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MASTER'S THESIS

Increasing Smartphone Screen Time Awareness using an Ambient Information System

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Author:
Roman PETERS
HCI-4017242

Supervisor:
dr. dr. Egon L. VAN DEN BROEK

Second Examiner:
dr. Christof VAN NIMWEGEN

Human Computer Interaction
Department of Information and Computing Sciences

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UTRECHT UNIVERSITY

Abstract

Faculty of Science
Department of Information and Computing Sciences

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by Roman PETERS

The use of smartphones has become ubiquitous in modern life, but the amount of time spent using them can be a source of conflict for many users. Digital-Self Control Tools (DSCT) are apps that aim to assist users in tracking and controlling their device usage, but they can be limited in their effectiveness and can sometimes cause irritation. In this paper, we propose the use of an Ambient Information System (AIS) as a novel approach to increasing awareness of screen time. For this, we combine different aspects of HCI research to design and develop the hardware and software for our AIS, based on a single-board computer, server and smartphone app. We discuss related work on DSCT and AIS', provide our own contextual research study ($N = 95$) and provide a user study that was conducted to evaluate the objective and subjective effectiveness of our implementation ($N = 16$). We observed a significant increase in screen time awareness among participants who used our system compared to those who did not ($F_{(1,14)} = 10.84$, $p = .0058$, $\eta_p^2 = .4548$). Furthermore, although not a significant effect, we also observed a positive trend between using our system and lower SAS-SV scores, indicating an improvement in digital well-being.

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Chapter 1

Introduction

Since their introduction, smartphones have increased in popularity and have become ubiquitous in modern society. Placing calls has become only a small part of the complete feature set of modern phones. Connected to the Internet and with a plethora of apps available, smartphones are now an important tool for many people. Aside from being used as a utility, smartphones are increasingly being used for browsing social networking sites, entertainment, passive activities, or as a distraction from day-to-day life. Previous work shows that many people feel conflicted about the time they spend on these activities. In many cases, using a smartphone has become habitual or even subconscious behaviour, making it easy to lose track of the time spent using the device. An important step in digital well-being lies in increasing the users' awareness of their screen time.

Digital-Self Control Tools, or DSCT, are apps that aim to assist users in creating screen time awareness and in controlling their device usage. In their most common form, DSCT tracks screen time and relays that information to the user. Additional features often include the ability to apply blocking rules for certain applications, at certain times or after a specified duration. The interest in healthy technology use has increased and DSCT has been built into the operating systems of smartphones in recent years. However, there are limitations to DSCT. Users can respond negatively to being confronted with their own screen time and blocking rules can often cause irritation or they might be easily circumvented. Another limitation of traditional DSCT is that they need to be accessed on the device of which the user tries to limit the usage. This could potentially increase the number of device pickups and device usage.

Smartphone users often have difficulty estimating how much time they spent with the device. DSCT, such as the ones included in smartphone operating systems, can help people gain insight into their smartphone usage and increase digital well-being. However, not all DSCT are created equal, their effectiveness largely depends on the implementation. One of the issues of current DSCT apps is their limited effectiveness at increasing screen time awareness. By design, a smartphone app is not always running in the foreground at the centre of attention. This means that traditional app-based DSCT have two potential approaches. The first approach is to allow the DSCT app to remain in the background, serving primarily as a reference for past smartphone usage, only being accessed by the user when they remember to check the app. However, this approach may have limited success in promoting awareness of screen time usage due to the limited interaction with the app. The second option is for the DSCT app to actively confront the user with their smartphone usage by sending notifications or even blocking apps that have exceeded their usage limits. Both these approaches may result in the user abandoning the DSCT app [19].

In order to solve this problem, we aim to distance the smartphone from its role as DSCT and introduce a new dedicated system to increase awareness of screen time, in the form of an ambient information system (AIS). The characteristics of an AIS make it a prime candidate for a solution which can increase awareness of screen time whenever the user is nearby, without being intrusive or relying on the smartphone itself. We hypothesise that the user needs to be aware of their smartphone usage first, in order to combat problematic usage and improve their digital well-being.

The next chapter will focus on related literature, including studies on screen time and problematic smartphone use, digital self-control tools, and existing ambient information displays. The contextual research chapter, starting on page 11, presents our preliminary research, which was conducted using a questionnaire to gain insights into problematic smartphone use and inform the design of our proposed system. The design chapter (p. 17) presents our proposed solution, a new AIS-based DSCT, which is implemented in the implementation chapter (p. 21). In the final chapter (p. 25), we describe our test of the system to assess its effectiveness in increasing awareness of screen time. We present the results of this test and provide our discussion and conclusion.

Chapter 2

Related work

The amount of time spent on a smartphone, or screen time, is often used as a measurement of problematic smartphone use [36, 29]. Increasing awareness of screen time could lead to a better understanding of smartphone use. Developers of smartphone operating systems have recently begun aiding this process, by including screen time tracking at a system level, which illustrates the increased interest in the subject [35, 7]. In our research we propose a new approach to screen time tracking, using an AIS to make the user more aware of their screen time. In this chapter, we first explore the established research on screen time, how it is measured and which potential negative health effects it exposes. We examine existing research in the field of smartphone screen time tracking, and we take a closer look at similar research to better understand AIS and its strengths and weaknesses.

2.1 Screen time and problematic smartphone use

Screen time is defined as the time spent while watching a display. In the past it has been associated with watching television, sitting behind a computer and since the last decade, using a smartphone or tablet [33]. While there is no consensus on the recommended daily screen time for adults, the World Health Organisation recommends limiting the screen time of young children to one hour a day [25]. In reality, the actual screen time of both children and adults often exceeds that recommendation [34]. The average daily screen time increases with age towards adulthood, with young adults accumulating the most screen time. In a recent study in the UK, the screen time for young adults averaged 8.8 hours a day [16]. It should however be noted that this was during the COVID-19 pandemic, which significantly increased the average screen time due to the restrictions which made people spend more time at home.

An excessive amount of screen time has often been linked to adverse health effects. Part of the physical health effects can be attributed to the sedentary nature of most screen time activities, most notably in the form of obesity [2]. Screen time can also have a negative influence on night rest. It has been linked to a decrease in sleep quality, and duration and an increase in sleep onset [5]. The cause of these sleep problems lies in the interference from light-emitting screens on the natural circadian rhythm [23]. In addition, excessive screen time has been linked to negative mental health effects, such as anxiety and depression [10]. Screen time as a metric can be used to measure Problematic Smartphone Use (PSU), which has become an increasing issue, especially amongst young adults [28, 32]. A recent study by Sohn et al., found that out of 1043 university students, 406 (38.9%) of them reported smartphone addiction [32]. A side note on this subject is that not everyone agrees with the use of the term 'smartphone addiction' here. In a reaction to the study, Przybylski questioned the validity of the measure, since smartphone addiction is not officially recognised as a psychiatric disorder, labelling it as such would be inaccurate [27]. In the context of our research, we use the term PSU, which makes no assumptions about the addictiveness of the behaviour. A point of critique on using screen time as a measure of PSU is that it might not give us enough information in order to make an assessment. For instance when it comes to mental health: A recent study from the University of Melbourne suggests that well-being is predominantly affected by screen quality, rather than screen time [38]. Screen quality, or meaningful use of screen devices, relates to the activity for which the device is used. Messaging a loved one is often a more meaningful activity than scrolling through a social media feed and could even have a positive effect on mental well-being. Wang and Vella-Brodrick suggest that it might be more beneficial to increase screen quality, rather than only decreasing the amount of screen time [38]. Whether screen time is an effective measure depends largely on the objective of the research. For instance, when studying its effects on night rest, the time of day at which the screen time occurs plays a major role. For our study, the notion that there are possible negative effects linked to excessive screen time use is enough to warrant the research. Our aim is to increase awareness of screen time, without focusing on specific possible negative effects of PSU.

2.1.1 Digital self-control tools

FIGURE 2.1: Example of an iPhone battery use screenshot from an Apple iPhone 6 with iOS 11 [9].

In this section, we examine research on traditional DSCT, which aims to solve similar goals to ours, albeit using a different method. An important aspect to note from the existing literature on smartphone use is that self-reporting without objective measurements is a very unreliable method [1]. Especially since self-reporting inherently assesses conscious efforts, it is not suitable for measuring automated behaviour. Fortunately, there are other methods available.

After the introduction of the battery health information screen on iOS, Gower and Moreno introduced a new method to track smartphone use [9]. Battery Use Screenshots (BUS) provide a way to accurately track device usage over time. Even more recently, additional screen time tracking functionality has been implemented into the two major smartphone operating systems. Devices running at least Android 9 or iOS 12, offer extensive insights into how the device is used [35, 7]. This system-level integration opens up new ways to gather detailed information on smartphone usage. Ryding and Kuss have done a literature review of passive smartphone tracking in the context of PSU [29]. The methods most used for passively tracking screen time are third-party applications or the built-in screen time tracking functionality. The drawback of BUS and the novel integrated smartphone usage functionality is that it relies on the participant to actively collect his data and that the data is only available after the monitoring has taken place. For our research, in addition to taking a passive tracking approach with objective measurements, the data needs to be collected continuously and processed in real-time to enable direct feedback to the user. Nearly all studies examined by Ryding and Kuss collected the device usage information afterwards, making it a different method to ours. A notable exception was by Boonstra et al., who developed their own custom screen time tracking application which did provide data directly instead of after the event [3].

In order for screen time tracking software to be used as DSCT, it will need to convey the smartphone usage to the user in a useful manner. Providing this information at an interval, for example with a daily or weekly report, can be useful to determine trends, however, providing this information during or right after it occurs is a better approach for our use case. Using near real-time updates, the user gains a better insight into their recent smartphone activities and how they affect overall screen time.

Qualitative research on the effectiveness of DSCT indicates that users generally dislike being confronted with their exact screen time [19]. There was a clear negative in response to the participants' own smartphone usage. It is important to take the user experience into account when designing DSCT since a negative response often results in the user abandoning the system [19]. In a similar vein, users often mention the desire for DSCT that actively block certain apps after they've reached their limit. However Monge Roffarello and De Russis point out that this often does not work well in practice; users either find a way to circumvent the block, or they get so annoyed by the DSCT that they disable it all together [19]. In our approach, we avoid limiting the user in any way, in order to maintain a positive user experience. Our DSCT also does not show exact statistics on the logged screen time, but instead shows a visualisation of the data which indicates the amount of screen time without a precise duration.

2.2 Ambient Information Systems

According to Pousman and Stasko, an ambient information system (AIS) is defined by the following characteristics [26]:

- The system visualises information that is important but not critical;
- It can move from the periphery to the focus of attention and back again;
- It focuses on the tangible; representations in the environment;
- It provides subtle changes to reflect updates in information, it should not be distracting;
- It is aesthetically pleasing and environmentally appropriate.

These characteristics show that AIS' are suitable for a specific set of use cases. Ambient systems are not a new phenomenon and have been used before in various settings. Before we implement our own ambient system, we first take a look at previous research, to better understand the strengths, weaknesses and limitations of such systems. We begin with work that proposed a similar method to ours but aimed at solving different problems.

A recurring use for ambient displays in previous work is social connectedness and well-being. Mynatt et al. designed the *Digital Family Portrait*: An ambient display, that provides qualitative visualisations of a family member's daily life [22]. Through various sensors, the system could track the activities of an elderly family member. Sharing this information increased a sense of connectedness and provided conversation material when they would check in with each other.

FIGURE 2.2: *Digital Family Portrait*, Mynatt et al. The icons in the frame convey information to the user.

While the *Digital Family Portrait* was designed for use in a personal setting, in many cases an ambient system is placed in a work environment. Consolvo, Roessler, and Shelton for example, evaluated *CareNet*: An ambient display for caregivers, which displayed information on food and medicine intake of elderly in assisted living [6]. Using their system, caregivers could see at a glance if there was any deviation from an elderly's daily routine. Both the *Digital Family Portrait* and the *CareNet* display are examples of ambient systems which successfully increase awareness of certain aspects in the daily lives of their users. *CareNet* also highlights the importance of not displaying too much information on an ambient display. In order for an ambient system to be successful in raising awareness without being a constant focus of attention, it needs to be readable at a glance.

FIGURE 2.3: *CareNet*, Consolvo, Roessler, and Shelton, uses a touch-screen tablet with a wooden frame.

The *Whereabouts Clock* by Sellen et al. is an ambient display that visualises the location of family members, based on their cellphone location data [31]. Sellen et al. emphasise the importance of readability at a glance. Rather than show the exact location of the family member, it displayed a coarse-grained category label, such as "work", "home" or "elsewhere". Their research has shown that the participants had meaningful interactions with the system, which improved their well-being, and similarly to the digital photo frame, such a system is suitable for a personal setting.

FIGURE 2.4: *Whereabouts Clock*, Sellen et al. A picture of the AIS in its frame and a close-up of the interface.

While the previously discussed works used an electronic display, an AIS can also take on other shapes and forms. For instance, Müller et al. evaluated *Ambient Timer*: A light strip which would increasingly illuminate its surroundings in anticipation of scheduled tasks [21]. In order for an AIS to be successful, its location placement requires careful consideration. In this case, the light source was mounted on the back of a monitor, so it could be used during office tasks as an unobtrusive reminder.

FIGURE 2.5: *Ambient Timer*, Müller et al. LED-Frame mounted on the backside of the monitor.

Voit et al. also used a light-based ambient reminder system, used here for reminder notifications to water a plant [37]. Here the system's light was embedded under the plant, to place the ambient notification in a suitable context for the user. For the AIS in our research, the location of the system is less obvious. Since we are focusing on smartphone interactions in the private environment and the AIS should be visible most of the time, especially during times that the participant's smartphone would normally be in use, a central place in the living room would probably be best suited for most participants. However, during the evaluation of our system, the participant is free to place the AIS wherever he wants.

FIGURE 2.6: *Smart Plant System*, Müller et al., a persistent display hidden in a plant pot.

While decoupling screen time tracking and the smartphone has its advantages, using an AIS as DSCT also comes with some drawbacks. For instance, since the AIS is stationary, there is no longer the assurance that the DSCT is nearby when needed. If the AIS is placed at home, the user will not be able to make use of it when he is at work, or otherwise away from home. Another possible disadvantage is privacy. Since screen time is often seen as a very personal statistic, users might not feel comfortable sharing this info with the people they live in the same house with who can also observe the AIS. Finally, a possible pitfall for AIS' is that they need to be aesthetically pleasing in order to be an acceptable addition to the user's environment.

2.2.1 Increasing awareness

Up until now, we have looked at AIS' aimed at solving different problems from our research. We will now take a closer look at research which not only uses a similar method but which has relatively similar goals as well. AIS' can be used to reflect updates in information, that are important, but not critical, over longer periods of time. This can be used to bring attention to certain behaviour or habits in a personal setting. For example, there are multiple AIS studies designed to increase awareness of sedentary behaviour. Jafarinaimi et al.'s *Breakaway* used a small animated sculpture which could change pose and gesture [12]. The sculpture would be placed on a desk and using a sensor in the desk's chair, it could detect when a user has been sitting for too long. Whenever this occurs, the sculpture would slowly change to a slouching position, reminding the user to take a break.

FIGURE 2.7: *Breakaway*, Jafarinaimi et al., shown in its upright position.

Mateevitsi et al. took a similar approach, but used a light strip inside a cylindrical shape, dubbed the *HealthBar* [18]. While the user is sitting, the *HealthBar* would slowly deplete and change colour from green to red. While standing or being away from the desk, it would recharge; reversing its changes. These two examples take place in an office environment, but similar to our research, they are aimed at increasing awareness of users' own, often subconscious, behaviour.

FIGURE 2.8: *HealthBar*, Mateevitsi et al., installed below a computer monitor.

Kim, Hong, and Magerko's research is another example of an ambient system aimed at increasing awareness of behaviour. They designed and evaluated *Coralog*, an ambient display which visualised the user's personal electricity usage throughout the day [13]. Increasing the user's awareness on this subject was used to promote a more sustainable lifestyle.

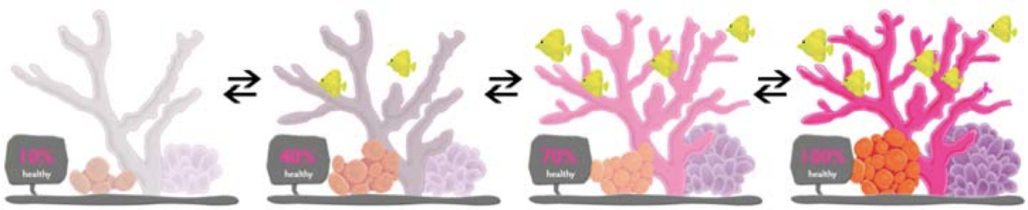


FIGURE 2.9: *Coralog*, Kim, Hong, and Magerko, Gradual change of coral reefs and fish to represent the user's electricity usage.

Breakaway, *HealthBar* and *Coralog* show that an AIS could be used to effectively increase awareness in behaviour, without interrupting other activities.

2.3 Research gap

Although not perfect for all objectives, screen time can be used as a measurement for PSU. In order to combat PSU we would like to increase smartphone use understanding, by increasing awareness of the user's screen time. Measuring smartphone screen time for this purpose has been done before, however, the amount of previous research which measured screen time in an objective manner is relatively small. The majority of previous research relied on self-reporting to gather their data [17], which is not an accurate method for tracking screen time [8, 24]. Additionally, manually tracking screen time requires action on the user's part, making it unsuitable to use for notifying the user of their behaviour.

Our study is not aimed at directly changing how participants use their smartphones, but rather to increase awareness and understanding of their personal screen time. Previous attempts at increasing awareness of screen time often made use of a dedicated smartphone app or notification prompt to do so [17]. While effective at times, this is arguably a rather backwards method of tackling the issue. Foremost, by using the smartphone itself, it increases smartphone usage while trying to accomplish the opposite. Increasing notifications and app usage is the opposite of what is trying to be achieved. An approach using an AIS could replace the smartphone in this scenario and provide non-obtrusive information while being in the background, without increasing the number of smartphone pickups. For our research, we examine if we can increase awareness of screen time using this method. Participants use a custom screen time tracker app which only runs in the background and which forwards information on their smartphone usage to the AIS. The system will visualise their screen time in a non-obtrusive manner. Based on our evaluation we determine whether this is an effective method to increase awareness of screen time.

Chapter 3

Contextual research

In order to gain more insight into PSU and participants' relation with their smartphone screen time, a web survey was sent out. The results of this survey are discussed in this chapter and are part of the preparation for designing and building the AIS-based DSCT.

3.1 Participants and procedure

A total of 95 people participated in this survey. Participants were recruited through different means. The first group of 40 participants was introduced to the survey through convenience sampling and snowballing. This group consists of friends and family and also the participants that they recruited in their turn. The remaining 55 participants were recruited over the internet and came from a variety of different countries. The participants of this second group were gathered by posting the survey on the social networking site Reddit. Users of this site are often more technically inclined and are likely to often use a smartphone in their daily life. Regularly using a smartphone was also the only requirement set for the participants.

The first part of the survey was aimed at gaining informed consent from each participant. Participation was in no way compulsory and participants were informed they could choose to not submit their answers. Participants were also informed that all their data would be handled anonymously. There was no reward offered for completing the survey. The survey was entirely based on self-reporting and there was no conductor present while completing the survey, although participants did have the opportunity to ask questions regarding the survey through text-based channels.

A total of 28 submissions were excluded from the research. Of which 7 because the participant replied negatively to the question "Do you regularly use a smartphone?" A set of 9 submissions was excluded because the participant was under 18 years of age. The remaining 12 were not included because they did not fully complete the survey.

3.2 Measurement

The survey included a section containing socio-demographic questions, a section with questions related to their own screen time and a section with questions related to PSU. The socio-demographic questions asked for the age group the participant belongs to, their gender and their level of education. the questions regarding specific information on screen time asked for an estimation of their average daily screen time, how they would rate the difficulty of estimating their screen time, and how they would describe their estimated screen time, on a scale ranging from "Very low" to "Very high". SAS-SV is a scale used for measuring smartphone dependence and PSU, consisting of 10 items rated "Strongly disagree" to "Strongly agree" [14]. For this survey, we used an adaptation of the SAS-SV which has not been formally validated. The adaptation is very similar to the SAS-SV, however, it is unclear whether its calculated score shows the same validity and internal consistency as the original scale. However, this does not affect our research, because we will be using the scale to identify which PSU issues are most common, not whether participants classify as addicted to their smartphones.

3.3 Results

The effective sample size was 67 participants ($N = 67$), of which 34 identified as female (50.8%), 31 identified as male (46.2%), 1 identified as non-binary (1.5%) and 1 preferred not to disclose their gender (1.5%). The age of the participants varied widely, although most participants were under 35 years old (77.6%).

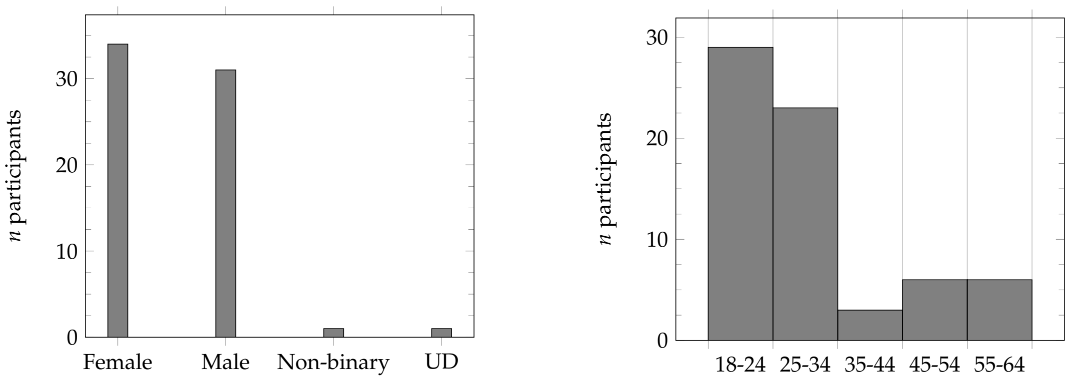


FIGURE 3.1: Participants' gender and age distribution.

The majority of the participants attended or had completed some form of higher education (77.6%). Figure 3.2 shows the distribution for the different degrees of education of participants. Other possible options were "No schooling completed", "Ph.D. or higher", "Trade school" and "Prefer not to say", but these answers were not selected by any participants in the effective sample.

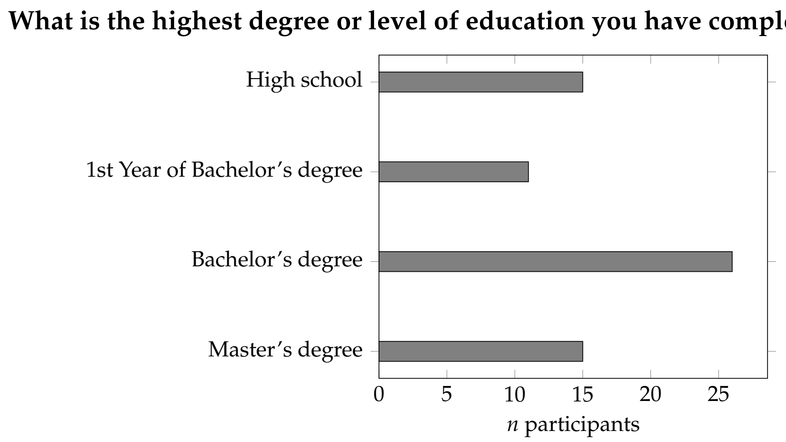


FIGURE 3.2: Education level of participants.

3.3.1 Screen time

The overall average estimated screen time is 4.7 hours a day ($SD = 2.5$). The average screen time for female participants was 5.2 hours a day, with a standard deviation of 3.1. The high spread was mainly due to two participants in this group picking the lowest and one participant picking the highest option. Male participants reported an estimated screen time of 4.2 hours on average ($SD = 1.5$).

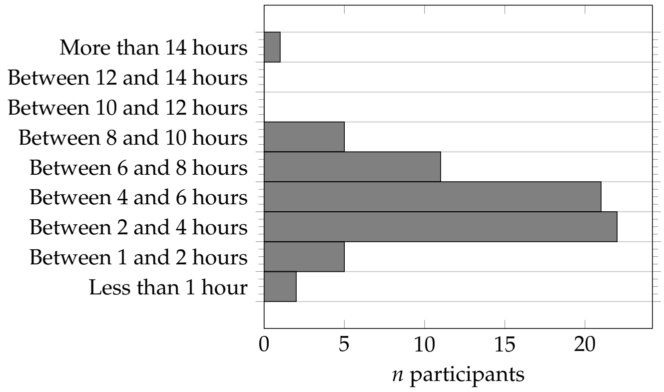


FIGURE 3.3: Estimated hours of daily screen time.

After the participants had estimated their daily screen time amount, they were asked to rate the difficulty of estimating their screen time. The majority of participants found it "Somewhat easy" to estimate their screen time (44.7%). On a scale of 1 to 5, ranging from "Extremely easy" to "Extremely difficult" participants averaged 2.6 ($SD = 1.0$), slightly more easy than difficult.

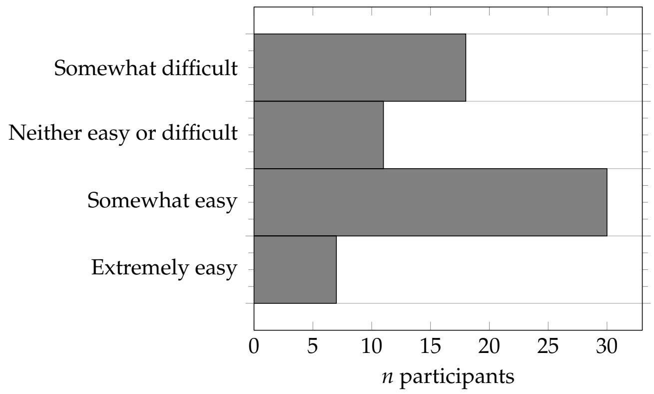


FIGURE 3.4: Difficulty of estimating screen time.

The participants were then asked to describe their screen time amount using one of these labels: "Very low", "Somewhat low", "Neither low nor high", "Somewhat high", "Very high". On average participants' rating of their estimated screen time is most closely related to the label "Somewhat high"; on a scale of 1 to 5, where 1 is "Very low" and 5 is "Very high", the average was 3.8 ($SD = 0.9$).

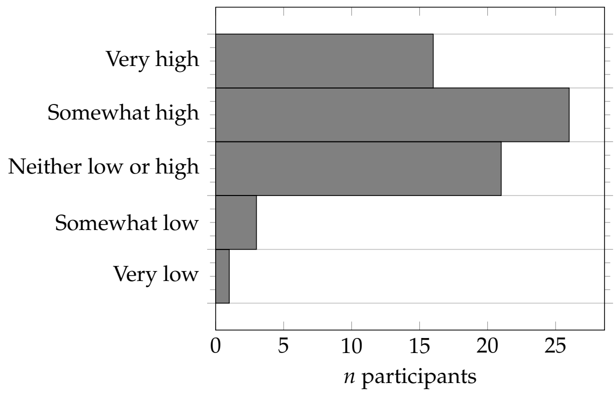


FIGURE 3.5: Self-categorised screen time amount.

When grouping the participants by estimated screen time, and comparing how they would describe their estimations, their answers for the most part correlate. In other words, the higher their estimated screen time, the more likely they would describe it as high as well. The only group who was of the opinion that their screen time was significantly higher than their estimated screen time, was the group of participants who estimated their screen time to be between one and two hours a day. This group described their screen time as being relatively high (3.4 on the aforementioned scale), much higher than the group below them, participants with an estimated screen time below one hour (1.5), and even a bit higher than the group above them, participants with an estimated screen time between two and four hours (3.3).

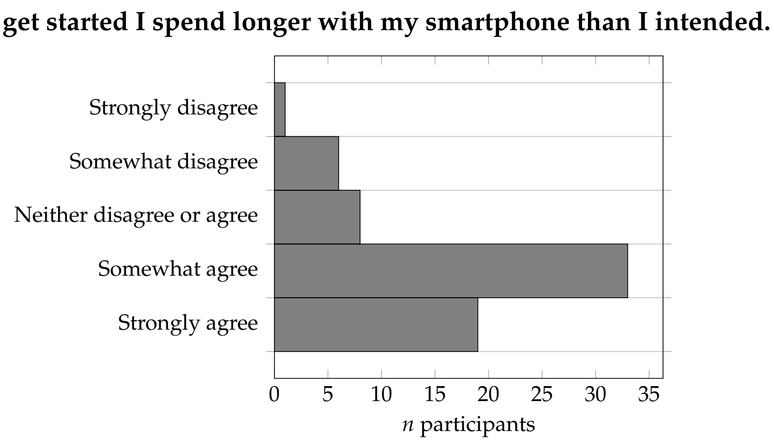


FIGURE 3.6: The most prevalent smartphone usage problem from the adapted SAS-SV.

3.3.2 Problematic smartphone use

The SAS-SV consists of 10 questions, which are answered on a scale of 1 to 5, where 1 is labelled as “Strongly disagree” and 5 as “Strongly agree”. Normally when using the SAS-SV, the sum of the participant’s answers then give an indication of smartphone addiction or PSU. If we were to use the same method for our adapted SAS-SV, the threshold for PSU would be exceeded by 50% of the participants ($n = 38$). The average cumulative score was 27.4 out of the maximum score of 50 ($SD = 1.24$).

	M	SD
I find it difficult to complete scheduled tasks because of the use of my smartphone.	2.7	1.5
Using my smartphone makes it difficult for me to concentrate on class or work.	3.3	1.5
I feel pain in my neck or wrist from using my smartphone.	2.3	1.3
I can't stand not having a smartphone.	3.4	1.3
When I don't have my smartphone to hand, I feel restless and irritable.	2.5	1.2
I keep thinking about my smartphone, even when I'm not using it.	2.0	1.0
I will never give up using my smartphone even when my daily life is already greatly affected by it.	2.8	1.2
In order not to miss any news, I have to constantly check my smartphone.	2.4	1.3
Once I get started, I spend longer with my smartphone than I intended.	3.9	1.0
People around me tell me that I use my smartphone too much.	2.1	1.1

3.3.3 Comments by participants

While the survey did not include an input field for remarks, some participants did react through text replies. Two participants noted that they had used their phone's built-in DSCT to find out their screen time and therefore did not find it difficult at all to make an estimation. Another remark was that a participant had adjusted his screen time estimation to exclude the time he used his phone for GPS navigation. Three participants commented that they found the survey confronting because they were faced with how much they use their smartphones. One participant also noted that her screen time was significantly higher due to the COVID-19 pandemic and its restrictions.

3.4 Discussion

The average estimated screen time participants reported varies widely. With an average of 4.7 hours a day, many participants seem to use their smartphones for a significant part of their waking hours. However, their estimates are significantly lower than the daily 8.8 hours that were measured by Lee Smith et al. [16]. This could mean that participants from our sample spent much less time on their smartphones, or that they are under-reporting their screen time. If the latter is the case and assuming the participants have no intention of under-reporting their screen time, it is possible that they are unaware of how much time they actually spent on their smartphones.

The amount of screen time participants have, does seem to have a relation with how high they score their issues on the adapted SAS-SV, which reflects the literature, indicating screen time can be used as a measurement for PSU [36, 29]

Participants checking their measured screen time using DSCT instead of estimating it will have had some influence on the results. It is possible that this skewed the difficulty participants reported in estimating their screen time to be somewhat easier. However even when taking that into account, participants did not seem to find it difficult to estimate their screen time. This does not necessarily establish that participants are aware of their screen time, but it does indicate that they think they are aware of their screen time.

The adapted version of the SAS-SV that was used for this survey was not validated as a measure of smartphone addiction, nevertheless, it still illustrates that many people struggle with smartphone-related issues. The answers given by participants indicate that some issues are especially prevalent, namely, spending more time on a smartphone than intended once started, disliking being without a smartphone and having difficulty concentrating on tasks due to smartphone usage.

Chapter 4

Design

The contextual research gave us insight into which issues are most common when it comes to smartphone usage and digital well-being. DSCT are designed to help users navigate their smartphone usage and balance their digital well-being. Using the related work, we have examined existing DSCT solutions, and we have established screen time as being an effective indicator of problematic smartphone usage. Our aim is to design a system meant to increase awareness of screen time, which is a goal similar to existing DSCT. The effectiveness of existing DSCT varies and is largely dependent on which strategies these systems take [29]. In order to create an effective DSCT, we will have to incorporate the findings from the related work and the contextual research into a sensible design. The following section illustrates the design considerations for developing a novel DSCT system.

4.1 Context and goals

The results from the survey show that many participants experience difficulties in their smartphone usage and digital well-being. Participants scored high on questions indicating problematic smartphone use, which substantiates the relevancy of the problem. For instance, participants indicated strongly that they often spend longer on their smartphones than they had intended once they pick them up. Likewise, participants mostly agreed that using a smartphone caused problems for them, such as difficulty focusing on studying or work.

The first step in supporting healthy smartphone usage is increasing awareness by providing the user with insights on their device usage. Providing usage statistics often forms the foundation of existing DSCT. The goal of our system is to increase the user's awareness of their screen time.

Participants reported not having much difficulty in estimating their screen time, although this could be a result of them not being aware of their screen time [16]. Their estimated screen time is much lower than the measured screen time from related research [32], indicating this might be the case. A differentiating feature from existing DSCT is to increase screen time awareness without the user needing to use their smartphone any more than they already do. The results from the contextual research indicate this might be advantageous since most participants said they spend longer on their smartphones than intended once they get started. By not increasing smartphone usage, the chance of increasing PSU is eliminated.

4.2 Existing solutions

Existing DSCT usually exist as a smartphone app, which tracks the users' smartphone usage. Information such as screen time is then relayed back to the user, through the app or through its notifications. Additionally, some DSCT can block other smartphone apps once specified limits are reached. Some DSCT, such as Apple's Screen Time app, allow users to set usage limitations on a per-app basis [35]. After the usage duration has elapsed, the user is presented with a notification and the app will be blocked for the day. There is also the option to enable downtime, during which only specific apps can be accessed.

As mentioned by Monge Roffarello and De Russis, DSCT that block content are often initially preferred by users but don't work as well in practice. DSCT that block content can often either be circumvented by the user or will annoy the user to a point that they disable the DSCT's blocking functionality [19]

Nearly all existing DSCT interact with the user through a smartphone app. The advantages of using app-based DST are the close integration with the smartphone and the high availability since the app is on the device in use. We argue that this close integration with the smartphone can also be a disadvantage when the goal is to limit smartphone usage.

4.3 Proposed solution

In this section, we will describe the rationale behind the design choices of our system. Similar to existing DSCT apps, in order to increase awareness of smartphone usage, we will track the screen time of the user, visualise this information and present it to the user. However, in order to achieve our goal of not adding any more smartphone screen time through the usage of our system, we will use a standalone system for the DSCT, instead of an app. Our system is not meant to replace the smartphone, since in many cases the smartphone can be an important tool, and a majority of the participants of the contextual research mentioned that they can't stand not having a smartphone. Instead, the system will act as an extension of the smartphone, similar to how a smartwatch or fitness tracker offers extended functionality. The system will not take away any functionality from the smartphone in the form of time locks or blocking certain apps.

Creating the system as a separate entity has its advantages and disadvantages. An important advantage is that it does not rely on the smartphone as much. Users who struggle with their digital well-being might want to keep their smartphone usage to a minimum. As seen in the results from the contextual research, most users spend longer with their smartphone than intended once they pick up the device, so it makes sense to keep the need for device pickups as low as possible. The necessity to check a DSCT app, or receive notifications from a DSCT app, could potentially lead to more device usage.

A disadvantage of decoupling the smartphone and the DSCT is availability. When the DSCT exists as an app, it can always inform the user while he is using the device. With the DSCT as a separate device, it is not certain if the information from the DSCT reaches the user; for instance, the user might have their smartphone, but not the DSCT system nearby. This means that our system might not always be able to give direct feedback to the user. It would be inconvenient for the user to always carry the system with them, instead, it makes sense to place it where it's available to the user most of the time, for instance at home. When the user is away from home, he would not be able to receive direct information on his screen time, this can however be mitigated somewhat by giving the user an overview of his device usage for the day. The user would then be able to look back at his device usage at a later time during the day, and still be made aware of his digital habits.

4.3.1 System design

Now that we have decided on the key design feature: "Decoupling from the smartphone", the most probable location for the system: "At home", and have set the main goal: "Increasing awareness in smartphone screen time", it is time to examine other specifications of the system and their design considerations.

The metric which we use to increase awareness is the smartphone screen time of the user over the day. Screen time is an easy-to-understand metric, which gives a clear overview of the device activity and which is an effective metric for assessing PSU [36, 29]. Traditional DSCT will often track screen time over multiple days and display these statistics in the DSCT app. Since we are designing a DSCT which is not centred around an app, but a device that is separated from the smartphone, we will need a different approach to relay this information to the user: For this, we have chosen to use an ambient information system. The behavioural characteristics of an AIS make it the medium of choice for this task. We will now consider Pousman and Stasko's description of these characteristics in relation to our design [26].

The system displays information that is important but not critical. Although the information is of importance to the user for increasing their screen time awareness, it is by no means critical information. When the AIS is not available to the user it will not directly affect them in a negative way, and screen time information can be viewed at a later time during the day.

The system can move from the periphery to the focus of attention. Increasing awareness happens over a longer period of time and is therefore not a single focused task. By moving to the periphery, the system can increase awareness without distracting or burdening the user. Additionally, the information should be quickly readable at a glance, making the interaction as simple as possible.

The system has a focus on the tangible; representations in the environment. The DSCT moving from the smartphone to the environment of the user, is a defining divergence from traditional DSCT and will prevent any additional smartphone usage by the user. The system provides subtle changes to reflect updates in information and should not be distracting. Since the AIS visualises smartphone screen time, changes in information will be gradual and only during smartphone usage. Since the system is intended for use at home, it is important that the system does not disturb any other activities by the user that might take place there.

The system is aesthetically pleasing and environmentally appropriate. This point is especially important while designing an AIS for use at home since generally people dislike putting any object into their home that is either hideous or which sticks out amidst their interior.

The main functionality of the AIS is to display the smartphone screen time information to the user. In its simplest form, our system would be an ambient display that shows the screen time by the user for the day, similar to how for instance a digital clock would display the time. However, in order for the system to be effective, there are a number of usability improvements we should take into account, which will help to keep the user invested in the system.

As mentioned by Monge Roffarello and De Russis, and which also became apparent from the comments by participants of the survey: Smartphone users generally dislike being confronted with their screen time [19]. To mitigate this problem, we let our system display a heat map visualisation of the screen time information over the day, instead of the exact screen time duration. Each section on the heat map represents a fraction of the day, the brightness intensity of the section shows how much time was spent using the smartphone at that time. This approach will not confront the user with the exact duration of their screen time but still allows for quickly estimating the current screen time at a glance.

Another comment by participants of the contextual research was that they desired to differentiate their screen time from activities such as using GPS navigation. Oftentimes a smartphone will be used as a tool; differentiating between, for instance, time spent being productive at work and time spent for leisure could be very useful information to the user. The system could accommodate this aspect, by allowing selected apps to be ignored in the screen time calculation.

Wang and Vella-Brodrick also argue for the importance of further differentiating in the quality of smartphone interactions [38]. A meaningful interaction, such as texting a loved one, has a more positive effect on digital well-being than endlessly scrolling through the feed of a social networking site, and does not produce some of the issues that are related to PSU [38]. Unfortunately, exactly and reliably determining either the usefulness or meaningfulness of smartphone interactions is not feasible, so we leave this task up to the user.

In order for the system's aesthetics to align with the home environment, we can take inspiration from other AIS', such as the *Digital Family Portret*, *CareNet* or *the Whereabouts Clock* [22, 6, 31]. When placing an AIS in the home, a common approach is for the system to mimic, or integrate with an everyday object, as for instance is seen with the smart plant sensor by Voit et al., which is part of the plant's pot [37]. The display from our system, which displays the heat map, could for instance be made to look like a painting, for it to better blend in with its environment.

In summary, the characteristics of an ambient display should make it a suitable medium for DSCT. For the DSCT to increase awareness of screen time, we will have to take usability into account, so as not to scare the user away. The system should be easy to read, non-confronting, non-intrusive and aesthetically pleasing.

Chapter 5

Implementation

The implementation of our system consists of three parts. An ambient information system, a companion app for Android, and a back-end server, each with its own custom software. The implementation of these three parts is described in this chapter.

5.1 Companion app

The companion app is written in Java and is based on the open-source Android application *AppsMonitor*[39], an app that is designed to collect data on the device usage for the user. By default, the app tracks the screen time of all the apps that have been used, but it also allows the users to select which apps should not be tracked. The original source code was inspected to ensure that it does not send any data to third parties. In order to use the app with the system, the app's source code has been extended with additional functionality. New functionality includes the ability to send the collected device usage data to the back-end server, at an interval of 5 minutes. The resulting app works on smartphones running Android OS 5.1 or newer and needs extended permissions before it can track device usage.

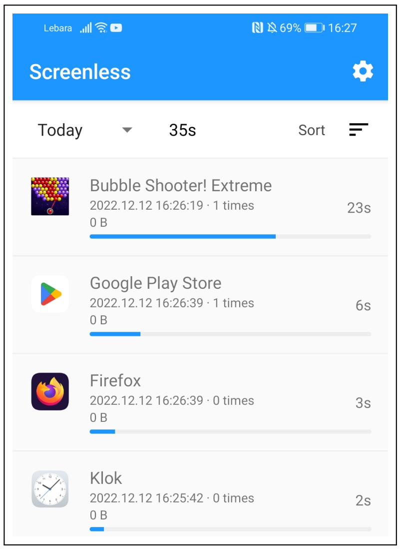


FIGURE 5.1: Screenshot of the companion app for Android.

5.2 Ambient information system

The AIS is based on a single-board computer (Raspberry Pi 4, 2GB RAM). A strand of 50 individually addressable RGB LEDs is connected to the computer, and the system is powered by a single 30 Watt power adapter. The electronics are hidden behind a painting canvas of 40cm by 120cm. The LEDs are spread out under the canvas to form a matrix of 12-by-4 lights, the remaining two LEDs are located at the bottom of the frame and act as indicator lights. The indicator lights alert the user when the device is not connected to the internet, is not paired with a companion app, or when an error occurs in the firmware.

Using its 12-by-4 LED matrix, the AIS can display information for the user, as shown in figure 5.2. The AIS displays a pattern based on the device usage recorded by the companion app. Each light on the AIS represents a time frame of 15 minutes, the 48 lights combined represent a time frame of 12 hours. The LED in the bottom left relates to 12:00h - 12:15h, the one to its right 12:15h - 12:30h and so on, from the bottom to the top row. This layout was chosen so each horizontal row of four LED lights corresponds to one hour.

During the day, when the companion app records screen time, this data is visualised by the AIS. When the participant uses his smartphone continuously during a 15-minute time frame, the LED corresponding to that time frame will increase its brightness to 100%. The brightness of each LED is based on the amount of screen time during that time, so when there has not been any device usage recorded during that time, the corresponding LED stays off. The AIS polls for new screen time information every few seconds, and dynamically updates when the companion app has recorded new device usage.

FIGURE 5.2: Picture of the AIS hanging on the wall, with some of its LED lights turned on.

While this system may seem complicated for the user, it is important to remember that the goal is not to give the participant their exact screen time information, which is often seen as confronting and not necessarily motivating. Instead, the AIS paints a picture of device usage over the day, without giving exact numbers, but it does give a general idea of the screen time and which can be viewed at a glance.

5.3 Back-end server

In order to improve the reliability of the system makes use of a back-end server, which acts as a middleman between the companion app and the AIS. The server is designed to always be online, to ensure some functionality remains when either the app or the AIS is unreachable. The back-end server contains a database, which stores the device usage received by the companion app. From this data, the server generates the visuals, which are stored as a matrix of brightness values, corresponding to the LED lights on the AIS, and which can be fetched through the server's API. Whenever the AIS requests an update, the server responds with the latest visualisation data.

5.4 Development

5.4.1 Hardware

The hardware of the system was developed in a series of iterations. In the first iteration, the Raspberry Pi and the LED lights were attached to the canvas using tape.

In later iterations the tape was replaced with hot glue and a case was designed and 3D printed for the Raspberry Pi, so it could be fitted behind a corner of the canvas. The wiring was also adjusted so that the Raspberry Pi and the LED lights could be powered by the same power adapter. A small 3D-printed toggle was added to the side of the AIS, which could be used to enable or disable the LEDs. This is useful for instance when the AIS is placed in the bedroom and the participant doesn't want to be kept up by the lights.

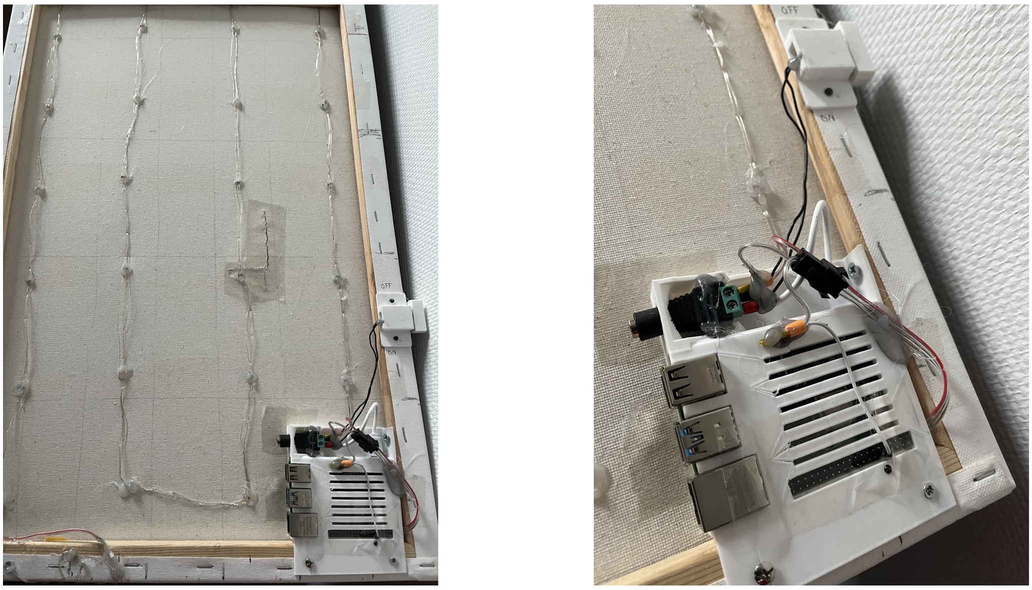


FIGURE 5.3: Backside of the AIS, on the right a closeup of the Raspberry Pi in its 3D printed enclosure with the switch toggle attached to the frame.

5.4.2 Software

Coding the companion app, back-end server and AIS firmware proved to be a challenging task. Various problems arose during development, most notably with the companion app. In order for the app to keep updating the server, it needed to be able to make external requests in the background while not in use. Different techniques were applied, to prevent Android OS from killing the app in the background. The issue was made even more difficult by the variety of Android systems. Different devices upheld a different strictness on allowing background tasks. In the end, the companion app would work on many Android devices, but not all. Since the system would be evaluated using each participant's personal device, this limited the selection of participants to those for whom the app was working correctly.

The programming of the back-end server and the Raspberry Pi was fairly straightforward, although it has been adjusted often in order for the system to work more reliably. The software on the Raspberry Pi has been purposefully kept simple, to ensure its reliability, since maintenance of the device would be difficult during the intervention periods. The Raspberry Pi's only task was to fetch the brightness information from the server and then turn on the corresponding LED lights, see the appendix on page 35 for some example code. Translating the screen time data to LED information is all done beforehand on the back-end server. The difficulty with the Raspberry Pi firmware was in creating a system that is easy to set up at the participant's home. In order to accomplish this, additional software was used for the onboarding. When the device is not connected to an internet network, it starts broadcasting itself as a device connectable over WiFi. The participant can then connect to the device directly, and securely input the credentials of their home WiFi network. After a reboot, the Raspberry Pi will then connect to the home network. Alternatively, an Ethernet cable can be plugged into the Raspberry Pi, however, this is not recommended, since it limits the locations for the AIS to places close to the home's router. Once the device is connected to the internet, it fetches the latest information from the back-end server and pairs it with the companion app that has last sent its screen time data. The pairing between the AIS and the companion app is reset upon a reboot of the Raspberry Pi.

5.5 Future revisions

A Raspberry Pi was chosen for ease of development, but in a future revision, it could be replaced with a much simpler WiFi development board, such as an ESP8266 or Raspberry Pi Pico W. This would decrease both hardware and electricity costs, which are already relatively low.

In order to protect the users' privacy a future revision could be designed without the external server. This would allow the system to be used without an internet connection over just the local network. A limitation of this architecture would be that the AIS does not update when the user is away from home, but since the AIS would not be visible to the user at that time anyway, this is likely to be a small payoff in functionality.

The pairing functionality of the companion app with the AIS could be improved, to make pairing to specific devices easier. Another useful future addition would be to add iOS support for the companion app and extend its functionality. The app could be improved by adding settings for the AIS to it, e.g. LED brightness, colour or pattern, and by allowing the users to customise the start time of their day, which corresponds to how the LED lights are mapped to different times of the day. Alternatively, a new version of the AIS that utilises twice the number of LED lights could represent a 24-hour duration instead of 12, rendering the start time irrelevant."

Chapter 6

Evaluation

This chapter describes the methodology, results and discussion of our research. Our novel approach in designing a DSCT using an AIS aims to increase screen time awareness. In our research, we used real-world trials of the system to measure screen time awareness, digital well-being and user experience satisfaction. To evaluate the system, our primary goal was to find out if it can increase screen time awareness (I).

The effectiveness of traditional DSCT is still actively being researched. Monge Roffarello and De Russis tested a traditional DSCT app using the SAS-SV scale and found no significant difference before and after using the app for a week [20]. Our approach is significantly different from traditional DSCT apps, it will be interesting to see whether we can measure a difference using the same SAS-SV scale. Hodes and Thomas underline that many smartphone users are not aware of how much time they spend on their device, and underestimate their screen time [11]. In our related work section, we outlined the negative consequences of smartphone overuse. Our hope is that by increasing screen time awareness, we can prevent smartphone overuse and increase digital well-being, although this will be difficult to prove (II). Additionally, we want to measure the user experience with our system, since this influences whether the user would prefer to use the system and would want to continue using it in the future (III).

I. Do users become more aware of their screen time after using our system?

II. Does using the system lead to an increase in digital well-being?

III. How does the user experience of our system compare to other interactive systems?

6.1 Method

6.1.1 Materials and environment

In order to answer our research questions, participants of the experiment group were supplied with our AIS, which follows the design specified in the previous chapter. Using an app installed on their smartphone, the AIS would visualise their personal screen time. Both the AIS and the app were connected to a central server over the internet, which logged their smartphone activity. The system was set up at the participants' homes, to see how it would be interacted with in their day-to-day life. Each participant also installed a normal DSCT app, which tracked their screen time. The data from this DSCT app was used to evaluate the system and measure the differences between the two groups. Each participant filled out two questionnaires, one at the beginning of the 2-day intervention period and one afterwards. The answers to these questionnaires form the basis to evaluate the system.

6.1.2 Participants

Our experiment had 16 participants in total ($N = 16$), of which 8 used the system (*group A*, 4 female, 4 male) and the other 8 acted as the control group (*group B*, 4 female, 4 male). The age of the participants ranged from 24 to 31 years old. The participants have been selected by convenience sampling, forming a group of fellow students and ex-students. Participants of the experiment group had the requirement of using an Android smartphone in their daily life, which was necessary for the companion app. Participants did not receive financial compensation for partaking in the study. Each participant in the experiment group got to use the system for two days. These testing periods were performed in parallel between group A and group B, over a period of roughly two months.

6.1.3 Pre-intervention questionnaire

The participants were administered the initial questionnaire right before the intervention period. In the first part of the questionnaire, each participant filled out a selection of socio-demographic questions and signed the informed consent form. This form aimed to inform the participants, that although their results would be anonymised, the system would handle privacy-sensitive data, such as which smartphone apps they use and for how long they use them. The form indicated that participants had the option to withdraw from the study at any point, that their participation was voluntary, that all collected data would be eliminated upon the completion of the research, and that any identifying information would be removed from the findings.

The pre-intervention questionnaire contained 10 questions from SAS-SV, which were also featured in the contextual research survey (p. 11). The participant was asked to answer these questions in relation to their recent smartphone use. Additionally, the participant was asked to give an estimate of their average daily smartphone usage in hours. The answers to this questionnaire were used to compare differences between participants and to establish a baseline for the post-questionnaire. The complete pre-intervention questionnaire can be found in the appendix on page 43.

6.1.4 Intervention period

Participants of group A would decide where in their home they would place the AIS, however they were advised to put it in a location where it's visible most often. Participants were allowed to change the location of the system later on. Each participant received instructions on how to connect the AIS to their home internet network, how to change the settings of the system and how to interpret the different visualisations produced by the AIS. Participants of group A also installed the companion app on their smartphone, which would link their device to the AIS.

Once everything was confirmed working, the participant was free to use the system however they preferred. Participants were not given any usage requirements or restrictions. During the testing period, participants were left unsupervised, however, the conductor of the experiment was available to contact in case of any technical difficulties or other issues. Participants of both groups A and B were asked to use a DSCT app to silently track their smartphone usage during the intervention period. While participants of group A could use the AIS to track their smartphone usage, none of the participants was allowed to use any other tool to monitor their smartphone usage.

6.1.5 Post-intervention questionnaire

After each intervention period concluded, the second questionnaire was given to the participant. The first part of this questionnaire is a repeat of the initial questionnaire, with questions on the participants' digital well-being and screen time awareness. However, this time the participants were asked to answer questions in relation to their smartphone usage during the intervention period. Each participant is again asked to give an estimate of their average daily smartphone usage in hours, as well as an estimate of their smartphone usage in hours for the day before the questionnaire was filled out. Once they filled out these questions, the participant was asked to open the DSCT app that had been running in the background on their phone and input their measured smartphone usage in hours for the day before the questionnaire was filled out.

At this stage, participants of group B had completed the questionnaire, while participants of group A were asked to fill out a final section. This section contains the User Experience Questionnaire (UEQ) [15]. The UEQ is a research tool used to assess the user experience of a product or service and consists of a set of 26 standardized questions that are designed to measure the attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty of a system. The questionnaire is typically administered after a user has interacted with the product or service, and the responses are used to provide feedback and identify areas for improvement. The UEQ has been widely adopted in the field of human-computer interaction and has been shown to be a reliable and valid measure of user experience. Furthermore, the UEQ can be used to compare the user experience of different products or services, allowing researchers and designers to identify strengths and weaknesses and make informed decisions about design and development. Each question in the UEQ is presented as a pair of contrasting attributes, and participants are asked to rate their agreement with the attributes on a scale of 1 to 7. The results from the UEQ can be used to compare the quality of the user experience relative to other systems that have also been evaluated using the UEQ. The complete post-intervention questionnaire, including the questions from the UEQ, can be found in the appendix on page 49.

6.1.6 Interview

After completing the post-intervention questionnaire, participants in group A were invited to participate in a brief interview. The interview was used to gather qualitative data on the participants' smartphone usage and their experience with the system. The interview consisted of four questions on digital well-being, the participant's relationship with their smartphone, their smartphone habits and their experience with estimating their smartphone usage. The interview also contained three questions on their experience with the system. The aim of these interviews was to let the participants freely talk, with only limited probes from the conductor. The complete list of interview questions and probes can be found in the appendix on page 56.

6.1.7 Data analysis

During the intervention period a collection of data was formed:

- Quantitative data from the questionnaires with two conditions: Before and after the testing period, and with two groups of participants: A and B.

- User experience data of participants of group A through the UEQ.
- Qualitative data was gathered through the interviews on the personal relationship between the participant and their smartphone and on the participant's experiences with the system.

The data collected from the questionnaires and interviews were analysed using descriptive statistics. Our main variable is screen time awareness, which we calculated by combining the measurements of the participant's estimated screen time and their measured screen time. Their accuracy gives us an indication of how well the system performed in its goal of increasing awareness of screen time.

The responses to the questions in the questionnaire were analyzed using their mean and standard deviation. The SAS-SV questionnaire was used to calculate pre- and post-scores for each participant's digital well-being by summing the answers to the questions. These scores provide an indication of the participant's digital well-being and smartphone addiction. In contrast to our contextual research, this study employs a validated version of the SAS-SV. The scale identifies a different range for males and females. For men, a score higher than 31 indicates smartphone addiction, with a high risk of addiction with scores between 22 and 31. For women, scores higher than 33 indicate smartphone addiction, with a high risk of addiction on scores between 22 and 33 [14]. The pre and post-scores were compared to see if the system had any effect on the participant's digital well-being.

Group A's answers to the UEQ, were analysed using the UEQ Data Analysis Tool (UEQ-DAT) [15]. The UEQ-DAT calculates the mean and standard deviation for each attribute, as well as the mean and standard deviation for the overall user experience. The results of the UEQ-DAT can be used to compare the quality of the user experience relative to other systems which have also been evaluated using the UEQ. In order to assess the quality of our user experience relative to other interactive systems, we compare our results to the UEQ benchmark by Schrepp, Thomaschewski, and Hinderks [30].

6.2 Results

6.2.1 Screen time awareness

We measure screen time awareness by examining the difference between the estimated and the measured screen time for the group that used the system (*group A*, $n = 8$) and the control group that did not (*group B*, $n = 8$). On average, group A overestimated their smartphone use by 15 minutes ($M = -0.2513$ hours, $SD = 0.7984$) and group B underestimated their smartphone use by 35 minutes ($M = 0.5725$, $SD = 1.39363$). The large variance for control group B indicates that the mean difference does not say much about their accuracy, since the group's overestimates and underestimates cancel each other out. To measure the accuracy of their estimates, we instead take the absolute value of the difference between their estimates and measurements. The absolute difference in screen time between the estimate and measurement is 31 minutes for group A ($M = 0.51$, $SD = 0.65$) and 83 minutes for group B ($M = 1.38$, $SD = 0.35$). The accuracy of the estimate compared to the measurement is 87.91% for group A and 57.38% for group B. As shown in Figure 6.1, most participants in group A demonstrated higher accuracy in estimating their screen time compared to participants in group B, with two participants achieving perfect estimates. Excluding one outlier, the results suggest that group A's performance was superior in this regard.

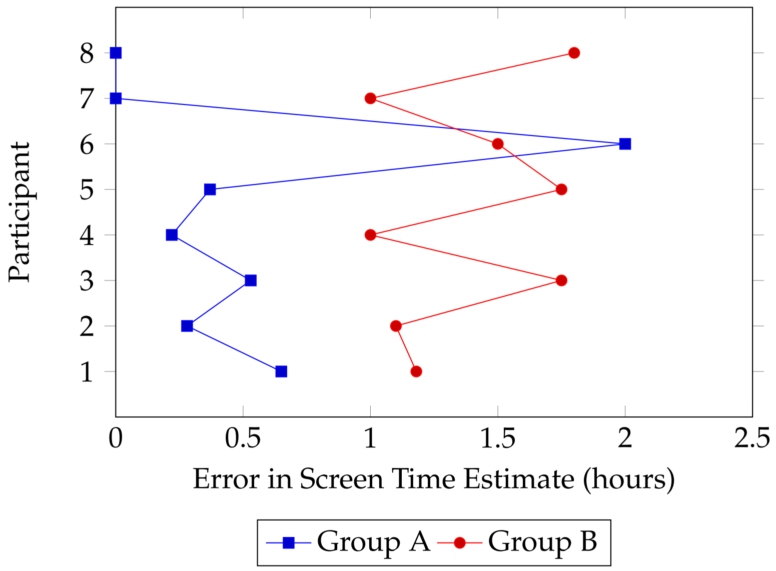


FIGURE 6.1: The absolute difference in estimated and measured screen time for participants in group A and group B.

We used ANCOVA to test for significant effects in the screen time estimate accuracy between groups A and B, using the screen time estimate as covariable. The results showed that there was a significant difference in screen time awareness ($F_{(1,14)} = 10.84$, $p = .0058$, $\eta_p^2 = .4548$). The F-value indicates that there is a strong relationship between the groups and the dependent variable. The p-value indicates that the difference between the groups is statistically significant, with a very low probability that the results occurred by chance. The partial η^2 indicates that the independent variable accounted for approximately 45.48% of the variance in the dependent variable. These results suggest that group A and group B differ significantly in their screen time awareness. There was no measurable significant effect between genders.

6.2.2 Digital well-being

Figure 6.2 shows the SAS-SV scores for the participants as measured by the questionnaires. The table shows the mean and standard deviation of the scores, while the boxplot on the right displays the distribution of the score differences between pre and post-intervention for both groups. The initial mean SAS-SV score for group

Group	Phase	*M*	*SD*
A	pre	32.75	6.23
	post	28.50	4.69
B	pre	32.63	5.85
	post	32.13	4.88

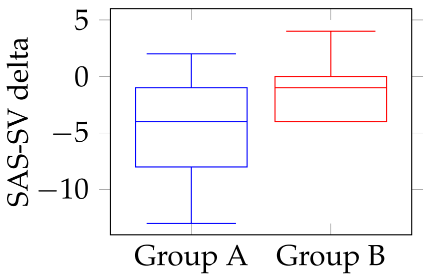


FIGURE 6.2: On the left, the SAS-SV score change from pre to post-intervention for groups A and B. On the right, the distribution of the difference between the pre and post-intervention SAS-SV score for groups A and B.

A is 32.75 ($SD = 6.23$), which decreases to 28.50 ($SD = 4.69$) after the intervention period. Group B's initial mean SAS-SV score is 32.63 ($SD = 5.85$) and its final mean SAS-SV score is 32.13 ($SD = 4.88$). It should be noted here that a SAS-SV score higher than 31 for men, or higher than 33 for women, indicates smartphone addiction. By this definition, 3 of our male and 4 of our female participants (44%) were classified as being addicted to their smartphones. The decrease in the mean SAS-SV score for group A indicates that the participants of group A experienced an improvement in their digital well-being, while the values for the control group stayed the same. In order to test for a significant effect, we used a t-test to compare the delta between the initial and final SAS-SV scores between group A and group B. The results of the study suggest that there is a trend towards a lower SAS-SV score for group A, indicating better digital health. However, the difference in change in SAS-SV scores between the groups was not found to be statistically significant ($t_{(14)} = -1.76$, $p = .10$).

6.2.3 User experience

We used the UEQ to assess the user experience of the system for participants of group A ($n = 8$). Figure 6.3 shows the mean scores for each of the UEQ's dimensions, as well as the standard deviation. The UEQ measures six different aspects of the user experience: Attractiveness, perspicuity, efficiency, dependability, stimulation and novelty. The scores for each item are calculated by the UEQ-DAT and then compared to the UEQ benchmark [30]. The system scored good on stimulation and novelty, and above average on perspicuity. However, the scores for attractiveness, efficiency and dependability are below average.

In addition to the UEQ results, we also conducted interviews with participants to gather more in-depth insights into their experience with the system. Here are some quotes from the interviews:

"I found the system really engaging, it made me more aware of how much time I was spending on my phone."

"I liked the visualizations and the way the information was presented. I think it was less confronting than the [DSCT] app I have on my phone"

"I think the system has potential for improving my digital habits. It made me more aware of when I was using my phone, and it became kind of a game to light up as little of the lights as possible"

These quotes provide further indication that the AIS offers a positive user experience, with users finding it engaging, easy to use, and helpful for promoting digital well-being.

The interviews also provided some insights into the negative aspects of the design. One participant mentioned they felt ashamed by how many lights the AIS showed, which showed their partner how long they had been on their phone. Another participant mentioned they dislike the fact that it needs to be plugged in since they don't find the power cord hanging from the AIS aesthetically pleasing.

Scale	*M*	*SD*
Att.	0.958	0.386
Per.	1.344	0.731
Eff.	0.781	0.589
Dep.	0.875	0.582
Sti.	1.438	0.547
Nov.	1.375	0.482

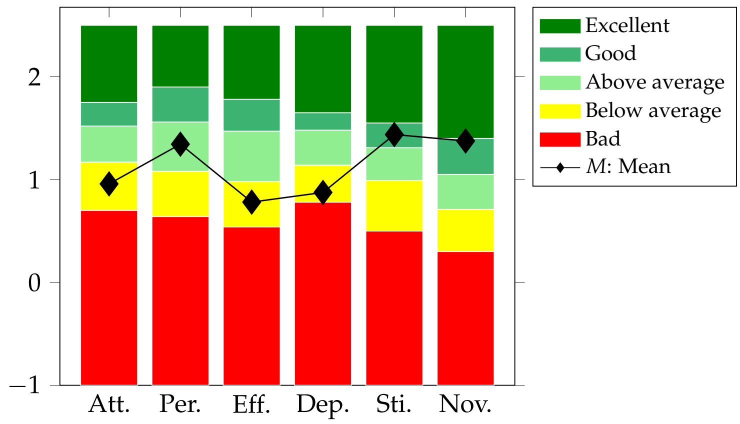


FIGURE 6.3: The six dimensions of the UEQ: Attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The table presents the mean and standard deviation of each aspect, and the bar chart compares those mean scores to the benchmark.

6.3 Discussion

In our study, we found that using an AIS for screen time awareness improved participants' screen time awareness. This suggests that AIS' can be an effective tool for helping individuals to become more aware of their screen time usage and potentially reduce their screen time. The user experience as reported by the UEQ and compared to the benchmark ranged from below average to good. Although the stimulation and novelty of the system are good, the attractiveness, efficiency and dependability of the user experience still have room for improvement. These aspects of the UEQ where the system scored below average might be attributed to the system being a prototype and not a finished product. Given more time in development and a more professional build of the hardware, these aspects are likely to score higher with future versions. The interviews were mainly positive, with most participants praising the system. Overall the findings are encouraging, as they suggest that an AIS may be a valuable tool for promoting digital well-being.

One of the key advantages of using an AIS for increasing awareness of screen time is that it allows for the provision of information in a passive manner. Unlike traditional DSCT, which requires the user to actively engage with the app, an AIS can provide information about screen time without requiring any input from the user. This makes it less likely to be ignored or abandoned by the user and may help to avoid the irritation that can sometimes be caused by more intrusive DSCT. Another advantage of the AIS is that it can continue to provide information about screen time even when the smartphone is not in use. By design, a smartphone app is only active when it is open and running in the foreground. This means that traditional DSCT are only able to provide information about screen time when the user is actively using the smartphone. In contrast, an AIS can provide information about screen time even when the smartphone is in the user's pocket or bag, which could help to prevent unnecessary smartphone pickups.

We were unable to demonstrate a significant decrease in SAS-SV score in response to using our system. Our findings are in line with a previous study which measured SAS-SV scores before and after using traditional DSCT and found no significant changes [20]. Our results of our study do indicate a trend in the right direction. This is particularly noteworthy given the small sample size of our study, as well as the limited time frame of the intervention. Overall, these results suggest that further research in this area may be warranted, to explore the potential benefits of increased screen time awareness on digital well-being.

We were also unable to demonstrate a significant difference in screen time awareness or SAS-SV scores between male and female participants. Previous research has suggested that there may be gender-based differences in screen time usage and digital well-being [14, 4]. However, the small sample size of our study may have made it difficult to detect these differences.

6.3.1 Limitations

The two main limitations of our study are the small sample size and the short intervention period of only two days. This means that our results may not be generalisable to a larger population, and further research is needed to determine the long-term effectiveness of the AIS. The limited sample size especially impairs our ability to accurately assess the user experience, as there were only a total of eight participants who used the system. Assessing the system over a prolonged period of time would also tell us more about the participant's engagement with the system, and whether they would abandon it, as is often the case with traditional DSCT apps. There are also more general limitations to measuring digital well-being using a questionnaire. The SAS-SV and the other included questions are self-report measures, which means that they rely on individuals to accurately report their own screen time usage and digital well-being. This can be problematic because individuals may not have an accurate or complete understanding of their own screen time habits, as shown by the discrepancy between their self-reported screen time estimates and objective measurements. Additionally, self-report measures are susceptible to biases and errors, such as social desirability bias, which can affect the validity and reliability of the results. The SAS-SV focuses on the participants' engagement with their smartphone and internet activities, and their psychological and behavioural symptoms of addiction, which may not capture the full range of factors that contribute to digital well-being. Other scales might be more suitable for measuring digital wellbeing than the SAS-SV. These scales could include multi-dimensional measures that assess a wider range of factors that contribute to digital well-being, and that use more objective and reliable methods for collecting data. These scales could provide a more comprehensive and accurate assessment of digital well-being, and could help to advance our understanding of the effects of AIS-based DSCT and other interventions on digital well-being.

Despite these limitations, our findings are encouraging, and we believe that the use of AIS' has the potential to be a valuable tool for promoting digital well-being. Further research is needed to fully understand the potential benefits and limitations of the AIS as DSCT, but we believe it could be a useful alternative to traditional DSCT.

6.3.2 Future research

Future research should aim to address some of the limitations of this study, such as the small sample size and the short intervention period. Larger sample sizes and longer intervention periods would allow for more robust and accurate results and would provide a better understanding of the effects of AIS on screen time awareness and digital well-being. Additionally, future research could investigate the potential moderating effects of factors such as age, gender, and previous screen time usage on the relationship between AIS, screen time awareness, and digital well-being. These studies would provide valuable insights into the effectiveness and potential benefits of AIS' for promoting screen time awareness and improving digital well-being.

It would also be interesting to investigate whether the passive nature of AIS' makes it more likely to be used, and effective in improving digital well-being compared to traditional DSCT, since we did not measure the effectiveness of traditional DSCT apps in our research.

6.4 Conclusion

Our study examined existing literature on ambient information systems and digital self-control tools. We performed a contextual research on problematic smartphone usage, the findings of which we used in designing our own AIS-based DSCT. We described the implementation of our system and built a usable version of our AIS. The AIS was a wall-mounted display that consisted of a canvas with LED lights arranged in a 12-by-4 pattern. The brightness of the LED lights corresponded to the amount of screen time the participant had logged on their smartphone. The participant's smartphone screen time was tracked using a companion app that communicated with the AIS via a server. In order to evaluate the system, we performed a user study with two groups of eight participants, to measure its effectiveness in increasing awareness of screen time usage and promoting digital well-being.

The results of the user study showed that the AIS was able to effectively increase awareness of screen time. Participants who used the system were significantly more accurate in estimating their screen time compared to the control group. The user experience as reported by the UEQ and interviews was mainly positive, although the system scored below average on attractiveness, efficiency and dependability.

Although we were unable to demonstrate that using our system led to a significant decrease in symptoms of smartphone addiction or distress, as measured by the SAS-SV score, our results did show a small trend indicating an increase in digital well-being for participants who used the system. We believe that an AIS-based implementation could be an engaging, low-cost and useful alternative to traditional DSCT, however, our small sample size and short intervention might have limited our findings. Future research should aim to address the limitations of this study, and further evaluate the long-term effectiveness of AIS' for promoting digital well-being.

Appendix A

Codebase

The Raspberry Pi (AIS) and back-end server software are implemented in Python, while the Android companion app is implemented in Java. The complete set of code for this project is available as open-source on GitHub at `https://github.com/Master-Thesis-HCI/`. Below, we provide some examples from the codebase.

A.1 Back-end server code snippet

The following code snippet demonstrates the use of the back-end server to convert screen time information to LED RGB values, which are subsequently published on the server's API for retrieval by the AIS.

```python
import webcolors

WINDOW_SIZE = 900  # seconds; 15 minutes
TOTAL_PIXELS = 48
COLOR = "lightblue"
MINIMUM_INTENSITY = 0.5
MAXIMUM_INTENSITY = 1

...

def screentime_to_rgb(window_screentime: int) -> tuple:
    """Converts screentime in seconds to rgb values for LED"""
    intensity = window_screentime / WINDOW_SIZE

    # Adjust intensity to be within pre-specified values
    intensity_range = MAXIMUM_INTENSITY - MINIMUM_INTENSITY
    intensity = intensity * intensity_range + MINIMUM_INTENSITY
    rgb = tuple(int(i * intensity) for i in webcolors.name_to_rgb(COLOR))
    return rgb
```

A.2 AIS code snippet

Code snippet of the program ran by the Raspberry Pi, to control the Adafruit NeoPixel WS2812 LED strand.

```
import logging
import json
import board
import neopixel

pixels = neopixel.NeoPixel(board.D18, 50,
                           brightness=config['brightness'],
                           auto_write=False)

...

def set_leds(path: str):
    """Load state from file and set LED lights accordingly"""
    # The state of the LED lights is saved to a JSON file
    # in case the program is interrupted.
    frame = json.loads(pathlib.Path(path).read_text())
    logger.debug(f'loaded␣frame={frame}')
    logger.debug(f"setting␣pixels")
    for window in frame["windows"].values():
        pixels[window["index"]] = window["pixel"]
    pixels.show()
```

Appendix B

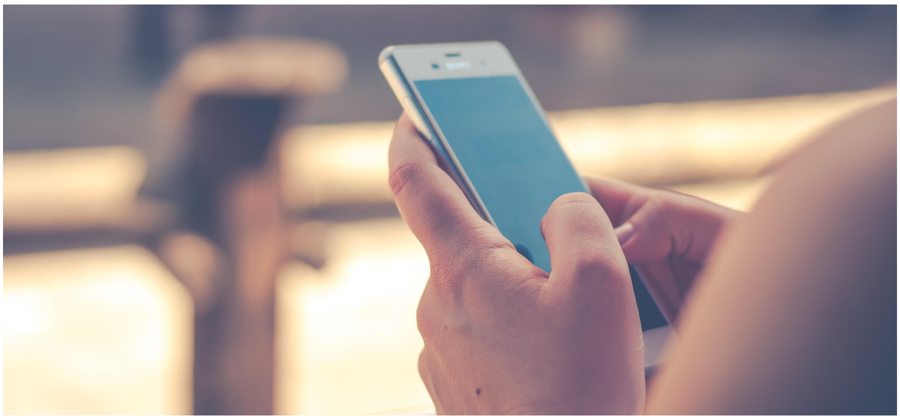
Questionnaires

B.1 Contextual research

The contextual research was used to gather information on problematic smartphone use. The final section of the survey contains the Smartphone Addiction Scale - Short Version (SAS-SV) [14]. The version in our survey erroneously used a five-point Likert scale instead of a six-point point Likert scale, which is why we could not use the scale as a validated measurement of smartphone addiction.

Utrecht University

Default Question Block



Smartphone screen time survey

This survey is part of a Utrecht University thesis research project. Answers to this survey will be used to gain more insight into personal smartphone usage. Participation in this survey is entirely voluntary. Only completely filled in surveys will be part of the research. If you do not want to participate you can close this survey at any time.
Your answers will only be used within the context of this research.

We will not link your answers to your name, email or other private information. Personally identifying information will not be used or published in any way.
This survey consists of two sections, of 4 questions each. The first section is for collecting demographic information, the second section contains questions related to smartphone use. Completing this survey will take approximately 5 minutes.

By submitting your answers you agree to the following:
- You have volunteered to participate and agree to be a part of this research;
- You have been informed about the tasks and procedures;
- You are aware that you can withdraw at any time.

Block 3

What is you age?

- ◯ Under 18
- ◯ 18 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 54
- ◯ 55 - 64
- ◯ 65 - 74
- ◯ 75 - 84
- ◯ 85 or older

What is your gender?

- ☐ Woman
- ☐ Man
- ☐ Non-binary
- ☐ Prefer not to disclose
- ☐ Prefer to self-describe: ______

What is the highest degree or level of education you have completed?

- ◯ No schooling completed
- ◯ High school
- ◯ 1st year of Bachelor's degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Ph.D. or higher
- ◯ Trade school
- ◯ Prefer not to say

Do you regularly use a smartphone?

- ◯ Yes
- ◯ No

Block 1

Smartphone Screen Time
With screen time we refer to the time you spent interacting with your smartphone on a given day.

How many hours do you estimate you use your smartphone on a daily basis (screen time)? If your daily use varies strongly from day to day, please give an estimate of your average use.

- ◯ Less than 1 hour
- ◯ Between 1 and 2 hours
- ◯ Between 2 and 4 hours
- ◯ Between 4 and 6 hours
- ◯ Between 6 and 8 hours
- ◯ Between 8 and 10 hours
- ◯ Between 10 and 12 hours
- ◯ Between 12 and 14 hours
- ◯ More than 14 hours

How would you rate the difficulty of estimating your screen time?

Extremely difficult	Somewhat difficult	Neither easy nor difficult	Somewhat easy	Extremely easy
◯	◯	◯	◯	◯

How would you describe your estimated screen time amount?

Very low	Somewhat low	Neither low or high	Somewhat high	Very high
◯	◯	◯	◯	◯

In relation with your smartphone use, please select whether you agree with the following statements.

	Strongly disagree	Somewhat disagree	Neither disagree or agree	Somewhat agree	Strongly agree
I find it difficult to complete scheduled tasks because of the use of my smartphone.	◯	◯	◯	◯	◯
Using my smartphone makes it difficult for me to concentrate on class or work.	◯	◯	◯	◯	◯
I feel pain in my neck or wrist from using my smartphone.	◯	◯	◯	◯	◯
I can't stand not having a smartphone.	◯	◯	◯	◯	◯
When I don't have my smartphone to hand, I feel restless and irritable.	◯	◯	◯	◯	◯
I keep thinking about my smartphone, even when I'm not using it.	◯	◯	◯	◯	◯
I will never give up using my smartphone even when my daily life is already greatly affected by it.	◯	◯	◯	◯	◯
In order not to miss any news, I have to constantly check my smartphone.	◯	◯	◯	◯	◯
Once I get started, I spend longer with my smartphone than I intended.	◯	◯	◯	◯	◯
People around me tell me that I use my smartphone too much.	◯	◯	◯	◯	◯

B.2 Pre-intervention questionnaire

Included here is the first questionnaire that participants of group A of the user study received. Aside from references to our system in the introduction, the questionnaire participants of group B received was identical to this one. Included in this questionnaire are the questions from the SAS-SV on a six-point Likert scale [14]. Note that we also added three questions on screen time awareness (smartphone usage questions 3, 8 and 13), however, these were not used in the final research since they were too leading.

Thesis project

We are interested in understanding how an ambient information display can help in screen time awareness. As a participant you will be able to use the system in your own home for a period of two days. During this time you do not have to actively perform any tasks.

You will be asked to install a custom app on your smartphone. This app tracks your screen time, which is privacy sensitive information. The system will not log which apps you use, but it will log for how long and at what times you use your smartphone. This data will be kept confidential and will only be used within the context of this research.

You will be also be asked to enable screen time screen time tracking within the settings on your smartphone. This will be used later to compare the accuracy of the system, however for the success of this research it is important that you do not actively check your screen time information on your phone, and that you disable notifications which tell you how long you've been on your smartphone, if you've enabled any.

Before and after using the system, you will be asked to fill in a survey on screen time and digital wellbeing. Your responses to these surveys will also be kept completely confidential. Each survey will take about 10 minutes to complete.

Your participation in this research is voluntary. You have the right to withdraw at any point during the study. The principal Investigator of this study can be contacted at r.peters1@students.uu.nl.

By clicking the button below, you acknowledge:

- Your participation in the study is voluntary.
- You are 18 years of age or older.
- You are aware that you may choose to terminate your participation at any time for any reason.

- I consent, begin the study
- I do not consent, I do not wish to participate

Demographic data

Participant ID

What is your age?

- 18 - 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 75 - 84
- 85 or older

What is your gender?

- Female
- Male
- Non-binary
- Prefer not to disclose
- Prefer to self-describe

What is the highest degree or level of education you have completed?

- High school
- 1st year of Bachelor's degree
- Bachelor's degree
- Master's degree
- Ph.D. or higher
- Trade school
- Prefer not to say

Smartphone usage questions

In relation with your smartphone usage over the past couple of days, please select whether you agree with the following statements.

	1 Strongly disagree	2	3	4	5	6 Strongly agree
I find it difficult to complete scheduled tasks because of the use of my smartphone.	○	○	○	○	○	○
Using my smartphone makes it difficult for me to concentrate on class or work.	○	○	○	○	○	○
I often reflect on how much I use my smartphone.	○	○	○	○	○	○
I feel pain in my neck or wrist from using my smartphone.	○	○	○	○	○	○
I can't stand not having a smartphone.	○	○	○	○	○	○
When I don't have my smartphone to hand, I feel restless and irritable.	○	○	○	○	○	○
I keep thinking about my smartphone, even when I'm not using it.	○	○	○	○	○	○
I am very aware of my smartphone usage.	○	○	○	○	○	○
I will never give up using my smartphone even when my daily life is already greatly affected by it.	○	○	○	○	○	○
In order not to miss any news, I have to constantly check my	○	○	○	○	○	○

smartphone.						
Once I get started, I spend longer with my smartphone than I intended.	O	O	O	O	O	O
People around me tell me that I use my smartphone too much.	O	O	O	O	O	O
I feel like I'm in control when it comes to how much I use my smartphone.	O	O	O	O	O	O

In relation to your recent smartphone usage, how many hours do you estimate you use your smartphone on a daily basis?

Please estimate an average by yourself, without the use of any screen time tracking tools.

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B.3 Post-intervention questionnaire

Included here is the final questionnaire that participants of group A of the user study received. The questionnaire participants of group B received was identical to this one, up until the user experience section, which they did not get to fill in. Included in this questionnaire are the questions from the SAS-SV [14]. Note that we also added three questions on screen time awareness (smartphone usage questions 3, 8 and 13), which were not used in the final research. The user experience section contains the 26 questions of the User Experience Questionnaire questionnaire [15].

In relation with your smartphone usage over the past couple of days, please select whether you agree with the following statements.

	1 Strongly disagree	2	3	4	5	6 Strongly agree
I find it difficult to complete scheduled tasks because of the use of my smartphone.	○	○	○	○	○	○
Using my smartphone makes it difficult for me to concentrate on class or work.	○	○	○	○	○	○
I often reflect on how much I use my smartphone.	○	○	○	○	○	○
I feel pain in my neck or wrist from using my smartphone.	○	○	○	○	○	○
I can't stand not having a smartphone.	○	○	○	○	○	○
When I don't have my smartphone to hand, I feel restless and irritable.	○	○	○	○	○	○
I keep thinking about my smartphone, even when I'm not using it.	○	○	○	○	○	○
I am very aware of my smartphone usage.	○	○	○	○	○	○
I will never give up using my smartphone even when my daily life is already greatly affected by it.	○	○	○	○	○	○
In order not to miss any news, I have to constantly check my smartphone.	○	○	○	○	○	○
Once I get started, I spend longer with my smartphone than I intended.	○	○	○	○	○	○

People around me tell me that I use my smartphone too much.	○	○	○	○	○	○
feel like I'm in control when it comes to how much I use my smartphone.	○	○	○	○	○	○

In relation to your recent smartphone usage, how many hours do you estimate you use your smartphone on a daily basis?

Please estimate an average by yourself, without the use of any screen time tracking tools.

How many hours do you estimate you used your smartphone yesterday?

Please make an estimate by yourself, without checking with any screen time tracking tools.

Q4

Please check the screen time tracking app on your phone and fill in how many hours you used your phone yesterday.

User experience

For the assessment of the system as a whole, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the system. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression. Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.

It is your personal opinion that counts; there is no wrong or right answer.

annoying	○	○	○	○	○	○	○	enjoyable
not understandable	○	○	○	○	○	○	○	understandable
creative	○	○	○	○	○	○	○	dull
easy to learn	○	○	○	○	○	○	○	difficult to learn
valuable	○	○	○	○	○	○	○	inferior
boring	○	○	○	○	○	○	○	exciting
not interesting	○	○	○	○	○	○	○	interesting
unpredictable	○	○	○	○	○	○	○	predictable
fast	○	○	○	○	○	○	○	slow
inventive	○	○	○	○	○	○	○	conventional
obstructive	○	○	○	○	○	○	○	supportive

good	○	○	○	○	○	○	○	bad
complicated	○	○	○	○	○	○	○	easy
unlikable	○	○	○	○	○	○	○	pleasing
usual	○	○	○	○	○	○	○	leading edge
unpleasant	○	○	○	○	○	○	○	pleasant
secure	○	○	○	○	○	○	○	not secure
motivating	○	○	○	○	○	○	○	demotivating
meets expectations	○	○	○	○	○	○	○	does not meet expectations
inefficient	○	○	○	○	○	○	○	efficient
clear	○	○	○	○	○	○	○	confusing
impractical	○	○	○	○	○	○	○	practical
organized	○	○	○	○	○	○	○	cluttered
attractive	○	○	○	○	○	○	○	unattractive
friendly	○	○	○	○	○	○	○	unfriendly
conservative	○	○	○	○	○	○	○	innovative

Block 3

You have now finished the survey!
Next up we would like to ask your consent for a small interview.

We would like to ask you questions related to digital wellbeing. Your answers will be used to gain qualitative data for this research. In order to create a transcription, the audio of this conversation might be recorded. Only the researcher (Roman Peters) will have access to this audio recording, and the recording will be deleted once it has been transcribed. Any statements you make during this conversation will not be linked to your personal details, and you will stay anonymous in the resulting thesis paper.

If you agree with the above, please fill in your name below and click submit.
If you do not agree for any reason, please do not fill in your name, but still click submit so that your answers to the survey are saved.

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Appendix C

Post-intervention interview

C.1 Interview protocol

The following list of questions was used by the interviewer and define the structure of the interview. The goal was to let the participant share their experiences with the system, with as little guidance as necessary from the interviewer. The interviewer could however use probes to steer the conversation in the right direction.

Digital well-being

- How would you describe your relationship with your smartphone?
  Probes: Are there any smartphone habits you've picked up in your daily life?
- How do you feel about your smartphone habits?
  Probes: Are there any smartphone habits you would like to change?

System evaluation

- How was your experience with the system (ambient information system combined with the companion app)?
  Probes: Any aspects that you liked or disliked? Did anything unexpected happen while using the system?
- Would you consider using a similar system to increase awareness of your smartphone usage?
  Probes: Why or why not? Would you recommend it to someone else? — why or why not?
- Where in your home did you place the ambient information display?
  Probes: What was the reasoning for that location? What would the best location be?

Screen time

- Did you use your smartphone over the last two days?
  Probes: Any changes in smartphone behaviour?
- How did it feel to estimate your own smartphone screen time?
  Probes: What did you think of the measured screen time?

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