“Shhh. be quiet!” Reducing the Unwanted Interruptions of Notification Permission Prompts on Chrome

Igor Bilogrevic, Balazs Engedy, Judson L. Porter III, Nina Taft, Kamila Hasanbega, Andrew Paseltiner, Hwi Kyoung Lee, Edward Jung, Meggyn Watkins, PJ McLachlan, and Jason James, *Google*

https://www.usenix.org/conference/usenixsecurity21/presentation/bilogrevic

This paper is included in the Proceedings of the 30th USENIX Security Symposium.

August 11–13, 2021

978-1-939133-24-3

“Shhh...be quiet!” Reducing the Unwanted Interruptions of Notification Permission Prompts on Chrome

Igor Bilogrevic Balazs Engedy Judson L. Porter III Nina Taft Kamila Hasanbega
Andrew Paseltiner Hwi Kyoung Lee Edward Jung Meggyn Watkins PJ Mclachlan
Jason James
Google
*{ibilogrevic,engedy,jud,ninataft,hkamila,apaseltiner,hwi,edwardjung,
meggynwatkins,pjmclachlan,jasonjames}@google.com*

Abstract

Push notifications can be a very useful feature. On web browsers, they allow users to receive timely updates even if the website is not currently open. On Chrome, the feature has become extremely popular since its inception in 2015, but it is also the least likely to be accepted by users. Chrome telemetry shows that, although 74% of all permission prompts are about notifications, they are also the least likely to be granted with only a 10% grant rate on desktop and 21% grant rate on Android. In order to preserve its utility for websites and to reduce unwanted interruptions and potential abuses for the users, we designed and tested both a novel UI and its activation mechanism for notification permission prompts in Chrome.

To understand how users interact with such prompts, we conducted two large-scale studies with more than 300 million users in the wild. The first study showed that most of them block or ignore the prompts across all types of websites, which prompted us to rethink its UI and activation logic. The second study, based on an A/B test using behavioral data from more than 40 million users who interacted with more than 100 million prompts on more than 70 thousand websites, show that the new prompt is very effective at reducing unwanted interruptions and their frequency (up to 30% fewer unnecessary actions on the prompts), with a minimal impact (less than 5%) on the grant rates, across all types of users and websites. We achieve these results thanks to a novel adaptive activation mechanism coupled with a block list of interrupting websites, which is derived from crowd-sourced telemetry from Chrome clients.

1 Introduction

The web browser is the main gateway to the World Wide Web for over 4.5 billion people [39]. Browser APIs allow websites to access resources and information on the client devices in a scalable and standardized way, enabling users to benefit from fast, interactive and personalized experiences without having to install and run dedicated applications. Some of those APIs provide access to sensitive data (such as geolocation or the microphone), and in those cases the website has to ask the user for permission before it can access such data [44]. Moreover, permission-gated APIs can provide an additional layer of security from other kinds of abuses, such as spam, phishing or deceptive marketing [5, 29].

Web push notifications are a very popular mechanism for websites to keep their users updated with timely content when a website is not open or is in the background. On Chrome, the telemetry shows that notification permission prompts account for 74% of all permission prompts shown to users during the month of March 2020. To receive notifications, users have to visit the website and grant the notification permission when prompted [45]. In order to help websites decide when to ask for the notification permission, Chrome and the Mozilla foundation have published a set of best practices to follow when asking for web push permissions [34, 46]. Chrome’s best practices are centered around two main principles: (i) users should show intent to receive notifications and (ii) sites should provide in-site management controls for notifications. Similarly, Mozilla’s best practises also caution developers to use them sparingly as they could be annoying [46]. In addition to being unwanted, such prompts can also be interrupting. Much prior work (see Section 2) has shown that poorly managed interruptions have multiple negative consequences, including an increased level of annoyance, anxiety, errors due to inattention and a desire to click-through without understanding the implications of doing so [7, 13]. A recent Mozilla study [31] concluded that notification prompts are indeed very unpopular. Even worse, certain websites try to trick users into granting the notification permission with misleading information about its actual purpose or by gating their content on the acceptance of the notification permission prompt [5]. Other websites could see it as an effective means to drive re-engagement [2, 15].

The problem we tackle here is how to reduce unwanted – and likely annoying – notifications for the majority of users without significantly impacting those who do want to opt in to

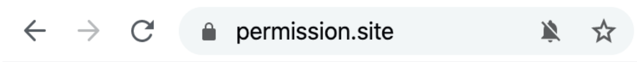


Figure 1: Chrome version 80, quiet prompt on desktop with an animated bell icon.

notifications. We design a solution that leverages the browser to manage the complex trade-offs that might arise between users who are unlikely to want to receive notifications, those that do seem to want them, and many website owners who might rely on them for increased engagement and higher service utility [16]. Our solution for Chrome has three main components. First, we introduce a "quieter" notification permission UI with a strikethrough bell (Figure 1), which is less intrusive and it allows users to enable notifications in a direct way should they want to. Second, we determine criteria when to show this UI to users based on their prior blocking choices. This is difficult not only because we need to simultaneously meet the needs of millions of users who exhibit a wide range of behaviors, but also because many behaviors are not explicit (e.g., when they simply ignore the prompts). Third, we determine the conditions under which Chrome activates this new prompt for websites. Doing this requires us to carefully balance the need to prevent abusive or spammy websites from interrupting the users, while not interfering with websites that use notifications responsibly and according to best practices. We note that other popular web browsers (Safari and Firefox) have independently introduced updates to the requirements and interface of the notification permission prompt [4, 21, 26, 31, 42], while Microsoft Edge has leveraged our solution [30] and enabled it by default for all users across all websites.

In this paper, we present the results of the largest and most comprehensive analysis, to the best of our knowledge, of the use of notification permission prompts in the wild, and show that our solution effectively balances the needs of both users and websites in Chrome. Our main contributions are:

- We conduct a first large-scale experiment to study the interaction of hundreds of millions of Chrome users with the notification permission prompt in the wild. Our findings show only 10% and 21% of notification permissions are granted on the desktop and Android, respectively, which suggests that the vast majority of users do not see a clear benefit from receiving notifications when prompted across all types of websites.
- We present the process that we adopted to rethink the notification permission prompt in order to reduce unwanted interruptions for users and potential abuses by websites, and at the same time not to penalize users that do want to receive notifications and websites that do adhere to the best practices when showing such prompts.
- We introduce proxy measures for unwanted notification prompts, and we conduct a second large-scale experiment with more than 40 million users as an A/B test, which shows that the new UI and its activation logic manage to achieve not only a desired reduction in unwanted interruptions, but also to have minimal negative impact on grant rates. Moreover, they provide a concrete incentive for websites to use the notifications API responsibly.

In particular, our second experiment shows that the new prompt and its activation logic reduce the interruptiveness of unwanted notification permission prompts by up to 30%, while limiting the impact on the grant rates to less than 5%. Finally, in order to provide transparency, accountability and accessibility of interaction rates with the notification prompt across websites, we include them in a publicly accessible online tool [18], which does not require any extra instrumentation from the websites.

The remainder of the paper is structured as follows. In Section 2 we discuss the related work, and in Section 3 we present the first experiment, in which we measured the interactions of more than 300 million Chrome users on more than 800 million notifications permission prompts, across more than 70 thousand websites. In Section 4 we describe the approach and measures we took to limit the interruptions due to unwanted notification permission prompts, and show in the second experiment how this approach has reduced unwanted interruptions to the browsing experience with a limited impact on the grant rates. In Section 5 we discuss the implications of our changes for the web ecosystem and present some of the limitations of our study. Finally, we present our conclusions in Section 6.

2 Related Work

In the 2000s when push notifications were first introduced, only mobile OSes (such as BlackBerry OS, iPhone OS and Android) supported them [6, 17]. The availability of push notifications on the web is much more recent, thanks to the development and adoption of the Notifications API in the mid 2010s. In this section, we discuss works that studied the effects of interruptions – such as notification prompts – on the primary task, and those that analysed deceptive notifications that could lead to privacy and security threats.

2.1 Interruptions due to Notifications

Bailey and Konstan [7] conducted a laboratory experiment to measure the effects of interruptions on task completion time, error rate, annoyance, and anxiety. They manipulated the time at which the interruption was displayed, either during the primary tasks or in-between tasks. They showed that, when the interruption occurs during the primary task, users experience up to 106% more annoyance, and "commit twice the number of errors" as well as "experience twice the increase in anxiety" as compared to when the interruption happens in-between the primary tasks. Moreover, as reported in numerous works surveyed in [25], not all interruptions have the same negative effect: while interruptions are not detrimental when performing simple and repetitive tasks, they do negatively affect task performance for complex tasks, especially when the primary task is unrelated to the interrupting one.

In the work by Felt et al. [13] on mobile app permissions, the authors proposed a set of guidelines on how to ask for permissions in order to reduce the habituation to permission prompts. One of the two principles – avoid interruptions – highlights the importance of avoiding interrupting users with security-related tasks while they are doing something unrelated – such as browsing a website. Otherwise, users are likely to "click through a dialog box...without fully understanding the consequences". Permission prompts by mobile apps and notification prompts in browsers are very similar in this respect, as they both interrupt the users' primary task.

Several other works have studied users' interaction behavior with notifications on mobile devices [14, 27, 28, 32, 36, 37]. For instance, the experiment conducted by Fischer et al. [14] showed that mobile notifications are dealt with more quickly and with a higher completion rate if they arrive at a moment where the users are in-between tasks rather than during the primary task, which is to some extent similar to previous findings by Bailey et al. [7] but in this specific context. Furthermore, the study by Pejovic and Musolesi [36] revealed that, in addition to the timing and primary task, other contextual features such as location, time of the day, emotion and engagement determine if a moment is suitable for receiving a notification. In another related work, Okoshi et al. [32] developed a mechanism that selects the best timing for delivering notifications based on the users' physical activity and UI events, which reduces by 71.8% the users' perceived workload as compared to other systems based on UI-only events. Similarly, Mehrotra et al. [27] used contextual information, such as the users' activity, and social relationship between senders and receivers to develop a machine-learning based system to select the most appropriate timing for the delivery of the notification. Their system outperformed mechanisms based on user-defined rules of their own interruptibility. More recently, Pielot et al. [37] showed that non-messaging notifications are significantly less likely to be acted upon quickly, which is a notion that malicious websites seem to abuse in order to mislead users into granting the notification permission [5].

Web push notifications appear to the users as native system notifications on both mobile and desktop platforms that support the Notifications API [43]. Therefore, as they are not different from app notifications in this respect, the results established in prior works apply to them as well. We were unable to find specific studies on web push notifications that tackled any aspect related to interruptibility, in a similar way to the studies on app notifications we described previously.

2.2 Deceptive Notifications

In addition to being potentially interrupting, web push notifications can be quite deceptive and pose a significant threat for the users' security and privacy, by means of phishing and spam [24, 35, 47], social engineering [41], forging and denial-of-service attacks [3]. Phishing is likely one of the most significant threats that malicious notifications can lead to. In their early work in 2012, Xu and Zhu [47] already showed how customized notifications could be successfully used to launch phishing attacks and post spam notifications in earlier versions of Android (2.3 and 4.0). More broadly, social engineering attacks – such as the ones studied by Vadrevu et al. [41] – were discovered on some ad landing pages, which were used in order to lure the user into granting the notification permission by promising access to access adult content. In Alepis's recent work [3] on Android version 7, the author shows how it is possible to forge notifications – even web push notifications – both locally (by a malicious app, for example) and remotely. Although the notification forging attack requires the user to install a malicious app, by either downloading it from the Play Store or another source, it shows once again how notification customization can be abused. While issues related to deceptive notifications are very important, our work does not tackle them directly. However, it has a positive side effect of limiting such abuses by automatically blocking intrusive permission prompts for many users.

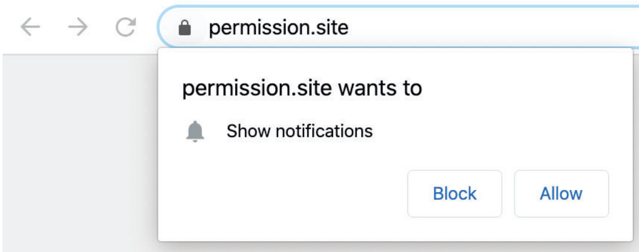
3 Interactions with the Legacy Notification Permission Prompts

In this section, we describe how Chrome users interact with the legacy notification permission prompt (Figure 2) which is the only one that was available until version 80. First, we introduce essential background information about the Notifications API, and then we describe our experiment and the results that made us rethink the experience with the notification permission prompt.

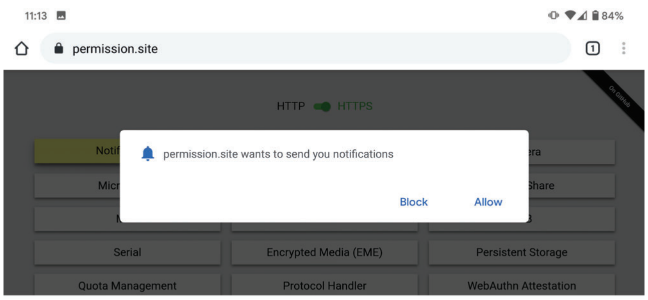
3.1 Background

Popular operating systems (OSs), such as Microsoft Windows, macOS, iOS, Android and Chrome OS, allow third-party apps to display push notifications as native system notifications to users [10, 11, 30]. Typically, each OS provides different APIs that apps – including browsers – can use to deliver such notifications. On the contrary, browsers usually implement a standard set of APIs that follow the specification described by the W3C [43], so that website owners do not have to develop and maintain different parts of code for the same functionality across different OSs.

The browser Notifications API [45] is one such standard API that allows websites to send system notifications even when users do not have the website open in their browser.



(a) Desktop platform.



(b) Android platform.

Figure 2: Chrome legacy notification permission prompt.

Users can therefore benefit from timely and relevant information from websites that they have opted in to receive notifications from. However, such functionality can also be prone to abuses, as it provides websites with an effective means to drive re-engagement rates [2, 15]. There are many examples where websites have abused this functionality, by either disguising the notification prompt as a chat window, by gating the website's content on the acceptance of the prompt, or by trying to circumvent existing abuse-prevention mechanisms [5, 12].

The API specification mandates that "Notifications can only be displayed if the user (or user agent on behalf of the user) has granted permission" [43]. Before asking for that permission, the website should check its current state, which could be one of *granted*, *denied* or *default*. The latter is equivalent to a *deny* decision and it applies if no prior explicit decision has been made yet. Hereafter we describe how Chrome users interacted with the *legacy* notification permission prompts (Figure 2), which are the only ones that were available before version 80. This analysis is important as it clearly shows how most of the legacy prompts unnecessarily interrupt the browsing experience, and it provides us with a compelling reason to rethink it in a way to reduce interruptions while keeping the benefits for the users who might want to receive notifications.

It is also important to note that there is a significant difference in the way the permission prompt is shown to users on desktop and Android Chrome clients. While on desktop users can continue to browse the website when the prompt is visible, this is not the case on mobile, where users have to click on one of the two buttons – "Allow" or "Block" – in order to continue to browse the website. This has a significant effect on the results of analysis we conduct in this section, and is also part of the redesign process we discuss in Section 4.

3.2 First Experiment

In order to better understand how Chrome users interact with the notification permission prompts, we conducted our first study using the telemetry data that Chrome normally collects from a subset of opted-in users. In Chrome, users can choose to send usage statistics, crash reports and URLs of pages they visit to Google in order to help improve Chrome's feature set and stability [19]. Usage statistics and crash reports are enabled by default on Chrome and can be disabled in Chrome's settings. For instance, 74% of all prompts that those users see are for the notification permission, a statistic we mention in the abstract and in Sections 1 and 6. Information containing specific URLs can only be collected if users choose to send the above information and also give extra consent for collecting that data by turning on the setting "Make searches and browsing better (Sends URLs of pages you visit to Google)" – this is enabled if the user enables Sync. Once enabled, Chrome usage statistics will also include information about the visited URLs, and are keyed by a unique random device identifier. Usage statistics and Sync can be disabled in Settings. If re-enabled, the unique device identifier is reset.

The telemetry data we analyse in this study comes from a 10-day period between the 7th and the 16th of March, 2020, during which Chrome collected the relevant behavioral data from a random subset of users who are signed-in to with their Google account, are sharing usage reports and crash analytics with Google and have enabled the browser Sync feature without a custom passphrase. The data used in these studies adheres to Google's guidelines for data collection and experimentation. In order to conduct any experiment with real behavioral data on such a subset of users, we need to obtain prior approval from key Google stakeholders in a number of areas, including legal, privacy, UX, engineering, product and leadership. Only after all of them gave their approval were we allowed to launch such an experiment. We are not subject to IRB review, however Chrome's approved process for rolling out new features (such as the Quiet UI and its activation logic) involves partially rolling out a feature to a subset of customers, and then using A/B testing to compare performance metrics before and after. We followed standard company practices in our A/B testing that enabled us to compute impact metrics for subsets of users.

Our measurement methodology includes a careful choice of which data to include and which to exclude. The specific data fields we process are:

1. The randomly generated unique device identifier, which can be reset at any time by the user
2. The OS platform on which the client is running, which can be either desktop or mobile. For the latter, we only study

data from Android mobile clients, as iOS (current version 13.4.1) does not support web push notifications.
3. The URL origin (e.g., https://subdomain.website.com) that displayed the prompt. Throughout the rest of this paper, we refer to URL origins also as websites or sites.
4. The type of prompt that was shown to the user (i.e., legacy or quiet). In this section, we only analyse data about the legacy prompts, whereas in Section 4 we compare and discuss both the legacy and the quiet ones.
5. The user's action on the prompt, which can be either grant, block, ignore or dismiss. A *dismiss* is recorded when the user closes the prompt without clicking on either grant or block, whereas an *ignore* is recorded when the user does not interact with the prompt at all. Throughout the rest of the paper, we refer to any action other than *ignore* as a *decision*. In Chrome, a single grant or deny decision on a website is recorded for all future visits to the same website. In other words, while ignoring or dismissing a prompt will allow the website to show it again at the next visit, granting or blocking it will prevent that website from showing it again. This holds until either the user changes the settings for that website, or re-installs Chrome, or also in case she dismisses the prompt three times in a row on that website.

Moreover, in order to limit the impact of test accounts or devices while retaining a large number of samples, we filter the data according to the following criteria:

- We only consider devices that saw at least 1 and at most 200 prompts, and that performed less than 100 grant, deny, or dismiss actions on them. Moreover, we also limit potential spammy reports by (i) removing clients that have reported more than 100 page load events to the same URL in any given day, and by (ii) only analysing reports from genuine Chrome clients that sign the reports with a valid cryptographic key provided by Google.
- We only consider URL origins with at least 1000 page loads and at least 100 decisions (i.e., grant, block or dismiss), from at least 50 different clients. Moreover, we consider only data from URL origins that allow automated crawling. We do not process any URL data from websites that have opted out from the Robots Inclusion Protocol [22], as specified in their robots.txt file.

3.3 Results

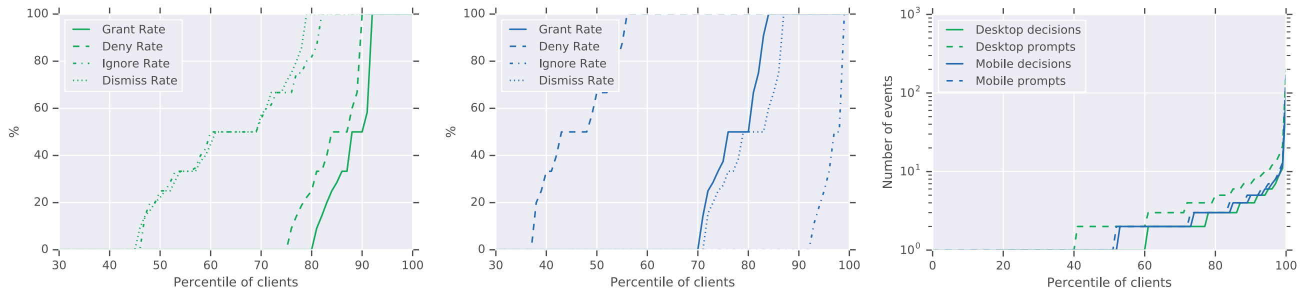
After filtering out the data samples that do not satisfy the above criteria, we are able to analyse more than 800 million actions on legacy prompts, coming from more than 300 million clients on more than 70 thousand websites. Overall, only 10% of such prompts are granted on desktop and 21% on Android. As described hereafter, we use the deny, ignore and dismiss rates as proxies to assess user annoyance and/or unwanted notifications. To measure those directly, one would have to allow users to carefully report on such aspects every time they interact with a permission prompt, which would add more interruptions to an already disrupted experience for many users. Alternatively, one could also interview users but that cannot be done on the scale of tens or hundreds of millions of participants. We chose those signals by consensus, after reviewing several candidate ones that were available during the experiments. In general, if a user denies a notification prompt, we believe it is a strong signal that either she is not interested in the service or that she is simply annoyed and does not want to be asked again. High ignore and dismiss rates indicate that users are either avoiding having to make a decision or are truly disinterested and simply want to quickly get beyond the prompt request. We use this trio of signals to capture the entirety of the unwanted and annoyed concepts. While we cannot completely disambiguate a user's intention, it is clear that any of these three choices captures either lack of interest and/or possible annoyance.

3.3.1 Clients

In order to better understand how clients interact with prompts, we look at the rate at which prompts are granted, denied, dismissed or ignored, over the total number of prompts seen. We compute numerous metrics, all of which together indicate users are not interested in the vast majority of notification prompts. The horizontal axes of Figure 3a and 3b show the percentile of clients that have a grant/deny/ignore/dismiss rate which is smaller or equal to the corresponding value on the vertical axes. They show that 80% of desktop clients and 70% of Android clients who ever saw a notification prompt during the 10-day period never granted it. Our first key observation is that most users do not grant the notification permissions at all. We also observe that most desktop users (55%) ignore or dismiss a prompt at least once. This indicates that most desktop users tend not to make a "permanent" decision which is remembered for subsequent visits to the same website.

The per-client average rates for desktop are: grant 12%, deny 15%, dismiss 37% and ignore 36%. For mobile, they are 23%, 54%, 19% and 3%. Our next key observation is that for both desktop and mobile, the deny and dismiss rates are greater than the grant rates, sometimes significantly so. We observe that on Android, the client behavior is quite different than desktop. The grant rate is almost double that of desktop clients, while the average deny rate is nearly 4 times that of desktop clients. Similarly the dismiss and ignore rates are much lower on mobile devices than desktops. While we believe that the blocking nature of the permission prompt on the Android platform has a significant influence, the telemetry data does not allow us to isolate its effect from others, such as the inherently different website designs and types of content that is consumed on a mobile platform as opposed to desktop.

Figure 3b shows that only 36% of Android clients never denied a permission request, meaning that 64% of clients denied it at least once. A third observation is that the majority of clients elect to deny at some point.



(a) Average grant, deny, ignore and dismiss rates on desktop.

(b) Average grant, deny, ignore and rates on Android.

(c) Number of prompts seen and decisions made.

Figure 3: Number of prompts seen and interaction rates with the legacy prompt, by percentile of clients.

Finally, Figure 3c shows the number of permission prompts seen and decisions made by client percentile. Desktop clients tend to see more prompts but they also tend to report fewer interaction with them. For instance, while 19% of desktop clients never clicked on a prompt, this was the case for only 3% of mobile clients. Moreover, although there are 59% of desktop clients who have seen 2 or more prompts, only 39% have interacted with them. On the contrary, almost all mobile clients who see a prompt tend to interact with it as well. This already points out the fact that notification permission prompts, when abused, are more interrupting on mobile devices than on desktop, and we therefore aim to significantly reduce unwanted interruptions especially on Chrome with the new quiet UI described in Section 4.

Taken together, all of these observations clearly indicate that users are either not engaging with notifications much overall, and when they do, they rarely grant them. It appears that most of the time, they see little benefit in receiving notifications.

3.3.2 URL origins

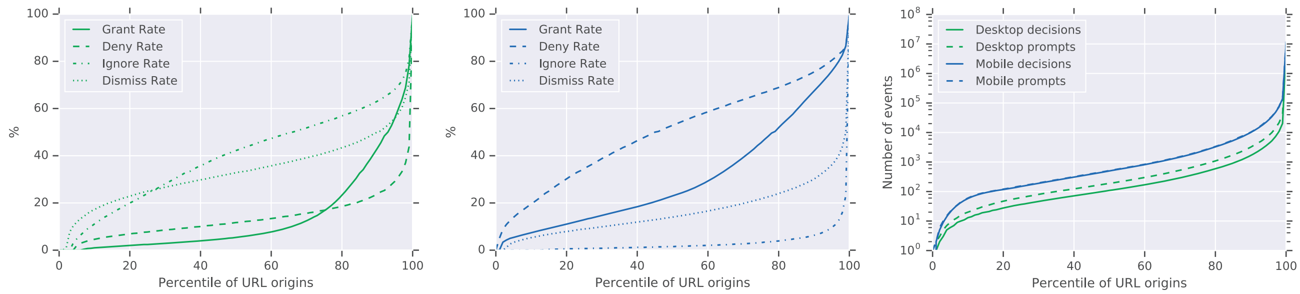
In addition to analysing the interactions with the permission prompt from the clients' point of view, hereafter we characterize such interactions from the websites' perspective. This is important because it takes into account the large differences in the types of websites on which the permission prompt is shown, and it is therefore crucial to understand how the current behavior and the redesigned UI affects websites with different characteristics.

When looking at the types of actions performed on the permission prompts, Figure 4a shows that on desktop there are 76% of websites where the deny rate is higher than the grant rate, both under 17%. Ignore and dismiss rates are much higher overall, although their relative ranking changes: dismiss rates are higher than ignore rates for 26% of websites, and they are lower for the remaining 74% of them. It is interesting to note that there is less than 1% of websites with a deny rate higher than 50%, whereas there are 8% of websites with a grant rate higher than 50%. This indicates that there are more than 8 times (in percentage terms) the number of websites that most users feel comfortable in receiving notifications from, as compared to websites where most users definitely do not see any benefit and therefore block notifications.

On mobile, the behavior is very different. Figure 4b shows that 56% of websites have a deny rate higher than 50%, which is a 58x increase as compared to desktop, whereas 22% have a grant rate higher than 50% (less than 3x the number for desktop). Clearly, when faced with a "blocking" action, mobile users tend to deny the prompt overwhelmingly more often than they tend to grant it. This is a clear signal that the "blocking" notification permission prompts are unwanted, and they are interrupting the browsing experience for mobile users much more than desktop ones. Hence, our strategy to address such unwanted interruptions has to revisit the "blocking" nature of the mobile prompt as well. As the ignore and dismiss actions on mobile require an additional interaction with the device – by either going to the previously visited website, closing the tab or exiting the browsing session – they are seldom recorded in large quantity; indeed, less than 1% of websites have ignore or dismiss rates greater than 50% for mobile clients.

Finally, Figure 4c shows the number of prompts seen and decisions made by percentile of websites. First, similarly to Figure 3c, we see that the number of decisions is practically the same as the number of prompts seen on the Android platform, whereas on desktop there is a higher number of prompts seen but not acted upon. Second, we also notice that the notification prompt volume seems to follow the power law distribution – which is used to model the number of visits to websites ([1, 9]) – where 20% of websites in our dataset showed less than 100 prompts, whereas much less than 1% showed more than 10 million prompts. The per-URL median number of decisions was 188 on desktop and 513 on Android.

Having observed how clients interact with the legacy notification permission prompt across websites, in the following section we present our revised UI for notification permission prompts on Chrome, and the new activation logic for clients



(a) Average grant, deny, ignore and dismiss rates on desktop.

(b) Average grant, deny, ignore and dismiss rates on Android.

(c) Number of prompts seen and decisions made.

Figure 4: Number of prompts seen and interaction rates with the legacy prompt, by percentile of the URL origins.

and websites.

4 Reducing the Interruptiveness of Notification Permission Prompts

Although notifications are an important tool for websites to send timely updates to their visitors, most users seem not to want them. Partially, we believe this is also a result of websites that see notification prompts as an unchecked means to drive engagement, which is not in the spirit of the web notifications API. Indeed, Chrome telemetry showed that most users choose not to grant notification permission prompts, on most of the websites. Ideally, a genuine website that provides a high quality notification experience would have a high grant rate, which is the opposite of what out telemetry shows today. Moreover, negative comments about the notification experience are also one of the most frequent complaints seen in Chrome's product feedback channels. We therefore want to improve the browsing experience for Chrome users by reducing the interruptiveness of unwanted notification permission prompts.

In order to achieve that goal, we focused our efforts on the following objectives, which resulted from several discussions among product leads, engineering teams, designers and user-experience researchers:

1. Making the notifications permission prompt UI less interruptive.
2. Reducing the number of notification permission prompts that users have to act upon, which reduces the cognitive load and permission fatigue.
3. Providing an easy and more obvious escape hatch if users want to change their choice after they have made it.

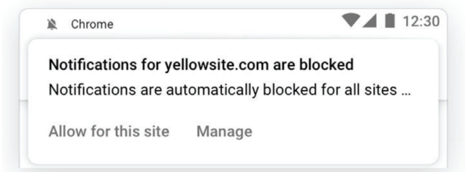
The telemetry data we analyse in this study allows us to measure the progress towards the objectives (1) and (2) above, but not objective (3). The latter requires additional qualitative measures and instrumentation that the current telemetry data does not have. Hence, a separate user study will be conducted in order to assess the progress towards achieving objective (3). To measure whether the new *quiet* UI (described hereafter) performs better than the legacy one with respect to the two goals, we rely on two proxy signals discussed in Section 3.3: the deny and ignore rates of the permission prompts. Ideally, the new UI should significantly increase the ignore rate and lower the deny rate – unwanted prompts should no longer require users to act on them – while preserving the grant rates for users who do want them. These users should still be able to easily grant the permission prompt.

To make the prompts less interrupting and to reduce the frequency of unwanted interactions, we introduce three new components:

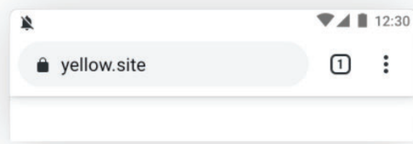
(i) The quiet permission prompt UI that Chrome users see when a website wants to show notifications.
(ii) The mechanism to activate the quiet UI on websites with a high average deny rate, which incentivizes a responsible use of the API according to the best practices.
(iii) The mechanism to activate the quiet UI for users who repeatedly block them, based either on their past behavior or opt-in setting.

4.1 New UI for the notification permission prompt

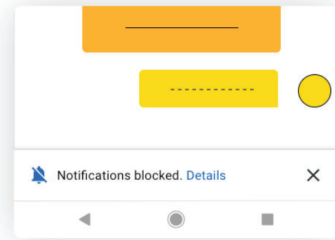
Since its introduction in 2015, the volume of notification permission requests has surpassed that of any other type of permission. Hence, it is also the most likely to annoy users if shown out of context or without an explicit user intent. Over the years, we have identified several other limitations of the legacy UI for the notification permission prompt. First, even when displayed in context, users might not fully understand what content they will see in notifications. Second, similarly to any web permission on Chrome, users might not understand that the two options "Allow" and "Block" are reused for every subsequent visit to the same website. Therefore, when uncertain, users are likely to ignore or dismiss on desktop, and might end up selecting an unintended or unwanted choice on Android just to make the prompt disappear and get to the website. Third, in case users want to change a previous choice,



(a) Variant 1: Heads-up notification.

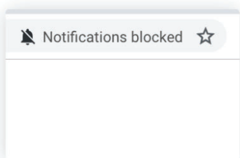


(b) Variant 2: Icon.

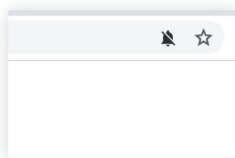


(c) Variant 3: Info-bar.

Figure 5: Tested notification permission prompt UI variants for the Android platform.



(a) Variant 1: Animated icon.



(b) Variant 2: Static icon.

Figure 6: Tested notification permission prompt UI variants for the desktop platform.

they have to find the right Chrome settings, or click on the page information dialog in the navigation bar, which is not an obvious entry point.

In determining the UI experiment variants, we chose to use the pre-existing messaging UI patterns in Chrome, in order to enable returning users to apply the interaction methods they are already familiar with. From the enumerated UI candidates, we eliminated the ones that were visually too loud, such as a prompt that covers a large content area or is completely hidden. The choice was also guided by the intent to provide less interruptive UIs that could still provide a more obvious entry point to change a previous choice. Finally, we chose the three design variants on Android (Figure 5) and two on desktop (Figure 6). The experimental UI variants displayed the "strike-through bell" icon to convey unavailability of notifications. Additionally, when there was enough screen real estate, the words "notifications blocked" were added to reinforce the meaning. This representation intended to respond to the two major statuses the user could be in. First, if the user did not want to receive notifications from the site, this representation confirms the desired state and the user does not need to take any action on the UI. Second, if the user wanted to receive notifications from the site, the represented status was clearly opposite, which could lead the user to act upon it to change it.

We implemented each of those variants and activated them as part of a controlled experiment on a 1% random sample of clients running the Beta version of Chrome 78, during a 7-day period in September 2019. Specifically, we selected 1% of Android clients for each of the three variants and an additional 1% for the control group that saw the standard legacy UI. Each of the clients only saw the UI variant which they were assigned, during the entire experiment. In total, 3% of Android clients running the Beta version saw the experimental UIs. Similarly, we enabled the experimental UIs for 2% of desktop clients, 1% for each of the two desktop variants, and a 1% the control group (2% of desktop clients saw the experimental UIs).

To decide which variant to release to all Chrome users, we monitored and compared the grant rates from the experimental groups with the control groups. Overall, the drop was significant across all variants on both platforms. Specifically, on Android we saw that the grant rate for variant 1 (Figure 5a) dropped by 81% compared to the control group, for variant 2 (Figure 5b) by 98% and for variant 3 (Figure 5c) by 89%. On desktop, the grant rate dropped by 79% for variant 1 (Figure 6a) and by 93% for variant 2 (Figure 6b), as compared to the control group.

In light of those results, we chose the mini info-bar (variant 3) for the Android platform and the animated icon (variant 1) for desktop. Although variant 3 on Android has a slightly lower grant rate compared to variant 1, we deemed the latter to be sub-optimal because, as a system heads-up notification, it would not be visible at all for users who have completely disabled notifications for Chrome at the app-level, which is likely to generate confusion.

4.2 Automated activation for websites with a low grant rate

As we have observed, the quiet UI undoubtedly leads fewer clients to re-engage with websites. As it is important that the improved user experience does not disproportionately affect the web ecosystem, it is crucial that the quiet UI can be enabled selectively for users and websites. In particular, we want to enable it for users who are unlikely to want to receive notifications at all, and for websites that have a very high average deny rate (such as 90%). Hereafter we describe how Chrome chooses those websites and how users can activate the quiet either manually or adaptively.

The analysis we conducted in Section 3.3 has shown that, fortunately, only 1%-2% of websites with a non-negligible user base in our dataset have such a high (standard) deny rate, although this is the case for more than 5% of websites if we consider the explicit deny rate (i.e., if only counting grants or denies). This signal can be interpreted as strong evidence that users not only do not see much benefit in receiving notifications, but they explicitly want to block them from ever asking again. In order to prevent those interrupting websites to send unwanted notification requests to the vast majority of their visitors, Chrome displays the quiet UI every time a user visits those websites, unless the user has created an exception for it in the browser's settings. When any such website wants to show the notification prompt, the user sees the quiet UI with an accompanying message that informs her that most people block notifications from that site. The user can still choose to enable notifications by clicking on the "bell" icon and subsequently on "Allow for this site".

Using telemetry from the Chrome users[1], we maintain two lists of interrupting websites on the Google systems, one for the desktop clients and one for the Android ones. We keep two separate lists because the data indicates that there is only a 14% overlap between interrupting websites reported by desktop and Android clients. We add a website to the corresponding desktop or Android platform list if it satisfies the following criteria:

1. Has displayed at least 1000 notification permission prompts, as reported by the Chrome clients, over the last 28 days on a given platform (desktop or Android). Furthermore, we exclude data from clients who revert their decision for a website too frequently, as those could also come from test account or devices. Specifically, we discard data from devices that report more than 3 grant or deny decisions for the same website and platform during the study period. This ensures that (i) there is enough evidence that most clients do not see a value in getting notifications from the website, (ii) the website is reasonably popular so that it has an incentive in providing value to the users through notifications, and (iii) the size of the interrupting sites list is small enough to be sent by using the Safe Browsing APIs (as described later). As many as 95% of all reported notification prompts come from websites and clients that pass this criterion.
2. Has a high-enough *explicit* deny rate ($> 49\%$) and a high-enough relative rank ($\geq$ 95th percentile) with respect to *explicit* deny rate as compared to other websites. We define the *explicit* deny rate as the ratio between the sum of deny decisions over the sum of deny or grant decisions only. This is different from the standard deny rate that we show in the charts, where the denominator includes grants, denies, ignores and dismissals. The reason we use the explicit deny rate for generating the interrupting websites lists is that we want to get as much explicit signal of unwanted or interrupting prompts as possible. As grants and denies are choices that are remembered for successive visits to the same website, we believe that they also convey the highest amount of information about unwanted or interrupting prompts. Second, by having two conditions on the explicit deny rate (i.e., rank and absolute value), we ensure that websites have a strong incentive to continuously improve their standing with respect to others, and that they are not unnecessarily penalized in case the whole ecosystem moves towards a state in which the average explicit deny rate drops significantly.
3. Is satisfying the previous condition continuously over a certain number of successive iterations. For instance, if we recompute the list of interrupting sites every day, we may add a website to it only if its average explicit deny rate and rank are consistently above the threshold over multiple successive iterations (e.g., during 28 successive runs). This would help to avoid adding a website and then removing it too frequently in case it is near the threshold.

With these very conservative initial thresholds, the interrupting website lists contains around 500 entries for the desktop and 2000 for the Android platform. In total, these websites typically surface 1% of all reported notification prompts on Android and 3% on desktop, which means that there is a margin to relax the threshold in the future. Users can see whether the website they are currently visiting is on the interrupting list by checking if there is a related message on the Chrome developer console. As we continuously monitors the product feedback channels for any user and website complaints due to these changes, we intend to relax these thresholds in the future in the absence of any significant negative feedback.

To limit the risks related to data manipulation by malicious clients, in addition to the other conditions for data inclusion that we already described in Section 3.2, we adopt additional security measures to limit the number of records that could come from test accounts or devices, the specifics of which are not public.

After a website has been added to the interrupting list, it clearly has an incentive to get off as quickly as possible, which usually happens after it starts to follow the best practices guidelines when showing notification prompts. For that, we need to be able to track its explicit deny rate on the legacy prompt. Therefore, Chrome shows the quiet prompt for a random sample of 70% of the clients that see the prompt on that website, while showing the legacy prompt to the remaining 30%. We then keep monitoring the explicit deny rate from the latter 30% of clients, and when any of the above criteria is not consistently met over a certain period of time (e.g., 28 days), we remove the interrupting website from the list. We chose to use a threshold of 30% as holdback as it would allow us to get at least 300 decisions on which to test

[1] Only from the set of users who have opted in to provide crash reports and usage statistics to Google, who are signed-in with their Google account and have the "sync" functionality enabled.

whether the criteria are satisfied. This would ensure a maximum error rate on the true statistic of at most ± 5% with a 95% confidence level, even for the website with the lowest amount of decisions in our dataset. Moreover, using a limited time window (e.g., 28 days) limits the effects of inter-day spurious variations that might be due to specific events that are not necessarily representative of the users' behavior on a site over a longer period of time.

For performance reasons, we use the Safe Browsing API – which is already in place to protect users from malicious websites – to regularly send a compressed version of that list to each Chrome client, as prefix sets [20]. Then, every time a website wants to display the notification permission prompt, the client first checks whether the website is present on the local prefix list of interrupting websites. If so, Chrome then verifies with the Safe Browsing service whether the website is indeed in the most recent version of the list. If and only if that is the case, it displays the quiet UI. This is the default way that Safe Browsing enforcement works in Chrome.

4.3 Activation Mechanisms on Clients

Having described the quiet UI and how we maintain the two lists of interrupting websites, we now outline the client-side changes that were introduced to support the redesigned permission prompt and the interrupting website lists.

In order to reduce the unwanted interruptions to the browsing experience, Chrome provides two ways for users to enable the quiet notification prompts, which are purely based on behavioral data that can be observed on the client, without any interaction with the Google's backend services:

1. A toggle in the Chrome settings page, which enables the quiet UI for all notification prompts, irrespective of whether the website is on the interrupting list. This gives users the choice to enable or disable the quiet prompts whenever they wish.
2. Automatic activation after three consecutive "deny" decisions are recorded for a client on any website over the last 28 days. This reduces the unwanted interruptions for users who are very unlikely to want to receive any notifications at all. The telemetry shows that this applies to 28% of Android clients and 14% of desktop ones.

The choice of the last parameter – the number of consecutive denies before the quiet UI is automatically activated on the client – was made after a careful analysis of the impact it would have on clients and websites. We chose to use three because our data showed that it would help a substantial fraction of users who are more likely to be interrupted, while not interfering with users who do not see many prompts in the first place.

In addition to these two activation mechanisms, we are further exploring the use of machine learning methods that can leverage a larger number of on-device signals, in order to show the quiet UI in more instances where clients are unlikely to grant the notification permission.

Parameter	**Exp. 1**	**Exp. 2**
Browser version	78	80
Channel	Beta	Stable
Experiment start	09/2019	02/2020
Experiment duration	7 days	10 days
Nr. of participants	≥300 M	≥40 M
Nr. of websites	≥70 K	≥70 K
Nr. of actions	≥800 M	≥100 M

Table 1: Experimental parameters.

4.4 Second Experiment

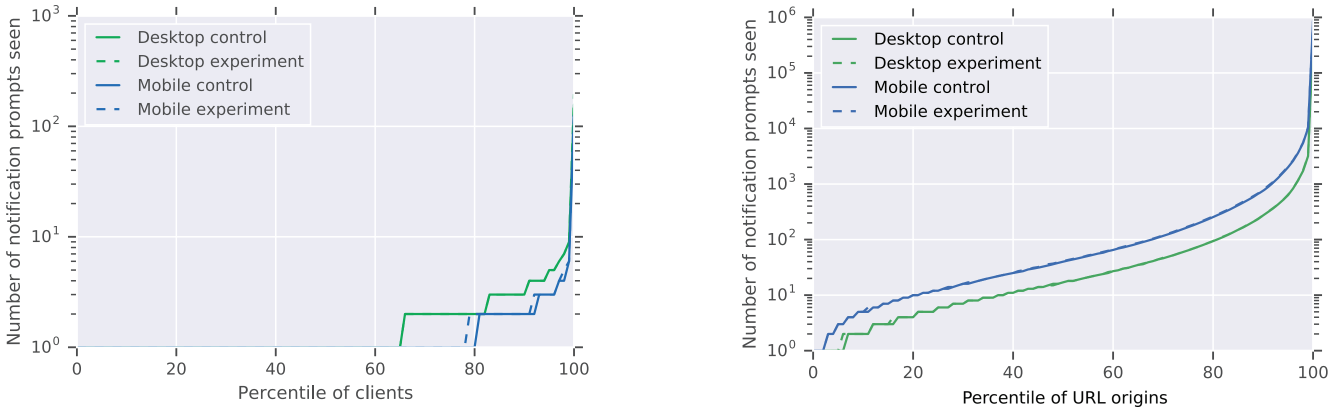
When designing the above mechanisms that enable the quiet prompts, we could mostly think of their effects in isolation with respect to each other. Taken independently, they should be able to help users to have a less interrupting browsing experience, to reduce the number of required interactions and to allow them to revert to the legacy UI more easily should they change their mind. However, it is difficult to evaluate the combined effect of these changes on the interaction metrics that we want to influence. That is why we conducted a second large-scale study on a subset of Chrome clients running the stable release of the browser, which is the default one that normal users install and use.

We conducted a 10-day A/B experiment between the 7th and the 16th of March, 2020. We selected a random sample of 9% of desktop and 9% of Android clients running the stable release of Chrome version 80 as the experiment groups, for which we enabled both the client activation logics of the quiet prompts (Section 4.3) and the one based on the interrupting website lists (Section 4.2). Similarly, we selected another set of 9% of clients on each platform as the control groups, for which we disabled the quiet prompt feature completely. In other words, the clients in the control group could only see the legacy prompt. The data for this experiment is subject to the same conditions as described in Section 3.2.

4.5 Results

More than 40 million clients participated in the experiment, half of which were assigned to the control group and half to the experiment group on each platform. We recorded more than 100 million actions overall, coming from more than 70 thousand websites.[2] Table 1 summarizes the parameters of the two large-scale experiments that we conducted. As shown in Figure 7a and 7b, there is a very similar distribution

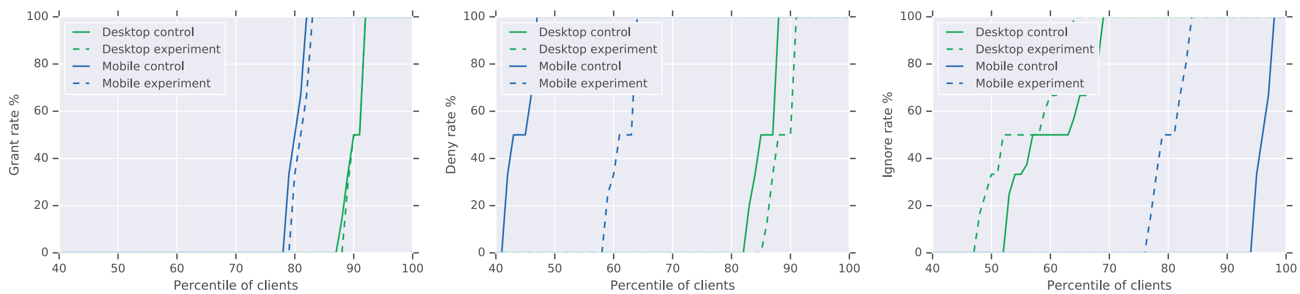
[2]Thanks to the extremely large number of samples in our experiments, we omit adding any statistical tests of the differences between the decision rates we report for the control and experiment groups, such as the Mann Whitney U Test. Even an extremely small difference, such as 10^{-6}, is statistically significant at the $p < .05$ level.



(a) By client percentile and experiment group.

(b) By percentile of URL origin and experiment group.

Figure 7: Number of notification permission prompts seen, by percentile of clients, URL origins and experiment group.



(a) Grant rate.

(b) Deny rate.

(c) Ignore rate.

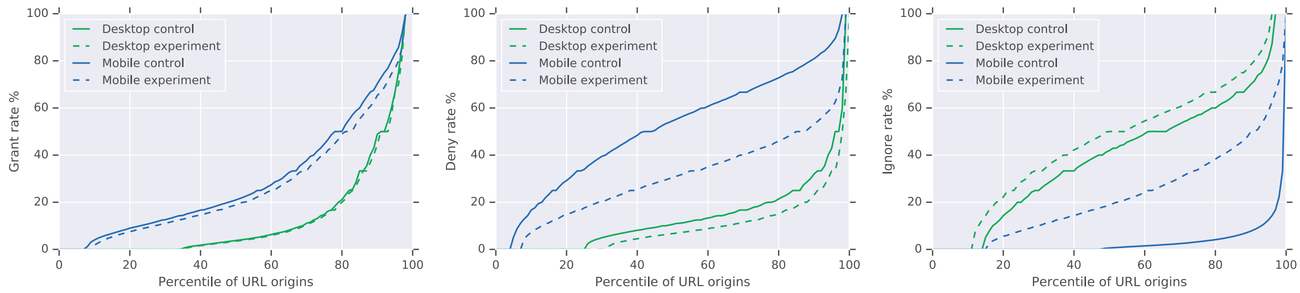
Figure 8: Comparison between the control and experiment groups of the grant, deny and ignore rates across client percentiles.

of prompts seen across the experimental and control groups, across both clients and websites. This indicates that the control and experiment groups should be comparable in terms of the browsing behavior and volume of prompts observed.

Next, we look at the actions that clients of both groups took on the prompts. The first key observation is that there is only a very small reduction of the grant rate in the experiment groups, as compared to the control groups. This is a positive result, as it indicates that the quiet prompt and activation logic did not significantly affect the grant rates for websites on both platforms. The per-client average grant rates are 10% and 9.8% on desktop for the control and experiment groups, respectively, whereas they are 20.1% and 19.1% on Android, respectively. Similarly, we did not observe any significant change in the grant rate percentiles across websites either (Figure 8a), with a per-website average grant rate of 13.6% and 13.1% on desktop for the control and experiment groups, respectively, and 29.8% and 27.1% on Android, respectively.

On the contrary, the deny rate distributions shifted significantly in the experiment group compared to the control group, as expected, in particular on Android. Figure 8b shows that there are 39% more clients in the experiment group that have never denied any prompt, as compared to the control group. This means that the quiet prompt has removed at least one unnecessary prompt for 15% more Android clients already during the initial 10-day period that the feature was active. The per-client average deny rate was 31.4% lower in the experiment group relative to the control group (38.5% vs. 56.1%). On desktop, the reduction of 17.5% in deny rate was smaller (from 14.5% to 11.5%) but significant nevertheless. We observed a similar trend also when looking at the per-website average deny rates (Figure 9b), where the experiment groups on both desktop and Android were reporting reduced deny rates across all types of websites. We observed a reduction of the per-website average deny rate of 22.5% on Android (31% vs 51.6% in the experiment and control groups, respectively) and on 30% on desktop (9.8% vs 14% in the experiment and control groups, respectively).

As for the ignore rates, they increased in the experiment groups across both clients (Figure 8c) and websites (Figure 9c), and in particular on Android. The per-client average ignore rate jumped by a factor of 5 from 4% (control) to 20% (experiment) on Android, and from 39.6% to 44.4% on desktop, respectively. Across websites, the per-website average



(a) Grant rate. (b) Deny rate. (c) Ignore rate.

Figure 9: Comparison between the control and experiment groups of the grant, deny and ignore rates across percentiles of URL origins.

ignore rate also increased more than 7 times on Android (from 3% in the control group to 22.7% in the experiment group) and from 39.8% to 46.2% on desktop. The increase in the ignore rate on Android is particularly important because it suggests that many of the clients who would choose to deny a permission request opted instead to ignore it, as the grant rates are only minimally affected.

Compared to the experiment for the choice of the quiet UI described in Section 4.1, the drop in deny rates and increase in ignore rates are smaller in this experiment. We believe that such differences are mainly due to the different user base that was sampled (Beta channel vs. Stable) in the two experiments. Users in the Beta channel willingly use a non-final version of Chrome that is used for experimenting with new features, which could suggest that users of the Beta version might have a different browsing behavior than the users of the standard Stable version.

Given the results of the experiment, we can conclude that the quiet UI and its activation mechanisms are very effective in achieving the two main goals: The increased ignore rates, the reduced deny rates and the marginally affected grant rates signal that the the browsing experience of Chrome users can be improved without negatively affecting the benefits for the websites and users who show a clear benefit of the web notifications API. We plan to roll out the quiet UI feature to all of the Chrome clients in the coming months, as we monitor feedback from both users and website owners. We did not observe any significant changes in reports from users due to the quiet UI so far (September 2020).

4.6 Releasing the Notification Action Rates to the Public

To complement our quiet UI efforts with an increase level of transparency for both end-users as well as website owners, Chrome includes the average grant, deny, dismiss and ignore rates as part of the Chrome User Experience Report [18]. This publicly accessible website enables visitors to obtain aggregated URL-level metrics about loading performance from opted-in users. By making this information public, we hope to provide a positive incentive for website owners to continuously improve their notification rates in order to meet the users' expectations. Moreover, this also makes it easier for medium and high-traffic websites to check the reported rates without requiring them to implement any additional data collection and processing on their properties.

5 Discussion & Limitations

Web push notifications can be a very useful feature for users to receive timely updates about information they care about, such as breaking news, instant messages or tweets. When asking for permission to send notifications, websites should follow a set of best practices, in order to ensure that users are asked for them within the right context and at the right time. For instance, websites should give visitors some time to allow them to understand the context of the page they are on, and they should wait for a signal of explicit intent to receive notifications before showing them the permission prompt. However, our telemetry indicates that 90% of the time websites fail to successfully enroll their visitors to notifications on desktop, and 79% of the time on Android. In other words, the vast majority of Chrome users do not see enough value in receiving notifications from the websites they visit, which means that notification prompts are most often unnecessarily interrupting their browsing experience. That is why we redesigned and rethought the process by which users interact with the notification permission prompt.

In Section 4, we described the main goals of the redesign of the notification prompt, which are to (i) make the prompt UI less interruptive, (ii) reduce the number of interactions that users have with them and (iii) make it easier to change the previous choice. In this study, which is focused on the former two objectives, we are able to show that the redesigned permission prompt is very successful in reducing both the "interruptiveness" of the UI and the number of interactions that users have to make.

When running such a large-scale behavioral study with real users, we understand that it is extremely important to account for the vast diversity of both users and websites that are accessible on the Internet. It is therefore crucial to assess the effect our redesign has on the entire population of users and websites. That is why, in addition to providing statistics about the average reduction in unwanted interaction rates (i.e., deny and dismiss actions), we show the more fine-grained results that cover each percentile of both users and websites. The fact that the positive effects – a minor reduction in grant rates compared to a double-digit reduction in deny rate and large increase in ignore rates – are consistent across all percentiles of both populations is extremely important. It shows that all sorts of users – those who interact with many different websites as well as those who seldom ever see a notification prompt – benefit from a more interruption-free browsing experience. Moreover, it shows that those users who want to be engaged with the websites through notifications are only slightly impacted. Furthermore, we expect the already minor reduction in grant rates to become even smaller, as more users and sites learn and adapt to the new permission prompt UI[3]. As it is extremely challenging to determine the necessity and context of notification prompts in general, Chrome has opted for a phased roll-out of the feature. Microsoft Edge – a Chromium-based browser, has adopted a different roll-out approach [40]; since the quiet UI code was publicly released in February 2020, Edge elected to leverage this and enabled it by default to all of its users and websites.

Designing a solution that effectively balances the needs of web users who are unlikely to want to get notifications, of those that do seem to want them and of the many websites who rely on them for increased engagement and higher service utility [16] is challenging. We showed that it is possible to achieve that by bringing together the following elements: user behavior data, website metrics, proxy metrics, a new UI, and an incentive mechanism for website owners to get off the block list. The quiet UI in Chrome takes a first step towards improving the user experience, which results in a small drop in grant rates for websites. By introducing activation mechanisms that depend on each user's past actions, users who often see unwanted notification permission prompts will also be the first ones to benefit from the quiet UI. As the quiet feature activates automatically only for users who denied the prompt at least 3 times in a row, it clearly benefits the more active users who see more prompts than the average user. This was a design choice, as users who see and deny the prompt more often are also the ones who are more like to experience unnecessary interruptions. As more and more users will eventually transition to the quiet UI, websites will have a strong incentive to rethink the way they use the Notifications API and to align it with the best practices, which ultimately will improve the browsing experience for all users.

[3]For instance, at the time of this experiment, several popular websites (such as twitter.com) guide their users on how to enable notifications on the web by assuming that users would see only the legacy prompt, instead of possibly also seeing the less visible quiet UI.

We also acknowledge several limitations of our experimental design and the data collection process, which are inherent to the nature of the methodology itself. The data we analysed in this study comes from a random subset of Chrome users, but not from a "fully" random set. As mentioned in Section 3.2 and 4, we collect and analyse telemetry only from users who satisfy certain conditions, in order to respect their privacy choices and preferences. We acknowledge that, although such a population represents a double digit fraction of the overall Chrome user base, we might miss on some of the notification interactions that might have occurred on less popular websites from users who do not satisfy the criteria for inclusion in our study. However, we made various efforts to limit the impact of spurious or extremely long-tail behavior on our results. For instance, we accept data only from genuine clients that report a limited number of samples for each website, and we only consider websites with at least 1000 decisions reported in the study period. According to the telemetry, those websites account for more than 95% of all reported notification prompts, and therefore they should provide an accurate view of the web push notifications landscape. Moreover, our study did not include qualitative user feedback, which might surface additional issues and user preferences.

Finally, although this study focused on notification permission prompts in Chrome, we hope its implications will spur research into further permission types and goals, such as time-limited and more granular web permissions, and a more fine-grained measurement of cognitive load and disaffection. More broadly, our multiple activation mechanisms that blend both the user's own behavior with those of other users have shown one possible way to quickly and effectively limit the unwanted interruptions for users who, at least initially, are likely to suffer the most from them. One challenge that remains when designing such solutions is to identify who those users are and to actually assess whether the issues that experts have identified are indeed the most pressing ones for the users. Several studies of a related problem – computer security practices and advice of security experts vs. non-experts [8, 23, 38] – seem to suggest that they might not always be the same.

As a note, the experiment was conducted during the first half of March, 2020, and lasted 10 days. In China and South Korea, this was at the time when the peak of the COVID-19 pandemic had already passed or was flattening. However, it was growing in several other countries in Europe (Italy, France, Germany, Switzerland) and to some extent in other parts of the world [33]. Therefore, we cannot exclude nor quantify the effect that this extraordinary situation had on our results.

6 Conclusion

Other researchers and web browser developers have observed that notification prompts for web pages are a source of annoyance for users and that users rarely agree to receive notifications. Our first contribution was to assess this on a very large scale. We conducted analysis that included more than 300 million users, 70 thousands websites and 800 million actions on the prompts. Chrome telemetry indicated that the notification permission is the most frequently asked for permission type (74% of all permission requests are for notifications), and yet with a grant rate of 10% on desktop and 21% on Android, respectively, it is also the least likely to be granted. The frequent requests, coupled with low grant rates on both mobile and desktop, as well as high ignore and dismiss rates on desktop, indicate altogether that notification permissions are interrupting and that mostly they do not lead to a useful experience. This motivated us to rethink how users interact with notification prompts. At the same time, our study showed that 20% of users on desktop, and 30% of Android users, do grant the permission at least once. Thus for users who do want to enable notifications, it is important not make it more difficult for them to do so.

Our second contribution was thus to take on the challenge of rethinking the conditions as to when and how users interact with the notification prompts. This required us to balance the dual goals of reducing interruptiveness for the large majority of users, while having negligible impact on users who do want to receive notifications. In this paper, we presented our the process and challenges that led to the redesign of the UI and the creation of a novel activation logic.

Our first analysis study also revealed that there are fundamental differences across desktop and Android platforms, partially due to the fact that on desktop the prompt can be ignored whereas on mobile it requires an interaction in order to continue browsing the website. Therefore our redesign made it possible for Android users to also ignore the prompt with a new UI that does not block the content of the website, while allowing interested users to easily enable notifications. To support users who want notifications, the quiet UI is still visible on both platforms, albeit in a less conspicuous way.

Our third contribution was a second large-scale study, wherein we evaluated whether the redesigned prompt is successful at reducing unwanted interruptions while limiting the negative effect on the grant rates across users and websites. Our A/B test with 40 millions users and 100 million actions on the prompts has shown that the new quiet UI, together with its activation logic on clients and the crowd-sourced list of interrupting websites, is very effective in reducing the unwanted interruptions while only slightly affecting the grant rates across users and websites. Specifically, the deny rate decreased by 22.5% on desktop and by 30% on Android, while the average grant rate decreased by 3.7% and 5%, respectively. As the legacy UI is particularly interrupting on Android, we were pleased to see that the ignore rate jumped by a factor of 7. Thanks to the positive results obtained in our experiments, we intend to roll out the quiet UI feature to all clients in the next few months, while we monitor the feedback from users and website owners.

Although our quantitative experiments have shown that the new UI is very effective in achieving the goals we set, they were not instrumented to capture more qualitative data about users' attitudes and understanding of the new UI. For that reason, we intend to conduct a separate user study to evaluate whether indeed the quiet UI is easy to use, find and understand via the iconography, setting discoverability, and activation mechanisms.

7 Acknowledgements

We would like to express our sincere gratitude to Adrienne Porter Felt, Stephan Micklitz, Ji Chen, Noelle Kvasnosky Luiten, Scott Monroe Westover, the anonymous reviewers and our shepherd for helping us to improve the quality of this paper.

References

[1] Lada A Adamic and Bernardo A Huberman. Zipf's law and the internet. *Glottometrics*, 3(1):143–150, 2002.

[2] Airship. New urban airship study reveals app publishers that don't message users waste 95 percent of their acquisition spend. https://www.airship.com/company/press-releases/new-urban-airship-mobile-app-retention-study/, 2017.

[3] Efthimios Alepis. Notify this: Exploiting android notifications for fun and profit. In *International Conference on Information Systems Security and Privacy*, pages 86–108. Springer, 2018.

[4] Apple. Safari 12.1 Release Notes | Apple Developer Documentation. https://developer.apple.com/documentation/safari_release_notes/safari_12_1_release_notes, 2019.

[5] Pieter Arntz. Browser push notifications: a feature asking to be abused. https://blog.malwarebytes.com/security-world/technology/2019/01/browser-push-notifications-feature-asking-abused/, 2019.

[6] Namraata Badheka. The history of push notifications. https://medium.com/the-pushcrew-journal/the-history-of-push-notifications-43343bdf2d85, 2017.

[7] Brian P Bailey and Joseph A Konstan. On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state. *Computers in human behavior*, 22(4):685–708, 2006.

[8] Karoline Busse, Julia Schäfer, and Matthew Smith. Replication: no one can hack my mind revisiting a study on expert and non-expert security practices and advice. In *Fifteenth Symposium on Usable Privacy and Security*, SOUPS, 2019.

[9] Carlos R Cunha, Azer Bestavros, and Mark E Crovella. Characteristics of www client-based traces. Technical report, Boston University Computer Science Department, 1995.

[10] Apple Developer. Notifications - Apple Developer. `https://developer.apple.com/notifications/`, 2020.

[11] Android Developers Documentation. Notifications Overview. `https://developer.android.com/guide/topics/ui/notifiers/notifications`, 2020.

[12] Balazs Engedy. Issue 900997: abuse technique: redirect to re-prompt for notifications. `https://bugs.chromium.org/p/chromium/issues/detail?id=900997`, 2019.

[13] Adrienne Porter Felt, Serge Egelman, Matthew Finifter, Devdatta Akhawe, David A Wagner, et al. How to ask for permission. *HotSec*, 12:7–7, 2012.

[14] Joel E Fischer, Chris Greenhalgh, and Steve Benford. Investigating episodes of mobile phone activity as indicators of opportune moments to deliver notifications. In *Proceedings of the 13th international conference on human computer interaction with mobile devices and services*, pages 181–190, 2011.

[15] Andrew Gazdecki. What is a push notification? and why should you care? `https://www.biznessapps.com/blog/what-is-a-push-notification/`, 2017.

[16] George Deglin – One Signal Podcast. The Importance of Good Notifications. `https://onesignal.com/podcasts/the-importance-of-good-notifications-w-pj-mclachlan`, 2020.

[17] Lauren Goode. A brief history of smartphone notifications. `https://www.wired.com/story/history-of-notifications/`, 2019.

[18] Google. Chrome User Experience Report. `https://developers.google.com/web/tools/chrome-user-experience-report#notification_permissions`, 2020.

[19] Google. Google Chrome Privacy Whitepaper. `https://www.google.com/chrome/privacy/whitepaper.html`, 2020.

[20] Google. Safe Browsing Update API (v4). `https://developers.google.com/safe-browsing/v4/update-api`, 2020.

[21] Johann Hofmann. Reducing Notification Permission Prompt Spam in Firefox. `https://blog.nightly.mozilla.org/2019/04/01/reducing-notification-permission-prompt-spam-in-firefox`, 2019.

[22] Gary Illyes, Henner Zeller, Lizzi Harvey, and Martijn Koster. Robots exclusion protocol. `https://tools.ietf.org/html/draft-koster-rep-00`, 2019.

[23] Iulia Ion, Rob Reeder, and Sunny Consolvo. "... no one can hack my mind": Comparing expert and non-expert security practices. In *Eleventh Symposium On Usable Privacy and Security*, SOUPS, pages 327–346, 2015.

[24] Jiyeon Lee, Hayeon Kim, Junghwan Park, Insik Shin, and Sooel Son. Pride and prejudice in progressive web apps: Abusing native app-like features in web applications. In *Proceedings of the 2018 ACM SIGSAC Conference on Computer and Communications Security*, CCS, pages 1731–1746. ACM, 2018.

[25] Daniel C McFarlane and Kara A Latorella. The scope and importance of human interruption in human-computer interaction design. *Human-Computer Interaction*, 17(1):1–61, 2002.

[26] PJ McLachlan. Introducing quieter permission ui for notifications. `https://blog.chromium.org/2020/01/introducing-quieter-permission-ui-for.html`, 2020.

[27] Abhinav Mehrotra, Mirco Musolesi, Robert Hendley, and Veljko Pejovic. Designing content-driven intelligent notification mechanisms for mobile applications. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '15, pages 813–824. ACM, 2015.

[28] Abhinav Mehrotra, Veljko Pejovic, Jo Vermeulen, Robert Hendley, and Mirco Musolesi. My phone and me: Understanding people's receptivity to mobile notifications. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pages 1021–1032. ACM, 2016.

[29] Tomas Meskauskas. Browser Push Notifications: Useful Feature Exploited by Deceptive Marketers. `https://securityboulevard.com/2019/08/browser-push-notifications-useful-feature-exploited-by-deceptive-marketers/`, 2019.

[30] Microsoft. Change notification settings in Windows 10. https://support.microsoft.com/en-us/help/4028678/windows-10-change-notification-settings, 2020.

[31] Mozilla. Restricting Notification Permission Prompts in Firefox. https://blog.mozilla.org/futurereleases/2019/11/04/restricting-notification-permission-prompts-in-firefox, 2019.

[32] Tadashi Okoshi, Julian Ramos, Hiroki Nozaki, Jin Nakazawa, Anind K. Dey, and Hideyuki Tokuda. Reducing users' perceived mental effort due to interruptive notifications in multi-device mobile environments. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '15, pages 475–486. ACM, 2015.

[33] Our World in Data. COVID-19: Daily new confirmed cases, rolling 7-day average. https://ourworldindata.org/grapher/daily-covid-cases-7-day, 2020.

[34] owencm@chromium.org. Best practices for push notifications permissions ux. https://docs.google.com/document/d/1WNPIS_2F0eyDm5SS2E6LZ_75tk6XtBSnR1xNjWJ_DPE, 2015.

[35] Constantinos Patsakis and Efthimios Alepis. Knock-knock: The unbearable lightness of android notifications. *arXiv:1801.08225 [cs]*, 2018.

[36] Veljko Pejovic and Mirco Musolesi. InterruptMe: designing intelligent prompting mechanisms for pervasive applications. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '14, pages 897–908. ACM, 2014.

[37] Martin Pielot, Amalia Vradi, and Souneil Park. Dismissed! a detailed exploration of how mobile phone users handle push notifications. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 1–11, 2018.

[38] Elissa M Redmiles, Noel Warford, Amritha Jayanti, Aravind Koneru, Sean Kross, Miraida Morales, Rock Stevens, and Michelle L Mazurek. A comprehensive quality evaluation of security and privacy advice on the web. In *29th USENIX Security Symposium*, pages 89–108, 2020.

[39] Internet World Stats. World Internet Users Statistics and 2020 World Population Stats. https://www.internetworldstats.com/stats.htm, 2020.

[40] Microsoft Edge Team. Reducing distractions with quiet notification requests. https://blogs.windows.com/msedgedev/2020/07/23/reducing-distractions-quiet-notification-requests, 2020.

[41] Phani Vadrevu and Roberto Perdisci. What you see is NOT what you get: Discovering and tracking social engineering attack campaigns. In *Proceedings of the Internet Measurement Conference*, IMC '19, pages 308–321. ACM, 2019.

[42] Anne van Kesteren and Johann Hofmann. Upcoming notification permission changes in Firefox 72 – Mozilla Hacks - the Web developer blog. https://hacks.mozilla.org/2019/11/upcoming-notification-permission-changes-in-firefox-72, 2019.

[43] W3C. Web Notifications. https://www.w3.org/TR/notifications/, 2015.

[44] MDN web docs. Introduction to web APIs - Learn web development | MDN. https://developer.mozilla.org/en-US/docs/Learn/JavaScript/Client-side_web_APIs/Introduction, 2020.

[45] MDN web docs. Notifications API - Web APIs | MDN. https://developer.mozilla.org/en-US/docs/Web/API/Notifications_API, 2020.

[46] MDN web docs. Web Push API Notifications best practices. https://developer.mozilla.org/en-US/docs/Web/API/Push_API/Best_Practices, 2020.

[47] Xu and Sencun Zhu. Abusing notification services on smartphones for phishing and spamming. In *Presented as part of the 6th USENIX Workshop on Offensive Technologies*, 2012.