Tackling smartphone overuse with onscreen usage feedback

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Contents

Abstract

This report describes the design, development and trialling of a smartphone application with the goal of tackling smartphone overuse. The app aims to create a subtle but continuous awareness of device use by employing on-screen usage feedback, in the form of a dynamic glow around the edge of the phone screen. The glow transforms in two ways, to help visualise overall progress towards a daily target of use and high concentrated usage of apps the user has indicated a desire to use less, with the aim of targeting particularly meaningless usage. A two-week trial of the application was undertaken, which found it to be effective at reducing usage of these user-selected apps, by a statistically significant daily average of 25.1%, while having a negligible impact on usage of other apps.

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Soli Deo gloria.

1 Introduction

This report describes the design, development and trialling of a smartphone application with the goal of tackling smartphone overuse. Since their inception, smartphones have rapidly approached ubiquity as personal computing devices, with 85% of adults in the UK now owning one – exceeding laptops [1]. However, there is an increasing awareness that usage of such devices can be, and commonly is, habitual to a problematic extent. 40% of respondents to a 2019 survey of 16-75 year olds in the UK felt they used their smartphone too much [2] – suggesting a third of all adults in the UK struggle with their usage.

A major aim of human-computer interaction is to make use of technologies easier, more intuitive and even more habitual, but this work examines how smartphones can become all of these things to a problematic extent. Based on a review of current work into problematic smartphone usage, a smartphone application with the purpose of assisting users in tackling smartphone overuse is designed, implemented, trialled, and evaluated. In particular, this application aims to reduce the extent of 'meaningless' smartphone usage — usage which is passive, less intentional, and often impulsive, and can leave users with feelings such as a loss of autonomy [3]. It does so by employing onscreen usage feedback — a constantly visible, yet subtle presentation of device usage, with the intention of increasing awareness and compelling the user towards non-use. A two-week trial of this application is then undertaken to assess the effectiveness of this technique.

In section 2, a review of previous work in this area is undertaken, including an analysis of current solutions.

In section 3, key findings from the literature review are summarised.

In section 4, an account of the design process for the smartphone overuse intervention application is given, from early ideas to a final design proposal.

In section 5, the implementation of this application is described in detail. The system in broken down into key components and problems, and the process of solving each of these is recounted.

In section 6, the process of conducting a trial of the finished application is described, and the results of this trial are given.

In section 7, the results of the trial are discussed. The successes and shortcomings are highlighted, a number of limitations of the results are listed, and areas of future work, both for the app and the wider field, are suggested.

This work builds upon a paper written by the author for the *Research Topics in HCI* module. Roughly two-thirds of the literature review is taken from that, and sections which have been largely copied across are indicated with a vertical bar down the left margin. Some wording in the introduction section is also adapted.

2 Previous work

2.1 Background to addictive and habitual behaviour

Goodman [4] defined addiction as 'a process whereby a behaviour, that can function both to produce pleasure and to provide relief from internal discomfort, is employed in a pattern characterised by (1) recurrent failure to control the behaviour (powerlessness) and (2) continuation of the behaviour despite significant negative consequences (unmanageability).' Moreover, addictive behaviours are 'characterised by loss of control and continuation, despite significant negative consequences.' Building on this, Goodman recommends that effective treatment of an addicted person should 'address not only the addictive behaviour but also the underlying addictive process' – that is, the dependence on an external action to regulate the internal state. The underlying state the addiction is medicating should be tackled. This is most important for addictive behaviours which have a role in healthy functioning, such as eating or sexual behaviour, where lifelong abstinence may not be a realistic or desirable goal. Rather, changes in personality are needed to enable healthy moderation.

Griffiths [5] and Brown [6] argue all addictions consist of a number of key components – salience, mood modification, tolerance, withdrawal, conflict and relapse. Salience refers to a particular activity becoming the most important activity in a person's life, dominating their thinking, feelings and behaviour. Mood modification is the subjective experience reported as a consequence of engaging in a particular activity. Tolerance is the process whereby increasing amounts of a particular activity are required to achieve the former effects. Conflicts, both between the addict and those around them, and within the individual themselves, can arise from the addictive activity. And relapse is the tendency for repeated reoccurrences of the addictive behaviour even after many years of abstinence or control. Griffiths posits that this 'components model' of addiction exists within a 'biopsychosocial' framework of addiction – that is, most addictions result from the interplay of factors including an individual's biological or genetic predisposition, their psychological constitution (personality, motivations, attitudes, expectations and beliefs), and their social environment, as well as the nature of the activity itself [7].

So, an addict may have become addicted because of their individual, personal vulnerabilities, or because of the situation or context they are in, or because of habit-forming characteristics of the activity they are addicted to – or most likely, a combination of all these things. In short, the aetiology of addictions is multi-faceted and will vary hugely from addiction to addiction, person to person.

A case has also been made that addictions are not entirely irrational; rather that decision making process is altered in some way by the addiction. Faced with a choice, addicted individuals choose the option with the greatest subjective utility to them [8]. Becker [9] argues that all individuals want to maximise their utility when making decisions, or forming 'behavioural usage intentions.' Rationality exists but is distorted by a modified perception system – the addiction makes the addict hypersensitive to rewards and stimuli, and psychological belief modification mechanisms such as emotional bias, confirmation bias, resolution of cognitive dissonance and after-purchase rationalisation also play a part. Memory- and learning-based mechanisms, such as feedback and sequential updating, also contribute to this distortive effect. Turel et al. [10] builds on this with a model encapsulating the effects of technological addiction, which they tested with a study of online auction site addiction. And indeed, 'addiction to online auctions formed a positive lens through which the system seemed somewhat easier to use and much better in fulfilling one's intrinsic and extrinsic needs.'

2.2 Technological addictions

Addictions are traditionally associated most with substances such as alcohol, tobacco or other narcotics, and behaviours such as gambling, but with the onset of personal computing in the past few decades a new category of addiction has been observed. Griffiths [5] discusses fruit-machine overuse as a form of technological addiction, noting how it meets the aforementioned components of addiction. The definition given to technological addictions here is non-chemical (behavioural) addictions which involve human-machine interaction and they are noted as being either passive, such as television, or active, such as computer games. And importantly this is not a mutually exclusive category; fruit-machine addictions are arguably gambling addictions at their core.

Internet addiction was the subject of much research from the late 1990s onwards. Young and Kimberley [11] claim it covers a wide variety of behaviours, categorisable into five specific subtypes: cybersexual addiction, cyber-relationship addiction, net compulsions, information overload, and computer addiction. The former two relate to the compulsive or over-use of the internet for sexual content or relationships. Net compulsions are defined as obsessive online gambling, shopping or day-trading, information overload as compulsive web surfing or database searches, and computer addiction as obsessive computer game playing. But like the fruit-machine example, there is argument as to whether these are types of internet addiction in its own right, or whether excessive internet use just fuels other addictions [12], most obvious with the examples of sexual addictions being played out online. Equally, in this instance the (perceived) anonymous, non-face-to-face, disinhibiting nature of the internet could clearly be seen to enable behaviours which a person might not indulge in 'real life.' [13] The fact that Griffiths makes both of these cases underlines the complexities and subtleties of 'internet addiction.' Widyanto & Griffiths' observation that there is a 'lack of theoretical basis' in much research in this area [14] is perhaps a result of this – development of a single unifying theory of internet addiction is complicated by the necessary distinction between addictions to the internet and addictions on it. Shaw's claim that the true prevalence of problematic internet usage was unknown, c. 2008, [15] is also attributable to this, especially when studies rely on the self-attribution of internet addiction by individuals.

2.3 Smartphones

Since the release of the iPhone, smartphones have become hugely popular devices, virtually replacing simpler mobile phones for much of the global population. In the UK, they are owned by 96% of those aged 16-34, 91% of 35-54 year olds and 55% of 55-66 year olds [16]. Overall ownership by adults was 85% in 2017, compared to 78% for laptops [1]. Accordingly, there has been considerable discussion of their effects on individuals and society, such as their addictive properties and potential for habitual usage.

2.3.1 Habitual use

Before the smartphone age, a more general 'compulsive checking' habit was also the subject of Rachman [17] who identified it as a form of OCD. Compulsive checking can be motivated by fear of criticism or guilt, and frequently reduces discomfort, it is 'preventive in intention' [18].

Limayem et al. [19] looked at the role habits play in information system continuance, finding them to be very important and eventually replacing intentions as the main cause of this behaviour. Four antecedents for habit formation were identified, and we can see that smartphones clearly meet these.

(1) The *frequency of prior behaviour* is important. As smartphones are always with a person there is great potential for frequent use. There is huge variety in the apps available for download, meaning there are many situations in which a smartphone could be used. And by notifying the user of updates such as text messages, emails, football scores, or even adverts, the smartphone can re-insert itself into a person's life without the user intending to use it.

(2) *Satisfactory experiences* with the behaviour build habits. Smartphones are a quick gateway to social networks, which as identified above can provide relationship maintenance, entertainment, time passing and companionship, which all have great potential for immediate satisfaction, and many of the millions of other available apps for smartphones seek to provide satisfaction through entertainment or distraction.

(3) A *stable context* is needed. This enables the behaviour to be formed with minimal cognitive monitoring, and thus more habitually. Although smartphones, by virtue of being portable, enter many different physical contexts, context also involves 'cues and goals.' The sight of a smartphone is a stable cue as smartphones and their interfaces do not change regularly, and goals such as passing time or checking messages are also stable. Furthermore, as described by Cox et al. [20], "design frictions" are increasingly ironed out of mobile devices, making the experience of using a mobile phone more continually 'stable'.

(4) Finally, the *comprehensiveness of use* is important, which is the extent to which the individual makes use of the full range of capabilities of a system. Limayem et al. argue those who use a system for a great

variety of purposes will use it a greater number of situations; the use will be more frequent, meeting the first antecedent, and also more pervasive, affecting multiple different facets of an individual's life. Though the degree to which a smartphone is used *comprehensively* depends on the individual, there is huge potential for varied and pervasive use of smartphones – which can function as media players, internet browsers, video games, document editors, navigation tools, cameras, instant messengers, and even telephony devices – throughout one's day and across one's life.

In short, smartphones powerfully meet the four antecedents for habitual use laid out here, to a greater extent than many other digital devices.

Furthermore, Limayem et al. posits that habitual use can supplant intentional use of information systems with time. '[Intention's] importance in determining behaviour decreases as the behaviour in question takes on a more habitual nature.' Though this can have useful effects, such as allowing efficient, low-cognition performance of regular tasks, the implication that one's *intentions* may become subservient to subconscious *habits* is not so positive where negative behaviour is concerned – it is no longer just a case of deciding one does not wish to do something. Additionally, behaviour that is not negative, such as checking emails, may become problematic if it is 'habitualised' and increases in frequency to a disruptive extent. Not all habits are addictions, but they exist on the same continuum [21] and habitual use has been shown to contribute to addictive behaviour of smartphones [22].

Oulasvirta et al. [23] argue that mobile phones are 'habit forming', with the habit being formed termed a 'checking habit' defined as the 'brief, repetitive inspection of dynamic content quickly accessible on the device.' The studies in this paper yielded a number of findings. Brief usage sessions make up a large part of smartphone use, and these 'checking habits' may increase the overall mobile phone use, as they act as a 'gateway' to other apps on the phone. This is easy to imagine – checking a mobile phone regularly increases the available opportunities for becoming distracted by the device and using it for longer than intended. Further to this, quick access to dynamic content can induce habits. If the informational value of an application – the 'reward' for opening it – is increased, the habit strength also increases.

Oulasvirta et al. take a largely positive view of this checking habit. As it is a gateway to many different possible 'next actions', they recommend designers actually leverage it. For example, a multi-part application could be designed where the use of one component is designed to become habitual, and other connected parts of the application take advantage of this by exposing other content or triggering further behaviours. The underlying assumption is that increased usage of a device is a good thing, as this leads to new uses of the device and increases its utility to the user. This is a 'grand opportunity' to make smartphones more 'personal and pervasive.' These terms are presented in a positive light, but it could be argued that they are just as synonymous with 'self-obsessed and inescapable' as they are with more positive language. Furthermore, the paper claims that smartphone habits are 'not yet perceived as problematic' based on answers given in diary studies from twelve participants over just two weeks – this is flawed because the users' own perception of themselves as addicted, or not, is taken at face value.

Lukoff et al. [3] goes deeper into the nature of problematic smartphone usage, asking what makes usage meaningful or meaningless – the large numbers of people who wish they could use their phones less being proof that much smartphone usage is not perceived as being meaningful. Through a combination of interviews, the experience sampling methodology, and mobile logging of usage sessions, it was found that habitual use, especially of social media and entertainment apps, is in general perceived as less meaningful than intentional use, and results in feelings such as a loss of autonomy. 'Active' use is contrasted with 'passive' use. Through a lens of 'meaningfulness' rather than more hedonistic 'feeling good' in the moment, this intentional, active use – such as sending an important text message, even if it is a 'sad' one – seems superior to passive, habitual use – such as watching a cat video, even if it makes the user feel happy in the moment. The latter contributes far less to a sense of meaningfulness than the former. There are also insights here into the beginnings of habitual use – "users turn to their phones out of habit and lose track of their intentions and fall into habitual patterns of engagement with their phone." ([20] also uses the word 'mindless' when describing the type of behaviour that results from 'frictionless' design approaches, suggesting this is also a factor in habitual use behaviour.) However, for Lukoff, meaningless smartphone usage was not exclusively perceived as negative – in specific contexts, such as escaping a negative situation, a 'meaningless' use could still holder greater meaning. All in all, this work presents a number of nuances to smartphone usage and overuse which I would like to both consider and address.

2.3.2 Factors in problematic smartphone use

Van Deursen et al. [22] conducted an online survey investigating a number of factors in relation to habitual and addictive smartphone use. Habitual smartphone use was found to be 'an important contributor to addictive smartphone behaviour', and using smartphones for social purposes was found to lead to faster formation of smartphone habits, reinforcing the claims that social media usage can make smartphones more addictive [24] and that smartphones are habit forming at all [23]. Process-related usage – usage for the pleasurable experiences gained during 'consuming or presuming media' – was a strong determinant in both habitual use and addictive behaviour. *Social stress* was also an influence in addictive behaviour. Social stress is the result of pressure on an individual to be socially available, via their smartphone. Many people are strongly attached to their smartphone, keeping it with them at all times; when it is not in reach, they can feel unreachable, socially disconnected and out-of-date. This is very similar to the 'fear of missing out' referred to by Blackwell et al. [25] in relation to social media usage. Smartphones are important in 'impression management' and so it is unsurprising that a greater awareness of this – more social stress – would lead to habitual use and addictive behaviour. Poor self-regulation was another factor, again unsurprisingly. Women, who use smartphones more for social purposes and experience more social stress, were at greater risk of developing habitual or addictive smartphone tendencies, and the elderly, who use smartphones less for both process and social usage, experience less social stress, and have better self-regulation, were less at risk.

The investigation of addictive smartphone usage undertaken by Lapointe et al. [26] revealed four smartphone user profiles, two of which exhibited addictive behaviour. 'Addicts' were motivated by boredom, self-consciousness and need for approval, while more extroverted 'copycats' were driven by a need for belonging and were less conscious of the negative aspects of their behaviour than those who exhibited lower addiction.

In their highly cited study of 'the dark side of smartphone usage' Lee et al. [27] found an 'external locus of control' contributes to smartphone addiction. This refers to a person's perception of the cause of events in their life and their own ability to affect them. 'Externals' are those with more passive tendencies and reduced self-control, who engage in compulsive, addictive behaviours to cope with stressors, and, it was found, are more likely to exhibit compulsive usage of smartphones. Materialism was also strongly linked, as was social anxiety and 'the need for touch', which smartphones meet with their large screens providing instant gratification. Along similar lines, an online survey of university students in Mainland China by Bian & Leung [28] correlated loneliness and shyness with smartphone addiction, and among Swiss students, Haug et al. [29] found that 'reporting that social networking was the most personally relevant smartphone function' was associated with smartphone addiction.

All in all, the factors associated with habitual and addictive smartphone usage can be summarised as *personality/psychology* and *technology* related. Many of the psychological factors identified – the need for approval or belonging, fear of rejection, and fear of missing out – can be categorised as social stress, and although this can be the result of external societal influences, the experience of social stress is partly contingent on one's psychology and attitudes. Those with an external locus of control may be more likely to be swayed by this stress towards compulsive and addictive coping behaviours. However, the theme amongst the other psychological factors, which include loneliness, shyness, and self-consciousness, is that they influence or reflect an individual's relationships with other people. It seems that the social affordances of smartphones cause them to be used, to a habitual or addictive extent, by individuals, to remedy relational issues and stresses.

These factors are exacerbated by *technological characteristics* of smartphones. Habitual use is promoted by their pervasiveness throughout a person's day and across many aspects of their life, both work and leisure, and their ability to insert themselves into a person's train of thought uninitiated through notifications. The touch-display means they provide instant gratification on a sensory level. The size of the device means there are few situations where the desire to use a smartphone cannot be gratified immediately, and the habit – or addiction – compounded. They provide quick access to dynamic content, and they are also reliable. If an individual wants to check their emails, or watch a short, mildly entertaining video, or be briefed on the day's weather, they are unlikely to be disappointed. Their experience may not drastically improve their life, but it is likely to be perceived, in the moment, as successful and satisfying. Companies are well aware of these dynamics and some actively prey on them – such as *Dopamine Labs* [30], which 'promises to significantly increase the rate at which people use any running, diet or game app.'

This summation aligns well with the 'biopsychosocial' framework of addiction presented by Griffiths [7] – that addictions form due to biological, psychological, and social factors, as well as characteristics of the addictive behaviour itself. Here we see smartphone addiction as a result of the individual's personality and psychology, their social influences, and the huge capacity for habit-forming inherent to a smartphone.

2.3.3 Role of social networking services

It is important to consider social media addiction when considering smartphone addiction, as one of the main uses of smartphones is to access social media feeds. While the particular device characteristics of a smartphone may be in themselves addictive, the content accessed on the smartphone would also contribute to the addictiveness of the device. Indeed, there is evidence that mobile phones can act as a 'multiplier' or 'enhancer' of the content on them, in terms of addictive tendencies. As is clear from its title, Salehan & Negahban's paper 'Social networking on smartphones: when mobile phones become addictive' [24] makes this case. The use of mobile social networking apps was found to be a significant predictor of mobile phone addiction. The hypothesised reasons for this were four particularly addictive features of mobile social networks in comparison to the typical characteristics of 'classic' phone apps; texting and calling. Social network apps typically have a much larger networks size than an individual's SMS contacts; they provide a more generalised audience; they allow for greater group discussion; and they provide global communication effectively for free, allowing for an 'audience' at any time of day or night.

It is also easy to see how smartphone checking habits and the enticing characteristics of social media can work in unison to build strong habitual use, and indeed, mobile social media usage is a predictor of smartphone addiction [24]. Social media feeds are a source of content from a variety of other sources, tailored to the user's interests, so they are highly attractive to begin with. Individuals are likely to have a pleasurable experience viewing them resulting in a great likelihood of wanting to view them again. In addition, they are dynamic, so the likelihood of new content having appeared is high compared to static websites, giving further motivation to the smartphone checking habit.

2.3.4 Interruptions

Smartphones are interruptive, due in large part to their notifications, which are dangerous both in creating bad habits and disrupting an individual's current thought processes. Leiva et al. [31] studied two kinds of interruptions on smartphones – incoming calls (unintended interruptions) and switching back and forth between apps (intended interruptions) and found that they can introduce a significant overhead, delaying task completion by up to four times. Even if a notification is not attended to, just the 'attentional cost' of receiving it and processing the implications of it can significantly reduce performance on the task at hand [32]. When they *are* attended to, just as an established checking habit can act as a gateway to further usage of a device beyond the intended checking [23], interacting with a smartphone in response to a notification creates the possibility of the user being distracted by something else. ([23] even suggests apps are designed *for* this) which grabs their continued attention. Reading an email leads to checking the weather, which leads to browsing Amazon for new raincoats.

Even short time away from a task can be damaging for productivity, as shown by the 'Memory for goals' cognitive model [33]. Based on the concept of 'activation' levels for goals — goals being things a person is working towards at any moment, stored in working memory — it posits that activation increases as a goal is worked towards, but falls when a goal is not being 'rehearsed.' There exists an activation threshold below which goals drop out of working memory and are 'forgotten'. So when a person switches from a task to use their smartphone, the goals related to that task drop in activation and are eventually forgotten. This makes returning to the task harder as information related to the goals needs to be re-encoded; 'remembered'. Hence, checking a smartphone — either in response to a notification, or as a result of checking habit — can be incredibly disruptive with respect to an individual's productivity.

If an individual has not formed a checking habit, notifications can help induce them. Firstly, they increase time spent on a device and frequency of use, as they are repetitive. Notifications are satisfying to attend to because they give a sense of completion, can be attended to in any physical context where a person has access to their phone, and the process for attending to them is similar each time. These are the four antecedents for habit formation outlined by [19]. The ability of notifications to present themselves – and mobile phone use, by extension – into a person's thoughts unsolicited is especially powerful. Parallels could easily be drawn between smartphone notifications and advertisements for tobacco, and the World Health Organisation recommends that the latter be completely banned [34]. Because of notifications, the independent desire of an individual to use a smartphone does not even need to be present for them to begin using it, — which then reinforces their habitual usage or even addiction.

2.3.5 Prevalence and perceptions

Habitual smartphone usage, and even addiction, is a well-document and accepted phenomenon in modern society. A 2019 analysis of studies of over 41,000 children and young people found that 23% exhibited problematic smartphone usage behaviour consistent with an addiction – such as distress when unable to access their smartphone, an inability to moderate the time spent on the device, and usage to the detriment of other activities. A consistent relationship was demonstrated between such usage and symptoms such as 'depression; anxiety; high levels of perceived stress; and poor sleep.' [35] A 2015 study of 1,519 students in Switzerland found that 17% had smartphone addiction. Deloitte's 2019 digital wellbeing survey found that 40% of the 4,000 respondents felt they overused their smartphones, yet 29% of these did not try to limit their usage in any way, and only 8% used any formal methods of limiting screen time such as apps – the most common methods involved silencing or blocking notifications [2]. 64% of 114 18- to 32-year olds surveyed by Ko et al. [36] said they overused their smartphones, and nearly as many – 60% – said they wanted to change their usage habits.

2.4 Analysis of current solutions

As awareness of the issue of problematic smartphone use has grown, a great number of different potential solutions have been suggested, tested, and even implemented in mobile operation systems. And as the number of such solutions has grown, different ways of classifying them have been developed. Pinder et al. [37] summarises the methods based on two dimensions: "location, on or off the device; and timing, before unwanted usage (e.g. choosing to restrict access), at the time of unwanted usage (e.g. just-in-time warnings), or afterwards (e.g. showing usage data", as shown in Table x. Roffarello et al. [38] categorise nineteen different features of digital wellbeing apps into two categories, *interventions* and *self-monitoring*. From my own research, I have found two different categories most helpful: building user awareness, and restricting and coercing users.

2.4.1 Building user awareness

A number of solutions centre on the idea that users, when presented with the extent of their smartphone usage, will be likely to take steps to reduce it. The suggestion is that many people would put their smartphone down if they just knew how much they had been using it.

Potential solutions which have entered the mainstream generally utilise awareness. Both the iOS and Android smartphone operating systems, which command virtually all of the smartphone market share [39], now contain tools to help with 'digital wellbeing', which most prominently leverage awareness – perhaps because any stronger interventions would too drastically interfere with smartphone use, which these platform's manufacturers rely upon. Amongst other things, Android users can block notifications from certain apps indefinitely, set a 'bedtime' after which notifications are silenced and the screen becomes grayscale, and monitor device usage on a per-app basis day [40]. On iOS, *Screen Time* also allows users to track time spent on each app and set limits [41].

Google's collection of 'Digital Wellbeing Experiments' [42], designed to 'help people find a better balance with technology', exhibit imaginative approaches to building awareness, such as visualising time spent on a device through a ticking clock on the home screen, 'Activity Bubbles' that grow with each screen-on session, and even a Chrome Extension that tracks scrolling distance and uses it to 'digitally walk' along the popular pilgrimage route *Camino Frances*. 'Anchor' visualises endless web-scrolling as a journey to the bottom of the ocean. As novel as these approaches are, their main value is in highlighting to a user the extent of their smartphone usage and putting it in some sort of perspective. For an addict, this is unlikely to do much more than showing them they need to change, and the effect of a visualisation of their usage on their lock-screen and home-screen is likely to wear off as they become desensitised to it. One screen-time tracking app [43] prompted users to consider cutting down on their usage, but there is no indication that they followed through with this intention. So while we cannot assume all addicts are already aware of their problem [26], creating this sort of awareness alone may have limited value.

This is evidenced by [36]. A number of strategies were employed by those surveyed to manage their smartphone use, such as physically separating themselves from their phones, turning them off or putting them in airplane mode, or deleting apps, but the general consensus was that such strategies, while initially effective, they did not last long and eventually failed, because of their reliance on the individuals' self-control: ' 'Simple limiting strategies tended to be overridden by the urge to use the smartphones.' Deleted bookmarks were simply entered by hand. Apps can be re-installed in seconds. The solutions based on building awareness seem especially weak. This is further supported by the fact that, despite fairly extensive tracking of app use now being built into iOS and Android, users continue to struggle with smartphone use [2]. While this is hardly conclusive – such tools may well be under-utilised and under-publicised at this relatively early stage in their implementation – if a complete solution was present here, it would likely have attracted more attention by now.

A mainstream example of building user awareness is the *Forest* app [44], which boasts over 4 million users and was named Google Play's Best App of the Year 2015-2016 [45]. The app helps people to "stay away from [their] smartphone and stay focused on [their] work" by allowing them to plant a virtual 'seed' whenever they want to temporarily put down their smartphone to focus on something else. Continued non-use allows the seed to grow into a tree but using the phone again will see it wither. Judging from its popularity and overwhelmingly positive feedback, Forest is a successful way of 'gamifying' non-use, especially in order to achieve something else.

An 'off-device' counterpart to Forest is perhaps *LockDoll* [46], a "tangible artefact that provides ambient feedback of smartphone usage." LockDoll is particularly aimed at group settings, where an individual being seen to give more attention to a smartphone than other group members can cause disharmony. LockDoll is a small, plastic cat that sits in a group gathering place and is connected to by group members' phones. If a device is unlocked, LockDoll begins to appear uncomfortable, and if the phone use is continuous it eventually becomes angry. Lights and motorised arm movements are used to convey these emotions. A study found it to be a promising intervention, with users feeling guilt at upsetting the LockDoll and being more careful with their phone use as a result.

Both of these have real promise and seem to be effective, but there are some drawbacks that prevent them from being full solutions to problematic smartphone usage.

For instance, in Forest the non-use encouragement is targeted at specific periods of time where the user wishes to do something specifically. It may be powerful at keeping the user working in this intentional period, and for a deeply habitual or addicted user the benefit of spending *any* time off their phone may be huge, but once it ends habitual usage is allowed to resume unopposed. Like previous techniques based on building user awareness, it requires the user to have a specific intention to do something, and to have the self-control to turn to Forest to achieve it. Though in theory a user could use Forest every time they want to read a book, or listen to some music undistracted, or be fully present in a conversation with someone, such usage seems clumsy, and only more prone to the desensitisation issue. Most of all, it seems unlikely to solve the underlying problem of habitual, addictive tendency towards picking up a smartphone in every waking moment – a person needing to see a virtual tree growing every time they want to achieve something could hardly pretend to be fully in control of themselves. Similarly, LockDoll is not a universal solution. It may mitigate the effects of habitual smartphone usage tendencies in situations where they are most harmful, but does not treat the underlying condition – like Forest it only helps with achieving a specific goal. And as useful as intentions and targets are, a person cannot live their whole life goal to goal, and unintentional empty moments can actually be rich for contemplation and reflection. Reflecting on his work, 'America's Poet' Billy Collins went as far as to say, "What I need to write is boredom... I need stretches of inactivity, of doing nothing in order for the poem to get generated. I think boredom is like the mother of creativity." [47] These are things which cannot be delegated to goals, targets or timers, or indeed, virtual trees and 3D-printed animatronic cats, but which need to arise naturally.

In short, both Forest and LockDoll seem to only make living *with* habitual smartphone usage tendencies more manageable, rather than addressing the behaviour itself. What they do demonstrate, however, is the potential power of making smartphone usage more than a statistic, but visible and tangible in some way that can be appealed to, through metaphor. Forest likens not using your smartphone to growing a tree, an incredibly pure and positive act that suggests sustainability and lastingness. LockDoll plays on the idea of keeping the peace and looking after a small animal. Metaphors such as these can be evocative and help to frame smartphone usage and non-usage in a way that can be positively exploited.

2.4.2 Restricting and coercing users

While awareness-based solutions seem weak, solutions based on restricting a user may seem too strong. Fogg [48] referred the idea of 'persuasive technology', "designed to change attitudes or behaviours of the users through persuasion and social influence, but not coercion". Coercion as a technique was at one point relatively unexplored [49], perhaps out of an unwillingness to outright disable functionality, or the belief that limiting a user will only result in a sense of frustration and a negative experience, resulting in an abandonment of the interventions altogether, and that it is far better to persuade the user towards positive actions.

However, Kim et al. [50] showed that coercion and restriction, when carefully employed, can be effective in helping to manage smartphone use and achieve goals, without frustrating the user. They developed 'PomodoLock', an app which allowed users to set a timer for a fixed period, based on the Pomodoro technique, during which objects of distraction and interruption, such as apps and website, were blocked. In their experiment, those who used PomodoLock had a lower perceived coercion and stress than those who did not, who had to rely on their own effort to achieve their goals. Apparently, rather than frustrating the users, the restricting technology took away some of the effort required for self-coercion, self-regulation and discipline, resulting in more positive emotions. The authors note, however, that the use of temporal restriction – locking away apps for 25 minutes at a time, rather than indefinitely – was likely a contributor to this, as the inconvenience was only temporary.

Goalkeeper [51] also explores restriction, and is of particular interest here because it tests it against a purely persuasive technique. This work developed an app in which users define a time-limit, and when this limit is exceeded an 'interaction lockout mechanism' intervenes – restricting or degrading interactivity with the device. Three levels of ILM were tested – *non-ILM*, which only delivered persuasive notifications once the limit was exceeded; *weak-ILM*, which locked the phone for increasing intervals of time when the limit was exceeded, but allowed further use for a certain amount of time after lockout; and *strong-ILM*, which locked it until midnight once the goal was exceeded. Participants in a trial of Goalkeeper preferred weak-ILM to non-ILM to strong-ILM, again showing that a certain level of restriction can be preferable to purely informing a user of their usage, which requires them to utilise only their own effort in overcoming their overuse. Users appreciated how strong-ILM forced them to do something else and abandon hope of returning to use their phone but found it very frustrating when they really needed to use certain functions of their phone, such as accessing a map or data in the phone for a report. This reinforces the findings from PomodoLock [50] that coercion and restriction are most effective when implemented in a careful, targeted, and temporary manner.

MyTime
Hiniker et al. [52] is another work which uses coercive techniques. They underline the idea that awareness-based solutions seems too weak, observing that 'though many people report an interest in self-limiting certain

aspects of their phone use, challenges adhering to self-defined limits are common.' They borrow the phrase 'lagging resistance' from Baumer et al. [53] and produced a taxonomy of intervention categories for such users:

- **Information:** Agnostically providing information to the user about his or her behaviour
- **Reward:** Rewarding the user for engaging in behaviours that are consistent with his or her self-defined goals
- **Punishment**: Punishing the user for engaging in behaviours that are inconsistent with his or her self-defined goals
- **Disruption:** A temporary barrier momentarily prevents the user from engaging in a specific behaviour
- **Limit:** Certain behaviours are time- or context-bound or otherwise constrained within defined parameters
- **Mindfulness:** The user is asked to reflect on his or her choices, before, during or after making them
- **Appeal to values:** Reminding the user about the underlying values that shaped his or her decisions about desired use and non-use
- **Social support:** Opportunities for including other individuals into the intervention

The 'digital wellbeing' systems built-in to Android and iOS mostly fall under *Information* and *Disruption*. *Limit* does feature to an extent, but in ways that can be worked around with minimal effort.

This study gave survey respondent mock-ups of intervention ideas based on each of these categories, and asked them which they liked and disliked, and why. Participants cited awareness of their behaviour, strict enforcement of limits, and being reminded of their priorities as reasons for liking features. Fears that ideas would diminish their experience of using an app they wanted to monitor their usage of, lack of enforcement, or that they would habituate to the feature, were among common reasons for disliking ideas, which underlines the fear of causing frustration as a reason for avoiding coercive or restrictive techniques.

MyTime, an Android app, was developed in line with these findings. The three ideas respondents said they liked were incorporated into a single app which monitored and displayed usage of the user's chosen apps, interrupted them when their specified 'app allowance' was used up, and presented them with their defined 'aspirations' (goals) for the day upon reaching this point. In a trial, participants reduced the time they spent on apps they deemed a waste of their time by 21%, and users were significantly more likely to quit the app they were using if they were presented with a self-defined aspiration.

This is presented as a significant result and proof that technological solutions to the problem are viable, as participants were able to only reduce the time spent on the apps which they deemed a 'waste of their time' and not those they thought were time well spent. It is argued that technological solutions that achieve this are far superior to more radical 'all-or-nothing' approaches such as locking a phone away mean useful functions of a smartphone are inaccessible. This may be true, but the reduction of 21%, while promising, is not hugely dramatic, and may or may not have been a reduction of the scale users were hoping to achieve. The app did not actually enforce non-usage of other apps, but just interrupted them repeatedly with intrusive notifications, as such this work is much more coercive than restrictive. As shown by Ko et al. [36], addicted users are not easily persuaded to stop using an app they are drawn to, so the usefulness of this may be restricted to users who do not exhibit full addictiveness.

Furthermore, screen-time does not tell the complete picture. One key danger of habitual smartphone usage and the 'checking habit' is that it interrupts other activities, breaking an individual's focus and flow. This study and this app do not account for that, though admittedly, the initial research undertaken did not highlight this as a specific concern of the users.

This study did not test mindfulness, reward, punishment, or social support techniques. The latter of these was implemented in the study outlined below, but a study investigating the others would be of value. In particular, mindfulness techniques, perhaps extended into a system that provides basic elements of cognitive behavioural therapy in line with observations about a user's activity, ought to be implemented and tested.

NUGU: Group based intervention

Another interesting study which attempts coercion is Ko et al.'s 'NUGU' [36] – 'when No Use is Good Use' – described as a group-based intervention app. Like *MyTime* it also has three components, which focus on self-monitoring, goal-setting, and social learning and competition. The self-monitoring component gives detailed insights into use. The goal-setting component covers activities such as studying or exercising, and 'goal-mode' forbids any other functions of the app other than receiving incoming calls. Intriguingly, during trials the developers modified the functionality of the app to accommodate for users' checking habits – unlocking the phone was initially a goal failure, but users wanted to be able to see their notifications and not be punished for it so a workaround was implemented that allowed notifications to be viewed mid-mission. This seems a missed opportunity to try and break the formidable smartphone checking habit with a 'zero-tolerance' approach. Finally, the social learning and competition component has two aspects: allowing users to learn from each other by displaying their limiting strategies, and motivation by displaying rankings – a 'gamification' element.

Our hypotheses about the inadequacy of pure monitoring techniques are supported by the trials of *NUGU*: 'According to the interviews, the main function of self- monitoring was primarily to enable users to understand their problematic usage behaviour rather than to motivate them to take action.' Although it was useful to track the outcomes of their limitation efforts and see how they were performing, participants said that motivation gained from seeing the problem deteriorated once they had grown used to this information.

The trials involved two variants of *NUGU*, with and without the social, group-based features. Users of the group features in *NUGU* saw their usage time and number of app executions decrease significantly post-intervention. They also set more goals and more impressive goals. Overall the group features yielded much better results, in terms of limiting smartphone use, indicating that social support features have great potential for limiting smartphone use. Groups that were based on close interpersonal relationships, such as family groups, reported the best results, strengthening this. Again, this supports the 'biopsychosocial' framework of addiction – if a person's social environment contributes to an addiction forming, it is not surprising that changing this environment, or introducing one which runs *against* the addiction, would be powerful.

Lockout Tasks

Drawing on the idea of design frictions [20], lockout tasks attempt to put a barrier between a user and an activity to encourage reflection on the use before it begins, to prevent mindless use based on instant gratification. As a form of restriction, these are interesting because the restriction is not total – if the task is completed the restriction is removed. This is a potential solution to the issue of smartphone use often being necessary, essential, or just 'fair' – for example watching YouTube to unwind after a hard day of work – in which cases restriction can be frustrating and downright unhelpful. LocknType [54] explores this, in the form of a text input tasks which aimed to slightly increase the interaction cost of accessing an app, in order to discourage, but not entirely restrict, app use. In the trial, 10- and 30-digit inputs were used, as well as a '0-digit' input that simply required the user to press 'OK'; a mindfulness pause. It was hypothesised that lockout tasks would help people engage in "cost-benefit analysis for self-regulating frequent app use", and this was supported by the results of the trial: while 0-digit inputs successfully discouraged only 13.1% of app uses, 10-digit inputs increased this to 27.4% and 30-digit even further, to 47.5%. This is a very promising result, though the work does not consider in much detail the mental effects of using LocknType, for example in increasing stress or frustration levels.

If thy right hand offends thee, cut it off?

One Google Experiment which does attempt restriction is *Envelope* [42]. Physical paper phone envelopes can be printed and folded around a smartphone, drastically reducing its functions to those physically printed onto the paper, such as making and receiving calls or taking photos. Envelope is not posited as a serious solution to smartphone addiction, but it does highlight the sort of solution that may be needed. Rather than alerting users to the extent of their addiction so they can try to manage it themselves through willpower, users need decisive *intervention* technology that powerfully prevents them from undertaking the behaviour to which they are addicted.

There is also a growing movement of people reverting to ‘dumbphones’ [55], phones with far smaller, non-touch screens, physical buttons, and much more limited capabilities mostly centred around communication and utilities. This solution, following the ‘cold turkey’ approach to beating addiction, is made difficult because of the ubiquity of smartphones in modern life. As Goodman [4] identified, abstinence is not a viable strategy for all addictions because some behaviours are essential for healthy living, and for some people some functions of smartphones, such as navigation or messaging through certain platforms are essential, perhaps for their occupation. Such functionality is not available on dumbphones. However, it is here that the modular nature of smartphones, as a result of their app-centric design, is helpful to remember. A smartphone without any social media applications, notifications or web-browsing capabilities could be seen as a ‘de-fanged’ device with significantly less ability to form and reinforce habits and build addictions. Users need to be supported in restricting the apps on their phone to the core functionality they need and removing their ability to re-install addictive apps in a moment of weakness.

But as Goodman says, it is preferable to treat the underlying addictive process – the dependence on an external action to regulate an internal state. For this, some level of abstinence is necessary, for which the aforementioned de-fanging of smartphones would be useful, so that an awareness of inner feelings and conflicts can be reached [4]. Then, the internal state can be addressed.

3 Analysis

My review of the literature can be condensed into a number of key findings which will inform my own work.

(1) **Stable internal context:** Smartphones are powerfully able to meet four key antecedents for habitual and addictive technology usage [19]: they have a high frequency of prior behaviour, tend to provide satisfactory experiences, are generally used fairly comprehensively for a large range of activities, and provide a stable context. This latter point is one of the most interesting, in that it is the one that seems easiest to change or disrupt. Relatively speaking, smartphones remain very stable. They are predictable and unsurprising, regardless of how a user's mood, location, context, or the time of day may change. This would firstly make them easy to slip back into at any moment due to the strong familiarity, especially as familiarity is often an attractive, comforting feeling. Secondly, when using a smartphone, the stability of the internal context of the device makes it easy to stay stuck in, regardless of the ongoing external context, as there are few instabilities or 'frictions' to throw the user off or remind them of the ongoing world outside [20]. Therefore, one point of exploration for my project is how this stable context of use could be disrupted in order to encourage smartphone non-use, or less 'mindless' use. This nuance of different types of usage is my next finding.

(2) **Meaningful use:** Problematic smartphone usage goes deeper than binary use and non-use [3]. When thinking about better smartphone usage, we should consider meaningful and meaningless use – a blanket reduction in smartphone use is not always the best thing. Although this idea does give us more reason to try to limit certain types of use – those which are less intentional and more impulsive, perceived as ultimately meaningless and, despite causing in-the-moment positive emotions, can lead to dissatisfaction and a loss of autonomy [3] – it also gives us reason to be wary of placing restrictions on uses that are meaningful to the user. It follows that restricting these uses, either while they are occurring or by preventing them from happening altogether, would be negative for the user. Practically, this encourages interventions that do not treat a smartphone as a single entity but a vehicle for multiple different experiences, which should be treated individually when it comes to limiting usage. This is backed up by works such as [50] and [51] which found that coercion and restriction were of value, but only when applied carefully – such as being targeted at user-selected problematic apps. As [46] showed, this is a feature which users value.

(3) **Restriction and coercion:** Further to this, coercive and restrictive techniques *can* be effective and well-received when used carefully. The fear that such approaches lead to frustration and risk a user disabling them altogether does not always hold – [50] found that perceived coercion and stress among participants experiencing mild coercion and restriction, with the aim of meeting a goal, were actually lower than those who had to rely solely on willpower to achieve it – who had to 'self-coerce'. What is key from this and [51] is that the restriction and coercion was limited, either being temporary or applying only to certain apps, and in both cases it was being applied in order to meet a goal set by the user, in the form of an amount of use or non-use. As such, the user would be aware that any frustration they were experiencing was in order to meet a specific goal they had set and bought into, hopefully lessening frustration.

(4) **A flaw in awareness-based solutions?** In my review of the literature, and indeed in the paper written for *Research Topics in HCI* upon which this review was built, a conclusion was reached that solutions for problematic smartphone usage which centred upon building awareness of, and drawing attention to, a user's smartphone usage are probably too weak. However, in reviewing the literature and current solutions, suggested or implemented, none were found which gave a continuous, ongoing presentation of the device use to the user. (Forest [44] and LockDoll [46] provide a sense of it, but only for specific, finite periods to achieve a specific goal) This information seems to be accessed in two ways – sought out by the user by accessing another app, or it may be brought to the user's attention in the form of an alert or notification. There are potential issues with each of these.

    Seeking out usage information from another app seems particularly ineffective, as it relies on a conscious decision by the user. If they have the willpower to leave an app to view their phone use, they (a) are uncommitted enough to their current activity to probably not be too at risk of using their smartphone to a problematic extent, and (b) have a continuous awareness of device usage strong enough to break the power of being sucked in. In short, if such a feature is being actively utilised, the level of smartphone overuse is probably quite low. Admittedly, this conjecture warrants more direct investigation.

Usage information being presented to the user – such as on-screen alerts when a limit or target is exceeded – is potentially more effective as it does not rely on the user taking the initiative. However, there are still drawbacks here. Firstly, in the absence of coercion and restriction, the alert still requires the user to take some action in response to it. They are generally easy to dismiss quickly – otherwise they would be classified as coercion or restriction. Secondly, such alerts come suddenly and with little warning. A user is interrupted out of the blue and forced to make a decision. The stable internal context is disrupted, but in a jarring fashion which could be more likely to instil feelings of frustration – especially as the user is not given any support in stopping their phone use, which as described above, is an advantage of restrictive methods that can potentially lead to *lower* perceived coercion. [50]

This latter point leads to the initial research question for the rest of this project: How can we create an ongoing, subconscious awareness of device usage in order to promote better, more meaningful use?

4 Design

4.1 Initial design space explorations

Based on the analysis and the resulting research question, a set of more concise, formal requirements for the potential smartphone overuse intervention system were created:

(1) It should create a constant, continuous, subconscious indication of device use.

(2) This indication should quantify device use in some way.

(3) It should be targeted towards particular types of use – in terms of apps and contexts – which are most meaningless.

(4) It should encourage the user to reduce their smartphone use in some way – using the device less, or leaving the app, should be the obvious course of action.

I then sketched out a few different ways to subtly convey smartphone usage with always-on-screen visual effects:

- *Usage bar*: assuming a daily target of screen-time is set by the user, this method would draw a slim line up one side of the screen, representing progress towards this target, with a complete line top to bottom representing the target being reached.
- *Marching ants*: A dotted border around the edge of the screen. The dots 'march' around the edge at a speed, increasing from stationary, as usage increases. The aim here is to instil a subconscious feeling of discomfort or even anxiety as usage increases, making phone usage less comfortable.
- *Fire ants*: A variant on *marching ants*, dots within the border would begin to move at random within a space around their anchor points, with increasing range, speed and volatility as usage increases. This would in theory create stronger sensations which are harder to get used to than linearly moving 'ants'.
- *Edge glow*: A glowing effect is drawn around the edge of the screen. Starting from very faint, this increases in size, visibility, and colour strength as phone usage increases, as though the phone is 'heating up', becoming more intrusive and disruptive.
- *Seconds*: Taking cues from simulated clock ticking in film soundtracks, to keep the continuous passage of time in the user's mind, a ticking effect – perhaps a white border flashing subtly each second, or even a very low haptic feedback buzz – would be employed, growing in intensity as usage increases.

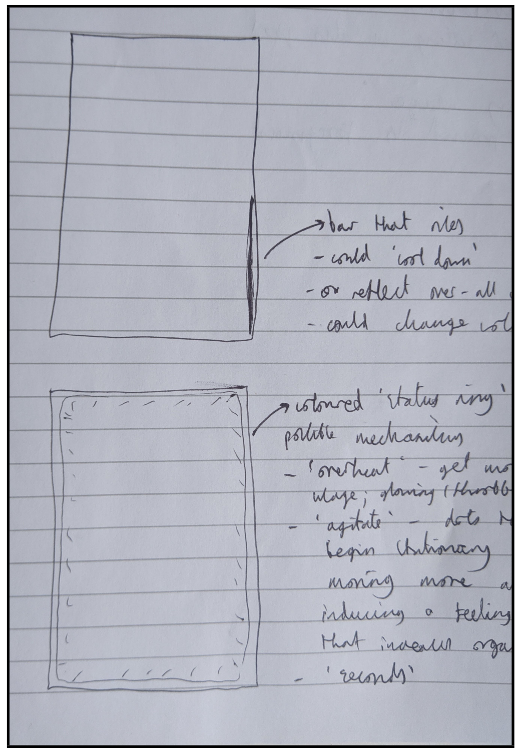

Figure 1: Early sketches of *usage bar* and *edge glow* ideas.

Sketches of *Usage bar* and *Edge glow* are shown in figure 1.

All these ideas scale their effect in line with some quantity referred to here as 'usage.' I realised there are different ways of measuring this. If the user is asked to set a goal for daily screen time, this could simply be progress towards that value. But as papers such as [3] suggest, there may be more to screen time than that. If getting 'sucked into' an app is what causes the most unsatisfactory experiences, recent usage of an app could also be tracked – for example screen time within a rolling window of the last fifteen minutes.

4.2 Final design proposal

My proposal is a hybrid of two of these ideas – one a bar along the edge of the screen, showing the percentage of a user's 'daily quota' of screen time that has been used, and the other a glowing ring around the edge of the screen that becomes brighter and more obtrusive as a device is used more. Combined, we have a glowing ring that works its way up the edges of the screen as a device is used more. Figure 2 shows a depiction of the proposal that was created prior to its development.

Based on the analysis outlined in section 3, the user will be able to pre-select a set of applications which they wish to use less, and a daily amount of usage for these apps – a goal. The ring will only grow 'upwards' when such apps are being used, and in such cases, it will become brighter and more obtrusive as recent usage of such apps increases. That is, more concentrated periods of use of, for example, Instagram will result in a stronger visual reaction – the intensity will be based on the total usage of tracked apps from the last fifteen minutes.

This is based on points 2 and 3 from the *Analysis* section, which found that coercive methods – and if my proposal is on screen permanently this will make it feel somewhat coercive – work best if targeted at specific apps and uses, rather than universally, and that more impulsive, mindless uses of a smartphone are the ones which are perceived most negatively by users. My proposal creates an increasingly strong visual effect when an app, which the user has expressed a desire to use less, is used for a long period of time: such uses are likely to be less meaningful.

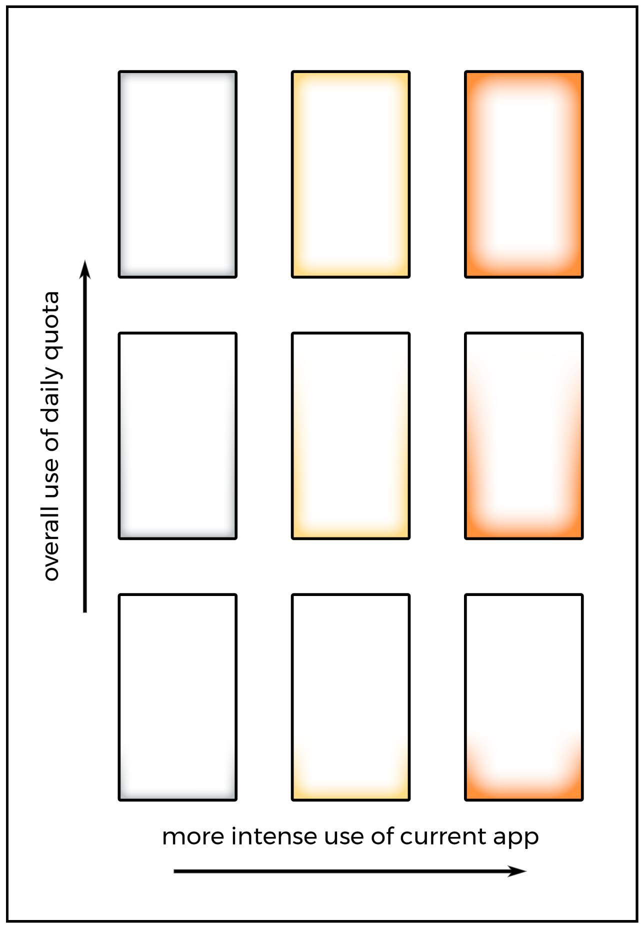

Figure 2: Illustration of the final design proposal

Targeting the visual effect at such apps and contexts is likely to reduce user frustration, as it will be a response to a conscious decision the user has made: to declare a desire to use an app less. The user has bought into the idea of reducing their usage of this app already. This should greatly reduce the number of instances where the user feels they are being unfairly 'penalised' for 'fair use' of their device, which is important because whenever this happens, the user will grow frustrated with the intervention and become more accustomed to ignoring it, or simply disabling it.

The effect itself, a glow with increasing size and intensity, is designed to be subtle, subliminal and subconscious. Rather than announce directly to the user at a single point that their usage is high, it creates a continuous impression of usage which will hopefully increase their mindfulness of their usage through its ever-present-ness. At no point is the user actually restricted from using their phone, but at no point are they unaware of their increasing usage. This will hopefully create a middle ground between surprising the user with sudden information and forcing them to make a change in the moment – which may be too great a disruption to the *stable internal context* resulting in non-compliance or sharp annoyance – and relying on them to track usage themselves. This uses a similar logic to [50], which found that perceived stress and coercion was lower when the user was assisted in meeting a goal – hopefully creating a continuous, subliminal sense of device use will reduce the mental effort the user needs to put in to track it themselves.

This draws on the idea of smartphones being a *stable internal context*, which leads to habitual usage – the on-screen effect reduces stability because the visual 'state' of the phone is never exactly the same when problematic apps are being used – usage is increasing and the user cannot really hide from it. The passage of time is always somewhat visible to the user, albeit in a subtle, hopefully subconscious way. The style of the effect was also a consideration. 'Glow' effects are not a recommended feature of Material Design, the Google design language that is very common in Android apps. This means the edge glow is less likely to be confused for another app, helping it to stay separate to the smartphone context and introducing something different and new. This could both avoid frustration, by lowering the risk of the user finding it interferes with their apps, and help to keep it subliminal – by occupying a different design style space, it may be easier for it to occupy a different mental space within the user's perception.

As described in the review of existing solutions, metaphors can be a powerful way of communicating an idea or perspective about smartphone use [44, 46] The colour-change effect attempts to draw on this, evoking ideas such as the device 'heating up' as it is used more. When something heats up it generally needs to stop being used for its – and the user's – long-term wellbeing, so employing this metaphor could work to encourage non-use, with increasing strength as a use-session increases. It also creates an element of discomfort and even frustration to the user as it obscures (though never entirely) the screen contents with a bright colour, which could further encourage non-use. The heating-up metaphor is supported by the fast that when the user stops using a tracked app the colour goes away, and when they return to one it returns at a 'cooler' shade. The immersion in this metaphor is only broken here by the fact that the cool-down is very quick, unlike real life. This is a conscious decision because the effect should not affect the user when they are doing things with their phone they have not chosen to do less – this risks frustrating them, which as previously described would be bad for long term compliance. However, it may be worth reconsidering this, because if high use of problematic apps leaves a temporary 'scar' on the device this could act as a further deterrent against such usage, and if it is perceived as self-inflicted the level of resultant frustration may be low.

In addition, as the quota is filled, this effect is multiplied as the ring surrounds more of the screen, so the visual effect of a long usage session when the daily quota is nearly used is much stronger. This may counter the effect of becoming desensitised to the effect throughout the day, as the size of the effect grows more prominent, in terms of vertical space taken up, as more of the quota is used up.

The fade effect at the top edges of the overlay not only work to avoid a jarring border where the glow ends, but also to make the exact size of the glow imprecise. We don't want the user to obsess over the exact amount of their usage they have used up, tracking percentage to percentage, which can cause them to lose sight of the 'bigger picture' of app use because they are concentrating on the relatively meaningless difference between 82% and 88% of their use, for instance. Rather, they are given a general sense of the scale of their usage within the day – whether they have spent (or perhaps 'wasted') only a small amount of time on apps they want to use less, or a decent amount of time, or have nearly used up their allowance, or are, in fact, all out. Visualising this data in the first place helps to put it into context and make it seem an amount out of an allowance, employing a sort of 'filling a cup' metaphor, and making the exact value non-discrete further emphasises this by removing the ability to look for exact values, which can be used to justify actions contrary to our aim. ('I'm at eighty-eight percent... I'll stop when I reach ninety!')

As not all smartphone usage is bad it is also important not to penalise users for 'fair use' of their devices. As such, the edge glow will remain visible but be at its smallest size and with a neutral grey colour when apps which the user does not wish to use less are open. This will hopefully create a continued awareness of device usage, but by removing the colour – the feature it is expected the user will react to most strongly – the sense of frustration which we want to instil when using problematic apps will be reduced greatly, hopefully to the point of being non-existent.

4.3 Other design decisions

App listing: An integral part of the app will be a screen in which the user selects apps they wish to use less. This is a key decision, so it is important the goal of this screen and this information presented are as clear as possible.

Goal setting: As explained, one aspect of the app is tracking daily combined usage of apps a user says they wish to use less. It was noted that individual's usage of apps can vary greatly – for some two hours of usage would be an achievement, for others this would be more than they usually use their phone! It is also difficult for users to estimate their own phone use – anecdotally, two participants in the trial (see section 6) expressed shock at the amount they used their phone when the app presented them with this. For these reasons, it was decided that the user should be presented with the amount they used the apps they have selected on average, per day, so that this value is well informed and meaningful to the user.

Sticking to it: I wanted to avoid the user changing the goal they set and the apps they selected on impulse (though admittedly, the user desiring to do this might indicate that the intervention is too strong and frustrating.) Equally, there are circumstances in which changing the settings might be beneficial, for instance in order to set a more challenging target, add further apps to the tracked list, or if an app was, for some reason, not functioning properly as a result of being tracked. Therefore, a lockout task [54] would be added, requiring the user to enter a long string of digits to access the settings. It was hoped that this would deter the user from impulsively changing the settings, while allowing them some level of freedom if they really needed to change the settings.

5 Implementation

I chose to implement my designed smartphone usage intervention app in the form of an Android app, primarily because this is the mobile programming language I have the most experience with. As Android commands 50% of the market share of mobile operating systems in the United Kingdom [56], and 86% worldwide [39], there would be no issue recruiting participants for a potential trial of the solution. Furthermore, Android gives more freedom to developers in terms of device-altering functions – the always-on-screen effects explored in the previous section were designed with an Android application in mind

The app, simply named *AppTracker*, can be divided into a number of requirements.

- **Usage of apps** on the device must be obtained and collated
- The user needs to be able to **select apps** they wish to use less, and a daily total usage target for these apps.
- An **edge glow effect** needs to be drawn on screen, on top of all other apps.
- This edge glow must be **continuously updated** to reflect the data from the previous two points.
- For trial analysis purposes, I needed to **collate and upload usage data.**
- The edge glow effect needs to be **permanently onscreen** while the device is in use.

In this section, I will describe in more detail how these requirements were met, and the various challenges that were overcome to implement them.

5.1 TrackingService

The TrackingService class is the bulk of AppTracker. As my app displays an edge glow over all other apps on the device, it was necessary to create a Service that can run and manage this overlay even when AppTracker is not in the foreground or being interacted with by the user, which will naturally be the vast majority of the time.

It was imperative that once begun, TrackingService would run 'forever' – until the device was turned off. This would prove to be the greatest challenge for AppTracker. To begin, I chose to use a ForegroundService for TrackingService. ForegroundServices are the least restricted by the Android operating system, compared to standard, 'background' Services, and designed for operations that are visible to the user, as a result apps such as music players will utilise them. In short, using a ForegroundService is the best way to ensure a service is not 'killed' by the system. ForegroundServices must display a permanent, 'sticky' notification while they are active in return for this freedom, but this was no great cost and a notification would be a useful feature.

TrackingService contains a great number of methods, but the central component is a *Runnable* class called *tracking* which once started is run every 2.5 seconds. The main purpose of tracking is to update the overlay to match the currently active application. To determine which app this is, I used the Foreground App Checker library (Appendix B, 2.) which provided a simple AppChecker class, with a self-descriptive getForegroundApp() method.

The order of operations of *tracking's* run method is shown below. These are in fact divided across the initial *run()* method and a few auxiliary methods it calls, for simplification of code. This is highlighted here because these operations are undertaken every 2.5 seconds.

1. Check if usage stats have been uploaded today; upload and set a flag if not.
2. Use an AppChecker to get the package name of the current foreground app.
3. Check if the current foreground app is a 'tracked' app – one which the user wishes to use less.
4. If the current app is tracked:

a. Query usage stats for current day and change the height of the edge glow to reflect the amount of the daily target which has been used up.

b. Calculate the amount of time tracked apps have been used in the last fifteen minutes, as a percentage of fifteen minutes.

c. Using this percentage, calculate the corresponding current colour for the edge glow. (section 5.2.2)

d. If this percentage is 100%, animate a 'pulsing' colour change effect.

e. Otherwise, animate a smooth transition of glow colour from the previous colour to the new colour.

f. Save the new colour to be used in step (e) next time this method runs.

g. Set *reset* to false to indicate the glow is currently 'active'.

Otherwise, check if the glow has been *reset* to the dormant state (for non-tracked apps) yet. If so:

a. Query usage stats for current day and change the height of the edge glow to reflect the amount of the daily target which has been used up.

b. Animate a smooth transition of the glow to the colourless, dormant state.

c. Set *reset* to true to indicate the glow is currently 'dormant'

5.1.1 Saving user preferences

The set of apps which the user had selected to track, and the goal set, needed to be stored so it could be retrieved each time that app was run. To do this Android's SharedPreferences were employed. Apps were saved as a single string of package names, delimited by an 'at' sign.

5.2 Edge glow effect

The edge glow is the most prominent feature of the app and required a lot of thought and planning in order to replicate the final design proposal, and all its subtleties, as well as possible.

5.2.1 Drawing the glow

At its core, the edge glow uses a 1920X1080 PNG image, which is a transparent image with a grey glow around the edge. The grey colour was chosen to ensure the glow, when in the 'dormant' state, maintains an acceptable level of contrast on both white, black, nearly-white, nearly-black, and coloured backgrounds.

The glow needs to do three things. Firstly, it needs to 'grow' up the edge of the screen, with a fade at the top edge of its current height. Secondly, it needs to change colour to become brighter and more intense. Thirdly, it needs to increase in size, in line with the colour change. Each of these added a new layer of complexity to the problem.

To make the edge grow, I needed to perform a 'bottom crop' of the image; crop an amount of the image out from the top edge. To accommodate for the small variation in screen sizes present on Android devices – not all have a 16:9 ratio – I at first chose to exploit the *scaleType* property of Android's ImageViews, which would scale the PNG image I had created to fit. However, this required the ImageView being the full height of the screen. This presented issues for the bottom cropped image – adjusting the height of the ImageView itself to match the current desired height of the glow meant that the scaleType scaling would be incorrect, scaling the entire background image to fit within this smaller ImageView, rather than to be in proportion to the entire screen, but with only the bottom portion showing. Finally, the obvious and simplest way to implement perhaps the hardest aspect of this, this fade at the top of the glow, was the powerful *FadingEdgeLayout* library (Appendix B, 1.). This provides a FadingEdgeLayout view, which is essentially a container that applies a fading edge effect to the edge of whatever content it holds. For this to work for my

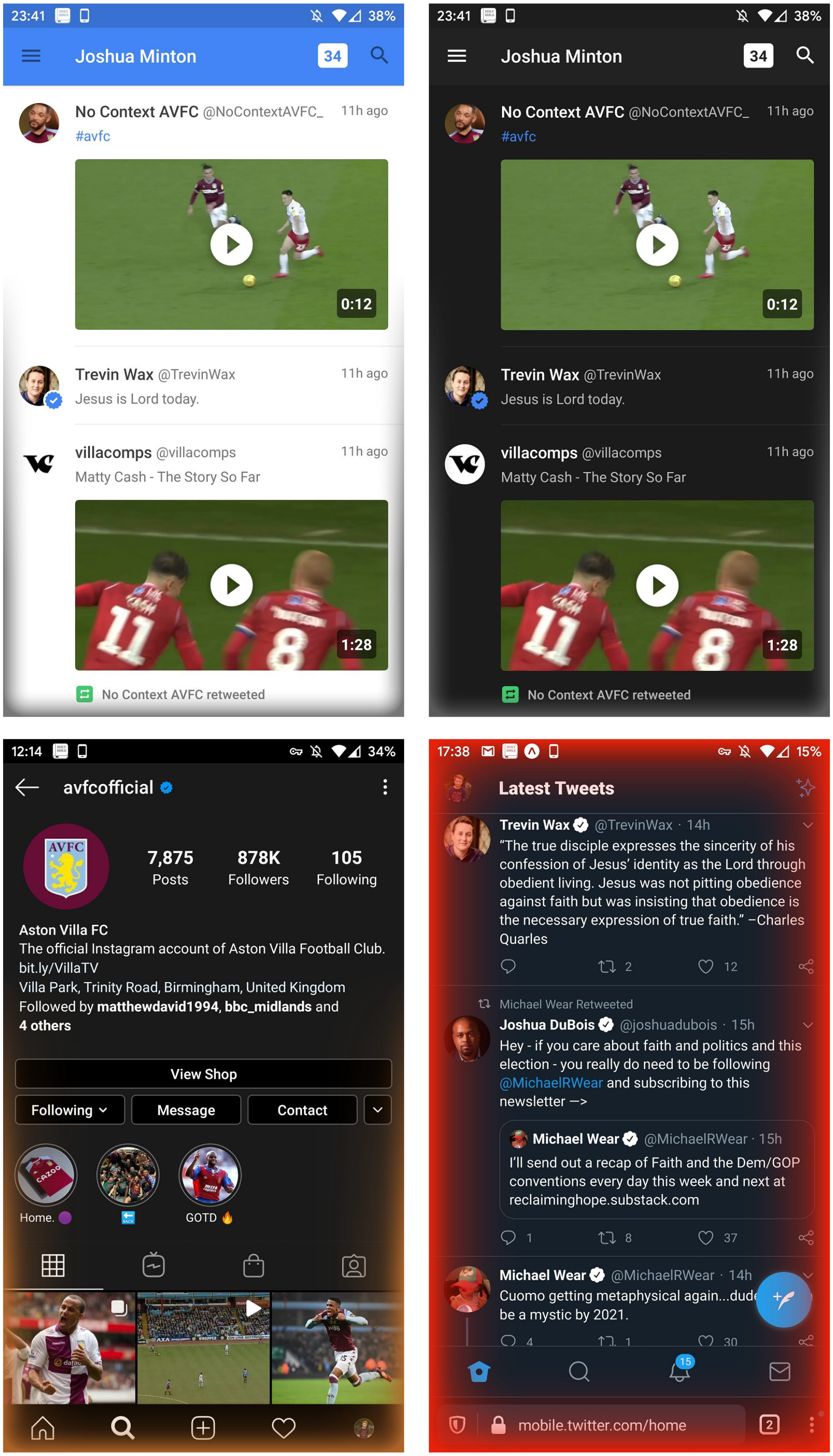

Figure 3: Clockwise from top left: ‘neutral’ glow on a light background, ‘neutral’ glow on a dark background, edge glow with daily target exceeded and heavy recent use, and edge glow with daily target half-met and moderate recent use.

purposes, the FadingEdgeLayout needed to be wrapped tight to the size of the ImageView within it. Again, this made using scaleType to scale the PNG image properly difficult, as even if the ImageView were able to be the same height and width as the screen itself, allowing scaleType to properly scale the image, while keeping only the bottom portion of the image within it visible, the fading edge effect would be applied at the top of the ImageView, rather than the point within the ImageView where the image stopped.

These three factors could not be reconciled, so in the end I decided to create a custom *GlowView* class, which would take the desired background image, the desired height of the glow, and the actual screen size to scale the background image to the screen, crop it down, and set this as the background of an ImageView only as high as the visible portion of the glow PNG. The scaling was done ‘manually’ using various calculations to determine the correct dimensions. This GlowView could then be wrapped tightly inside a FadingEdgeLayout, so that the fading edge effect applied along the top edge correctly faded out the visible part of the edge glow. The FadingEdgeLayout itself was constrained to the bottom of a ConstraintLayout, to keep it at the bottom of the screen, growing ‘upwards’, at all times.

Further complicating matters was the need to make the edge glow grow ‘thicker’, taking up more of the screen, and also change colour as recent usage of a problematic app increased. Once GlowView was implemented, colour was handled by adding a *setColour()* method to provide an integer colour value, which was then used in the GlowView’s *onDraw()* method. When the background image was drawn at the desired crop, a PorterDuffColorFilter with this colour was also applied. This replaced uses of the *tint* property of ImageViews used in earlier iterations.

In the end, thickness was handled by simply drawing a second, thicker glow effect PNG on top of the main one, and increasing its transparency to make it more visible. This does not capture exactly the design proposal, but is very close to it, and avoids use of any further, more complex graphics libraries which would likely hinder device app performance (and have required much more learning to setup correctly). So GlowView, which extends View, is further extended by an InnerGlowView and OuterGlowView class which refer to the two different glow images. The final structure of the *glow.xml* defining the edge glow effect is shown in figure 4.

All this describes a glowing edge ‘object’ which can be manipulated to copy the different ‘states’ present in figure 2. Managing this manipulation, and smoothly handling changes between states, was the next half of the task.

5.2.2 Using and manipulating the glow

Firstly, in order to draw on top of all other apps, from within the TrackingService I access the system window service, in the form of a WindowManager. I then inflate the custom *glow.xml* layout as a View, as a variable within TrackingService, and use the WindowManager’s *addView* to attach it. A number of different *LayoutParam* flags are set to ensure this View is added on top of all other apps; as an ‘overlay’. There were only two drawbacks to this method — this View would not be displayed on top of the lock screen, the notification panel, or the Settings app. Ideally it would have been displayed universally, but these are unavoidable operating system restrictions and I do not believe the effectiveness of the edge glow would be massively decreased by this — none of these are settings that are likely to be used during actual problematic use.

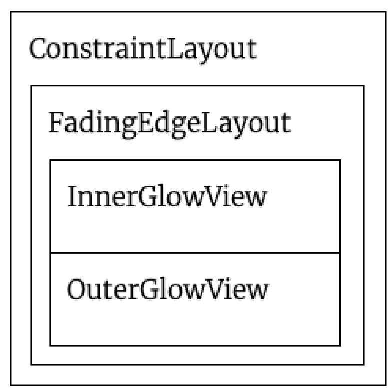

Figure 4: The final structure of the *glow.xml* defining the edge glow effect.

It was important that the edge glow was around the furthest edges of the screen itself, not just the ‘active’ area between the status bar at the top and the navigation bar at the bottom. Since Android 5.0 apps have been able to alter the colour of these so they appear more like overlays themselves than separate sections of the screen, so there are many instances where the edge glow being bound to the inner edges of these would appear incongruous. To avoid this, the ‘true’ screen size was obtained using *WindowManager.getDefaultDisplay().getRealSize()*, and these dimensions were used when calculating the width and height of the edge glow.

The different views within the *glow* overlay – the FadingEdgeLayout, and both the thinner and thicker glows, can be accessed and their properties altered using *findViewById()* on the *overlay* variable referencing it. The size of the fade is set at 300dp, however this is adjusted when the height of the glow is more than 90% of the screen size. At this point the fade length is scaled linearly to become zero when the height is 100% of the screen height, so the glowing edge is fully visible around the edge of the screen.

It was very important that the edge glow effect is subtle and 'subliminal', never drawing attention to itself quickly. Instantaneous changes between different states would be jarring for the user and run counter to these aims. Therefore care was taken to ensure the glow only ever changes smoothly between these states. Any time the coloured warning glow disappears or appears, for instance if a user switches from a tracked app to a non-tracked app and then back, the opacity of the thicker glow is controlled with the View's *animate* method, as described in Android's online developer documentation (Appendix B, 9.). This logic was put inside dedicated *show* and *hide* methods to keep this effect consistent throughout the app. Very similar logic was used when changing colours, but with the added complexity of calculating the new colour for the glow.

Calculating this new colour was delegated to a *getColorFromPercentage()* method, which took as a parameter the amount of usage of tracked apps from the last fifteen minutes, as a percentage of fifteen minutes. Following suggestions online (Appendix B, 11.) the HSV colour space was chosen for this as two *hue* values could be chosen to specify a range of colours to transition across. Maximum and minimum hues of 0° and 60° – red and yellow respectively – were selected, and the final hue calculated based on this range and the percentage given to the method – so 50% would result in a hue of 30°. The opacity of the colour was also set as this percentage for a smooth colour transition – from the 'dormant' grey colour of the PNG, to a dull yellow, to a brighter orange, and finally a deep red, as depicted in the proposal.

For these transitions in both colour and opacity, the animation duration was set as half of the update interval (2.5 seconds, as described in section 5.1). This would ensure that there was plenty of time for the animation to finish, in the event of delays, avoiding jumps between incomplete animation states which would cause further visual jarring.

Finally, a subtle 'pulsing' effect was needed when tracked apps had been used for the full previous fifteen minutes, to bring further attention to the extent of the user's phone usage. To achieve this, once the fifteen minute window was 'maxed out', the new colour for the glow was set as the colour given by *getColorFromPercentage()*, but with the 'V' value of this HSV colour – corresponding to the *brightness* of the colour – changed to 0.8; resulting in a 20% less bright colour. A simple *glowSwitch* boolean was used to alternate between changing *to* and *from* this less bright colour, resulting in the desired pulsing colour change effect.

I also had to take into account landscape orientations of phone use. To ensure the glow was always stretched out to the edges of the screen, and avoid the portrait glow ever being displayed in landscape mode, I overrode the parent *OnConfigurationChanged()* method of TrackingService with a method that simply triggered the overlay update as soon as a configuration change was registered. A shortcoming of my solution is that the same, portrait-intended glow PNG was used but just skewed to landscape height and width, meaning the edge glows were quite out of proportion, with more time and forethought I would have created an alternative landscape-intended PNG for use in landscape mode.

5.3 Tracking app usage

My app needed to keep track of two quantities – total usage of apps for the current day, and usage of apps in the last fifteen minutes. For both of these quantities we are mostly interested in usage of the apps the user is tracking – ones they wish to use less – but not exclusively.

Since version 5.0, Android has provided a UsageStatsManager which provides access to device usage history and statistics, and via the *queryUsageStats()* method we can obtain a list of apps and the time they were used for in a specific period, down to millisecond accuracy. However, this data is aggregated to one of a number of specified intervals, and the smallest interval type permitted is twenty-four hours. We needed much finer granularity, in order to obtain usage stats for the last fifteen minutes, and for the current day. So, using a method given online (Appendix B, 10.), I chose to use UsageStatsManager only to obtain a log of every relevant 'usage event' from a given period (using the *queryEvents()* method, which has no aggregation) and then read through these usage events in order to determine the usage of apps from this period – UsageEvents have a type, an associated package, and a time, and so can be used to work out how long each app was on screen for. This functionality was combined in a *queryUsageStatistics()* method which returns a map of package names to AppUsageInfo classes, which contain a timeInForground variable, which is the total time an app has been in the foreground, in milliseconds. *queryUsageStatistics()* takes *startTime* and *endTime* variables, which set the period for which usage data is retrieved.

While the Service was running, I maintained a store of all apps on the phone, in the form of a collection of TrackedApp objects (an admittedly poorly named class, as this was also used for apps the user was not 'tracking'). I used a HashMap accessible by package name for fast access. This collection, *apps*, was populated with every app on the phone when the service started, along with its name and app icon (for use in the app selection screen). Only apps with a 'launch intent' were selected – those which the user can open themselves and are visible in the app drawer. This store is mainly used for determining which apps are being tracked and for populating the app selection screen.

Up to date usage information is required each time the *run* method described in section 5.1 is run, in two different formats. Firstly, when *updateHeight()* is run, *queryUsageStatistics()* is called to get a HashMap of app use since the day began (5.30am is used as the cut-off between days, in line with Android's UsageStats-Manager). The *apps* HashMap is used to determine which of these apps is tracked, so a total of tracked app usage since 5.30am can be calculated. This value, along with the target value for daily tracked app use, is used to change the height of the glow effect.

Usage information is also required for changing the colour and size of the glow to reflect recent usage. To do this, *queryUsageStatistics()* is called again, but this time only for usage information from the last 15 minutes. Similarly, the total amount of time tracked apps have been used in the last fifteen minutes is calculated, which is used to update the appearance of the edge glow.

queryUsageStatistics() runs surprisingly fast, considering it, at worst, iterates through every app event recorded since 5.30am. Still, I was careful to ensure *queryUsageStatistics()* runs only twice each time *run* is called, even though the information it returns is used in a few different places, to limit the effect on device performance as much as possible. None of my trial participants reported changes in their phone's performance after two weeks of use, so I consider these efforts successful.

One further use of app usage data was to give an estimate of each app's usage in the last two weeks, when presenting the user with a list of apps to choose those they wish to use less of from. For this case, the default UsageStatsManager's *queryUsageStats()* method's aggregation by day was acceptable, so I ran this method on the period starting two weeks before the present moment, until now, and for each app divided the total usage by the number of days counted to get an average.

5.4 A continually running service

Keeping the service responsible AppTracker's always-on-screen edge glow running was one of the greatest challenges in the development process.

A *BootUpReceiver* class, which extends BroadcastReceiver, was implemented (Appendix B, 18.) and registered in the AndroidManifest file, which is triggered every time the device restarts, and in turn starts up the TrackingService, to ensure that AppTracker starts running when a device is turned on. A number of devices which run Android variants require the user to specifically enable this functionality for an app in order for it to work. This is implemented differently on different devices, so I turned to the *AutoStarter* library (Appendix B, 4.) which provides methods to check if this auto start permission is required on a device, and also open the appropriate window if it is. I added an instruction to users to enable this permission on the home screen of the app. In hindsight I could have added this on the initial permission-setup screen for greater prominence, however as there is no way to check that this permission has been set, as there is with the others, bringing continuous attention to it on the home screen also makes sense.

As described previously, a foreground Service was used to limit the chances of the Android system killing the service. TrackingService's *onStartCommand()* method returns *START_STICKY*, which tells the system that if it is forced to kill the service, it should restart it when possible.

However, it is apparent that a number of devices which do not run 'stock' Android implement their own, stricter, service management, generally to conserve battery. Such is the scale of this problem that an entire website, *dontkillmyapp.com* [57] has been produced to inform developers of it and detail the extent of it on different devices. The full scale of this problem did not become apparent until late on in the development process, with the discovery of this website and various articles it in turn references, however I was still able to attempt a few different ways to get around it.

Firstly, I tried to trigger various BroadcastReceivers to check if AppTracker was running, and start it up if not, as *BootUpReceiver* does upon receiving the *BOOT_COMPLETED* intent (and a few other similarly purposed intents.) Triggers such as *POWER_CONNECTED* and *POWER_DISCONNECTED* were tried and would potentially. have been quite effective as these are likely to be frequent events. However, since Android 8.0, the vast majority of these 'implicit broadcasts' have to be registered for by an app at runtime, rather than in the app manifest, meaning that the app needs to be manually run before it will receive these intents. *BOOT_COMPLETED* is exempted by *POWER_CONNECTED* and other useful intents are not. As this runtime registration will stop working when the app crashes or is stopped by the system – which are the scenarios I want to register for these broadcasts in order to recover from – this strategy was rendered useless.

Secondly, I tried to use AlarmManager and similar Android functions to schedule some code to run in the future, to start up *TrackingService* if necessary, but – similarly to implicit broadcasts – it became apparent that such scheduled operations were cancelled if the app crashed or was stopped by the system. Furthermore, as evidenced by continuing existence of *dontkillmyapp.com*, the standard Android method of recovering from the system stopping an app – returning *START_STICKY* – is not respected by these stricter Android variants where the problems most commonly lie.

A more successful mitigation of this issue came with the discovery of the *Doki* library (Appendix B, 3.). *Dontkillmyapp.com* also provides users and developers with workarounds for different devices, such as disabling battery optimisation for an app. These rarely solve the problem completely but can make a difference. There is a webpage for each phone manufacturer with a guide for disabling battery optimisation on that manufacturer's devices, and the Doki library detects the relevant manufacturer for the device it is run on, and then displays information from the corresponding page on *dontkillmyapp.com*. I integrated Doki into my app, adding a button on the homepage, alongside the AutoStart button, to open the guide in a pop-up dialog. So ultimately this issue of AppTracker's life being cut short could not be solved satisfactorily, but I am confident that I did as much as possible, given the scale of my project, to mitigate it. I also took extra care to ensure my app never crashed, knowing that the chances of the service being restarted by the system on many devices were very slim.

5.5 Permissions

Two important permissions were required for my app to run – accessing device UsageInfo and displaying on top of other apps. As these are critical for AppTracker to work, I created an initial 'landing screen' for my app which displayed the status of both of these permissions, and provided buttons for the user to press to be taken to the page in device settings where the permission could be granted. This screen detects the status of these permissions and advanced to the rest of the app once both were granted, advancing in any other way is not possible. The permission status is checked each time the app starts up, so that if permissions are granted and then taken away, the app cannot be started again. To gain overlay drawing permission I used the OverlayHelper library (Appendix B, 5.), which handles differences in granting this permission between Android versions. UsageInfo permission granting is more straightforward. Red and green colours and tick and '!' icons were used to clearly communicate the status of both of these permissions and what was required of the user in order to advance.

5.6 Collecting trial data

When trialling my app, it would be very useful to collect metrics of how much the device – and in particular, apps the user was trying to use less – were being used. As mechanisms for obtaining this data were foundational to my app and already implemented this was mostly a case of collating it and uploading it to a repository I could access. This also needed to be done in an anonymous way.

I used Google's *Firebase* platform (Appendix B, 6.) to achieve this. A Firebase project, linked to my app, was created, and the relevant dependencies for Firebase and its Storage module were added to my app. Following Google's online documentation, it was straightforward to upload a file to a specific folder in the online storage. To differentiate between devices, I chose to use the unique *ANDROID_ID* which can be accessed with Settings.Secure.ANDROID_ID. This ID was used as the name of the folder in which a device would upload its usage stats to. This was ideal as it was randomly generated and unique, so impossible to link to a specific trial participant.

The data itself was stored as a CSV file, for easy analysis by, for instance, a Python script. I looped through the usage stats provided by UsageStatsManager's *queryUsageStats()* for the maximum time period, adding each usage stat – which describes the amount of time a single app was on screen on a single day – as a row in the CSV file. The date, the package name, the user-friendly app name, the time used, and whether the app was being tracked at the point at which this file was being created, formed the columns. At the end of the CSV file I appended a list of all tracked apps, and the usage target the user had set themselves, as these would also be useful for analysis.

This data collation and uploading was triggered whenever AppTracker was opened, and AppTracker also checked whether it had uploaded usage data yet today each time the continually repeating *run* method (see section 5.1) was run, uploading if it hadn't.

5.7 User Interface

AppTracker has quite a limited user interface as its primary function is to display over *other* apps, but there were a few necessary setup screens which needed to be implemented carefully to ensure the user got as much out of AppTracker as possible, and that the intervention was well-tailored to them and effective. Poor communication could destroy the subtleties described in the design proposal and jeopardise the app's usefulness.

The first screen a user will be presented with is the permissions screen. As described in section 5.5, because these permissions are essential, the user cannot advance to the rest of the app until both permissions are enabled. Therefore, this is a very simple screen with just two buttons. These are colour coded red and green to signify permissions being required or already granted, tick and exclamation mark icons further indicate this. Dialog windows are shown when each is pressed with some explanatory information and 'proceed' or 'cancel' button. In the case of usage stats, it is explained that no personal information from within apps will be exposed. Once both of these permissions are granted, the app automatically advances to the next screen.

If the app has not been run before, or it has been run but the setup process has not been completed, the user is then presented with the app selection screen. All apps on the phone are displayed here (other than system apps which the user cannot launch themselves, of which there are many, and which the user will almost certainly have no need to track their usage of.) The apps are displayed, with their default icon for better recognisability, and their average usage per day from the last two weeks is displayed below to aid the user in choosing which to use less. Additionally, they are ordered by this value – highest first – so the apps the user is mostly likely to need to spend less time on are brought to their attention immediately. Selecting apps is as simple as tapping the list entry, which is highlighted immediately to make it very clear which have

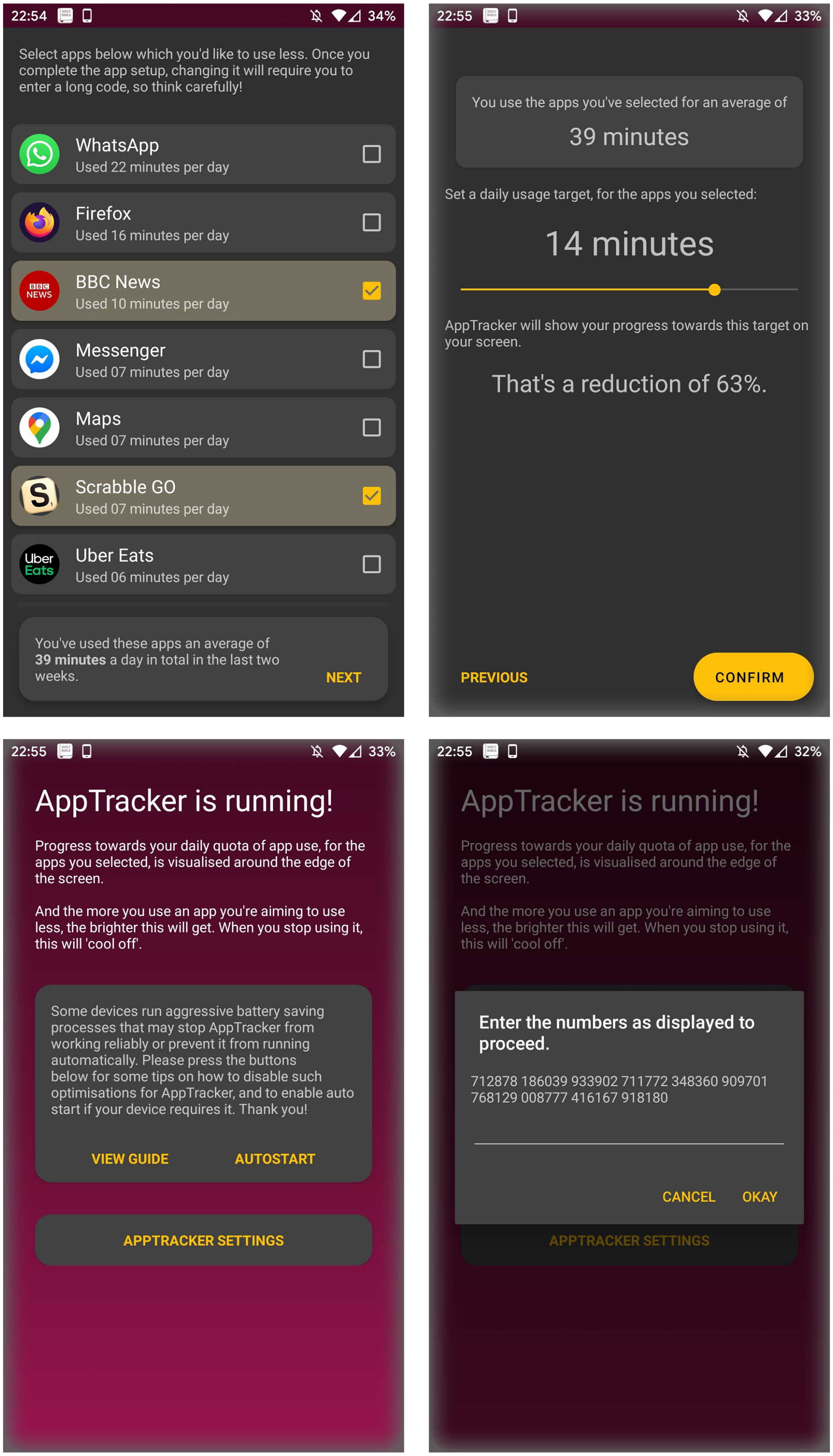

Figure 5: Clockwise from top left: app selection screen, daily usage target selection screen, lockout task, and AppTracker 'home' screen

been selected. A popup box at the bottom keeps a running tally of how long, on average, these apps are cumulatively used per day, to encourage the user to select more apps.

The next screen is for selecting a daily usage target. The user is presented with the amount of time they have used selected apps for, and slider below allows them to select a target in this range. The slider ranges from 150% of this amount to 0%. 150% was chosen so that if recent usage has been unusually low, for instance if the user has been on holiday, there is some leeway to enter a slightly higher amount. A dynamic message below encourages them to set a target that is less than their current usage, displaying the percentage reduction in usage meeting their target would entail. A prominent yellow button completes the setup process. I chose to keep these three setup windows all dedicated to single functions to make the user's task at each point in the setup process as obvious as possible and avoid overloading them with too many choices to make.

The main screen of AppTracker contains a large message informing the user that AppTracker is running. Short expository text about how the app functions is displayed. I chose to keep this somewhat unspecific in order to add an element of discovery and uncertainty, I wanted to avoid a scenario where the user was entirely aware of the mechanisms at work in altering the glow, to the extent that they were desensitised to it to some extent already. Feedback from my app trial would expose the effectiveness of this decision. Below this, in a separate Material Design 'card' style box is an explanation of the issues with battery optimisation on some devices, which I aimed to keep as concise but clear as possible to maximise the chance of users reading it. It has two obvious option buttons, leading to the Doki *dontkillmyapp* guide in a dialog window, and the AutoStart permission. I styled this box similar to Android notifications to indicate this was an item for the user's attention, as it was important that they read and followed the instructions within.

Below this, a large button leads to the app setup screens detailed above, however the user must first complete a 'lockout' task. A dialog window encourages the user to stick to their current target, and I switched the proceed and cancel buttons around to make returning to the home screen the more prominent and natural option. If the user does proceed, a further dialog window presents them with a 60-digit string, in the form of 10 6-digit blocks to make the task somewhat more manageable, which must be entered to proceed to the setup windows.

Though the app contains only four different screens, a colour theme of yellow and claret was adopted for visual consistency. Automatic light and dark modes were also implemented.

5.8 Performance and stability

As my app would be running on trial participants' devices '24/7', it was incredibly important that the app be stable, and efficient in terms of battery usage and phone performance. Stability was crucial because even if the TrackingService only crashed every hour, this would quickly become frustrating for users and clearly go against the aims of the app to be subtle and subliminal. As explained already, there was no guarantee that a crashed app would successfully restart, and it would dramatically reduce the effectiveness of the edge glow effect if it disappeared so often and needed to be restarted manually. Efficiency of performance, ie. not slowing down the rest of the device, was crucial for maintaining a good user experience and not causing frustration with the app which would risk it being disabled by the user. That the app did not have a noticeable impact on battery life was key for similar reasons.

To achieve stability, I tested the app on an emulated Android device, and four different physical devices. On three of these devices I had the app running for long periods of time — hours and days — so that even incredibly rare bugs would eventually crop up. In the later stages of app development, pinning down these rare but lingering bugs which were causing TrackingService to stop running became a priority. At this point I turned to Firebase's 'Crashlytics' error reporting library (Appendix B, 6.), allowing me to see all exceptions which occurred within an online console, rather than having to plug the device into a computer and search through Logcat logs. This greatly helped me in eliminating a number of bugs late on which might have eluded me otherwise because they so rarely occurred.

To maintain high efficiency, I designed the architecture of TrackingService carefully to ensure only the minimum amount of processing was carried out. Requests for usage data were consolidated into single calls to a dedicated function. I was careful to make sure the *glow* layout was inflated only once in the lifecycle of a TrackingService instance, meaning the PNG images were loaded only once. Rather than run the *run* method every 100ms, which would have given the best responsiveness to app switching, I sacrificed a very small amount of responsiveness, which I judged to not be noticeable, for the sake of only refreshing the edge glow every 2.5 seconds. The successes of my efforts at achieving stability and efficiency are evident in the *Results* and *Discussion* sections.

5.9 Iterative development process

To ensure a functioning solution was both viable and produced in time, I followed a highly iterative development process when implementing AppTracker.

As soon as I decided upon implementing some form of constantly on-screen usage information, I set about trying to implement a 'proof of concept' app which did this at a very basic level — initially drawing a solid, unchanging red outline around the edge of the screen on top of all other apps. The final proposal for what the edge glow should look like was finalised a couple weeks later, by which point I had already built the systems for obtaining the necessary usage data which the glow would make use of. Following this process ensured I made good use of the limited development time available to me, and had enough time to run a trial of the app, and then analyse and write-up the results of this trial. It also meant I was assured when I settled upon the final design proposal that what I was attempting was largely possible, even if some of the intricacies were yet to be discovered. In hindsight, discovering the full extent of the service killing problems earlier was a slight oversight, but also not something I could necessarily have predicted given that it is not an issue in 'stock' Android.

6 Trial and results

To evaluate the effectiveness of the smartphone usage feedback mechanism, implemented as AppTracker, a two-week trial of the app was run.

6.1 Recruitment and procedure

Participants were recruited through social media posts and an HCI mailing list, inviting them to sign up to an initial expression of interest form. Respondents to this were then sent a registration form which gave a fuller explanation of the trial and obtained consent for their anonymised usage data to be collected and processed. 18 people registered on this second form, of whom (presumably) all installed and opened the app after being emailed a link to the APK file. Given the issues with the app being 'killed' by the Android system, participants were carefully instructed to follow the in-app instructions to switch off battery optimisations for AppTracker and asked to re-open it whenever they noticed it had closed.

Of the usage reports received, 14 were suitable for evaluating AppTracker. Of the rest

- one tracked only one app which was not used at all for the last six days of the intervention period, resulting in highly anomalous data,
- one was the result of a participant who had to leave the study because of a problem with their phone (unrelated to the trial),
- one set a target of 0 minutes, and tracked only one app which was used for less than a minute each day,
- and one did not select any apps to track.

As Android keeps a log of usage stats for a device, I decided I did not need a pre-trial data collection period to give a baseline average to compare against – I could simply extract this log on the first day of the trial. However, my initial belief that logs were kept on the device indefinitely proved to be false – the length of time varies, with some devices storing more than others. The average 'usage history' was 8.9 days. Non-uniformity in this is unfortunate, but I do not believe it affects my results hugely. The average number of days with AppTracker installed for which usage data was obtained was 13.7 days. As the trial was intended to be two weeks, I believe this was mainly due to users installing the app two or three days after receiving the initial email.

One resulting point of concern was that, with the trial beginning on a Monday, pre-trial data lasting roughly 9 days might contain a higher concentration of weekend days than the post-install data, lasting roughly 14 days, and any significant difference in usage habits on weekends would therefore impact the reliability of the results. However, analysis of the data shows that the average time spent on tracked apps on Saturdays and Sundays was 95.7, and on weekdays it was 97.4 – a difference of only 1.8%.

6.2 Questionnaire design

A questionnaire was also sent to all participants at the culmination of the trial, in order to gauge participants' experience and perceptions of using AppTracker for two weeks. Eight questions were devised.

1. *To what extent do you think using AppTracker helped you to reduce, or better manage, your phone use?* (4-option multiple choice: *to a great extent*, *to a decent extent*, *to a little extent*, *not at all*). Though a more meaningful indication of this would be given by the app usage data, it would also be interesting to see users' perception of how their app use changed as a result of using AppTracker.
2. *Use this space to explain your answer further* (free text-entry). To also capture any nuances in user perception of changes in their usage, an optional free text-entry field was also provided.
3. *How would you rate your experience using AppTracker?* (5-option Likert Scale, from *Very negative* to *Very positive*). This question aimed to pull out feelings and emotions the user had about AppTracker

– for instance frustration or satisfaction. Care was taken to place this question *after* the first so that respondents would be less inclined to talk strictly about how their app usage changed, and because directing participants towards specific emotions such as frustration as an example could form a leading question.

4. *Use this space to explain your answer further* (free text-entry). For the same reasons as 2.
5. *In your own words, please describe AppTracker's on-screen visual effects, and how they changed and responded to your phone usage* (free text-entry). A point of interest was how easily understandable the on-screen effects would be – whether the user would gain an understanding of what they meant. This 'in your own words' question was used to give insight into this.
6. *Assuming it ran flawlessly (without crashing or needing to be re-opened in order to restart it), if you wanted to manage your smartphone usage, would you continue to use AppTracker?* (Yes/No). A carefully worded question based on the suppositions that the app ran perfectly, and the user desired to manage their smartphone usage better.
7. *If you answered no, please briefly explain why and say what -- if anything -- you would want to change in order to answer yes instead?* (free text entry).
8. *Use this space for any other thoughts or comments about AppTracker you would like to share.*

6.3 Results

Using the data received from participants' devices, it was shown that average daily usage of apps each user chose to use *less* reduced by 25.1% on average for the period after installing AppTracker. A paired t-test of the results shows a P value of 0.0284; a statistically significant result which means the null hypothesis that *AppTracker* use has no impact on usage of user-selected problematic apps can be rejected. Additionally, average daily usage of all apps on the smartphone reduced by 9.5% – a paired t-test of this result shows a P of 0.0533 so this is not statistically significant, but AppTracker was not concerned with reducing this value so this is less relevant.

Additionally, average daily usage of apps the user *did not* choose to use less reduced by only 1.7%.

The average usage target set by users was a 49.5% reduction.

6.3.1 Results of post-trial questionnaire

The questionnaire received twelve responses which are outlined, by question, below.

1. *To what extent do you think using AppTracker helped you to reduce, or better manage, your phone use?* (4-option multiple choice: *to a great extent*, *to a decent extent*, *to a little extent*, *not at all*).

   3 respondents chose *to a great extent*, 7 chose *to a decent extent*, 1 chose *to a little extent* and 1 chose *not at all*. This largely supports the statistical findings of the test; that on average participants reduced their usage by 25.1%, which does seem 'a decent extent'. It is only positive that all but one of the respondents felt their usage had decreased, and that a quarter felt this was to 'a great extent'. The relation of user perception of usage to actual usage, and the effectiveness of interventions, did not appear in my review of the literature and is an interesting question.
2. *Use this space to explain your answer further* (free text-entry). Most answers here referred to increased awareness and consciousness of phone usage. A couple talked more explicitly about compulsion or discouragement from using apps as a result of the effect; generally answers focused on increased awareness. Only two made reference to desensitisation.
3. *How would you rate your experience using AppTracker?* (5-option Likert Scale, from *Very negative* to *Very positive*). 3 respondents chose the neutral option, 6 chose the medium positive option, and 3 chose 'very positive.'

4. *Use this space to explain your answer further* (free text-entry). Answers were largely positive, reflecting on the increased awareness of phone use (*"increased awareness brilliantly"*) and the resulting decrease in usage of specified apps. In general there was little negative impact on phone use reported with the app described as working *"very well"* and being *"very straightforward"*, though one user reflected that the experience of using a tracked app was degraded significantly even if usage was far below the daily target. The lockout task was described by a couple of respondents as being a frustration. One accepted that it was working effectively, but also stated that adjusting what was an ambitious target would have been appreciated.

5. *In your own words, please describe AppTracker's on-screen visual effects, and how they changed and responded to your phone usage* (free text-entry). Answers here were mostly accurate in their assessment. However, it was unclear how much some users grasped the nuance of the fifteen-minute intensive use period affecting the colour, rather than the overall daily quota usage. Some may simply have not articulated this clearly in their responses but others may not have realised this. Either way, there were a number of answers which left it ambiguous.

6. *Assuming it ran flawlessly (without crashing or needing to be re-opened in order to restart it), if you wanted to manage your smartphone usage, would you continue to use AppTracker?* (Yes/No). 10 out of 12 responded yes.

7. *If you answered no, please briefly explain why and say what – if anything – you would want to change in order to answer yes instead?* One user specified that they do not need AppTracker as they already have Android wellbeing features. Another wondered if the warning border could be limited to tracked apps only, and also suggested the ease of use could be further improved, though did not specify how.

8. *Use this space for any other thoughts or comments about AppTracker you would like to share.* Some positive comments were left – with one participant stating *"[I] enjoyed the concept of this and the subtle hints, prefer this as opposed to notifications or a blanket banning of opening the app."* However, there were a number of suggestions:

   - The purpose of the usage target set up when the app is first opened was unclear for one user, who requested it be made clear that this was for all app use, rather than an individual target for each tracked app.
   - One user suggested that the app work like this, setting individual targets for tracked apps rather than a single, global target.
   - One respondent reported feeling they hadn't used the app effectively to begin with: *"I hadn't decided what I was going to do with the time I saved not going on social media!"* They suggested adding a 'how to make the most of the app' section with tips for better use of time.
   - Two respondents suggested that being able to see how much they had used apps on their phone, even if the target hadn't been met but the usage had still decreased.
   - The possibility of outright restricting app use once the target was reached was also brought up.

7 Discussion

7.1 Results of trial

The statistically significant average reduction of use of user-selected apps of 25.1% is promising for my app, and the wider technique of real-time usage feedback – putting usage statistics into constant, subtle view of the user. It is a reasonable reduction, considering the issues my app faced with running continuously, as described in the implementation section and evidenced in questionnaire results. It is comparable to the results of MyTime [52], which achieved a 21% reduction in the use of apps users considered a waste of time, and used a number of coercive and arguably more intrusive methods. The fact that my app achieved similar reductions purely through visualising device usage seems an achievement, though there are still limitations to be discussed (section 7.3).

The fact that the reduction of non-selected apps over the same period was only 1.7% is also encouraging and worth highlighting, as it shows that the intervention successfully targeted those apps which the user wanted to use less, which was the aim of the intervention. It cannot be proved, but it would seem likely that the 'meaningful' uses discussed in the literature review and analysis were therefore preserved to a great extent. To attain this without explicit restrictions being in place on the phone seems an achievement. This result also suggests that external factors, such as holidays (the trial occupied the two middle weeks of August), weekends and varying workloads had little to do with the reduction, as usage of other apps remained stable – though admittedly, the usage of meaningful and meaningless apps may naturally change differently in such scenarios so this cannot be stated with certainty.

One less positive finding, however, is that the average target set by users — a 49.5% — is far higher than the average reduction — 25.1%. This suggests that although the use decreased, the edge glow was not especially effective at communicating a target. It could be that the dual-purpose nature of it actually obscured the two distinct dimensions, and users focused more on the intensity of the edge glow than the amount of the screen it surrounded. However, I do not view this result as overwhelmingly negative, because reducing app usage by a half is an ambitious goal, and some way above what works such as MyTime [52] were able to achieve. It is possible that pushing users to set more ambitious goals, by the nature of having a slider going all the way to a 0% target, was a factor in achieving the 25.1% reduction.

7.2 Responses to questionnaires

The results continue to largely encourage when coupled with the questionnaire responses.

The majority of respondents said that AppTracker gave them an increased awareness of their phone usage, and linked this to better managing their use. There is some sense in the answers of subconscious compulsion to use apps less because of the edge glow (*"When the screen flare came up in a colour, very often .... I would feel compelled to stop using the app"*), and a more conscious compulsion (*"When I was using that app excessively it was annoying enough to drive me to stop"*). Additionally, there was a level of nuance to this — the former caveated that the compulsion came *"when not using an app in an essential way"* and the latter added *"it was bearable for a while"*. Another stated they were *"much more aware of my app usage, especially later at night."* This is positive, as the intention was to cut into non-essential, long usage sessions, rather than every single time a problematic app is opened.

Most responses that talked about increased awareness said it was awareness *of particular apps*, which also suggests the app was successful in communicating this nuance to the users.

However, the mentions of desensitisation to the edge glow, in two of the responses, are some cause for caution. The responses suggest that non-use was mainly driven by increased awareness of smartphone usage. My review of the literature suggested that awareness alone is not strong enough to be a long-term remedy to smartphone overuse, so the desensitisation is not surprising. However, there are some reasons why AppTracker might be more resilient to it. Firstly, although a compulsion to use apps less as a result of the edge glow was only mentioned by a couple of participants, as this is intended to be a *subconscious* effect, it is quite possible that more users experienced it, but not prominently enough to mention it in the questionnaire. Secondly, one of the main arguments behind my proposal was that constantly on-screen representations of device use may be a much stronger, lasting form of awareness. Desensitisation is discussed further in section 7.3.

It is somewhat intriguing that the fact that users very rarely achieved their targets did not come up in the responses here. This lends credence to the suggestion that overall targets of use were perhaps overlooked in favour of the moment-to-moment intensity of the edge glow; a user could easily exceed their daily target without ever seeing the bright red effect, if they kept their sessions within tracked apps a bit shorter.

Additionally, participants' experiences of using AppTracker for two weeks are largely positive. A main factor in this was the belief that the app was effective in reducing their usage. This is likely to be the reasons very few qualms with the edge glow effect within tracked apps were mentioned. One user went as far as to use the word 'invasive' when describing it, a term relatively employed in a positive sense. As mentioned in the Previous Work and Analysis sections, if a user has *bought into* a goal — eg. using an app less — negative experiences which are clearly intended to achieve that goal are likely to be viewed positively. The fact that the experience was only degraded, and not outright restricted, is also likely to be a factor.

Still, one respondent out of twelve stated dissatisfaction here, stating that *'if you are intentionally spending time on the apps you have selected below your target amount, the quality of experience on those apps is significantly decreased.'* The use of the word 'intentional' here is interesting, as this language was used by works that proposed the idea of 'meaningful' and 'meaningless' use. Though this is just one response, it does indicate that my attempts to target only 'meaningless' uses were not completely effective. This is not surprising because, as [3] said, typically 'meaningless' apps can be utilised in more meaningful ways in certain instances, for example when intentionally trying to wind-down at the end of a day. Given that the target could be viewed as an 'allowance' of fair use by some users, it is not unreasonable that those users would be more frustrating by their experience within that allowance being degraded. Further work is needed here to distinguish and target truly meaningless uses only.

Following on from this, the permanent white glow around the edge of the screen was mentioned by a couple of respondents as being annoying, who suggested that this be removed altogether. It is possible that, along similar lines, some users did not like their experience of apps they had not said they wanted to use less being affected whatsoever, and that this visual effect was more prominent than intended. Equally, a majority of respondents did not mention this.

The lockout task seems to have been very effective at preventing people from changing their target and tracked apps impulsively — there was only one instance of a user changing their daily quota of app use. It was mentioned by a small minority of users in the questionnaire. One stated that it was effective, but that they might have liked to have altered their target for 'reasonable reasons' — either to reduce their usage even less, or raise what had been an 'ambitious' target, so that they weren't constantly missing it. Therefore the lockout task did not fully meet its intended purpose of being a restriction that was flexible enough to allow for more genuine reasons to adjust the settings.

Another recurring theme was the desire to be able to view usage statistics through AppTracker. Separate to the questionnaire, one participant expressed disappointment that they could not view the usage stats shown in the app selection screen again, as they wanted to see if their attempts to reduce their usage were succesful. It is possible that the lack of this feature was a reason that achieving the daily target was such a rare occurrence, as users could not easily reflect on their usage statistics and see where it was in relation to that over time.

It is positive that nowhere in the survey were negative effects on device performance or battery life mentioned. Therefore it seems likely that I was successful with my efforts to develop an app which avoided such consequences (as described in section 5.8), which is not unimpressive considering it displayed a constant, continuously changing screen overlay.

A recurring theme in responses was, as expected, the issue of the app being killed by the system and needing to be restarted. No respondents went as far as to claim that they regarded the usefulness of AppTracker as completely undermined by these technical problems — so I am pleased that my efforts to both alleviate and make participants aware of the issue were somewhat successful. Equally, the problem was certainly present for most users, which will have affected my results. This is discussed more in section 7.3.

One further issue mentioned by two respondents was that AppTracker needed to be disabled in order for banking apps to work. Again, this is a technical limitation which needs to be overcome.

7.3 Limitations

The results of the trial are promising, but there are a number of reasons to be cautious when considering them.

Firstly, the trial length of two weeks is average for studies of this type, but still short. Factors such as desensitisation to the edge glow effect, which are already mentioned in some questionnaire responses, will only become more of an issue the longer AppTracker is used. As AppTracker is based entirely on a visual effect, and much emphasis was placed on the way it disturbs the normally stable context of a smartphone, it is quite likely that a desensitisation would be observed to some extent with more time. Though there are reasons to be optimistic, as discussed already, the robustness of AppTracker to this effect is simply unknown, and a much longer trial is needed to judge this.

Additionally, much was made of the probable weaknesses of awareness-based solutions as a long-term solution to problematic smartphone usage, but it can undeniably have a powerful effect in the short-term, and as App Tracker presents all users with a summary of their smartphone usage as soon as they use it, it is quite possible it benefitted from this factor. One participant, who was unable to use the app for technical reasons, confided *"when I first set it up it told me that using my top apps 50 percent less would reduce my screen time to 2 and a half hours a day. . . and that has shocked me into using it less."* The existence of this shock factor obscures the exact effectiveness of the edge glow as a technique for reducing usage.

One large drawback of my trial was the much-discussed issues with some phones killing AppTracker frequently, which could have affected results in a few different ways. Firstly, awareness of device usage may also have been artificially increased by the user noticing the app had stopped working and having to open it again. This would naturally draw their attention back to their device usage. This would have been compounded by the fact that I asked participants to look out for the app not running and to restart it if necessary. I think this was necessary, both to increase the amount of time the app was running on devices for, and to explain that this was not intended behaviour of the app, as this would likely have confused participants further. Nevertheless, in an ideal trial the app would have run continuously without any user intervention to reduce as much uncertainty as possible over the causes of any resultant changes in behaviour.

Furthermore, the fact that the app was prone to being killed by devices means that it is quite likely there was significant portions of time when it was not running. As it was designed to be a subtle, it is also very possible that users would not have noticed immediately that it had stopped. This will clearly have undercut the effectiveness of the app and may be one reason why daily usage targets were rarely achieved.

Though the sample size of 14 is a reasonable size, given the scope and constraints of the project, it also relied on participants responding to calls to take part in a study about problematic smartphone usage. Self-selection bias could be an issue; the likeliness of someone who does use their smartphone to a problematic extent participating versus someone who does not is another concern.

Additionally, participating in a study about problematic smartphone usage will, in itself, make people more aware and conscious of their smartphone usage and so alter the effectiveness of the app. Even more, participants may have felt a subconscious desire to 'perform well' for the trial, or even assist the researcher by providing good results, as a number of participants are personal acquaintances. Again, this will impact the results.

Though the reasonable sample size, and relative stability in non-tracked app usage before and after the installation of AppTracker give some reassurance, it is also very possible that individual changes in situations could have affected the results. For example, a participant going on holiday for a week during the two-week trial might have reduced their phone usage significantly.

7.4 Future Work

7.4.1 Possible improvements to AppTracker

Based on my trial, there are a number of ways that AppTracker's effectiveness as a smartphone usage management tool could be improved.

- **Stability:** firstly, AppTracker still has some problems maintaining a constantly running service, which has clear implications for its effectiveness. Perhaps the most obvious improvement to be made is to fix this, though from my experience and the experience of other developers [57] it is not immediately obvious whether this can be achieved for all users.
- **Refine the lockout task:** while it was seemingly highly effective in preventing users from simply disabling the on-screen effect for apps they wanted to use unhindered, it could in some cases punish users for setting a target which is too optimistic, leading to feelings of frustration or failure, or prevent them from trying to set a more ambitious target or limit their usage of a greater number of apps, by being so strong a deterrent that even these activities were unachievable. These are all things to be avoided, and setting a more ambitious target should be encouraged, if anything. One way to fix this might be to reduce the length of the lockout task. Alternatively, the lockout task could be applied only if users attempted to give themselves *more* time or to *remove* apps from the tracked list, in order to allow better goal-setting. Additionally, if a target is consistently missed, the app might suggest lifting the target a little, to avoid the user becoming frustrated or despondent. In this case the lockout task would be bypassed.
- **Consider simplifying or refining the edge glow:** The fact that users rarely met their daily usage targets is hard to overlook. As stated, it is possibly that the subtleties of the 'dual-purpose' edge glow were in fact too subtle. It may be worth considering a clear exposition of how the effect works, perhaps through guided video tour or simulation of the effect. Alternatively, the edge glow might be simplified. The suggestion from some questionnaire respondents that the target should be set on a per-app basis could be integrated here. Showing progress towards a different quantity for each app would mean the vertical size of the edge glow would vary much more, making the meaning of this visualisation clearer. Additionally, the two quantities could be switched, with intensity representing overall usage within a day, and height representing recent usage — the latter employing the metaphor of keeping a cup from overflowing. There is much room to experiment here.
- **Take users on a journey:** following on from this, a more adaptive app might track how well users are meeting their goals, and suggest increasing or decreasing their target accordingly, or tracking apps that are used a lot — perhaps drawing on a list of commonly tracked apps. This could help to increase the modest 'gains' made by AppTracker, and similar apps from other works — a 25% reduction is not insignificant, but not enormous, especially if the user is still using their phone a lot by 'normal' standards. Presenting updates such as goal suggestions could also help maintain long-term compliance and perhaps fight desensitisation.
- **Show users their progress:** along similar lines, a few participants expressed interest in being able to view their usage statistics while using the app to see how well they are managing their usage. In the case of someone who has set an ambitious goal, seeing that their usage has dropped, even if it is not yet at the goal, would show them they are making progress and motivate them to keep going. *Progress tracking* of this sort is a common feature of goal-centred apps and should be implemented into AppTracker.
- **Promote better habits:** though outside the initial remit of AppTracker, one participant's suggestion that the app give suggestions of ways of spending time 'saved' by smartphone non-use is very worthy of consideration. Fostering new habits is a good way to kick old ones, so this could increase the effectiveness of AppTracker. Presenting users with a clear alternative to using particular apps could also make putting the smartphone down easier, by answering the 'what else could I do?' question for them. Works such as MyTime [52] and Forest [44] have found success by focusing on goals. Equally,

as described in section 2.4.1, it is the author's belief that true 'downtime', allowing for reflection, problem-solving, creativity and imagination, is also important to promote.

- **Consider cultural meaning:** I did not give much thought to the ways the colours I used for the edge glow, and the metaphors I employed for it, might be perceived differently in other cultures. Orange and red and generally 'danger' colours in Western contexts, but in China, for example, red symbolises "good fortune and joy" [58] so making the screen more red may have an inverse effect to what is desired. The metaphors I attempted to use — heating up and filling up — may also have different connotations globally, for example gradual emptying of an originally filled quantity might be more powerful to some users. I do not think this is a serious drawback for AppTracker, but it would be worth exploring were it to be developed further and targeted at a wider audience.

7.4.2 Directions for future research

My work has also raised a number of areas for future work and research. AppTracker would benefit from most of these, but they are more general questions relevant to the whole field of problematic smartphone usage, so are presented separately.

- **Targeting the checking habit:** the checking habit described in section 2.3 is one of the most dangerous aspects of habitual smartphone usage. Satisfying the urge to reach for a smartphone while engrossed in another task can be disruptive, causing current goals to drop out of working memory [33], making returning to them more difficult. Although my app is potentially effective at limiting use of problematic apps once a smartphone is being used, it is generally designed to limit it to minutes, rather than seconds. It does nothing to prevent the checking attempt in the first place, and even a small switch of context from a task, to a smartphone, and back, will have a negative effect. One way to address this might be to show the usage feedback on the lock-screen, if that were possible, show the user is conscious of it before unlocking their phone. The checking habit itself does not receive a huge amount of attention in the rest of the literature in this field, but it is potentially one of the most dangerous parts of habitual smartphone use. Moving away from just thinking about screen-time totals, to considering the frequency of usage sessions, is a direction not just for my app, but for this field of research.
- **Better identification of mindless use:** One of the key aims of AppTracker was to limit 'meaningless' smartphone usage in particular and preserve more meaningful use. This was attempted by targeting not just specific apps, but also longer usage sessions of such apps, with a scaled approach that increased the strength of the intervention with time. The positive attitudes towards the app in the trial suggest this was somewhat successful, but there remained a small level of frustration that even with this, some 'fair' uses were being detrimentally affected. There remains some work to be done on detecting exactly which uses are meaningless and can therefore be fairly disrupted. Context is one factor — using YouTube in the evening after the day's tasks have been completed in order to relax, for example, is more likely to be meaningful than watching it during the working day. An app addressing this might use information such as a person's calendar, or the state of their daily to-do list, to make meaning judgements. Further to this, at face value, viewing an educational video generally seems more likely to be meaningful than a compilation of cat videos — but if a person is recovering from a traumatic event, the latter example might ultimately be most meaningful of all. Perhaps unsurprisingly, gauging which activities hold true meaning is a task with no end of complexities.
- **Exploring visual feedback:** There are a number of ways which the edge glow technique developed in my project, and the 'logic' transforming it, might be altered in order to meet the above goals, in addition to those mentioned under *consider simplifying or refining edge glow.* Firstly, the intensity of the edge glow, and overall progress towards the usage target, is scaled linearly to the amount of time an apps have been used for. However, this does not need to be the case, and a more refined view of phone usage might treat it differently. If the act of checking is indeed considered especially harmful, opening an app might add a 'penalty' to the user's usage score, in order to discourage away from frequent checking and towards more spaced out, intentional usage. Secondly, the current system

does not really reward users for non-use, other than by not increasing their usage stats, as is expected. To further incentivise intentional usage of smartphones, the daily target might initially be set at an intermediate value, with the user able to 'gain' more time through lengthy periods of complete non-use, with greater reward being given when the phone is silenced or switched off. Like LocknType [54] and GoalKeeper [51], this could encourage mindfulness of the consequences of use, and cost-benefit analysis of smartphone interactions, but without employing the restrictive mechanisms those works did.

8 Conclusion

In the course of this project I have produced a functioning Android application designed to tackle smartphone overuse, drawing on a number of theories of smartphone overuse and its potential solutions, gained from a thorough reading of the relevant scientific literature. The application was designed to target potentially meaningless smartphone usage by building continual, subconscious awareness of usage of user-selected apps and intense usage sessions through on-screen effects employing different metaphors. Additionally, I successfully carried out a two-week trial of the app, completed by fourteen participants, which found it reduced usage of user-specified apps by a statistically-significant average of 25.1%, while having a negligible impact on average usage of other apps, although users' daily usage goals were rarely achieved. A clear majority of participants regarded the app positively. While there are a number of clear limitations to my study, such as the sample size, the length of the trial, and issues with the reliability of the app, the results show some promise for this technique, and there is ample room for further work building upon it.

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A Project repository

All code for this project can be found at https://git-teaching.cs.bham.ac.uk/mod-msc-proj-2019/jdm638

The contents of the repository are the contents of an Android Studio project, which can be compiled and run successfully on Android devices running Android 8.0 or higher, using Android Studio or similar software.

B Supporting libraries and code

In developing AppTracker, I made use of a number of libraries.

1. **FadingEdgeLayout:** used as described in section 5.2.1 to achieve the fade effect at the top of the edge glow. https://github.com/bosphere/Android-FadingEdgeLayout
2. **Foreground App Checker:** used by the TrackingService class to get the package name of the current foreground application, as described in section 5.1. https://github.com/ricvalerio/foregroundappchecker
3. **Doki:** used to present information from dontkillmyapp.com, as described in section 5.4. https://github.com/doubledotlabs/doki
4. **AutoStarter / AutoStartPermissionHelper:** used to bring up the autostart permission manager, as described in section 5.5. https://github.com/judemanutd/AutoStarter
5. **OverlayHelper:** used to bring up the 'draw over other apps' permission, as described in section 5.5. https://github.com/adriangl/OverlayHelper
6. **Firebase:** used for retrieving usage statistics using the 'Storage' module, and tracking exceptions using the 'Crashlytics' module. https://firebase.google.com/

I also consulted a number of sources when developing different parts of the app, listed below. In most cases it is a few lines of code, but cases where it is more substantial are indicated both here and in the source code.

7. The technique for creating a permanent onscreen overlay. Actual code left in my project amounts to a few lines, but this was key in starting my project so it is referenced here. https://gist.github.com/MaTriXy/9f291bccd8123a5ae8e6cb9e21f627ff
8. The technique for determining the full dimensions of the screen, including status and navigation bars, if present. https://stackoverflow.com/a/16416682/3032936
9. The method for neatly revealing or hiding an object onscreen. https://developer.android.com/training/animation/reveal-or-hide-view
10. The method for determining usage statistics for intervals less than a day. A fairly substantial piece of code amounting to the *queryUsageStatistics* method in TrackingService. Though it is adapted to fit my exact needs, the underlying technique is not my own. https://developer.android.com/training/animation/reveal-or-hide-view and https://stackoverflow.com/a/50647945/3032936
11. I drew heavily on a suggested technique for mapping to a range of colours using the HSV colour space. https://stackoverflow.com/a/44326986/3032936
12. Firebase's online quick setup guides. https://firebase.google.com/docs/android/setup
13. Various cues for how to handle checkbox states in an Android RecyclerView. https://blog.oziomaogbe.com/2017/10/18/android-handling-checkbox-state-in-recycler-views.html
14. The code for requesting UsageStats permission. https://blog.usejournal.com/building-an-app-usage-tracker-in-android-fe79e959ab26
15. Guidance and technique for using startActivityForResult, as used in MainActivity class. https://www.tutorialspoint.com/how-to-manage-startactivityforresult-on-android
16. Guidance and technique for gathering a list of installed applications. https://inducesmile.com/android/android-list-installed-apps-in-device-programmatically/
17. Technique for creating a receiver for power connection events. https://stackoverflow.com/a/20392715/3032936

18. Technique for creating a broadcast receiver for device boot events.
    https://stackoverflow.com/a/16954799/3032936
    https://stackoverflow.com/a/6440759/3032936