4.87**	**4.03**	**3.65**	**2.57**	**3.78**	**4.79**	**3.00**	**3.07**
	1.76	1.83	1.81	1.80	1.73	1.61	1.75	1.67	1.66	1.74
Control	**4.70**	**4.28**	**3.97**	**4.23**	**4.40**	**4.78**	**4.33**	**4.15**	**4.78**	**4.69**
	1.71	1.65	1.72	1.61	1.64	3.66	1.66	1.56	1.56	1.61
Concern about data Usage	**2.78**	**4.67**	**5.21**	**4.31**	**4.31**	**2.74**	**4.40**	**4.45**	**3.04**	**4.05**
	1.79	1.82	1.74	1.89	1.82	3.66	1.80	1.87	1.82	1.82
Consider risk when purchasing	**3.59**	**4.29**	**5.19**	**4.56**	**4.32**	**3.22**	**4.28**	**5.23**	**3.74**	**3.74**
	4.87	1.83	1.68	1.85	1.75	1.88	1.78	1.63	1.79	1.79
Familiarity	**3.40**	**5.75**	**3.29**	**2.74**	**5.15**	**3.73**	**4.32**	**3.49**	**4.29**	**5.56**
	1.93	1.51	1.80	1.70	1.73	2.10	1.86	1.90	1.84	1..63
Frequency	**4.74**	**5.02**	**3.21**	**3.27**	**5.77**	**5.96**	**4.18**	**5.37**	**5.14**	**5.78**
	2.25	1.90	2.10	1.89	1.67	1.88	1.85	2.06	1.65	1.77
Benefits	**3.97**	**4.56**	**3.08**	**3.25**	**4.93**	**4.58**	**4.36**	**4.04**	**4.85**	**5.13**
	2.01	1.71	1.87	1.94	1.67	1.92	1.73	1.78	1.71	1.55
Knowledge of Risk	**3.54**	**3.81**	**3.58**	**3.03**	**3.84**	**3.62**	**3.79**	**3.95**	**3.74**	**3.87**
	1.68	1.51	1.67	3.54	1.50	1.73	1.54	1.51	1.59	1.59
Vulnerable groups interactions	**3.11**	**3.78**	**4.66**	**5.51**	**3.71**	**3.05**	**3.71**	**3.34**	**3.30**	**2.98**
	3.58	1.66	1.88	1.56	1.73	1.65	1.74	1.72	1.72	1.59

Risk Tolerance

The main inferential statistic applied to participants' 9 dependent measures of the five CPIC randomly presented to them is the principle component analysis (PCA) which was used to develop the metric of risk tolerance. To start with, there was no need to standardise the ratings, because each of the 9 ratings were on the same scale. To ensure that the scores met the conditions of the PCAa correlation matrix was created, featuring all of these variables, in order to check that all of the variables had at least one correlation where $r \geq 0.3$ (Tabachnick & Fidell, 2001). All of the variables did and thus were retained for the primary analysis, this carried out for each data set collected for each of the three studies.

A PCA was subsequently conducted on the aggregated data for Study 1, and separately for Study 2 and again for Study 3, using a Varimax rotation. Note that the analyses were only based on ratings for the same 10 CPICs that were present in each of the three studies. The PCA applied to each of the three data sets revealed a two-component solution. For Study 1, the PCA explaining 89.3% of the variance, for Study 2 87.4% of the variation was explained and for Study 3 86.8% of the variation was accounted for (**see**

Table 6). The first component termed **concern** (Study 1, 50.2%; Study 2, 46%; Study 3, 46.6%) consisted of 'worry' (extremely worried), 'control' (no control at all), 'concern' (extremely concerned), and 'consider risk when purchasing' ('would consider a lot'). The second component termed **benefits** (Study 1, 39.1%; Study 2, 41.1%; Study 3, 40.1%) consisted of 'familiarity' (extremely familiar), 'frequency of use' (daily), 'knowledge of risk' (known precisely), benefit (very great benefit), 'vulnerable groups interaction' (completely disagree). Higher scores on the concern component were positively correlated with scores on the benefits component, indicative of high levels of risk tolerance.

Table 6. ***Loadings from the PCA – Aggregated Data for Study 1, Study 2 and Study 3 for the same 10 CPIC.***

	Study 1		**Study 2**		**Study 3**	
	Component		**Component**		**Component**	
Risk Dependent Variables	Concern (50.2%)	Benefits (39.1%)	Concern (46%)	Benefits (41.4%)	Concern (46.6%)	Benefits (40.1%)
Worry	.956		.944		.946	
Control	-.978		-.877		-.974	
Concern about data Usage	.980		.924		.906	
Consider risk when purchasing	.939	-.171	.955	-.203	.914	-.261
Familiarity		.854		.873		.809
Frequency	-.518	.768	-.457	.774	-.447	.828
Benefits	-.496	.822	-.446	.864	-.469	.841
Knowledge of Risk	.101	.949	.182	.921	.243	.911
Vulnerable groups interactions	.524	-.734	.511	-.719	.464	-.769

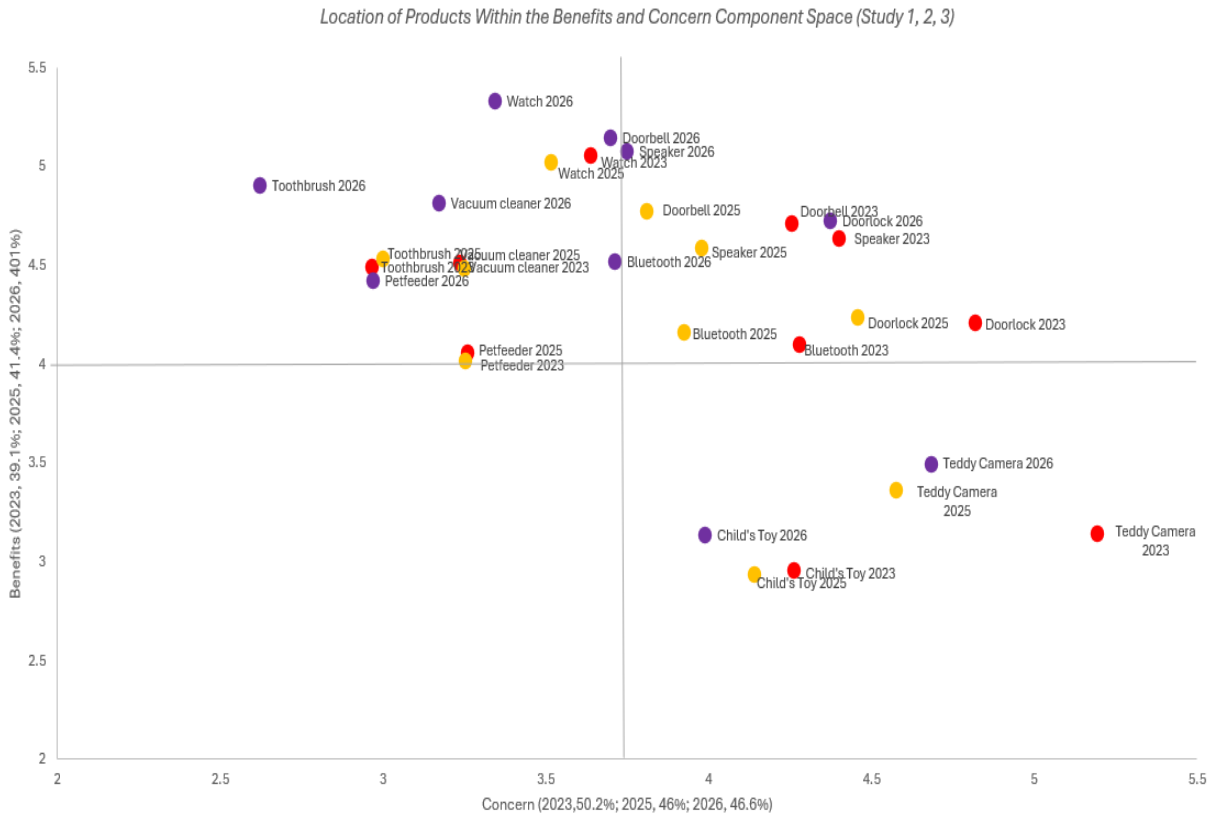
Having identified the two components, it was then possible to plot each of the 10 CPIC by study onto a risk tolerance map to reveal if there are stable responses which would be indicated by the CPIC appearing close to each other in space across time **(see Figure 1)**. In Jenkins and Osman's (2026) baseline study (study 1, 2023) they reported that overall, of the 10 CPIC, those that were attributed with the highest risk tolerance (i.e. highest benefits and lowest rewards – Top left panel in Figure 1) was the watch.

Toothbrush and vacuum cleaner are in the same quadrant, and while the concerns are lower (x axis) the benefits (y-axis) are also lower as compared to the watch. The top right quadrant indicates CPIC for which the public's risk tolerance is moderate, there are moderate to high benefits, but also moderate to high concerns. In this quadrant, for the baseline study, we see Bluetooth tracker, door lock, doorbell, and speaker. The bottom right quadrant indicates CPIC that are attributed with low risk tolerance, that is, they are perceived to be of high concern and low benefits.

For the baseline study we see a very obvious pattern, which is that both CPIC in the low risk tolerance quadrant are products targeted towards children (Teddy Camera, Child's

Robot toy). We see no products appear in the bottom right quadrant which would indicate moderate risk tolerance, but in this case low benefits, but also low concerns.

Figure 1. Location of the same 10 CPIC within the Benefits and Concern Component Space for Study 1 (2023), Study 2 (2025), Study 3 (2026)



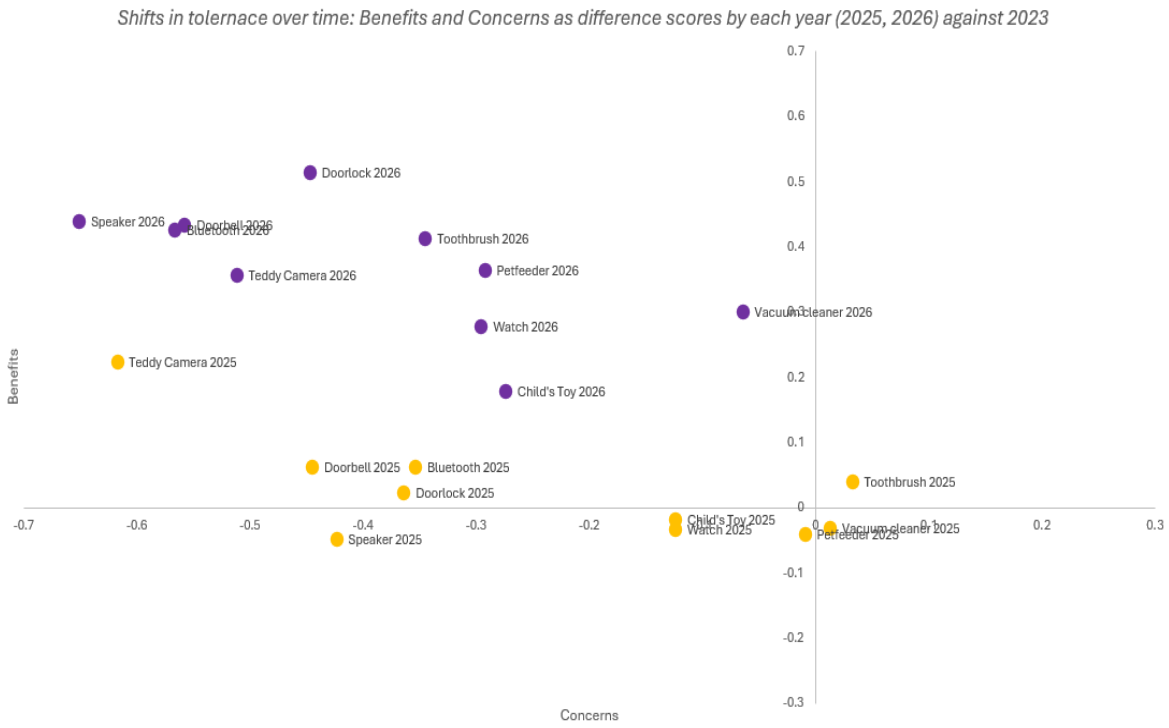
The question of interest is, how stable is the public's risk tolerance for the same 10 CPIC over time? For instance, a good illustration of this is the CPIC Pet feeder and Toothbrush, which at least between the baseline year (2023) and 2025 they appear to have not moved over time, for both we see that for 2026, there is a substantial shift upwards and to the left indicating that perceived benefits have increased and perceived concerns have decreased. In other words, between 2023 and 2025 risk tolerance for Pet feeders and Toothbrushes stayed the same, but by 2026 risk tolerance has increased. In general, we see this same pattern for many CPIC, for which there is a close correspondence between the baseline study of 2023 and 2025, we generally see a slight decrease in concern for CPIC between 2023 and 2025, with perceived benefits not substantively shifting. When comparing risk tolerances of the 10 CPIC between 2023 and 2026 we see an overall shift towards the top, and to the right, which is greater tolerances of the risks.

In order to get an accurate picture of the differences over time, the benefits and concerns scores for each participant for each of the 10 CPIC from Study 2 were subtracted from Study 1, and the same procedure was repeated for Study 3. Turning to **Figure 2** we can see the shifts over time for the same 10 CPIC, close to zero on both axis would indicate no difference between the new study (i.e. 2025, 2026) and the baseline study (i.e. 2023). What we see is that for Study 2, the CPIC are located close to zero on the y-axis (benefits) but are above zero on the x-axis (concerns), with a shift to the left indicating overall lower

concern. The only exception is the toothbrush where the benefits haven't changed, but the concerns have marginally increased over time. For vacuum cleaner and pet feeder we see no change over time, and the most dramatic decrease in concern is for the Teddy Camera.

What we see for Study 3 is that, for the vacuum cleaner level of concern has only marginally changed from baseline, but there is an increase in benefits. For all other 9 CPIC we see shifts away from zero on both axes, indicating that concerns are reducing, and benefits are increasing, put succinctly, overall risk tolerance for 9 out of the 10 CPIC between 2023 and 2026 has increased.

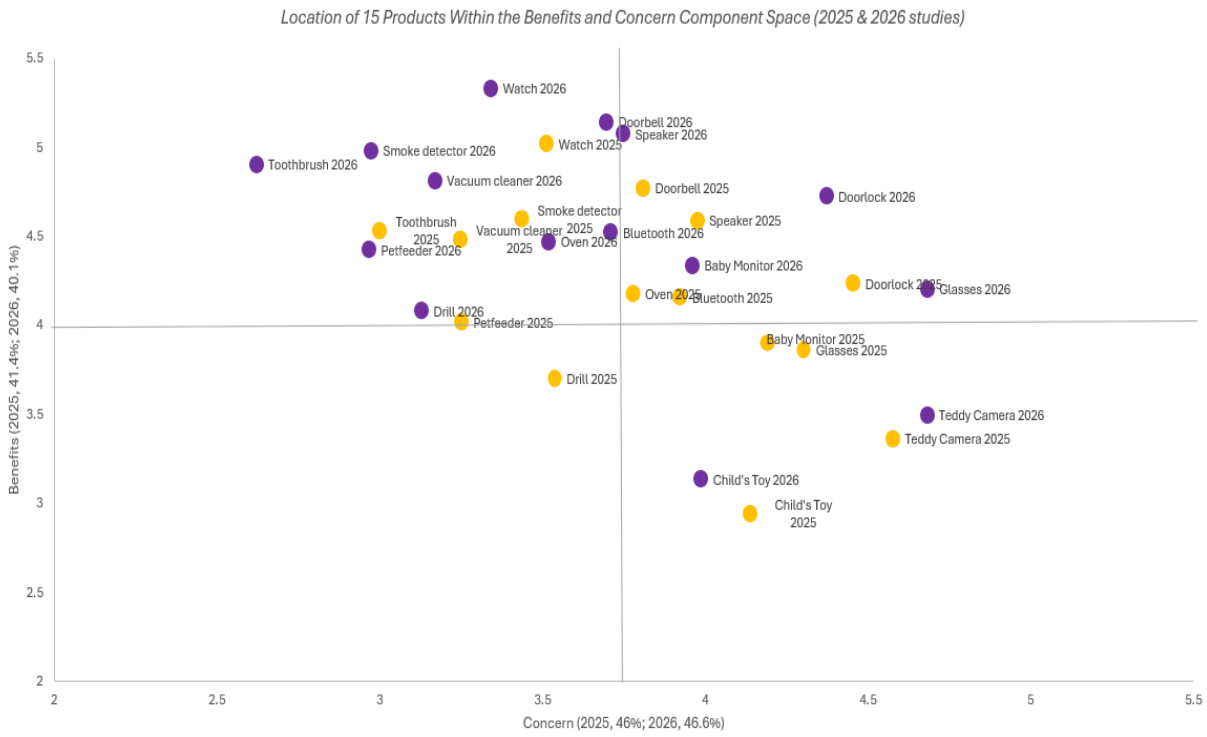
Figure 2. Shifts in tolerance of the 10 CPIC in the Benefits and Concern Component Space when comparing Studies (Study 2, 2025; Study 3, 2026) against the Baseline Study 1 (2023)



Along with the 10 CPIC that were consistently presented across the three studies, there were also 5 new CPIC that were presented to participants in Study 2 and Study 3 (see **Figure 3**). We see that for glasses between 2025 and 2026 the shift is towards the top right quadrant, where benefits increase but so do concerns. For drill, baby monitor, oven, and smoke detector, all four we see substantive shifts towards the top left quadrant, indicating that concerns are reducing between years, but correspondingly perceived benefits are increasing.

The point worth highlighting here is that the general trends between 2025 and 2026 for the new CPIC that were included (with the exception of one CPIC) reflect the general trend between 2023 and 2026, which is that risk tolerances are increasing over time.

Figure 3. Shifts in tolerance of the 15 CPIC in the Benefits and Concern Component Space for Study 2 (2025) and Study 3 (2026)



General Discussion

The aim of the empirical work presented here was to address two questions, which were identified as a means to close evidence gaps around CPIC, and public's risk tolerance of them. To date, much of the work in this domain, and historically (i.e. automated devices and appliances in the home), has looked at public risk perceptions, barriers to adoption, and perceived benefits separately. In addition, the other common methodological approach taken in this domain is to look at user perceptions and experiences of individual devices and appliances. Regardless of the various methodologies employed, even when considering the history of research of one type of device (i.e. automated vacuum cleaners – now robot sweepers), spanning 25 years or so of work, the review of the literature exposes consistent stable patterns in user perceptions. Regarding barriers to adoption, which are often treated as an index of concerns, the two consistent aspects that present are the complexity of the functionality of the product, which also implies difficulty in determining what self-initiated actions it takes, as well as how to control them. The second is security and privacy, particularly around control over data that is collected and stored. When it comes to perceived benefits the two most consistent features are that they are in the long run cost saving, and time saving, because they reduce daily burdens on household's daily routines.

Based on these insights, the present empirical work answered the following two questions, by specifically focusing on measuring risk tolerance, which has been shown to be a better predictor of behaviour than risk perceptions. Risk tolerance takes into account both the benefits as well as the concerns that are expressed by users of CPIC.

1. Are there stable trends in public tolerances of risk of a range of CPIC over a short span of time?
2. Do public tolerances of risk generally tend towards increasing over time for the same range of CPIC?

Across three years (2023, 2025, 2026), using the first as a baseline, it was possible to show that there are indeed stable patterns of risk tolerance for CPIC. Looking at the responses to 9 different measures of risks and benefits separately for the same 10 CPIC, the only significant changes overall were increases in perceived benefits across years. Where there are more substantive differences in ratings, were not by year, but rather based on the individual CPIC. Here, the most consistent pattern of the 10 CPIC was located for the two products that were orientated towards children (Children's robot toy and Children's Teddy Camera). Compared to all other CPIC, and of the 9 different measures, we see that for four of them, the patterns were such that CPIC aimed at children had lower familiarity, lower attributed usage and lower perceived benefits while at the same time received the greatest level of worry of all 10 CPIC.

The analyses that considered patterns of risk tolerance over time indicated two main findings. The first which complemented the pattern of findings when looking at the 9 dependent measures individually, is that there is an overall increase in perceived benefits, though this was pronounced when comparing baseline with 2026. Between the baseline and 2025, there was a pronounced reduction in overall concern for the CPIC and was more pronounced between baseline and 2026. That is, between 2023 and 2025 concerns reduced, and between 2023 and 2026 perceived concerns reduced and perceived benefits increased.

Between baseline and 2025, the only exception to the aforementioned patterns is the toothbrush where the benefits haven't changed, but the concerns have marginally

increased over time. For most other CPIC their position regarding risk tolerance hadn't changed (e.g. vacuum cleaner, pet feeder) or else concerns reduced (Teddy Camera). Between baseline and 2026, for the vacuum cleaner there was a minor increase in level of concern but with a corresponding increase in benefits, suggest that there was an overall increase in risk tolerance, which was in keeping with the other 9 CPIC.

It is worth highlighting that for products oriented towards children (Children's robot toy and Children's Teddy Camera) when compared to baseline there was a reduction in concerns (2025, 2026), as well as an increase in benefits (2026), but that for all studies, the position of these products in the risk tolerance space was in the lower right-hand quadrant. That is, they were perceived to be of the highest concerns relative to the other 8 CPIC that were consistently presented across all years. So while risk tolerance for these two products increased over time, they are still deemed somewhat problematic when compared with products that were of moderate concern but perceived as having high benefits (e.g. doorbell, speaker, Bluetooth tracker). This also broadly complements the findings as revealed when looking at individual CPIC by the 9 dependent measures, where Children's robot toy and Children's Teddy Camera fared the least well in terms of familiarity, usage, benefits and worry.

For 2025 and 2026 5 new CPIC were included (i.e. glasses, drill, baby monitor, smoke detector, oven). Between the two years the overall pattern in risk tolerance for these new CPIC was that concerns are reducing and perceived benefits are increasing. The only exception to this is glasses where concerns increase as well as perceived benefits.

Conclusion

Consistent with previous findings, we do see that overtime there are stable patterns in the way the public perceive the risks, benefits, and where their concerns remain. Overall, what the findings from the present research indicate is that measures of risks, concerns and benefits can individually reveal patterns when considered individual, but that presents a partial picture of how users appraise CPIC.

The novel contribution that the present research is able to make is that, when viewed through the lens of risk tolerance, it is possible to understand overall trends, i.e. reducing concerns, and with further understanding and experiences reduction in concerns and increasing perceived benefits. At a granular level it is also possible to follow the trajectory of risk tolerance for individual products across time, and also relative to each other, for which CPIC orientated towards children did not fare well, and new products such as glasses also present high concerns.

Potential policy considerations

Understanding trends in public tolerances of perceived risks of CPIC is an important approach to interpreting consumer behaviour. From a risk management perspective, public tolerances of risk is a relevant consideration, and more so than risk perceptions because the former is a more reliable predictor of behaviour. When taking into account multiple sources of evidence to inform risk management decisions (e.g. test reports, risk assessments) to determine what appropriate action to take, understanding how the public interpret and make decisions regarding products such as CPIC indicates the practical impact that a regulatory action could take. For instance, if the evidence (e.g. test reports, risk assessment) suggest that CPIC does not present a risk to the public, but nonetheless the public's perceived tolerance of the risks is low, then efforts could be taken to develop public awareness campaigns to inform the public of the minimal risks posed by the CPIC. Correspondingly, there may be instances where the mismatch between the public's perceived risk tolerance over years is increases, while the evidence (e.g. test reports, risk assessment), suggest that there is a risk posed to the public. Here also, public awareness campaigns may be a viable strategy to support the public as to how to protect themselves from the risks, if they can be managed.

The evidence from the empirical work presented here shows that over a short period of time (2 to 3 years) the public tend to show greater tolerance of risks that CPIC present. However, if anything this trend is largely with respect to perceiving greater benefits from them rather than dramatic reductions in concerns. That is, with more understanding and awareness of the CPIC, as well as familiarity of them either because they are reported on in the news, or through direct personal experience of them, the public tend to conduct the trade-off in such a way that they appreciate the risks, but nonetheless see the overall utility of the CPIC.

The main point to highlight from the work presented here is that not all CPIC are perceived in the same way. While the main focus was to explore public risk tolerances of 10 CPIC, for which there are clear patterns across time, and for which this was expanded to 15 in Studies 2 ad 3, there is scope to expand the list to include more CPIC in subsequent studies (while preserving the same 10 original CPIC). By doing this, there would need to be an effort to develop taxonomies that group the CPIC in ways that helps to better interpret the direction of change for types of CPIC (e.g. by functionality, by complexity,

hybrid hazards, hybrid harms); there is emerging research to support a classification system. Classifying multiple CPIC in an expanded public risk tolerance study would enable an even more granular approach to interpreting the underlying properties of CPIC to support risk analysis of associated hazards and harms, along with the patterns of user behaviour as revealed through the public's perceived tolerances of their risks. The point to emphasis here is that the present work suggests a standardised approach to measuring public risk tolerance, for which there are clear robust patterns that were exposed across three years. In fact, carrying out this study on an annual basis would also provide an index of the potential impact of risk management interventions, by determining beforehand the expected shifts in risk tolerances which can then be evidenced by measuring the changes using the methodology introduced here.

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