Self-reported Side-effects of Ultraviolet-C Disinfection Devices

Adams, Zoë[*] [1], Bechlivanidis, Christos [2], Osman, Magda [3], O'Hagan, John [4], & Naldzhiev, Dzhordzhio [5]

[1] Queen Mary University of London, [2] University College London, [3] University of Cambridge, [4] Loughborough University, [5] Department for Business, Energy and Industrial Strategy, Office for Product Safety and Standards

* Corresponding author email: z.adams@qmul.ac.uk (Zoë Adams)

ABSTRACT

The COVID-19 pandemic increased sales of portable UV-C devices as a means of inactivating the SARS-CoV-2 virus. Research suggests that excessive UV-C exposure to the eyes and skin can lead to side-effects, primarily photokeratitis and erythema, but these findings are limited to case studies. This study explores self-reported side-effects of UV-C devices by collating five waves of UK consumer survey data from April 2020-December 2021 (*N*= 26,864). 30%-46% of owners report a side-effect after using a device claiming to emit UV-C. However, detailed analysis of Wave 4 data (*N* = 309) highlights inconsistencies between reported and plausible side-effect(s) associated with skin or eye exposure from UV-C devices. Alternative explanations are considered, namely that the reported side-effect(s) were psychosomatic or misattributed to direct exposure of UV-C radiation. Data regarding awareness of warnings about device side-effect(s) supports the misattribution explanation. For risk assessment purposes, limited reliable information about specific irritation or injury to the eye and skin was found from self-reporting surveys. To optimise future data collection, we recommend addressing recall errors by: reducing the period under investigation, supplementing responses with empirical measures, and incentivizing respondents to provide accurate information about the make and model of the UV-C device.

INTRODUCTION

The COVID-19 pandemic has brought to the fore discussions regarding the effectiveness of UV-C in inactivating viruses both via far-UV-C (1), which use lower range wavelengths, and portable UV-C devices. Specifically, there has been a rise in the sale of the latter for use in various settings (workplaces, homes, transport) and for purposes such as disinfecting the air, surfaces and objects (2–7). However, the relative benefit of using portable UV-C devices to reduce the risk of COVID-19 transmission in individual settings, compared to other mitigation measures, is still unknown (8). Moreover, despite the potential benefit of virus inactivation (9), case studies report that excessive UV-C exposure to the eyes and skin can lead to side-effects, namely eye pain (photokeratitis) and skin rash (erythema), in the workplace (10–14), home (12, 15) school (16–19) and clinical settings (20, 21). The extent to which ultraviolet radiation may induce these side-effects is dependent on the wavelength of UV radiation, the dose of UV radiation and the susceptibility of the individual (7, 22, 23). Due to the potentially undesirable impact on human health, caution is therefore advised with regards to using UV-C devices in domestic and commercial settings (24). Currently, there is limited data that extends beyond a case-study approach to examine how and why risks of UV-C exposure may occur from a consumer perspective.

It is important to contextualise the purpose of this research project. Previously published survey findings by the UK's consumer product safety and measurements regulator, the Office for Product Safety and Standards (OPSS) revealed that people reportedly used portable consumer-grade UV-C devices on their skin (4). Consumers reported these intentions despite World Health Organization (WHO) advice not to use UV lamps to sterilise their hands or other parts of the skin (25). It led us to a working hypothesis that consumers could potentially experience adverse side-effects when using

portable consumer-grade UV-C devices. This context motivated the questions which specifically included terminology that is commonplace in regulatory practice, such as ‘harm, ‘severe’, and ‘injury’ (26), though we acknowledge that some of the terminology in the surveys may not align with public health definitions. We understand that from a scientific methodological point of view, neutral wording is optimal to avoid priming respondents, thereby avoiding survey design issues (27). However, we believe the results and design limitations can still both inform our understanding of UV-C device usage and provide useful recommendations for future research and decision-making when balancing the risks and benefits associated with the use of these devices.

MATERIALS AND METHODS

This report first collates the findings from five waves of surveys from April 2020 - December 2021 in the UK before offering a comprehensive analysis of Wave 4. As we will see, findings in Waves 1-3 initially suggested that UV-C devices were associated with side-effects, thus motivating Wave 4 to explore this further. However, detailed analyses of these results indicate self-reported injury or harm data may be unreliable, thus Wave 5 contained more targeted questions aimed at providing deeper insight.

All five surveys were conducted by two market research companies who sampled a total of 26,864 consumers as outlined in Table 1. Each wave aimed to collect data from a nationally representative sample of the UK population, but as each response did not have a unique identifier, the number of unique responses may be slightly lower than the total sample size. Despite variation in survey length, each wave of questions examined the use of the device and potential side-effects (see Supplementary Materials).

<Table 1>

For Wave 4, the market research company contacted the participants who previously reported to owning or having access to a UV-C device in Wave 3 and the questions were divided into five themes aiming to assess the risk and reported side-effects of portable UV-C devices: (1) Perceived risk; (2) Type and severity of harm (3) Tolerance of side-effects; (4) Perceived utility; (5) Motivation for purchase. The consumer products covered within the survey questions are: boxes for disinfecting items (such as mobile phones or keys), handheld wands, lamps for the floor or wide areas, and handheld or robot vacuum cleaners fitted with UV germicidal lamps.

At the outset, it should be noted that despite attempting to gather data on the make and model of the UV-C devices via open questions, only 42% (n = 130) respondents answered. Of these responses, only 4% (n = 12) were of sufficient quality where a specific product could be identified, traced back to the open market and purchased for supplementary testing. Conversely, the remaining responses were ambiguous by referring to brand names, unrelated terms, or random text.

Identifying specific products is important from a regulatory perspective as corrective actions may be needed by relevant regulators if products are found not to meet the relevant requirements (28, 29). Due to the insufficient quality of the survey responses, it was therefore not known which particular devices led to side-effects, and so they were not independently tested to confirm that they were indeed emitting UV-C. Khazova et al. (30) found that some UV-C devices on the market did not emit any UV-C despite claims to the contrary, while other devices were designed to prevent direct skin and eye exposure. As we discuss, this plays an important role in our understanding of the reported side-effects.

RESULTS

Summary of waves

In this summary, we report the results for two questions which asked whether respondents owned or had access to a UV light sanitising device (Waves 1, 2, 3, 5), and whether they had experienced any side-effects when using the device (Waves 2-5). Beginning with Wave 1, findings revealed that 5% of respondents (n = 204) had recently purchased a device claiming to emit UV-C, but side-effects were not measured in this wave. Reported ownership increased in Wave 2, such that 19% (n = 437) of respondents had access to or bought a device claiming to emit UV-C, and of these respondents, 46% (n = 200) had reportedly experienced one or more side-effects. Wave 3 results showed a decrease in ownership - 5% of respondents (n = 527) – and reported eye pain or skin irritation 30% (n = 159). The focus of this paper, Wave 4, does not have ownership data because, as mentioned, respondents were those who reported owning or having access to a UV-C device in Wave 3. It did, however, highlight that 30% (n = 92) of respondents reported a side-effect, while the latest findings from Wave 5 revealed that 7% of respondents (n = 688) purchased a device claiming to emit UV-C, of whom 37% perceived to experience a side-effect (n = 254). A summary of ownership and reported side-effects by demographics is presented in Table 2 and 3.

<Table 2>

<Table 3>

The high proportion of reported side-effects in Wave 2 and 3, along with previous research findings, warranted further investigation, which is why Wave 4 aimed to delve deeper.

However, some results are not consistent with scientific evidence of feasible adverse reactions due to skin or eye exposure to UV radiation (e.g., type and duration of symptoms) or device design capabilities (e.g., battery life, dimensions, in-built safety features preventing skin or eye exposure). We now explore two candidate explanations for the reported side-effects supported by additional findings from Wave 4.

Wave 4 – reported side-effects analysis and misattribution

As outlined above, Wave 4 sampled a total of 309 consumers, who confirmed that they either purchased, or have access to, a UV-C device. Out of the surveyed population, 30% (n = 92) reported experiencing a side-effect, with 10% (n = 32) reporting multiple side-effects. Of those who experienced one side-effect, respondents primarily reported headaches (7%, n = 22), followed by nausea (4%, n = 13), eye pain (3%, n = 8), skin burn (3%, n = 8) and then skin redness or rash (2%, n = 7), as shown in Fig. 1.

<Figure 1>

The relatively high prevalence of headaches is intriguing given that both previous OPSS research (28) and academic studies (10, 11, 15) on UV-C devices primarily report the risk of photokeratitis and erythema, with a much lower incidence of nausea and no evidence for headaches. Both headaches and nausea are known as ‘non-specific symptoms’ in that they can be reported but not medically observed.

In terms of the duration of the side-effects, among those who reported at least one, 51% (n = 47) reported that recovery took between 3 days and 1 month (Fig. 2).

<Figure 2>

This reported time period is longer compared to previous studies, which found a shorter time frame of roughly 1 to 7 days from the beginning of treatment (e.g., lubricating eye drops, topical creams) (10) or the onset of symptoms (12).

To understand the distribution by type of side-effect, Fig. 3 shows the duration by type of reported side-effect.

<Figure 3>

We can see that most respondents report that skin redness (n = 9), burns (n = 8) and nausea (n = 9) primarily last between 3 and 10 days, whereas eye pain (n = 8) and headaches (n = 10) most often last between 10 days and 1 month. From a causal perspective, these findings are counterintuitive, particularly the duration of photokeratitis and erythema because they are both typically short-term effects that last between 6-24 hours (31). This means that the reported persistence is only possible if it wasn't a result of direct skin or eye exposure to UV radiation, but the respondent was continually exposed to another trigger, for example, headaches can be caused by the noise of some vacuum cleaners, or chemicals in common cleaning agents amongst other things (32). Equally, 6 participants also report that non-specific symptoms, headaches and nausea, lasted between 3 and 6 months, which does not seem plausible if direct skin or eye UV-C exposure was the cause of these side-effects. This is supported by usage data, as most people reported that they use these devices only a few times per week (21%, n = 64).

Moving on to the link between reported side-effects and particular devices, Fig. 4 shows the distribution of reported side-effects by device type.

<Figure 4>

Nearly half of respondents who owned a lamp experienced a side-effect (48%, n = 19), which is consistent with existing research that has reported side-effects after exposure to UV-C (12, 14, 15). One reason these devices could be associated with adverse side-effects is because of generally higher irradiance and that the access to direct UV exposure of skin and eye are not prevented by design consideration, i.e., they are free-standing open sources, unlike other device types. The low prevalence of reported side-effects for boxes (20%, n = 11) also aligns with research suggesting that these devices are often fitted with safety features, such as a tilt sensor which terminates emission when opened (30) or tilted upwards or it is too small to enable skin or eye exposure. The causal relationship between the high frequency of reported side-effects associated with UV-C vacuum cleaners (50%, n = 13) is more difficult to explain based on the existing literature. Whilst research indicates that vacuum cleaners fitted with UV-C emitters may be effective in inactivating bacteria (33), human access to UV radiation from these devices is not feasible in practice as UV emission is possible only when cleaning head is in contact with the surface. Side-effects therefore may be better explained from the usage of the vacuum cleaner itself, potential release of ozone, or other indoor pollutants, during operation or alternatively the sound levels and potential hyperacusis experienced by people (32, 34). This finding reinforces our hypothesis that the reported side-effects with certain products may be caused by other factors rather than direct skin or eye UV-C exposure.

Lastly, Fig. 5 shows how the side-effect that was reportedly ‘most serious’ for each device relates to the length of time until the side-effect became apparent.

<Figure 5>

25 instances of the 'most serious' reported side-effects emerged between 16 and 30 minutes of exposure, and 34 respondents reported they became apparent between 1 and 15 minutes. However, side-effects such as eye pain and skin burn can take hours to develop. For example, these symptoms were observed after 2-19 hours in Trevisan et al.'s (18) subjects, while Zaffina et al.'s (21) patients began complaining 4-6 hours after exposure. Taken together, these results suggest that the side-effects reported in the survey may not be causally linked to direct skin or eye UV-C exposure from these devices.

This is known as misattribution where people incorrectly identify the cause of their arousal (i.e., side-effects) (35). The misattribution of side-effects is common, particularly when they are non-specific symptoms (e.g., headaches, nausea, dizziness) (36), which were the most frequent in Wave 4. In this case, it may therefore be that the side-effects respondents experienced were misattributed to skin or eye exposure to UV-C radiation when the cause was, in fact, unrelated to the device. It is important to note that misattribution does not cause the effect per se, rather it is experienced and *then* incorrectly attributed. This differentiates misattribution from an alternative explanation which may have led to reported side-effects: the nocebo effect.

Wave 4 – assessing the nocebo effect

The second possible explanation for the reported side-effects relates to the nocebo effect: adverse effects produced by expectations (37). To explore this possibility, we report the findings of two questions. The first asked whether participants saw a warning about the UV-C device they had purchased, and whether this was from a website, packaging, instruction manual, word-of-mouth or other. Fig. 6 shows the proportion of participants

who reported a side-effect after using a UV-C device and reported seeing any kind of warning in relation to the device (excluding 39 ‘don’t know’ responses).

<Figure 6>

Out of those who saw a warning, the proportion who reported a side-effect (45%, $n = 79$) was lower than those who did not report a side-effect (55% $n = 97$). However, the fact that nearly half of respondents saw a warning and reported a side-effect is still indicative of the nocebo effect, especially given also that 91% ($n = 86$) of those who did not see a warning also did not report a side-effect.

Although misattribution and the nocebo effect are closely related, Faasse et al.(38) make a useful distinction. Misattribution is regarded as a ‘perceived’ nocebo effect because it does not induce any symptoms other than those that would have occurred regardless, but participants attribute them to an incorrect source, which in this case is the UV-C device. Conversely, the ‘true’ nocebo effect involves different processes because it induces actual symptoms. Some devices on the open market contain instructions such as ‘Ultraviolet radiation can cause skin and eye burns, so please use carefully, and follow instructions exactly’. However, the exact content of the warnings that consumers saw prior to using the device is unknown, and so we cannot ascertain what adverse side-effects they expected would occur. Nonetheless, we can tease apart misattribution and the nocebo effect by examining responses to a second question which asked respondents the degree to which they reportedly read the manual (Fig. 7).

<Figure 7>

Of consumers who reported a side-effect, most reported not reading the instructions/manual initially, but consulted it later on (70%, n = 30) compared to 30% (n = 13) who did not report a side-effect. This indicates that they consulted the instructions/manual later potentially because they experienced a side-effect. In other words, we argue that consumers consulted the instructions/manual *after* the side-effect emerged. Therefore, it is less plausible that the 45% of respondents in Fig 6. who reported seeing a warning and experiencing a side-effect is evidence of the nocebo effect because the warning was most likely read *after* the side-effect and not before. Although it is complex to differentiate the nocebo effect and misattribution, we argue that these findings support the latter. This is important given the prevalence of both phenomena. This data does not disprove the possibility that the reported side-effects were caused by the use of the UV-C device, yet not necessarily by direct skin or eye exposure. Otherwise put, it is not the case that there is no evidence of a link between use of UV-C devices and side-effects reported here. However, it is important to exercise caution when interpreting the findings in light of the aforementioned inconsistencies and acknowledge the role of other explanations.

Having argued for the misattribution explanation, we now turn our attention to why this may have occurred in relation to UV-C devices. We acknowledge that the media has been found to play a role in the perception of symptoms (38). For example, studies reference Pierpoint's (39) 'The Wind Turbine Syndrome' as a motivating factor in the misattribution of reported symptoms by patients after they have been in close proximity to wind turbines (40–44). The media coverage for UV-C devices has not been substantive but there are several exceptions such as news articles like 'People are damaging their eyes trying to kill COVID-19 with UV lamps' (45), 'Have you bought a UV light? Experts are urging shoppers to think twice before buying devices that claim to kill viruses and bacteria after safety tests show some can cause painful BURNS and eye damage' (46) and 'Why

you should think twice before buying that UVC infection gadget' (47). The extent to which the media shaped respondents' expectations regarding side-effects of the UV-C may also be linked to coverage about SARS-CoV-2. Since March 2020, the global focus on the pandemic may have made people hypervigilant about their own health. Specifically, studies around the world have found a relationship between virus-related fear and somatization, that is psychological concerns manifesting in physical symptoms (48–51). Research has also shown that somatization tendencies can exacerbate misattribution (52–54). Given Wave 4 data was collected between 13th and 29th August 2021, it is possible that the wider context intensified the perceived side-effects even if the devices claimed to emit UV-C and inactivate the virus. In sum, exposure to health-related news may have triggered new or exacerbated existing somatization tendencies, thus leading to the attribution of side-effects to the UV-C device.

Wave 4 – risk tolerance

Our findings may also be explained through participants' tolerance of risk which is influenced by the perceived benefit of and voluntary engagement in the risk generating activity, given the perceived risk (55). By risk tolerance we mean people's estimate of the perceived benefits (e.g. utility) over and above the perceived costs (e.g. harm) they attribute to a product. Whilst the relative benefit of portable UV-C consumer-grade devices in reducing SARS-CoV-2 transmission is unclear (8) people may still perceive these devices to be effective, thus tolerating higher levels of risk and adverse side-effects compared with those who regard the devices as less effective. In our study, we utilised people's belief regarding the effectiveness of the device (i.e., inactivation of the SARS-CoV-2 virus and/or reducing transmission) as a proxy for their tolerance of risk. Fig. 8

shows the extent to which participants believed the device was effective and the distribution of consumers who either reported or did not report a side-effect.

<Figure 8>

Of those who did not report a side-effect, 41% (n = 89) did not know whether the device was effective. These findings must therefore be interpreted with caution because, as noted by Mickalide(56), a high proportion of 'don't know' (DK) responses suggests low face validity – whether, according to participants, the questions measure what they intend to measure – and the overall proportion of DKs for this question was 32% (n = 100). Nonetheless, among those who did report a side-effect, 53% believed the device was very or moderately effective compared with 36% (n = 33) who believed the device was somewhat or not at all effective. Combined with the likelihood that all participants used their UV-C device voluntarily, as these devices are available on the open market, it seems that participants who reported a side-effect were more inclined to tolerate risk than not. In turn, this increased risk tolerance resulted in misuse (via manner or duration) as reflected in the reported side-effects.

Risk tolerance could also theoretically relate to misattribution. One might argue that high risk tolerance (i.e., high perceived effectiveness - the high utility placed on the protective properties the device has) might reduce misattribution, and therefore reporting, of any side-effects to the UV-C device. This is because perceived effectiveness may shift people's attention from negative media coverage, for example, towards protection from the virus. Conversely, lower risk tolerance (i.e., low perceived effectiveness - the low utility placed on the protective properties the device has) might increase misattribution, and therefore reporting of, side-effects to the UV-C device. There does not appear to be evidence of this interpretation here as perceived effectiveness was greater among those

who reported side-effects. However, given face validity concerns for this question as well as a low sample size, the relationship between risk tolerance and misattribution cannot be fully addressed. As this study applied a methodology relying on self-reported experiences of side-effects in relation to particular device type, the potential for biases is now investigated.

Wave 4 – recall error

Aside from misattribution, self-reports can also lead to recall bias – an inaccurate recollection about past exposures or outcomes (57) – and therefore erroneous conclusions about the cause of the injury (58–61). Wave 4 did not measure when exactly participants experienced the side-effect(s) that they reported. However, as mentioned earlier, the results for Wave 4 stemmed from a subset of respondents (n = 309) who answered 'yes' to purchasing or having access to a UV-C device in Wave 3. Specifically, they were asked: 'Have you purchased the following for use against bacteria and viruses, including COVID-19?' Fig. 9 outlines that 20% (n = 132) reportedly purchased their device at least 17 months prior to the survey. While this does not signal a bias to over- or under-report side-effects per se, it does suggest that respondents were asked to recall side-effects that occurred a long time ago, thereby increasing the likelihood of inaccurate reporting. As such, this may explain the discrepancies between reported and feasible side-effects due to skin or eye UV exposure.

<Figure 9>

Answering survey questions is cognitively demanding; it requires that participants understand the question, retrieve information from memory, interpret this information into

a single judgment, then translate this judgment into one of the available responses (62). Therefore, recall errors are likely exacerbated if the respondent must recall memories that are too far in the past. This issue has been found in other studies, for example, in research on injury and memory decay, Jenkins et al. (63) found that recall rates were significantly different at three time periods: 108/1000 for two months, 66/1000 for 12 months, and 19.2/1000 for 10 years. They conclude that injury recall is likely to be underestimated if it occurs two months after the incident, but it is important to acknowledge that the study concentrates on injuries whilst the focus here is reported side-effects which may be even more easily forgotten. Elsewhere, Baker et al. (64) compared self-reports of specific ailments with medical data and found considerable error, that is both false negatives and false positives. In terms of recall of non-specific symptoms, Hopwood and Guidotti (65), studied symptom recall immediately following and six months after a toxic exposure incident. They found a high-level bias after six months with a greater level of disagreement regarding primary symptoms associated with exposure to nitrous oxide (e.g., cough, shortness of breath) than non-specific symptoms. In fact, headaches were the only symptom to show a high level of agreement compared to chance without recall errors. In addition, five respondents reported that their symptoms persisted contrary to expectations from the toxicology report which stated that they should have subsided after one week. This is consistent not only with the high proportion of side-effects that are less commonly associated with UV-C exposure (headaches, nausea), but also the reported duration of these side-effects. Lastly, it is relevant to recognise the context of this research data for regulatory purposes and outline potential wording issues that may have impacted discrepancies in the results.

Wave 4 – survey wording analysis

Another relevant aspect of the study which may have impacted reported side-effects is the survey design. One of the questions, for example, used standard rather than specific quantifiers: 'How often, if at all did you follow the instructions/warnings when using your UV sanitising device? Never, rarely, sometimes, other, always (i.e., every time I use the device).' Even though respondents prefer expressing their opinions through words rather than numbers (66, 67), studies have shown that the intervals between the labels on questions measuring self-reported frequency are not equidistant, e.g., the perceived distance between 'always' and 'often' is much greater than the difference between 'seldom' and 'never' (67). In addition, the subjective understanding of quantifiers in psychometric data can vary depending on the context. For instance, the above question asks respondents about how often they follow instructions/warnings, but findings on device usage reveal variation from 'more than once every day' (7% n = 22), to 'I have only used it once or twice' (9% n = 37). If two respondents both answer 'often' to reading the manual/instructions but they differ greatly in usage, then the meaning of 'often' diverges. We also note here the use of a slash '/' between two terms with different meanings, for example in the question above, respondents are asked about 'instructions/warning' which are safety communications with different functions. A warning informs people about a hazard whereas instructions inform people about how to avoid or minimise undesirable consequences such as injuries (68). If a participant has only read the instructions but not the warning, or vice versa, it may be difficult to know how best to answer which also reduces face validity. While consumers are likely to read both as instructions often include warnings, it is still possible to attend to one and not the other. An instruction booklet, for instance, may contain warnings at the beginning, but consumers may skip this information and only read the instructions.

CONCLUSION AND FUTURE DIRECTIONS

Taken together, across Waves 2-5, 30%-46% of respondents who reportedly used a UV-C device claiming to emit UV-C self-reported experiencing a side-effect. However, in-depth survey data from 309 consumers in Wave 4 highlighted inconsistencies between reported side-effect(s) and plausible side-effect(s) associated with skin or eyes exposure to UV-C. For example, while research has found that symptoms of photokeratitis and erythema usually emerge at least a few hours after exposure, our respondents reported that their eye pain and skin burn became apparent within 15 minutes. The survey responses were designed to help inform risk assessments evaluating side-effects from a range of UV-C devices at scale. This finding suggests that survey data, in isolation of other empirical evidence, did not produce sufficiently reliable results in revealing how many people experienced side effects.

We offer three explanations for this outcome. Primarily, we acknowledge the role of misattribution rather than the nocebo effect. This is exacerbated by individual somatization tendencies along with media exposure for which there is an evidence base, albeit small, regarding UV-C devices. The second possibility is that recall errors impacted respondents' ability to accurately remember details of their experiences with UV-C devices. Lastly, the design of the survey, which was originally produced for regulatory purposes, potentially primed respondents to report their side-effect as more severe, or led to multiple interpretations, for example, 'skin burn' may be understood differently as it was not defined. We therefore propose several recommendations of how these issues could be reduced in further research alongside limitations of the survey methodology, which may need to be supplemented with wider data collection in order to validate any findings.

First and foremost, supplementing subjective data with more empirical measures, such as hospital accident and emergency records or observations from health professionals would provide a more holistic understanding of perceived and actual side-effects. This is not to say that self-reports do not have value. Chan (69) observes that on occasions, such as measuring distress from a safety incident, self-reports are preferable. However, the validity of self-reported data, compared with medical records, has been questioned numerous times. This is not just because of recall errors or misattribution but also because respondents can overreport safety behaviours, such as reading the instructions or manual, and underreport risky behaviours (56). Given the difficulties of obtaining such information, another more feasible option is to collect self-report measures at two time points in relation to a specific side-effect. However, participants may experience multiple side-effects and be unable to accurately provide details of the side-effect in question.

Second, it is helpful to reduce recall errors where possible by limiting the reference period to 2-4 weeks (70) or 2 months as a maximum (63). This poses challenges if the device is used sparingly, and so, a useful exclusion-criterion for future research could screen respondents by when they last used the device.

Third, using specific intervals for measuring the frequency of behaviour could mitigate varied interpretations of verbal quantifiers. Here, we recognise that decisions regarding the design of this survey were within the context of regulatory delivery in order to assess the potential risks and harms posed by use of UV-C devices. However, future surveys which are hypothesis-driven could employ neutral language where possible to align with best practices, which includes minimising ambiguity by avoiding multiple terms with different meanings and pilot testing questions to monitor the proportion of DK responses.

Fourth, it is important to elicit information about the make and model of the UV-C device. Despite asking respondents to provide this information, answers were either not provided or of insufficient quality. From a survey design perspective, it is paramount to address this obstacle so that respondents feel incentivized to retrieve the relevant information. This data could be used in an independent assessment to confirm that survey answers pertain to devices that emit harmful levels of UV, and skin or eye exposure is feasible by equipment design. A causal diagram presented in the supplementary material is an example of the possible relationships that might underlie some of the findings presented in the manuscript.

Future surveys on the role of misattribution in reported side-effects of UV-C devices would benefit from measuring respondents' exposure to media about the device, as well as individual differences. For example, studies on misattribution and non-specific symptoms have included Spielberger et al.'s (71) 40-item version of the State and Trait Anxiety Index as well as Barsky et al.'s (72) Somatosensory Amplification Scale (73, 74) which assesses one's tendency to experience somatic sensations as distressing. Further research regarding the role of perceived benefit and risk tolerance in this regard may be beneficial.

However, despite these shortcomings, we believe that this study offers valuable insights into how consumers interpret side-effects after using UV-C devices. Therefore, together with the aforementioned survey design criteria, this research lays fertile ground for work in an emerging area where consumers balance the relative benefits and potential side-effects from using UV-C devices available on the open market, and more broadly, consumer products associated with some risk.

ACKNOWLEDGEMENTS: We would like to express gratitude to Marina Khazova for her invaluable technical guidance and comments on earlier versions of the manuscript. We would

also like to thank members of the SAGE Environmental and Modelling (EMG) group for their feedback and comments that provided insight into how to improve the survey design. Lastly, we also acknowledge Hannah Lockley for helping to facilitate and run the survey. This research was made possible by funding provided by the Office for Product Safety and Standards.

REFERENCES

1. Eadie, E., Barnard, I. M. R., Ibbotson, S. H. and Wood, K. (2021) Extreme exposure to filtered far-UVC: A case study. *Photochem. Photobiol* 97, 527–531.
2. Azevedo, M.-A. (2020) Hospital-disinfecting robots: Xenex sees surge in orders as COVID-19 pandemic escalates. Available at: https://news.crunchbase.com/news/hospital-disinfecting-robots-xenex-sees-surge-in-orders-as-covid-19-pandemic-escalates/. Accessed on 20 October 20 2021.
3. Kunthara, S. (2020) Amid coronavirus outbreak, UV sanitizing startups see surge in sales. Available at: https://news.crunchbase.com/news/amid-coronavirus-outbreak-uv-sanitizing-startups-see-surge-in-sales/. Accessed on 20 October 2021.
4. Office for Product Safety and Standards (2020) OPSS Covid-19 Consumer Survey. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/921375/covid-consumer-survey-summary.pdf Accessed on 21 October 2021.
5. Transport for London (2021) Installation of UV light devices on tube escalators is latest step in TfL's extensive anti-viral cleaning regime. Available at: https://tfl.gov.uk/info-for/media/press-releases/2020/october/installation-of-uv-light-devices-on-tube-escalators-is-latest-step-in-tfl-s-extensive-anti-viral-cleaning-regime. Accessed on 11 March 2022.
6. Thaper, R., Fagen, B. and Oh, J. (2021) Decontamination of respirators amid shortages due to SARS-CoV-2. *Photochem. Photobiol. Sci.* 20, 955–965.
7. Horton, L., Torres, A. E., Narla, S., Lyons, A. B., Kohli, I., Gelfand, J. M., Ozog, D. M., Hamzavi, I. H. and Lim, H. W. (2020) Spectrum of virucidal activity from ultraviolet to infrared radiation. *Photochem. Photobiol. Sci* 19, 1262–1270.
8. Scientific Advisory Group for Emergencies – Environmental Modelling Group (2020) Health effects of UV-C lamp radiation final version scientific committee on health, environmental and emerging Risks SCHEER opinion on biological effects of UV-C radiation relevant to health with particular reference to UV-C lamps.
9. Aroso, R. T., Schaberle, F. A., Arnaut, L. G. and Pereira, M. M. (2021) Photodynamic disinfection and its role in controlling infectious diseases. *Photochem. Photobiol. Sci* 20, 1497–1545.
10. Das, S., Panigrahi, P. and Pareek, D. (2021) Photokeratitis following exposure to germicidal ultraviolet lamps during the COVID pandemic. *Indian J Health Sci Biomed Res* 14, 279–281.
11. Oliver, H., Moseley, H., Ferguson, J. and Forsyth, A. (2005) Clustered outbreak of skin and eye complaints among catering staff. *Occup Med* 55, 149–153.
12. Sengillo, J. D., Kunkler, A. L., Medert, C., Fowler, B., Shoji, M., Pirakitikulr, N., Patel, N., Yannuzzi, N. A., Verkade, A. J., Miller, D., Sliney, D. H., Parel, J. M. and Amescua, G. (2021) UV-Photokeratitis associated with germicidal lamps purchased during the COVID-19 pandemic. *Ocul Immunol Inflamm* 29, 76–80.
13. Stripp, M. P., Dulaney, A. R., Beuhler, M. C. and Langley, R. L. (2018) Photokeratitis among restaurant workers: A case series. *Am J Ind Med* 61, 780–782.
14. Wang, Y. M., Lou, J., Ji, Y. and Wang, Z. Y. (2021) Increased photokeratitis during the coronavirus disease 2019 pandemic: Clinical and epidemiological features and preventive measures. *Med* 100, e26343.
15. Ching, K., Leung, P., Chuen, T. and Ko, S. (2021) Improper use of the germicidal range ultraviolet lamp for household disinfection leading to phototoxicity in COVID-19 suspects. *Cornea* 40, 121–122.
16. Chaiear, N., Saejiw, N., Dithisawatwet, S., Polpila, P., Paratako, K. and Chuntum, K. (2006) The discovery of an unusual cause of indoor radiation pollution. *Asia Pac J Public Health* 18, 46–50.

17. Shih, G. (2018) Chinese schoolchildren burned by UV lamp left on in the classroom. Again. Available at: https://www.washingtonpost.com/world/2018/11/16/chinese-schoolchildren-burned-by-uv-lamp-left-classroom-again/. Accessed on 25 October 2021.
18. Trevisan, A., Piovesan, S., Leonardi, A., Bertocco, M., Nicolosi, P., Pelizzo, M. and Angelini, A. (2006) Unusual High Exposure to Ultraviolet-C Radiation. *Photochem. Photobiol.* 82, 1077–1079.
19. Youth CN (2021) Available at: https://t.m.youth.cn/transfer/index/url/news.youth.cn/sh/201812/t20181204_11804469.htm?from=timeline. Accessed on 14 January 2022
20. Lyons, A. B. and Hamzavi, I. H. (2020) Ultraviolet C-induced skin reaction from ultraviolet germicidal irradiation of N95 respirators during the COVID-19 pandemic. *Photodermatol. Photoimmunol. Photomed* 37, 159–160.
21. Zaffina, S., Camisa, V., Lembo, M., Vinci, M. R., Tucci, M. G., Borra, M., Napolitano, A. and Cannatã, V. (2012) Accidental exposure to UV radiation produced by germicidal lamp: Case report and risk assessment. *Photochem. Photobiol.* 88, 1001–1004.
22. Clydesdale, G. J., Dandie, G. W. and Muller, H. K. (2001) Ultraviolet light induced injury: Immunological and inflammatory effects. *Immunol. Cell Biol.* 79, 547–568.
23. Sklar, L. R., Almutawa, F., Lim, H. W. and Hamzavi, I. (2013) Effects of ultraviolet radiation, visible light, and infrared radiation on erythema and pigmentation: A review. *Photochem. Photobiol. Sci.* 12, 54–64.
24. Sellera, F. P., Sabino, C. P., Cabral, F. v. and Ribeiro, M. S. (2021) A systematic scoping review of ultraviolet C (UVC) light systems for SARS-CoV-2 inactivation. *J. Photochem. Photobiol.* 8, 100068.
25. World Health Organisation (2020) Can an ultraviolet disinfection lamp kill this new coronavirus? Available at:
26. Office for Product Safety and Standards (2021) Risk Lexicon. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1017251/opss-risk-lexicon.pdf Accessed on 14 January 2022.
27. Bowling, A. (2005) Mode of questionnaire administration can have serious effects on data quality. *J Public Health* 27, 281–291.
28. Office for Product Safety and Standards (2021) Home use of ultraviolet radiation disinfection products Research Report. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/978581/home-use-of-ultraviolet-radiation-disinfection-products.pdf Accessed on 20 October 2022.
29. Office for Product Safety and Standards (2022) Product Safety Database-Product Safety Report.
30. Khazova, M., Johnstone, L., Naldzhiev, D. and O'Hagan, J. B. (2021) Survey of Home-Use UV Disinfection Products. *Photochem. Photobiol.* 97, 560–565.
31. International Commission on Non-Ionizing Radiation Protection (2004) Guidelines on limits of exposure to ultraviolet radiation of wavelength between 180nm and 400nm (Incoherent Optical Radiation). *Health Phys* 87, 171–186.
32. Ke, J., Du, Y., Tyler, R. S., Perreau, A. and Mancini, P. C. (2020) Complaints of people with hyperacusis. *J Am Acad Audiol* 31, 553–558.
33. Lutz, E. A., Sharma, S., Casto, B., Needham, G. and Buckley, T. J. (2010) Effectiveness of UV− C equipped vacuum at reducing culturable surface- bound microorganisms on carpets. *Environ. Sci. Technol* 44, 9451–9455.
34. Claus, H. (2021) Ozone generation by ultraviolet lamps. *Photochem. Photobiol* 97, 471–476.

35. Schachter, S. and Singer, J. (1962) Cognitive, social, and physiological determinants of emotional state. *Psychol Rev* 69, 379–399.
36. Rief, W., Avorn, J. and Barsky, A. J. (2006) Medication-attributed adverse effects in placebo groups. *Arch. Intern. Med.* 166, 155–160.
37. Colloca, L. and Miller, F. G. (2011) How placebo responses are formed: a learning perspective. *Philos. Trans. R. Soc. Lond. B. Biol. Sci* 366, 1859–1869.
38. Faasse, K., Helfer, S. G., Barnes, K., Colagiuri, B. and Geers, A. L. (2019) Experimental assessment of nocebo effects and nocebo side effects: Definitions, study design, and implications for psychiatry and beyond. *Front. Psychiatry* 10.
39. Nina Pierpoint (2009) Wind Turbine Syndrome: A Report on a Natural Experiment . K Selected Publications, Santa Fe.
40. Bolin, K., Bluhm, G., Eriksson, G. and Nilsson, M. E. (2011) Infrasound and low frequency noise from wind turbines: Exposure and health effects. *Environ. Res. Lett.* 6.
41. Crichton, F. and Petrie, K. J. (2015) Health complaints and wind turbines: The efficacy of explaining the nocebo response to reduce symptom reporting. *Environ. Res.* 140, 449–455.
42. Crichton, F., Chapman, S., Cundy, T. and Petrie, K. J. (2014) The link between health complaints and wind turbines: Support for the nocebo expectations hypothesis. *Front. Public Health* 2.
43. Ellenbogen, J., Grace, S., Heiger-Bernays, W., Manwell, J., Mills, D. and Sullivan, K. Wind turbine health impact study: report of independent expert panel. Prepared for Massachusetts Department of Environmental Protection and Massachusetts Department of Public Health.
44. Rubin, J., Burns, M. and Wessely, S. (2014) Possible psychological mechanisms for "wind turbine syndrome". On the windmills of your mind. *Noise Health* 16, 116–122.
45. Brown, L. (2020) People are damaging their eyes trying to kill COVID-19 with UV lamps. Available at: https://nypost.com/2020/11/26/people-damaging-their-eyes-trying-to-kill-covid-19-with-uv-lamps/. Accessed on 2 March 2022.
46. Chadwick, J. (2021) Have you bought a UV light? Experts are urging shoppers to think twice before buying devices that claim to kill viruses and bacteria after safety tests show some can cause painful BURNS and eye damage'. Available at: https://www.dailymail.co.uk/sciencetech/article-9530269/Which-warns-dangers-UV-light-sterilisers.html. Accessed on 2 March 2022.
47. Fox, H. (2021) Why you should think twice before buying that UVC disinfection gadget. Available at: https://www.which.co.uk/news/2021/05/why-you-should-think-twice-before-buying-that-uvc-disinfection-gadget/. Accessed on 2 March 2022.
48. Biermann, M., Vonderlin, R., Mier, D., Witthöft, M. and Bailer, J. (2021) Predictors of psychological distress and coronavirus fears in the first recovery phase of the coronavirus disease 2019 pandemic in Germany. *Front. Psychol.* 12.
49. Ran, L., Wang, W., Ai, M., Kong, Y., Chen, J. and Kuang, L. (2020) Psychological resilience, depression, anxiety, and somatization symptoms in response to COVID-19: A study of the general population in China at the peak of its epidemic. *Soc. Sci. Med.* 262, 113261.
50. Shevlin, M., Nolan, E., Owczarek, M., McBride, O., Murphy, J., Gibson Miller, J., Hartman, T. K., Levita, L., Mason, L., Martinez, A. P., McKay, R., Stocks, T. V. A., Bennett, K. M., Hyland, P. and Bentall, R. P. (2020) COVID-19-related anxiety predicts somatic symptoms in the UK population. *Br. J. Health. Psychol.* 25, 875–882.
51. Colizzi, M., Bortoletto, R., Silvestri, M., Mondini, F., Puttini, E., Cainelli, C., Gaudino, R., Ruggeri, M. and Zoccante, L. (2020) Medically unexplained symptoms in the times of COVID-19 pandemic: A case-report. *Brain, Behav. Immun. Health* 5, 100073.

52. Barsky, A. J., Saintfort, R., Rogers, M. P. and Borus, J. F. (2002) Nonspecific medication side effects and the nocebo phenomenon. *JAMA* 622–627.
53. Brown, R. J. (2006) Medically unexplained symptoms: a new model. *Psychiatry* 5, 43–47.
54. Leigh, H. (2010) Reality perception spectrum syndromes (imagination, dissociation, conversion, somatoform, misattribution somatization, Psychosis). In *Genes, Memes, Culture, and Mental Illness*, pp. 249–259. Springer New York.
55. Baird, B. N. R. (1986) Tolerance for environmental health risks: The influence of knowledge, benefits, voluntariness, and environmental attitudes. *Risk Anal.* 6, 425–435.
56. Mickalide, A. (1997) Threats to measurement validity in self-reported data can be overcome. *Inj. Prev.* 3, 7–8.
57. Everson, T. M. and Marsit, C. J. (2020) Epidemiological concepts in environmental epigenetics. In *Environmental Epigenetics in Toxicology and Public Health* Vol. Vol. 22 (Edited by R. Fry), pp. 89–105. Academic Press, London.
58. Bourne, P. A. (2009) The validity of using self-reported illness to measure objective health. *N. Am. J. Med. Sci.* 1, 232–238.
59. Gabbe, B. J., Finch, C. F., Bennell, K. L. and Wajswelner, H. (2003) How valid is a self-reported 12 month sports injury history? *Br. J. Sports. Med.* 37, 545–547.
60. Lilienfeld, D. E. and Stolley, P. D. (1994) *Foundations of Epidemiology*. Oxford University Press, New York.
61. Rothman, K. (2002) *Epidemiology: An Introduction*. New York: Oxford University Press.
62. Tourangeau, R., Rips, L. J. and Rasinski, K. (2000) *The Psychology of Survey Response*. New York, Cambridge University Press.
63. Jenkins, P., Earle-Richardson, G., Slingerland, D. T. and May, J. (2002) Time dependent memory decay. *Am. J. Ind. Med,* 41, 98–101.
64. Baker, M., Stabile, M. and Deri, C. (2004) What do self-reported, objective, measures of health measure? *J. Hum. Resour. Manag.* 39, 1067–1093.
65. Hopwood, D. G. and Guidotti, T. L. (1988) Recall bias in exposed subjects following a toxic exposure incident. *Arch. Environ. Health.* 43, 234–237.
66. Wallsten, T. S., Budescu, D. v and Kemp, S. M. (1993) Preferences and reasons for communicating probabilistic information in verbal or numerical terms. *Psychon Bull Rev.* 31, 135–138.
67. Pohl, N. F. (1981) Scale considerations in using vague quantifiers. *J. Exp. Educ.* 49, 235–240.
68. Wogalter, M. S., Laughery, K. R. and Mayhorn, C. B. (2012) Warnings and hazard communications. In *Handbook of Human Factors and Ergonomics*, pp. 868–894. Wiley.
69. Chan, D. (2009) So why ask me? Are self-report data really that bad? In *Statistical and Methodological Myths and Urban Legends* (Edited by C. E. Lance and R. J. Vandenberg), pp. 309–336. Routledge, New York.
70. Massey, J. T. and Gonzalez, J. F. (1976) Optimum recall periods for estimating accidental injuries in the national health interview survey. *American Statistical Association* 584–588.
71. Spielberger, C. D., Gorusch, R. L. and Luschene, R. E. (1970) The State Trait Anxiety Inventory. Palo Alto: Consulting Psychologists Press.
72. Barsky, A. J., Wyshak, G. and Klerman, G. L. (1990) The Somatosensory Amplification Scale and its relationship to hypochondriasis. *J. Psychiatr. Res.* 24, 323–334.

73. Bräscher, A. K., Raymaekers, K., van den Bergh, O. and Witthöft, M. (2017) Are media reports able to cause somatic symptoms attributed to WiFi radiation? An experimental test of the negative expectation hypothesis. *Env. Res.* 156, 265–271.
74. Verrender, A., Loughran, S. P., Dalecki, A., Freudenstein, F. and Croft, R. J. (2018) Can explicit suggestions about the harmfulness of EMF exposure exacerbate a nocebo response in healthy controls? *Env. Res.* 166, 409–417.

Table 1. Summary of OPSS research Waves 1 – 5

Wave	Dates	Sample size	No. of questions
1	April – July 2020	3,811	2
2	February – March 2021	2,261	6
3	May – June 2021	10,296	26
4	August 2021	309	42
5	November – December 2021	10,187	12

Table 2. Demographic data of UV-C device owners (excluding Wave 4) PNT = Prefer not to say, ABC1 = middle class C2DE = working class

	Wave 1		**Wave 2**		**Wave 3**		**Wave 4**		**Wave 5**	
	n	%	n	%	n	%	n	%	n	%
Total	204	5%	437	19%	527	5%	309	-	688	7%
Gender										
Male	149	73%	308	70%	294	56%	164	53%	383	56%
Female	54	26%	126	29%	234	44%	145	47%	304	44%
PNT/Other	1	0%	3	1%			-		-	-
Age										
16-34	130	64%	265	61%	259	49%	129	42%	353	51%
35-54	63	31%	131	30%	171	32%	117	38%	204	30%
55+	11	5%	41	9%	97	18%	63	20%	130	19%
Social Grade										
ABC1	115	56%	249	57%	303	57%	163	53%	363	53%
C2DE	89	44%	188	43%	224	43%	146	47%	325	47%

Table 3. Demographic data of UV-C device owners who reported side-effects after use (excluding Wave 1). PNT = Prefer not to say, ABC1 = middle class C2DE = working class

	Wave 1		**Wave 2**		**Wave 3**		**Wave 4**		**Wave 5**	
	n	%	n	%	n	%	n	%	n	%
Total			200	46%	159	30%	92	30%	254	37%
Gender										
Male	-	-	162	81%	93	58%	54	59%	153	60%
Female	-	-	36	18%	66	42%	38	41%	101	40%
PNT/Other	-	-	2	1%	-	-	-	-	-	
Age										
16-34	-	-	132	66%	88	55%	52	57%	181	71%
35-54	-	-	64	32%	58	36%	37	40%	64	25%
55+	-	-	4	2%	13	8%	3	3%	9	4%
Social Grade										
ABC1	-	-	123	62%	88	55%	59	64%	142	56%
C2DE	-	-	77	39%	71	45%	33	36%	112	44%

Table 3. Demographic data of UV-C device owners who reported side-effects after use (excluding Wave 1). PNT = Prefer not to say, ABC1 = middle class C2DE = working class

FIGURE CAPTIONS

Figure 1. Type of reported side-effect after using UV-C device (*N* = 309). PNS = Prefer not to say

Figure 2. Duration of reported side-effect after using UV-C device (*n* = 92)

Figure 3. Duration of reported side-effect after using UV-C device by type of side-effect (*n* = 126). While 92 respondents reported at least one side-effect, *n* = 126 as some respondents reported multiple side-effects. Counts are provided rather than proportions due to low numbers.

Figure 4. Device type by reported side-effect (*N* = 309).

Figure 5. Length of time until reported side-effect appeared for each device (*n* = 92) Counts are provided rather than proportions due to low numbers.

Figure 6. Extent to which warnings were reportedly seen by reported side-effect (*N* = 270)

Figure 7. Extent to which manual was read by reported side-effect (*N* = 309)

Figure 8. Perceived effectiveness of UV-C device by reported side-effect (*N* = 309)

Figure 9. Timeline of purchasing behaviour of UV-C devices (*n* = 646)

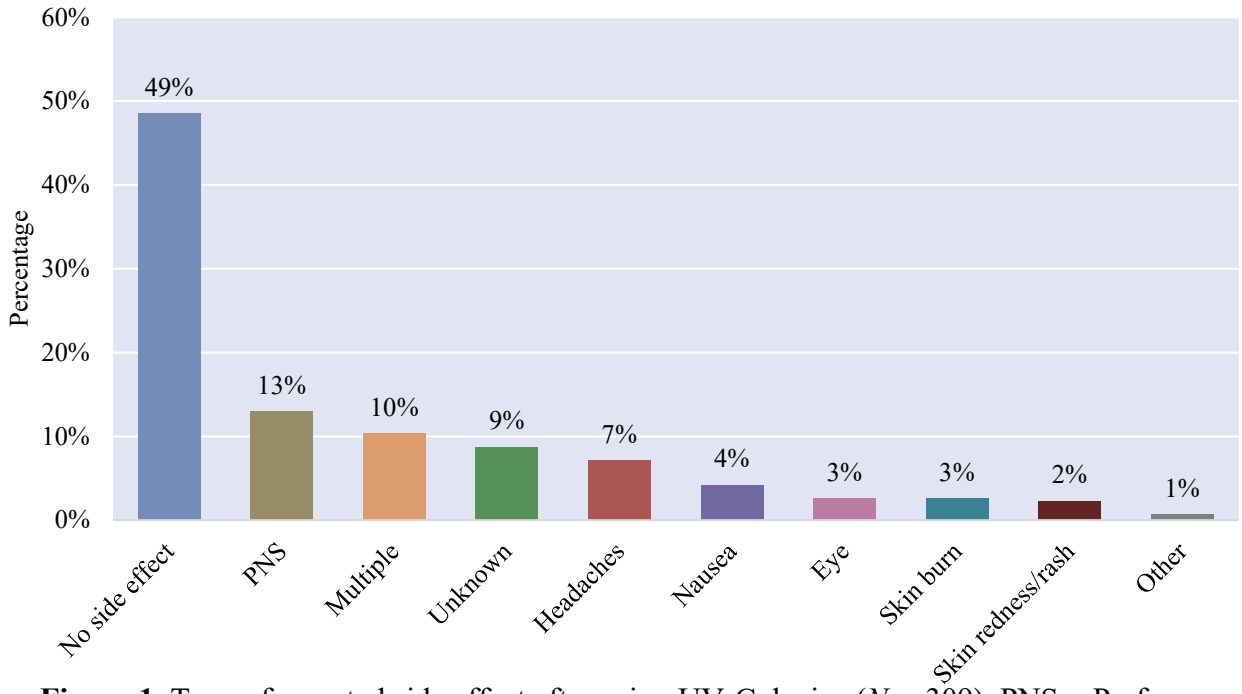

Figure 1. Type of reported side effect after using UV-C device (*N* = 309). PNS = Prefer not to say

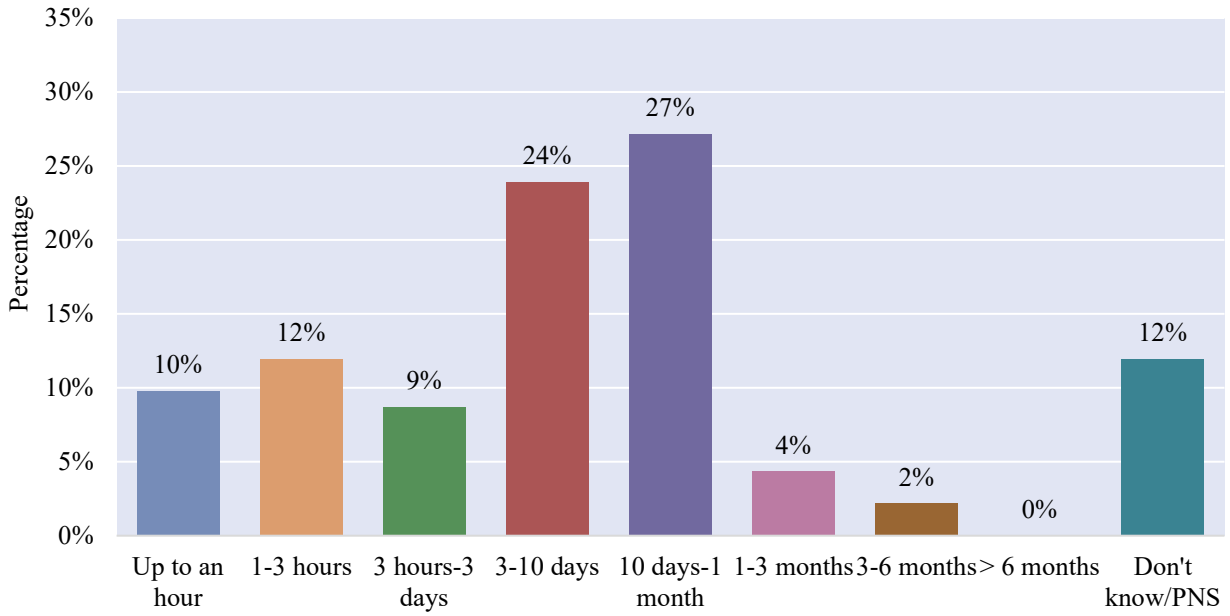

Figure 2. Duration of reported side effect after using UV-C device (*n* = 92)

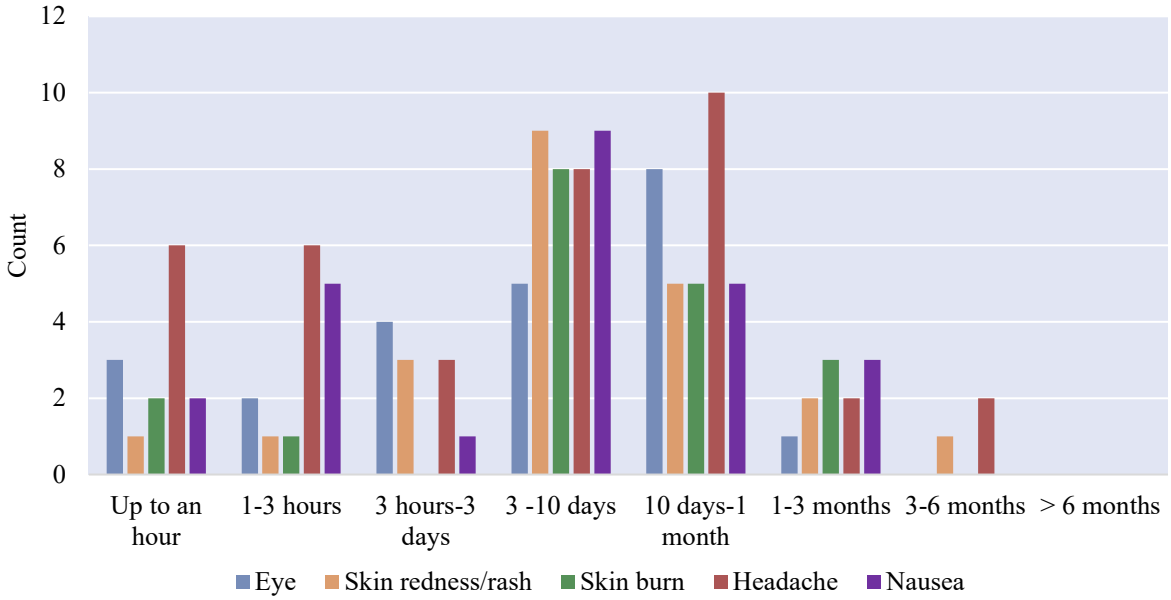

Figure 3. Duration of reported side effect after using UV-C device by type of side effect (n = 126). While 92 respondents reported at least one side-effect, n = 126 as some respondents reported multiple side-effects. Counts are provided rather than proportions due to low numbers.

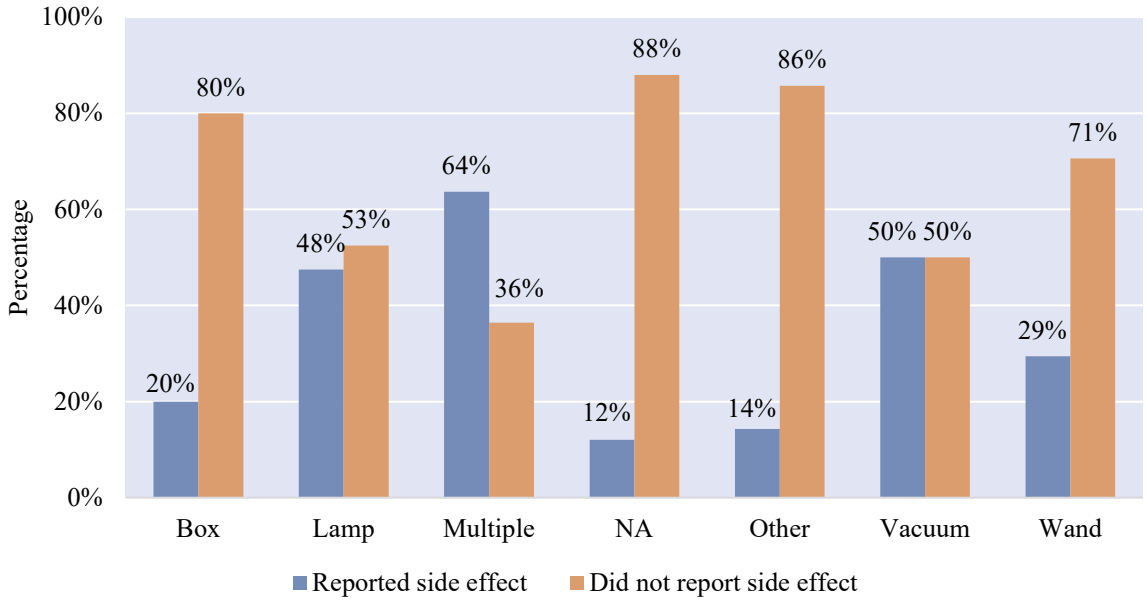

Figure 4. Device type by reported side effect (N = 309)

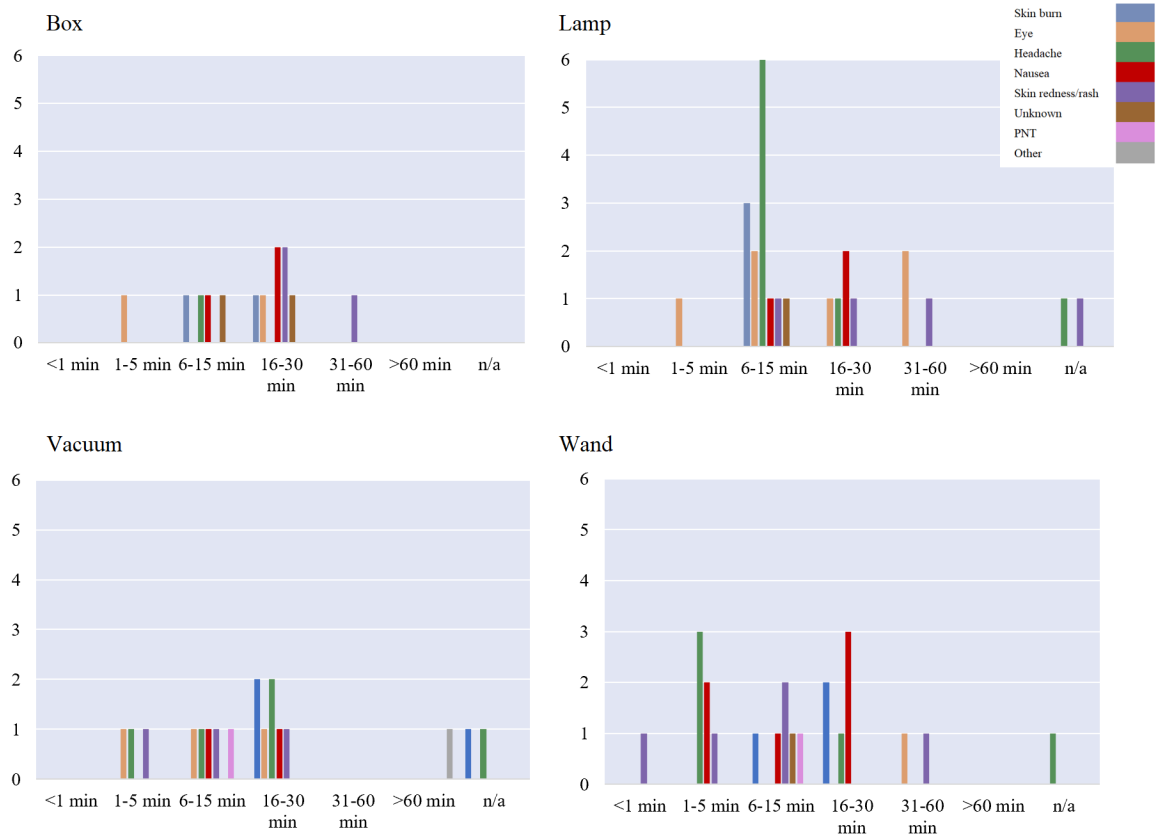

Figure 5. Length of time until reported side effect appeared for each device (n = 92). Counts are provided rather than proportions due to low numbers.

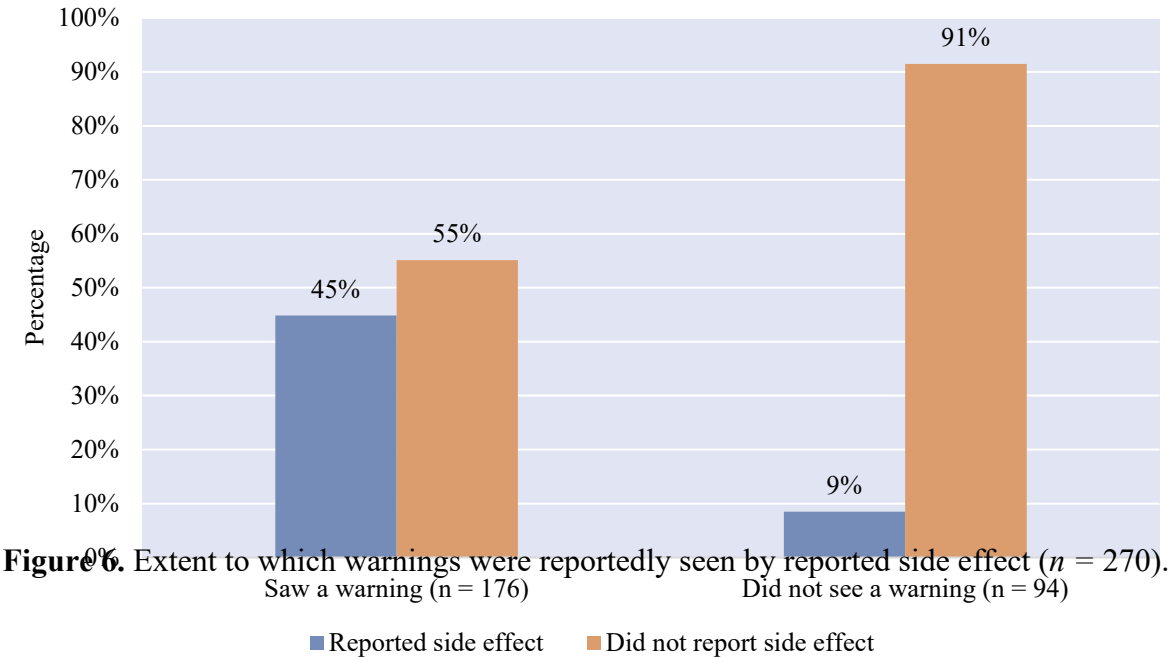

Figure 6. Extent to which warnings were reportedly seen by reported side effect (n = 270).

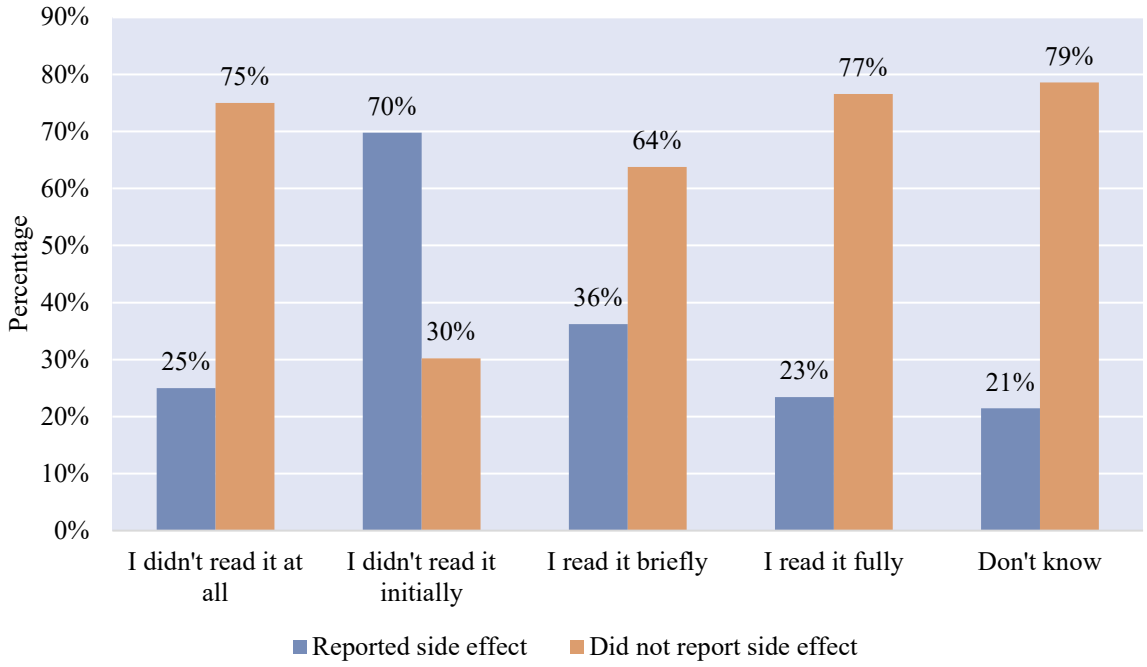

Figure 7. Extent to which manual was read by reported side effect (N = 309)

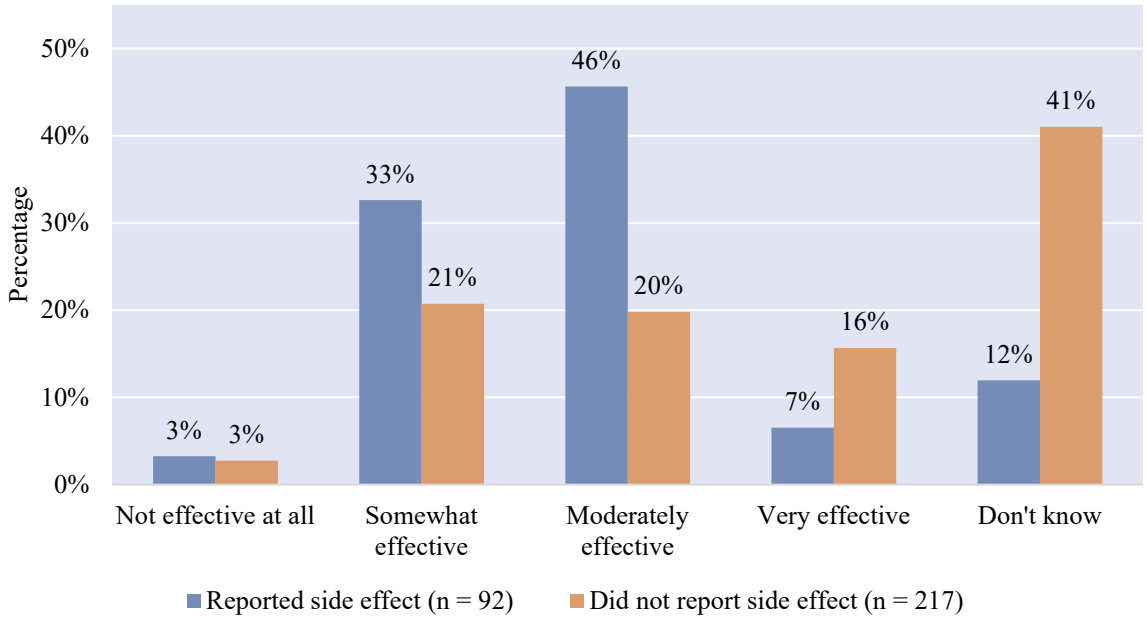

Figure 8. Perceived effectiveness of UV-C device by reported side effect (N = 309)

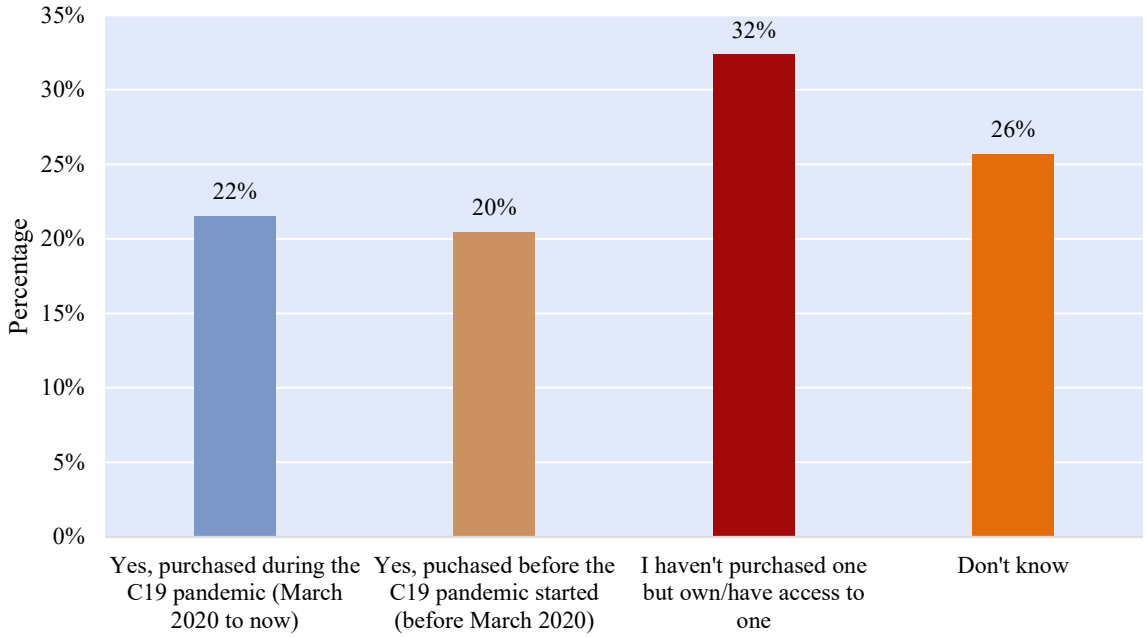

Figure 9. Timeline of purchasing behaviour of UV-C devices (n = 646)