Design and Evaluation of the Chai Wallpaper: A Mindfulness-Based Persuasive Intervention for Absent-Minded Smartphone Use

by

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Abstract

Problematic smartphone use (PSU) is a growing concern that hurts users' daily lives and activities. This thesis first examines existing interventions for PSU and identifies research gaps. Previous studies have emphasized the importance of developing mindfulness and self-efficacy concerning smartphone use rather than solely focusing on reducing usage. However, there needs to be more research on developing and evaluating digital interventions specifically targeting absent-minded smartphone use.

To address this gap, we developed the Chai wallpaper application as a novel intervention for absent-minded smartphone use. The application was evaluated over two weeks with 121 participants at different stages of behavior change for smartphone use. The intervention successfully reduced absent-minded smartphone use overall. Although our analysis suggests that the intervention's effectiveness may differ among individuals at different stages of change, additional tests conducted afterward did not validate this observation. Participants found various features of the intervention persuasive, with no significant differences based on gender or stage of change.

This thesis provides valuable insights for advancing human-computer interaction (HCI) research on PSU and enhancing future interventions, including improvements to the Chai wallpaper intervention that will ensure its relevance and usefulness. Additionally, the results raise important questions for future research, such as tailoring interventions to address the specific needs of individuals at different stages of change regarding PSU. Future studies are recommended to explore the relationship between perceived persuasiveness, actual persuasiveness and behavior change. Finally, we contribute to the discussion on the applications of mindfulness in persuasive technology, the challenges and future research areas.

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Chapter 1

Introduction

As of January 2023, there are an estimated 5.44 billion unique mobile phone users in the world, representing 68% of the world's total population [88]. Smartphones have become a part of the lives of many people in all parts of the world. They are used for communication, entertainment, education, work, and other purposes. It is more portable than the laptop and most other computing devices, so it can be used in practically all places and at all times [19]. Indeed, it can be said that the smartphone is indispensable for productivity at school and work.

However, the use of smartphones can become problematic in many ways. When people use their smartphones in unhealthy ways or times, or become addicted to certain apps on their smartphones, it detracts from their experiences and relationships in the real world. This results in a lower quality of life. This problem has become an important issue at the forefront of Human-Computer Interaction (HCI) and other discourses, especially since the onset of the COVID-19 pandemic and the resultant social distancing measures that came with it [8]. HCI researchers have been hard at work developing solutions to problematic smartphone use [199].

In this work, we[1] present a review of the existing solutions for problematic smartphone use (PSU). Then we developed and evaluated a novel contribution, the Chai wallpaper, targeting a specific aspect of PSU, absent-minded smartphone use, building on existing studies and interventions, and using strategies drawn from persuasive technology, mindfulness, and digital nudging.

1.1 Problem Statement

The slang term "Crackberry" was once used to highlight the addictive nature of BlackBerry mobile devices and to compare it in this regard with hard drugs [196]. Since

[1]The first-person plural voice (*we, our, etc.*) is used in this thesis to reflect the fact that the work was done by me, Emeka, under the supervision of Dr. Rita Orji.

the launch of the iPhone in 2007, introducing the current popular smartphone slate form factor, and followed by the first Android phone launched in 2008 [204], smartphones have improved to become even more useful and powerful, and increasingly so with passing years. Many mobile apps have become more immersive, and some, primarily social media apps that depend on advertisement revenue, have been designed to hold the user's attention for as long as possible. This makes self-regulation of smartphone usage a challenging issue, especially for young people who must contend with strategies like notifications and infinite media content feed that are personalized and addictive by design. The problem gets trickier when the same phone is needed for more productive tasks like education or work. This exposes the user to the temptation of attention-seeking and time-consuming apps.

In a 2014 publication titled *"Public Health Implications of Excessive Use of the Internet, Computers, Smartphones and Similar Electronic Devices"* [206], the World Health Organization (WHO) described excessive smartphone and internet use as a significant public health concern in some parts of the world. While noting that the line between normal use and excessive use is hard to define and might be dependent on culture, time, and occupation, the report compared the behavioral disorders that involve the use of the smartphone to substance use disorders because of the manifestation of behaviors like "irresistible urge, impulse or drive to repeatedly engage in an action and an inability to reduce or cease this behavior (loss of control) despite serious negative consequences to the person's physical, mental, social and/or financial well-being" [206, p. 8]. This behavior encompasses a wide range of internet or digital media activities including social media, gaming, gambling, and online pornography.

PSU is frequently studied as a single phenomenon facilitated by the addictive design of smartphones and smartphone applications [199]. There is a large body of work on the negative effects of excessive smartphone use. It has been found to correlate with several negative health conditions such as low self-esteem [49], distraction or frequent inattention, depression, poor sleep quality, sleepiness among students, and lower academic performance.

To make matters worse, when the COVID-19 pandemic struck, several physical distancing measures were put in place simultaneously in almost all countries of the

world. Many workers were made to work from home, students also took classes remotely, and many people were encouraged to stay at home and avoid public social gatherings. This meant that people had to depend on their smartphones or other digital devices for social interaction. More time away from other people meant more time available for smartphone apps. This consequently led to an increase in smartphone use [8, 178, 12]. The pandemic was also a period of increased mental and emotional health issues which are often linked to problematic smartphone use. A recent systematic review of studies that measured smartphone addiction using the Smartphone Addiction Scale [102] found that smartphone addiction is on the rise in many countries of the world [140].

Apart from the mental health impact on the users, problematic smartphone use also poses a threat to the physical safety of the users and others. The term "smartphone zombies" have been used to describe people who use their smartphones while walking on the road, inattentive to the traffic around them [163]. There have been numerous accidents caused by smartphone use by pedestrians.

In summary, while owning and using a smartphone can be very important for productivity and connection, excessive or dysfunctional smartphone use can reduce an individual's overall quality of life.

1.2 Solution

We note again that the smartphone is a very useful tool. It is important to maintain a balance in its use. Completely eliminating smartphone use, even for short periods of time, may not be the ideal solution [25].

There has been a trend, starting in the 1970s, of mindfulness gradually moving from being a tradition found only in Buddhism to integration in mainstream Western sciences [128]: Medicine, Psychology, Psychotherapy, and Human-Computer Interaction (HCI). In HCI, this trend is frequently associated with the digital wellbeing movement, or "The Mindfulness Revolution" as it is referred to by some. One important aim of this movement is to ensure that, in an increasingly digital world, human beings can maintain control over the technologies they use in their daily lives, not the other way around [63]. Over the last two decades, there has been an increase in the number of mindfulness studies in HCI [191] as well as an increase in the number

of consumer applications that integrate various components of mindfulness.

On the other hand, the field of persuasive computing offers several well-studied methods for encouraging users to change to and maintain healthier behaviors. Several strategies have been proposed within different persuasive design models including the Persuasive System Design (PSD) model [135], Cialdini's Principles of Persuasion [38], and Fogg's persuasive technology tools [52]. Combining both mindfulness principles and persuasive technology strategies, we came up with a solution that will subtly discourage absent-minded use of the smartphone. We designed a mindfulness-based Android live wallpaper designed to keep the user aware of their usage patterns and of the real world with the goal of helping them use their devices in a healthier way. This intervention is designed to be well integrated into the user's daily lives, without interrupting or interfering with their other activities, and hence it is hoped that the self-regulation learned from the intervention will be retained even when the intervention is withdrawn.

1.3 Contributions

The contributions of this thesis include:

First, a systematic review of existing digital interventions targeting problematic smartphone use. The results of this review and the subsequent discussions will furnish researchers or other individuals interested in this domain with a comprehensive overview of the existing interventions, and insights into the gaps in the literature.

Second, we designed, developed, and evaluated a novel intervention, the Chai wallpaper, based on the findings from the review. The intervention seeks to build on existing knowledge to create a more sustainable solution to absent-minded smartphone use.

1.4 Overview of the Thesis

The rest of this thesis is organized as follows:

In Chapter 2, we provide a background to the work we have done in this thesis, including the definition and effects of problematic smartphone use. Then we review related works, describing the process and results of a systematic review

of existing interventions in HCI targeting problematic smartphone use, and going into details of the theoretical foundations of the interventions.

In Chapter 3, we detail the various stages of the design and development of the Chai wallpaper application.

In Chapter 4, we outline the processes of the user study that we conducted to evaluate the Chai wallpaper application.

In Chapter 5, we present the results of the user study.

Chapter 6 is a discussion of the results from the user study, recommendations, and implications for future work.

In Chapter 7, we conclude the thesis with a summary of the work done and a discussion of the limitations of the study and how they can be surmounted in future work.

Chapter 2

Background & Related Work

In recent years, issues around smartphone use have been of interest to both researchers and the general public. In the media, there is a growing concern about the negative effects of smartphone use on the mental health of users with films like *The Social Dilemma (2020)* [147] and *BlackBerry (2023)* [81] highlighting the problem. In the research community, there is a growing body of literature exploring the effects of smartphone use on sleep, mental health, depression, and other factors related to quality of life.

In this chapter, we start by defining and discussing in more detail the problem of problematic smartphone use. Following that, we report the method and results of a literature review of digital interventions that target problematic smartphone use. In the discussion of the reviewed interventions, we focus on the theoretical foundations of the solutions developed. These include persuasive technology and strategies (with a focus on the widely used persuasive systems design model), mindfulness, digital nudging, and other concepts. While doing this, we pay closer attention to the concepts and interventions that relate to or influenced the design and evaluation of the Chai wallpaper developed in this study.

2.1 Problematic Smartphone Use

2.1.1 Definition

Problematic smartphone use (PSU) is defined by Busch and McCarthy as "a compulsive pattern of smartphone usage which can result in negative consequences that impair the daily functioning of the user" [29, p. 2]. There are several specific components that are part of this problem including online gambling, social media overuse, online pornography addiction, and many others [206]. While there are studies that focus on some of these specific aspects of PSU as against a holistic approach [123],

the problem has frequently been viewed and defined as a misuse of the technology itself, to the detriment of other aspects of life [29, 23].

The problem is commonly traced to the launch of the iPhone in 2007 [199, 47, 69, 158, 86, 17] even though smartphone overuse had been studied before then [196]. Some of the factors that facilitate problematic use of the smartphone have been shown to include constant availability and the addictive design of smartphone applications [199], as well as the emotional health of the user [29]. These point to the fact that the smartphone itself, as the vector for all these unhealthy behaviors, is an important factor that deserves attention.

To further clarify the terminology, we should mention that there are some other related or overlapping terminologies that are used in the literature such as *smartphone addiction*, *smartphone dependence*, *nomophobia* (fear of being without the smartphone), *smartphone use disorder* [168], *problematic mobile phone use* [181], *problematic internet use* (or *pathological internet use*) [44], *problematic social media use* [123], etc. Some of these terms are encompassed within the scope of PSU, others are synonymous, while others, like smartphone addiction, are not widely accepted to be representative of the problem [152, 186]. In this thesis, we lean towards the more commonly accepted term PSU. We outline the scope of this term in the next section and subsequently introduce absent-minded smartphone use which is the specific problem that we focus on later in the thesis.

2.1.2 The Scope of the Problem

PSU encompasses a wide range of behaviors including but not limited to compulsive use, social media addiction, and use of smartphones while in conversation with others or while driving. There has been plenty of research on the effects of PSU. PSU is a problem on many levels. It is a problem for the individual who misuses the smartphone, for the family and friends of the individual, and for the society or the organization that they belong to.

At the individual level, problematic smartphone use has been found to be linked with low self-esteem [49, 105, 126] and stress, anxiety or depression [4, 71, 70]. Longer screen time has been associated with poor sleep quality [206, 36, 213, 104, 209, 212, 209, 213] and lower quality of life [106] and lower academic performance [174, 73,

127, 97].

With family and friends, PSU can lead to conflict and tension [23] and can also cause financial problems [23]. At the societal and organizational levels, excessive attachment to the smartphone leads to a loss of sense of community [199]. The impact of PSU is also manifested on the roads in the form of dangerous driving due to distraction from smartphones [183] or accidents caused by pedestrians who are distracted by their smartphones while using the road [206], a phenomenon referred to colloquially as being a *smartphone zombie* [13]. Mobile phone use leading to driver distraction has been identified to be a serious road safety concern [205, 211]. PSU can also lead to a loss of productivity in the workplace [23]. Smartphone use also has an environmental impact as the use of digital media (especially online video) contributes a significant amount to the global carbon footprint [46].

2.1.3 Absent-minded Smartphone Use

Absent-minded smartphone use can be considered a subset of PSU, manifested in the habitual, aimless use of the phone leading to periods of mindless smartphone use that cause feelings of guilt or regret later. While it is the focus of some of the interventions we have discussed [190, 68], there has been generally little research output specifically on absent-minded smartphone use.

It is nonetheless an important part of the problem. Multiple research evidence has emerged to show that quantity matters less than quality when it comes to time spent on smartphones. For example, Shaw et al. [180] found that self-reported PSU scales were more strongly associated with mental health than objective logs or markers of smartphone use or subjective estimates of those objective markers. Keller et al. [86] conducted a study with a goal-directed smartphone use intervention and found that improvement in self-efficacy correlated with a reduction in PSU. Higher mindfulness has been associated with lower strengths of risk factors for PSU such as boredom and impulsivity [169]. In line with this, more recent research seem to focus less on disengagement, and more on promoting intentionality about smartphone use, ensuring that people do not feel guilty about or regret time spent on their devices [25, 33]. A critical part of promoting intentionality is mitigating absent-minded use.

2.2 Review of Existing Digital Interventions for PSU

From the foregoing discussion, PSU is a problem that has a wide range of consequences. Especially given the difficulty of self-regulation, it is important to develop interventions that can help people to moderate their use of the smartphone and to live more fulfilling lives.

There has been an increasing interest in the field of HCI to develop solutions for problematic smartphone use. This has resulted in several digital interventions targeting this challenge. We conducted a literature review of such interventions for PSU. The goal of the review was to identify the different approaches that have been used to address the problem of PSU on digital platforms, what platforms have been used, evaluation methods for these solutions, and identify the gaps in the literature that our work can fill.

In this section, we report the method by which the systematic review was conducted, discuss the reviewed works and how their implementation and theoretical foundations influenced or served as context for the intervention reported in the subsequent chapters of this thesis.

2.2.1 Method

We followed a systematic process to search for and review related literature as described below. A flow chart of the study identification and screening process as recommended by the updated Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) [151] is shown in Figure 2.1.

Database search Guides to systematic reviews recommend that researchers conduct their search with at least two databases [182]. We searched four databases: the ACM Full-Text Collection through the ACM Digital Library (ACM DL), IEEE Xplore, Scopus, and Web of Science (WoS). ACM and IEEE are premier publishers of HCI and computer science studies. WoS and Scopus are aggregator databases that we used to ensure that we find relevant studies that may not have been published by either ACM or IEEE. Our search term for all the databases are given below:

("smartphone" OR "smart phone" OR "mobile") AND ("use" OR "usage"

OR “addict*” OR “problematic” OR “absent-minded”) AND (“intervention” OR “prototype”)

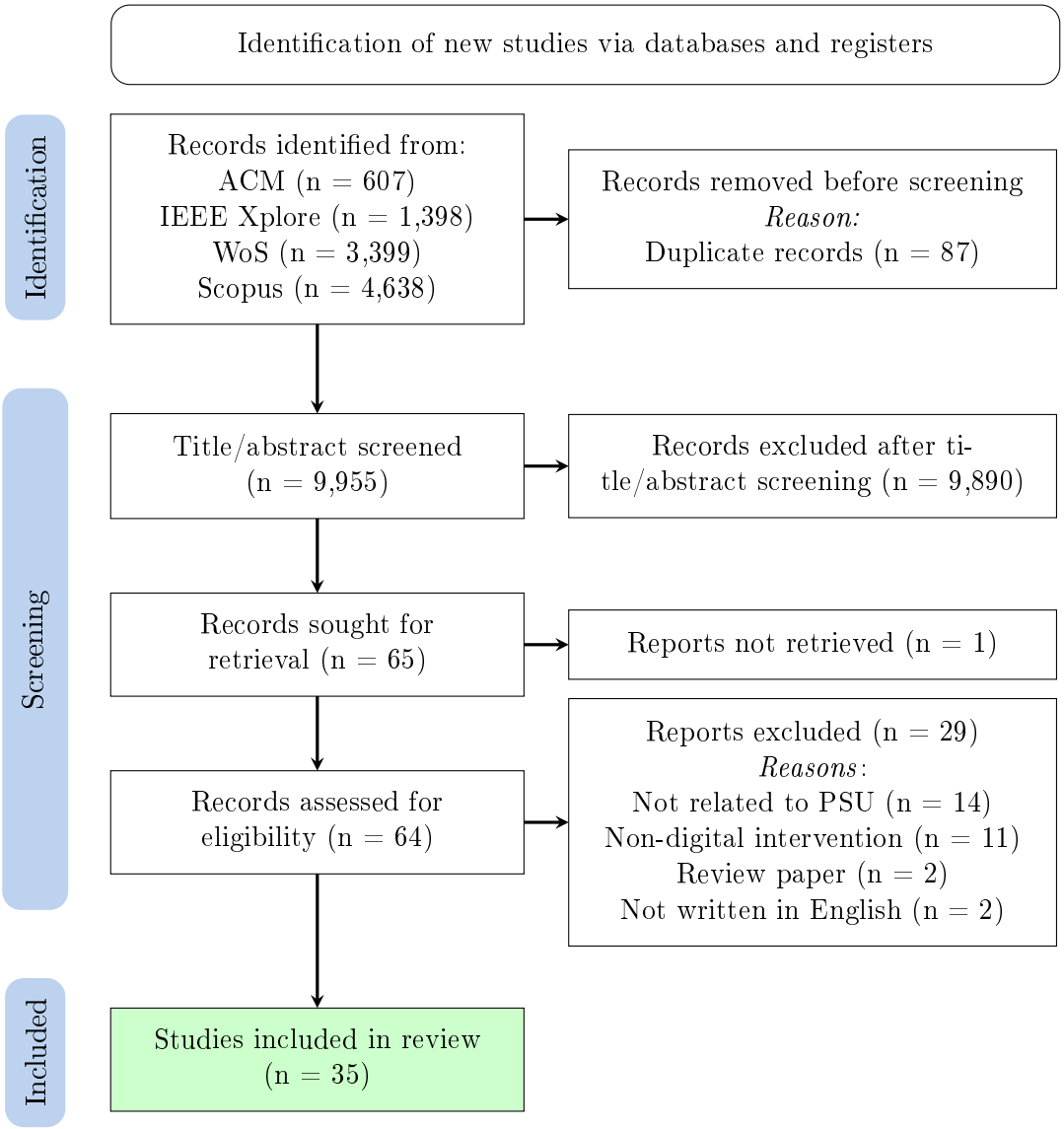

Figure 2.1: Study identification and screening flow diagram.

We limited the search to papers published within the past 10 years (2012 to 2023) to make sure that we got the most relevant related works. The search was conducted twice: ACM and WoS were last searched on the 26th of February 2023. In order to obtain additional results, we further searched IEEE Xplore and Scopus on June 23rd, 2023 using the same query. 10,042 results were obtained in total (607 from ACM, 1,398 from IEEE Xplore, 3,399 from WoS and 4,638 from Scopus).

Title and abstract screening We made use of ASReview Lab [197] to screen the search results based on title and abstract. ASReview uses an active learning algorithm to accelerate the screening stage of the systematic review by presenting the most relevant papers to the researcher based on the already included papers.

Our inclusion criteria included: (1) the study had to have designed, developed and evaluated a digital system for reducing problematic smartphone use, (2) the paper is written in English.

The screening was done by a single human researcher. In order to increase the rigor of the procedure, we employed zero-shot annotation using FLAN-T5-XL [37], a large language model (LLM) developed and made open source by Google researchers. The use of LLMs in collaboration with human researchers in computational social sciences has been studied and found to be advantageous in previous research [215]. The FLAN-T5 models in particular achieve strong zero-shot performance because they have been finetuned on a wide range of sequence-to-sequence tasks [37]. To use this model, we wrote a Python script utilizing the Huggingface Transformers library to run boolean QA inference for each of the retrieved papers. Our query was *"yes/no, is an intervention for problematic smartphone usage developed in this study?"* together with the paper title and abstract as context for the query. This is a simplification of our inclusion criteria. The aim of using the transformer at this stage of the screening was to reduce the probability that a paper was wrongly included or excluded by the researcher. So after running the inference, we re-screened the studies where the human researcher and the LLM disagreed and manually resolved those cases.

Full-text review & coding After the screening, we commenced the full-text review. 35 studies were included after the full-text review. While reviewing the studies, we used a spreadsheet to extract and code the relevant information about each study.

2.2.2 Distribution by Year of Publication, Country & Publisher

The studies included in our review were published between 2013 and 2023 with a sharp increase starting from 2020 possibly showing a rising interest in the problem among researchers (Figure 2.2).

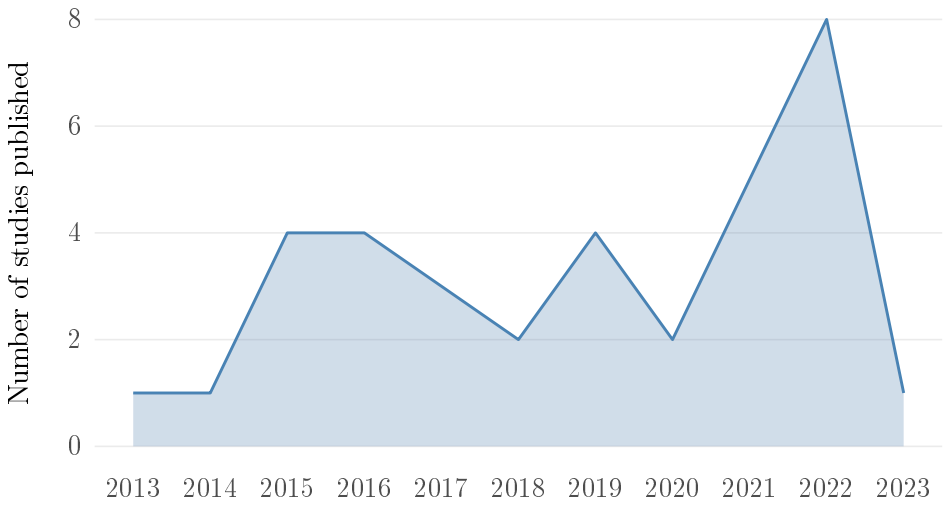

Figure 2.2: Number of works per year

This roughly corresponds to the inception of the COVID-19 pandemic, suggesting that the pandemic might have contributed to the increased research interest.

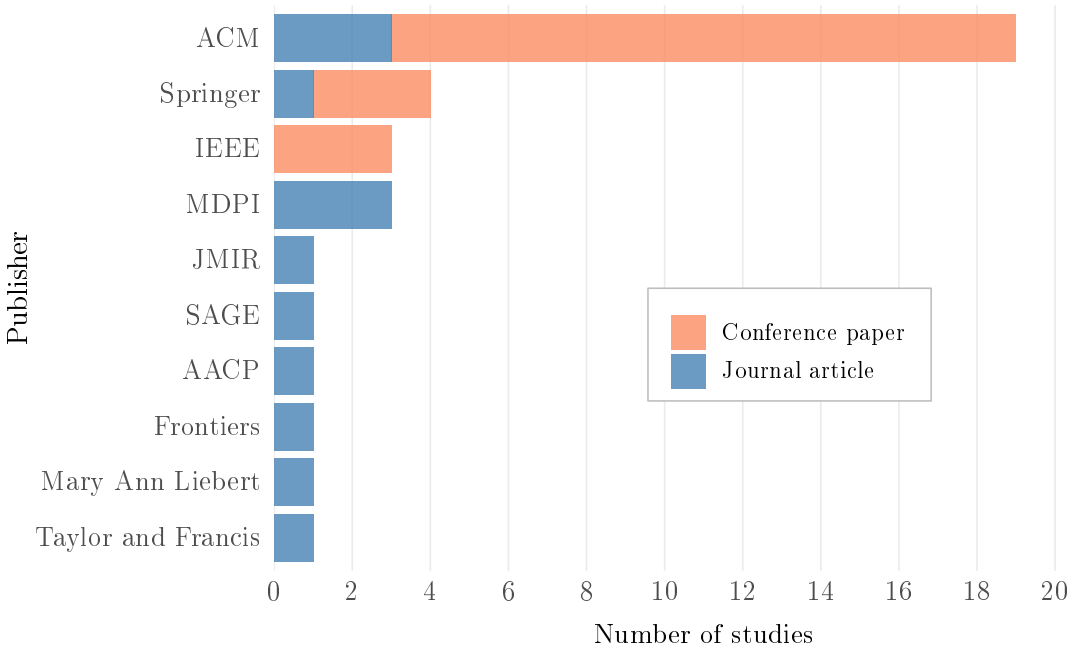

Figure 2.3: Distribution by publisher and venue type

The studies were published by 10 different publishers with ACM being the most

frequent (Figure 2.3), and by researchers in 10 different countries (Figure 2.4).

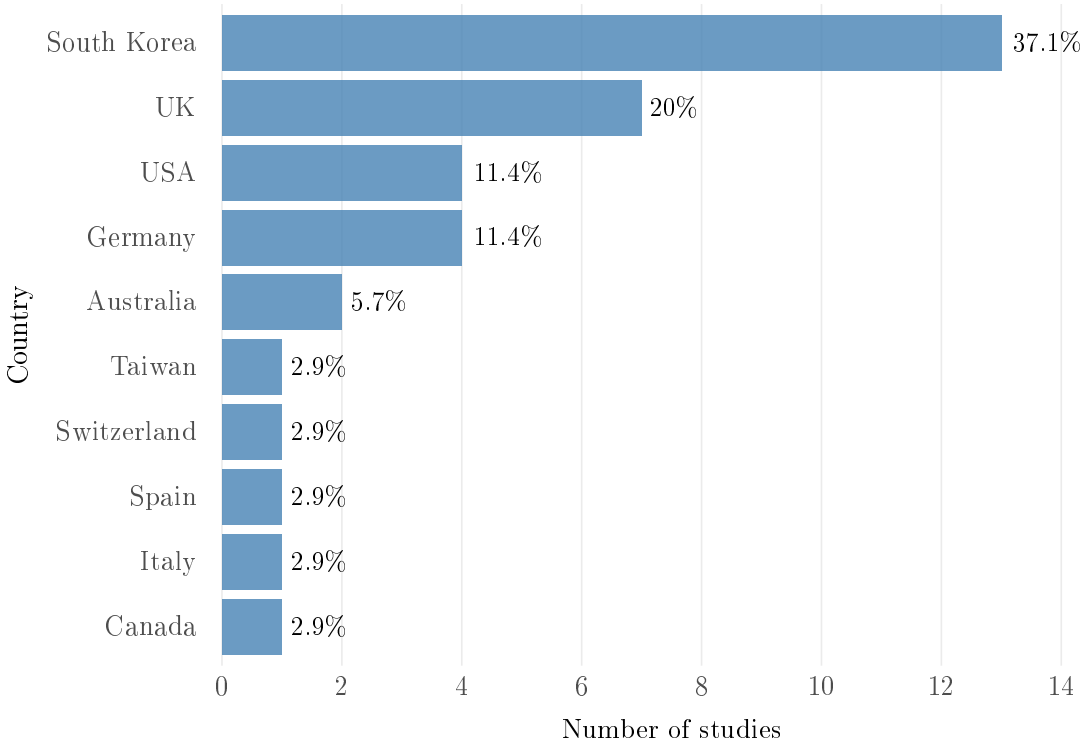

Figure 2.4: Distribution by country where the research was conducted. South Korea has a rather large representation in our corpus.

There is a large number of studies from researchers in South Korea, representing 37% of all the reviewed studies (Figure 2.4). This could be the result of the combination of several factors. South Korea has had one of the highest smartphone penetration rates in the world [84, 184] as well as one of the best mobile network experiences in terms of download speed and 4G availability [24]. The South Korean government has also introduced and supported interventions to contain smartphone and internet addiction [79]. The amount of problematic smartphone research from the country and some other Asian countries has been noted in previous studies [152] and can be used to highlight the culture-bound nature of what is seen as problematic smartphone use. Societies that encourage communal or collective living and interactions would likely regard excessive smartphone use as more problematic than individualist cultures.

2.2.3 Intervention Stages

Interventions for problematic smartphone usage are applied before, during or after the user engages in the problematic behavior.

When applied **after** the behavior (also known as reactive interventions), the intervention aims to track the user's smartphone usage and make the user reflect on their behavior after they have completed said behavior. Some examples of systems in this category include NUGU[1] [100]. Several screentime monitoring applications available for Android and iOS also fall in this category, such as Google Digital Wellbeing [63] and Apple Screen Time [14]. Most interventions that target the user before and during the behavior also include elements of self-monitoring as additional features. Self-monitoring alone after the behavior has been shown to not be effective for PSU behavior change [216].

When applied **during** the behavior, the intervention seeks to stop the user at the moment when they are actively engaged in the behavior. These are commonly implemented in the form of popup dialogs like in MyTime [75] or haptic feedback like in GoodVibrations [138] that are activated when the user spends more time on their device or on some specific app beyond a set time limit.

When applied **before** the behavior, the intervention seeks to prevent the user from engaging in unproductive use of their device. When delivered right at the onset of the target behavior, they are known as just-in-time interventions [175]. These are more effective for preventing absent-minded smartphone use. Some examples of interventions in this category include TypeOut [207] where the user is required to type the answer to a self-affirmation question each time they open some selected applications, and MindPhone [190] where the user is presented with a question for reflection each time they unlock their device. The Chai application developed for the purpose of this thesis is an example of an intervention for problematic smartphone use that targets the user before they engage in the behavior.

2.2.4 Platforms

The large majority (62.9%) of the studies we reviewed developed interventions available only to users of the Android operating system, as shown in Figure 2.5. There

[1]NUGU: **N**o **U**se is **G**ood **U**se

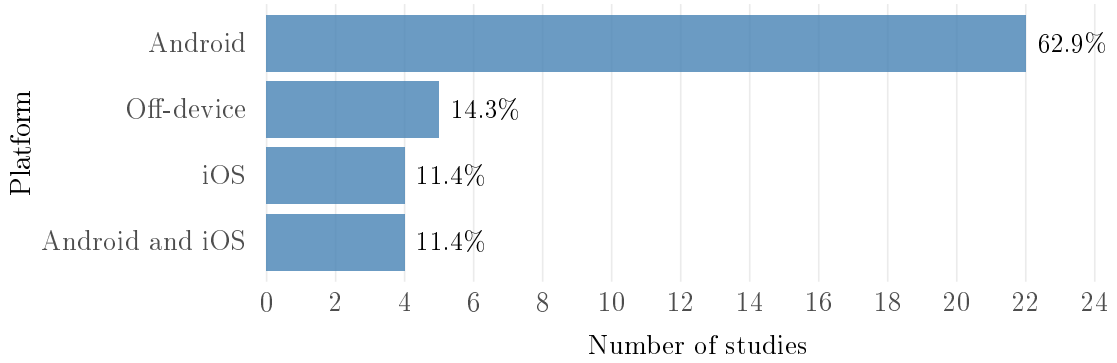

Figure 2.5: Distribution of platforms on which the interventions were deployed. There are only a few of the reviewed digital interventions for PSU available on the iOS platform.

were only 8 software-based interventions that targeted iOS users. This is most likely because of the more restrictive nature of the iOS platform. For instance, some of the functionalities of AppDetox will require elevated or root access on iOS to be implemented there. Functionalities that leverage OS-specific features of Android may simply not be possible on iOS. For instance, Kim et al. [93] reported the inability to block notifications or prevent the launch of apps on the iOS platform. Again, the live wallpaper feature of Android that was used in the development of the Chai wallpaper is not available on iPhones. This exposes a research gap that could be closed by future interventions since iOS users make up a significant proportion of smartphone users. It is also worth noting here that iOS users have been found to be more receptive to tools to monitor or control smartphone use than Android users [1].

On the other hand, there is a notion that interventions for problematic smartphone use should not be deployed on smartphones. Hence some recent interventions for problematic smartphone use are based on some other platform aside from the smartphone itself. In Haliburton et al. [68] a physical box by the bedside is used as a physical barrier between the user and the device; Pinder et al. [159] used a CBM-Ap intervention on a table-top to counter automatic approach biases towards smartphones; in Choi et al. [35], a physical doll is used to regulate smartphone use by individuals in social situations. Stepanovic et al. [187] explored alternative physical form factor designs for smartphones to support intentional use.

Table 2.1: Summary of the reviewed interventions for PSU with brief descriptions of the mechanism by which they persuade the user. The studies are roughly sorted to start with the more recent ones. A more detailed table is available in Appendix A

Intervention	**Brief description**
Zimmermann & Sobolev [217]	Participants switched phone display to grayscale and used the Screen Time app for **self-monitoring**.
TypeOut Xu et al. [207]	Just-in-time interventions on target app launch that require users to **type out messages** based on the **self-affirmation** theory.
MindPhone Terzimehić et al. [190]	A **mindfulness**-based intervention that **prompts** users to answer (type out or reflect upon) a question when they unlock their phone, to reduce absent-minded use.
Haliburton et al. [68]	A study with a box as a **physical barrier** between the user and their device to regulate bedtime usage.
Ochs & Sauer [134]	One of two design changes is applied to participant phones: grayscale display, or move apps into folders a few pages removed from the main home screen.
Olson et al. [139]	Various intervention strategies including reducing phone brightness, turning off notification sounds, disabling touch/face id, leaving phone at home, etc.
Lyons et al. [120]	Interruption-based service that allows users to select applications and set time periods within which they wish to use those applications.
Myers et al. [129]	Various intervention strategies including changing phone display to **greyscale**, turning off social media notifications, removing social media icons from the home screen, etc.

Continued next page

Table 2.1 – continued from previous page

Intervention	**Brief description**
MindsCare Lee et al. [108]	"... when the target time is exceeded or if it is predicted to be problematic, the smartphone's alarm announces that usage time is being managed." [108, p. 3]
GoldenTime Park et al. [155]	An app that **rewards users with virtual gold coins** followed the time limit rule that they set for themselves, as well as sends them **reminders** when they exceed or are near the time limit.
FeelHabits Roffarello & De Russis [171]	A system with which users can set **limits of use on applications** on both smartphone and PC browsers. Users either get **notified** when the time limit is crossed or **access to the app is blocked**.
Not Less But Better Keller et al. [86]	An intervention in the form of a series of exercises to promote psychological resources for **goal-directed smartphone use**.
Holdable devices Tiersen & Calvo [194]	"Biofeedback-based tangible interfaces that sense when smartphones are used inattentively or compulsively from the motion of the hand behind the phone and gently alert users to regain **mindfulness** through haptic feedback and abstract visualization." [194, p. 1]
Phone Life Balance Kent et al. [89]	Timed messages delivered to the participants' smartphones. The contents of the messages were **personalized** based on the **users' set goals**.
Potapova et al. [160]	An application to **visualize smartphone usage** and **block distracting apps**.

Continued next page

Table 2.1 – continued from previous page

Intervention	Brief description
Throuvala et al. [193]	An evaluation of the effectiveness of 3 consumer apps for reducing distraction from smartphones. The apps offered **mindfulness**, **self-monitoring**, and **mood-tracking** features.
GoalKeeper Kim et al. [95]	A smartphone intervention app that **locks the user into self-defined daily use times** with restrictive intervention mechanisms.
LocknType Kim et al. [96]	An intervention that makes the user **type in some digits** with varying workloads when they try to launch any of some previously selected apps.
Lu & Lo [118]	A **popup reminder** or blank screen that is shown on the user's smartphone when walking is detected to remind them not to use their phone while walking. Push notifications are also hidden.
Pinder et al. [159]	Push away smartphones on a bedside table and pull toward the user a book.
GoodVibrations Okeke et al. [138]	An intervention that uses **haptic feedback** to remind users that they have exceeded their set time limit.
Interaction Restraint Park et al. [156]	**Mandatory cognitive tasks** that users have to complete before launching selected applications.
Let's FOCUS Kim et al. [93]	Location-based virtual rooms when a user is in one of them, they are not able to launch certain applications, and **notifications from those apps are also muted**.
SCAN Park et al. [153]	A social context-aware smart notification system for breakpoint-based notification management.

Continued next page

Table 2.1 – continued from previous page

Intervention	Brief description
PomodoLock Kim et al. [94]	Based on Pomodoro technique principles, users can **block out interruptions** from multiple devices for specific periods of time during which they intend to focus.
MyTime Hiniker et al. [75]	A system that pops up a dismissible "Time's Up!" dialog when the user-defined time limit for selected apps has elapsed. Also, a timer in the notification and **daily aspiration prompts**.
MindsCare Lee et al. [107]	A PC app used for **visualization and self-monitoring** of smartphone usage.
LockDoll Choi et al. [35]	A tangible cat-shaped doll that reminds users to not be distracted by their devices when in a group.
PreventDark Ruan et al. [173]	An Android app that can automatically detect and send a **warning message** when the user is using the smartphone in a dark environment.
NUGU Ko et al. [100]	An app for self-regulation of smartphone use through leveraging **social support**: groups of people limit their use together by sharing their limiting information.
Park & Gweon [154]	A **decisional balance exercise** used to resolve the ambivalence of smartphone users by making them aware of the pros and cons of PSU.
Eddie et al. [45]	"...a series of **discouragement messages** that become steadily more intrusive as the user continues using their phones." [45, p. 3]

Continued next page

Table 2.1 – continued from previous page

Intervention	Brief description
Lock n' LoL Ko et al. [99]	An app that allows the creation of virtual rooms in which smartphone use is limited by **locking the screen and the usage of other apps**, as well as **muting notifications**.
ATLAS Lubans et al. [119]	An app that accompanies a non-digital intervention. Mostly for **self-monitoring**.
AppDetox Löchtefeld et al. [115]	An application for creating rules for **restricting access to selected apps** on the user's device.

2.2.5 Evaluation of the Interventions

The most common evaluation method for the developed interventions was the pre-post study design [139, 190, 159, 86, 119]. Semi-structured interviews or focus groups were also used in some studies after the participants have interacted with the intervention, especially with interventions developed for off-device platforms which are not widely available for the participants [94, 119, 35, 99]. One study, the AppDetox study [115], monitored and analyzed anonymous user logs from the app over 8 months.

Because of this variation in the types of studies, the number of participants used for the evaluations ranged widely from seven to 11,700. Figure 2.6 shows the ranges and frequencies for participant count in the reviewed studies. More than half of the interventions were evaluated on 50 participants or less.

In terms of the duration of the user study, many of the studies with pre-post design employed a 1, 2, or 3-week intervention period [138, 96, 100, 68, 94]. In addition to this, some of the studies included an initial 1 week for baseline data collection [138, 155, 95, 96], and some included 1 week follow-up period to study the participant behavior after the intervention is withdrawn [68, 138]. There are also larger-scale longitudinal studies that included several participants for longer periods of time [108, 207]. Focus group or interview duration ranged from a few minutes to a day or went unreported [194, 118, 35, 119, 99]. See Appendix A for more details about the studies including the study durations.

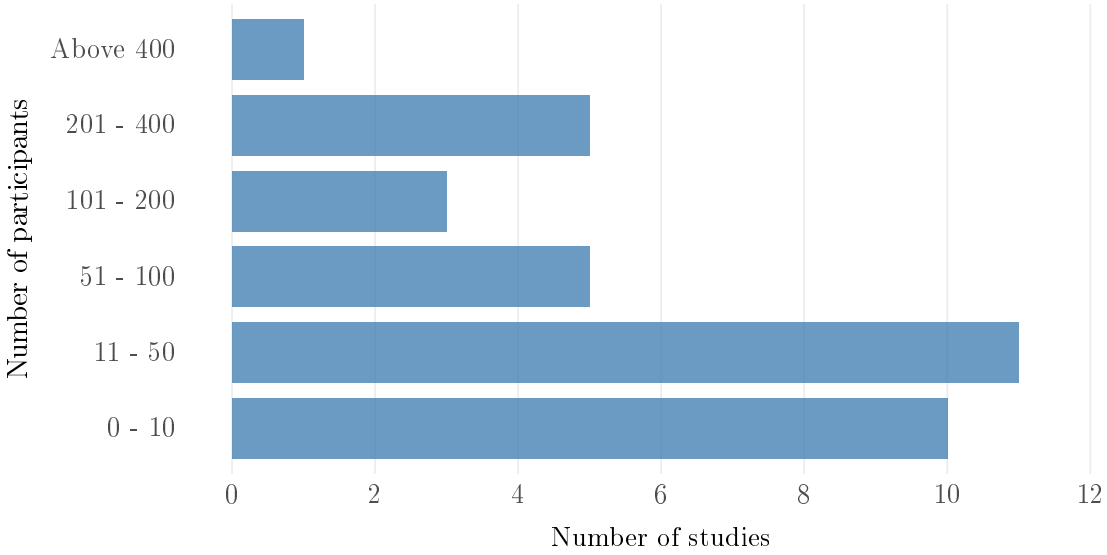

Figure 2.6: Distribution of participant numbers in the studies

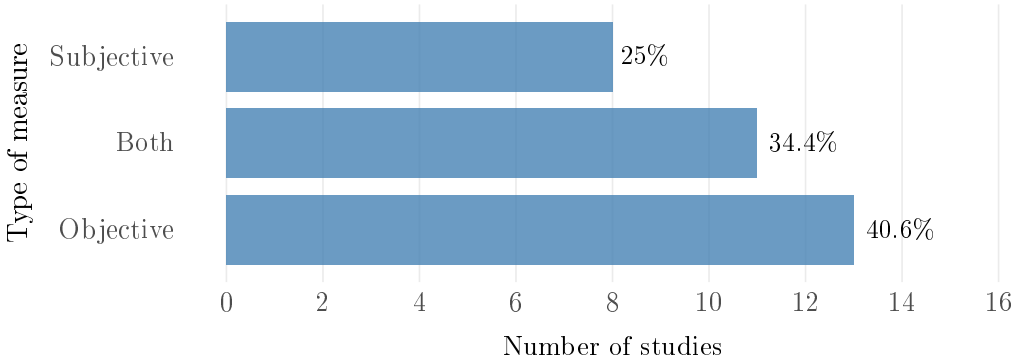

Figure 2.7: Distribution by type of PSU measure

The reviewed studies used various instruments to measure PSU, including objective measures such as screentime and number of unlocks, as well as self-reported or subjective survey scales. 14 studies used solely objective measures to measure PSU, while the remaining studies used subjective measures like self-reported scales, sometimes together with objective measures (Figure 2.7). We also found that all but three of the more recent studies (published not later than 2020) incorporate subjective measures of PSU, and some of those that did not reportedly plan to include it in their future evaluations [108]. This is important as previous studies have found that self-reported PSU scales were more strongly associated with mental health than

objective measures [180] and that objective and self-reported measures correlate very weakly with each other [48, 157]

The scales used to measure PSU or related variables are presented in Table 2.2. The Smartphone Usage Questionnaire - Absent-minded (SUQ-A) scale, which is used to measure absent-minded smartphone usage was used in only two of the reviewed studies. The PSU-related scales are used together with other measures depending on the research questions. For instance, the Mindful Attention Awareness Scale (MAAS) [28] was used in some of the studies to measure mindfulness [89], while scales like Positive and negative affect scale (PANAS) [201] were used to measure wellbeing [134, 139].

Table 2.2: PSU-related scales used in reviewed studies

Scale	Studies
Smartphone Addiction Scale (SAS) [102]	[194, 207, 154, 100]
Shortened Smartphone Addiction Scale (SAS-SV) [101]	[107, 139]
Smartphone Usage Questionnaire - Absent-minded (SUQ-A) [124]	[190, 68]
Mobile Phone Problematic Usage Scale (MPPUS-27) [22]	[134, 89]
Mobile Phone Problem Use Scale (MPPUS-10) [51]	[86]
Smartphone Dependence Scale (SDS) [200]	[217]
Social Media Disorder Scale (SMD) [198]	[194]
Problematic Use of Mobile Phones (PUMP) [125]	[194]
Smartphone Distraction Scale (SDS)	[193]
Online Vigilance Scale (OVS) [170]	[193]
Bergen Social Media Addiction Scale (BSMAS) [11]	[193]
Fear of Missing Out Scale (FoMOS) [165]	[193]
Nomophobia Questionnaire (NMP-Q) [208]	[193]
Internet Addiction Test (IAT) [210]	[89]

2.2.6 Findings from the Interventions

Excluding studies like [173] which did not report evaluation for PSU efficacy but only the usability of the intervention, we categorized the results reported in the studies into three groups based on the significance of the impact on problematic smartphone use, as shown in Figure 2.8.

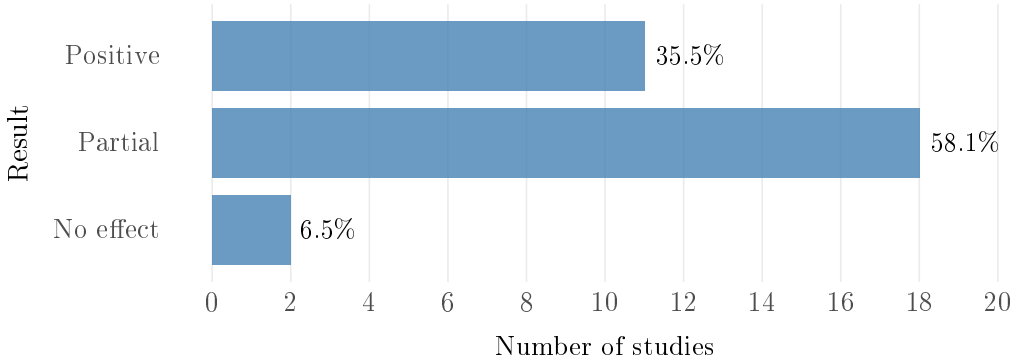

Figure 2.8: Distribution by result category

1. *Positive*: For studies in this category, the results show significant effectiveness for reducing PSU. For instance, the TypeOut intervention [207] reduced objectively measured app usage and app opening frequency. Similarly, interventions using strategies like interaction restraint [156] or design friction like setting display to grayscale [217] reported significant reductions in objective smartphone use measures.

2. *Partial Positive*: In this category, the results are mixed, showing potential effectiveness for reducing PSU but with some inconclusive evidence or mixed findings. Examples include results such as a decrease in self-reported measures but not in some objectively measured variables [86, 193] or vice versa [134]. Qualitatively evaluated systems were also included here if there were limitations reported like inconveniences on the part of the participant, as in the Lock n' LoL system [99].

3. *Neutral/No effect*: The results failed to reject any of the stated or implied null hypotheses, or did not significantly reduce PSU. We had two studies in this category, including the study by Lu and Lo [118] where user interface redesign

was not found to reduce the risk of impaired visual attention due to smartphone use while walking.

2.3 Theoretical Bases of Existing Interventions

In this section, we review the existing interventions by looking at the theories or models underpinning their implementations. These include persuasive systems design and mindfulness, both of which we discuss in some detail because they were important to the design of the Chai wallpaper. In addition, we discuss other strategies such as digital nudging, and lockout.

2.3.1 Persuasive Systems Design

PSU as we have seen is a behavior or habit problem. This means that it can be (and has been) tackled with persuasive systems, which are the tools that HCI researchers and industry practitioners use to influence users for healthy behavior change. For a formal definition, persuasive systems are "computerized software or information systems designed to reinforce, change, or shape attitudes or behaviors or both without using coercion or deception" [136].

Within the domain of persuasive computing, several frameworks or design models have been proposed including the Persuasive Systems Design (PSD) model [135, 137], Cialdini's Principles of Persuasion (which includes six persuasive strategies) [38], and Fogg's persuasive technology tools [52]. There are other models that are frequently used to guide the understanding of various components or concepts that relate to persuasion: the ARCS model of motivation [87], the Transtheoretical Model (TTM) of behavior change [164]. These frameworks are frequently combined with each other in the evaluation of persuasive systems.

The Persuasive Systems Design (PSD) Model

The PSD model was introduced by Oinas-Kukkonen and Harjumaa [135] in 2008 as a systematic framework for the design and evaluation of persuasive systems. It categorizes 28 persuasive design principles into four groups: *primary task support*, *dialogue support*, *system credibility support*, and *social support*. Each of the four

groups contains seven strategies or design principles. A schema of the PSD model is shown in Table 2.3.

Table 2.3: The PSD model (Source: Lehto and Oinas-Kukkonen [109], adapted from Oinas-Kukkonen and Harjumaa [135])

	Persuasive Design Features			
Persuasion Context	**Primary Task Support**	**Dialogue Support**	**Credibility Support**	**Social Support**
The Intent Persuader Change type The Event Use context[a] User context[b] Technology context[c] The Strategy Message Route	Reduction Tunneling Tailoring Personalization Self-monitoring Simulation Rehearsal	Praise Rewards Reminders Suggestion Similarity Liking Social role	Trustworthiness Expertise Surface credibility Real world feel Authority Third party endorsements Verifiability	Social learning Social comparison Normative influence Social facilitation Cooperation Competition Recognition

[a] Problem domain dependent features
[b] User dependent features e.g. goals, motivation, lifestyles, and others
[c] Technology dependent features

The strategies in the **primary task support** category aid the user in carrying out their primary tasks. The strategies in this category are reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal. *Reduction* requires that the persuasive system should reduce the effort the user has to put in to perform the target behavior, while *tunneling* involves providing the user with a well-defined path to the target behavior. *Self-monitoring* is one of the most common strategies and it is a means of providing performance tracking for users. It allows a user to observe themselves as they work towards a goal. *Personalization* and *tailoring* means that the system content is customized to the individual user and their needs (personalization), or to user groups (tailoring). *Simulation* gives the user the opportunity to observe the cause-effect relationship between behavior and outcome, and similarly, *rehearsal* provides a means for users to practice the target behavior.

The **dialogue support** category strategies facilitate computer-human dialogue for the purpose of persuasion. It includes praise, rewards, reminders, suggestion, similarity, liking, and social role. *Praise*, *rewards*, *reminders*, and *suggestion* are all features that can be embedded in a user's interaction with a computer system to nudge them towards a target behavior. *Liking* is a strategy that involves making the system appealing to the user. *Similarity* is a strategy that involves making the system mirror the user in some way. *Social role* is a strategy that involves making the system assume a social role in the life of the user, for example a virtual therapist.

The **system credibility support** category includes strategies that make the system more credible and hence more persuasive. It consists of trustworthiness, expertise, surface credibility, real-world feel, authority, third-party endorsements, and verifiability principles. The principle of *trustworthiness* implies that the system should provide truthful and unbiased content. *Expertise* requires the system to manifest expertise. *Surface credibility* means that the system must look competent and professionally developed. *Real-world feel* requires that the system provide information about the real people or the organization developing the system. *Authority* means the system should cite or refer users to expert sources. *Third-party endorsements* means that the system should provide information about the third-party endorsements or validations it has received. *Verifiability* requires the system to provide a means for the user to verify the information or content in the system.

The **social support** category includes strategies that leverage social influence to persuade users. These include social facilitation, social comparison, normative influence, social learning, cooperation, competition, and recognition. *Social facilitation* means that the system should provide a means for the user to observe other users who are performing the target behavior. *Social learning* goes further to allow the user to observe the outcome of the behaviors of others, while *social comparison* compares the user's performance with those of others engaged in the target behavior. *Normative influence* leverages social norms of individuals in a group to promote a behavior. *Cooperation* and *competition* involve providing means for people to cooperate or compete while working towards the target behavior. *Recognition* requires the system to publicly acknowledge users who perform the target behavior.

We have only defined briefly the categories and strategies that make up the PSD

model; more information about the design principles including example implementations can be found in the original paper [135]. In the next section, we discuss how some of these principles are being used in the design of persuasive systems; and further, how they have been used for tackling problematic smartphone use.

Applications of the Persuasive Systems Design Model

So far in this chapter, we have defined the PSD model and the design principles or strategies outlined in that framework. These design principles or strategies have become one of the major guides to the design and analysis of persuasive systems in many different domains, with health being the most significant area of application [98].

Physical activity promotion interventions can help users adopt healthy physical activity behaviors and improve their overall well-being. A fitness app, for example, may use the principle of self-monitoring to encourage users to track their daily physical activity levels. Social support strategies of competition (leaderboards), social comparison (showing how a user's activity levels compare to those of their peers), and cooperation are also commonly used in persuasive apps [9] as a source of motivation for users to increase their physical activity. There are numerous other examples of persuasive interventions for physical activity [218, 195, 111], as well as several physical activity apps available on the Google Play Store or Apple App Store.

In the same way, these strategies are also applied to various other health domains [143] including smoking [90, 20], healthy eating [50], dental health [130], sexual health [132], disease self-management [31] and stress management [7].

Outside the promotion of health and wellbeing, persuasive systems have been used for changing attitudes in other areas too. The PSD model has been used to design interventions that encourage users to engage in eco-friendly behaviors toward environmental conservation. For example, a smart thermostat app may use the principle of feedback to show users how their energy usage compares to that of similar households. Additionally, social support strategies, such as showing how many other users are engaging in eco-friendly behaviors, can motivate users to reduce their energy consumption [3]. By applying these persuasive strategies, environmental conservation interventions can help users reduce their environmental footprint and

promote sustainable living. Attitudes and behaviors of technology users towards online security can also be improved with persuasive interventions [202, 179, 56, 32]. In essence, there are many ways in which persuasive systems can be applied for the benefit of technology users and the environment.

Furthermore, there is research on the best way to select and combine these strategies. The factors to consider when choosing persuasive strategies include the user demographic [142, 150], the personality of the user [144] and the stage of change of the user [149]. This direction towards more tailoring and personalization has been shown to be effective, especially for health-based persuasive interventions.

Persuasive system design and problematic smartphone use

In this section, we discuss some strategies from the PSD model that are used in the reviewed studies to combat PSU.

Self-monitoring This is a very common persuasive strategy, being among the most used strategies reported in review studies [5, 6, 10, 109]. It is also commonly used together with goal-setting so that users observe themselves as they work towards a goal.

Self-monitoring or goal-setting is used in many of the reviewed studies [100, 155, 119, 108, 107]. In Lubans et al. [119], self-monitoring is employed to help users track their physical activity (step count) which is recorded using a pedometer, as an alternative to use of the smartphone. In other studies, self-monitoring is used to keep track of smartphone usage metrics like screen time and unlocks.

Rewards Some of the interventions reward the users for disengaging with their phones. A notable example is the GoldenTime app [155] which used a micro-incentive mechanism in the form of virtual gold coins to encourage users to disengage from their devices.

Reminders This is a very common strategy. It is used in many of the reviewed studies [75, 155, 138]. Reminders are frequently shown in the notification panel while the user is using an app for which they have set a time limit, for example in the MyTime app [75]. Other implementations of reminders involve showing the

users a dialog whenever they open specific apps that are being monitored by the intervention as is the case in TypeOut [207]. These reminders might also pop up over the app to interrupt the user when they have exceeded the time limit for that app [120].

The content of the notifications in the reminders might be based on some theory to further strengthen their effectiveness. For example, the self-affirmation theory, which aims to remind people of their internal goals or identity to increase motivation for attaining some goal or behavior change [185], is used in the TypeOut system [207] where users are reminded of their self-declared values each time they are about to use specific apps on their phones. They are required to type out the value (with autocomplete disabled) and are encouraged to reflect on why that value is important to them.

Personalization and Tailoring The tailoring strategy was employed in the smartphone companion to the ATLAS[2] program developed by Lubans et al. [119] to promote physical activity and reduce screen time. Motivational messages delivered to the users were tailored to the preferred outcomes selected by the user. The outcome options included appearance, health and wellbeing, school performance, and social interaction.

Normative influence Normative influence as a persuasive strategy refers to the leveraging of peer pressure or group effect to increase the likelihood that a person will adopt a target behavior [135]. In the case of problematic smartphone use, leveraging groups, especially groups of people that are physically located close to each other in the real world, is especially important because it gives the user alternative social contexts to engage in.

Two of the interventions (LocknLol [99] and Let's FOCUS [93]) incorporate the idea of 'virtual rooms' to delineate environments where user interaction with the smartphone should be restricted because the user is supposed to be actively engaged with the real world. Functionalities like notifications and some applications are restricted while in the virtual room. In both interventions, the users in the virtual rooms are individuals that are physically located close to each other in the real world.

[2]ATLAS: **A**ctive **T**een **L**eaders **A**voiding **S**creen time

In Let's FOCUS, they are students in a classroom, while in LocknLol, any group of people can create a room so long as they are physically located close to each other.

LockDoll [35] is a tangible doll with ambient light effects that are used to discourage users when they are detected to be distracted while in a social group.

NUGU [100] was the only intervention reviewed that leveraged online social communities for normative influence. The social groups in the application serve to support users attempting to self-regulate smartphone use. However, this strategy exposes the paradox that an online social group is used to encourage disengagement from similar social applications.

2.3.2 Mindfulness

The meaning of mindfulness is varied but overlapping [191]. In as much as there are differences in definition from one researcher to another, there are common points on which most researchers agree. First is that mindfulness practice originated from Buddhist philosophies. Mindfulness was introduced into Western medical and psychology research in the 1970s. Jon Kabat-Zinn, who made one of the earliest efforts to incorporate mindfulness in the medical field [191], defined it as "the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment" [83, p. 2]. This definition highlights other concepts that are now widely accepted to be components of mindfulness: being *aware* of the *present*, *without judgment*. We adopt this as a working definition for this thesis.

With the latter approach, several different interventions have been developed to use mindfulness to achieve various goals. These interventions are termed Mindfulness-Based Interventions (MBI). The first of these is the Mindfulness-Based Stress Reduction (MBSR) [82] developed by Jon Kabat-Zinn in 1977 [177] and another is the Mindfulness-Based Cognitive Therapy (MBCT) by Teasdale et al. [189]

Mindfulness in HCI

What does mindfulness mean in the HCI field? And how has it been applied in existing research? Terzimehić et al. [191] introduced a framework for mindfulness research in HCI studies, deconstructing the concept along four perspectives: role,

type of practice (formal or informal), longevity (state or trait) and co-aspects of mindfulness. This framework is shown in Figure 2.9.

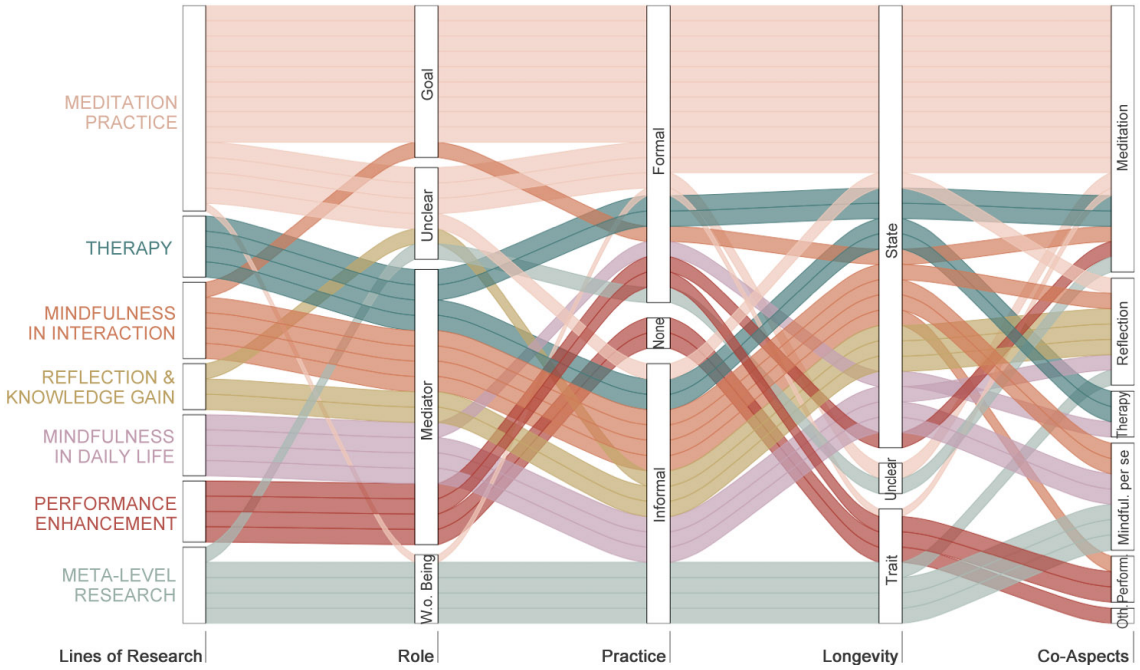

Figure 2.9: Mindfulness in HCI framework proposed by Terzimehić et al. [191]

The role of mindfulness According to Terzimehić et al. [191] role refers to whether (1) mindfulness is used as a mediator to reach a goal, (2) mindfulness is the goal itself, or (3) mindfulness is a way of being. In the first case, mindfulness is pursued as a way to attain a goal such as stress reduction, or, as we will show later on, less absent-minded smartphone use. In the second case, with mindfulness as the goal, the individual works towards being slower and more attentive in their daily lives or meditating more regularly. In the third case, mindfulness is simply part of the individual's life and is not actively pursued or 'used' for any goal.

State and Trait Mindfulness State mindfulness is a temporary measure while trait mindfulness conceptualizes mindfulness as a trait people have that they retain for the long term.

Formal and Informal Mindfulness Formal mindfulness practice involves regimented sessions. Mindfulness meditation is the most common form of formal mindfulness practice. However, mindfulness can have several dimensions beyond formal mindful meditation practices. For instance, some practitioners perform mindful eating or mindful walking - the practice of mindfulness is integrated into their daily activities [110]. Informal mindfulness involves cultivating mindfulness in everyday life [191]. This has been studied in works like Khot et al. [91] where the influence of screens on mindful eating was explored, and Nakamura et al. [131] where the *eat2pic* interactive system was used to encourage reflection and slower eating. Many other informal mindfulness systems encourage self-reflection. These include Inner Garden by Roo et al. [172] and Mind Pool by Long et al. [116].

Co-Aspects of Mindfulness This perspective of mindfulness embodies the diverse ways in which the term is used in the literature. For instance, a study might use the term mindfulness to refer to the practice of (mindfulness) meditation, or the term might be used to refer to a therapy program, or a system aimed at encouraging people to be more reflective.

There are other ideas about mindfulness in HCI, with one of the most notable by Zhu et al. [214]. In this work, following a review of mindfulness applications on the App Store, the authors introduced 4 levels of digital mindfulness. Level 1.0 (*digitalized mindfulness*) is where mindfulness practice or guidance normally done in the physical world is now digitized. In level 2.0 (*personalized mindfulness*), the apps are personalized to the users' context or preferences. In level 3.0 (*quantified mindfulness*), devices like wearables are leveraged for sensing of user performance and giving adaptive feedback. In level 4.0 (*Presence-in and presence-with*), the goal is to foster a sense of presence with and in the moment, and not to be used as a tool.

> "An important quality of digital mindfulness 4.0 is also integration with everyday life. In the context of modern life, digital mindfulness 4.0 doesn't rely on tools or rituals. We don't have to schedule a regular time or place ourselves in a specific space. Being mindful can be integrated in our everyday lives and practices." [214, p. 6]

Some concepts and prototypes of level 4.0 are presented in the paper, including a digital aquarium and digital wall paintings or artwork that constantly change in response to changes in the season or to the physiology of an observer. This level of mindfulness implementation is very comparable to the role of mindfulness as a way of being as presented by Terzimehić et al. [191].

Mindfulness for regulating smartphone use

Now that we have clarified what mindfulness is and how it is used in HCI studies, we turn to the question of whether mindfulness-based interventions are effective for tackling problematic smartphone use. Owen et al. [148] studied the relationship between trait mindfulness and problematic smartphone use using a survey of 401 students. This study found that attention and awareness, together with other mindfulness factors such as describing, non-judging of inner experience, and acting with awareness, showed a statistically significant negative correlation with elements of problematic habitual use of smartphones. This suggests that if the various factors that characterize mindfulness are cultivated, the individual will be in a better position to use smartphones in a healthy way and without feeling guilty. In another study, Regan et al. [169] found that higher mindfulness was significantly associated with lower boredom proneness, impulsivity, and PSU. These results suggest that absent-minded use of the smartphone, which is a form of PSU, can be reduced by cultivating mindfulness.

Mindfulness for absent-minded smartphone use is the theme of the MindPhone intervention [190]. MindPhone is an MBI for reducing absent-minded phone usage. The application prompts the user to answer either one of two questions each time they unlocked their phones. The question was either an intention question ("Why do you want to use your phone right now?") or an activity question ("What activity do you want to do after you finish using your smartphone?"). The activity question was designed to keep the user in touch with the real world while they use the app. The study found that while the intention question did not significantly affect the usage behavior of the participants quantitatively, the activity question significantly reduced usage, leading the researchers to conclude that the real world matters in the implementation of mindfulness interventions for smartphone usage. The study also

found that it did not matter the reflection mode of the users to the question; in other words, the prompt was quantitatively effective whether the participant wrote down the response to the question (active mode) or they mentally reflected on it (passive mode).

These two findings from [190] are instrumental to the design of the Chai intervention where we use the symbol of the tree to give the user a connection to the real world. The knowledge that the tree responds to the physical activity of the user in the real world was also important for the real-world connection. The Chai application also does not require the user to engage actively with it; instead, the falling leaf animation is meant to subtly draw the attention of the user to the act they are performing and thereby reduce absent-minded usage.

Outside the HCI domain, mindfulness-based interventions have been variously used for tackling PSU. Lan et al. [103] developed a group mindfulness-based cognitive-behavioral intervention (GMCI) for smartphone addiction. The study found that the intervention significantly decreased smartphone use time among the participants. A similar study using group mindfulness was proposed by Tang and Lee [188]. Choi et al. [34] developed a school program consisting of mind subtraction lectures and meditation for adolescents and reported improvements in the participants' smartphone usage. Others include Liu et al. [112] which also reported significant improvements in smartphone use behavior after a brief mindfulness breathing and body-scanning exercise session.

2.3.3 Digital Nudging

A digital nudge refers to events where digital artifacts steer people in particular directions while also allowing them to go their own way [21]. While it can and has been used for nefarious purposes, digital nudges in persuasive computing are commonly used to influence people to adopt healthier behaviors.

In our reviewed systems, we see an application of digital nudging in GoodVibrations [138] where haptic feedback is used to subtly remind the user that they have exceeded the time limit for the current app. Digital nudging is also the rationale behind the strategies adopted by Olson et al. [139]. The strategies include reducing phone brightness, turning off notification sounds, disabling touch/face id, or simply

leaving the phone at home. By introducing slight inconveniences, these strategies are meant to subtly nudge the user towards disuse of the smartphone while also leaving the user with the agency to decide whether or not to use or continue using the smartphone.

While not specifically termed digital nudging, a similar strategy was employed in the study by Myers et al. [129] where the participants were asked to take measures like switching their smartphones to grayscale mode, removing social media icons from the home screen. The authors aimed to reduce the psychological attachment of the participants to their smartphones. Other interventions similarly sought to reduce the appeal of the smartphone, or introduce 'design friction', to make it less desirable to the user [217, 134].

2.3.4 Lockout Strategies

Whereas with digital nudges and self-monitoring-based interventions users retain agency to engage in or desist from a behavior, with lockout strategies, access to the device or parts of it is limited for some time. As a strategy for PSU, it ranges from application-level lockouts to systems that lock the user out of their device completely. This strategy is frequently used together with the goal-setting strategy so that the users get to determine the time limit before the lockout is triggered [115, 95].

Some systems that employ lockout of some feature of the smartphone for any period of time include AppDetox [115], GoalKeeper [95], and PomodoLock [94]. Interventions like LocknType [96] and Interaction Restraint [156] lock some selected applications but allow the user to access it only after they have completed a task with varying workloads.

2.3.5 Physical Activity

Some previous work explored physical activity as an alternative to smartphone use. In Precht et al. [162], reduction in smartphone use was combined with increased physical activity to reduce PSU and promote mental health. Promoting physical activity was also the main strategy in the ATLAS program by Lubans et al. [119], an intervention for boys at risk of obesity.

Results from Terzimehić et al. [190] suggest that nudging users towards the real

world could be effective for reducing absent-minded smartphone use. By reflecting on alternative activities they could engage in in the real world, participants left their phones sooner.

2.4 Other Interventions for PSU

So far we have discussed interventions for PSU based on published studies found through our literature review search. In this section, we will discuss some related apps that are available for consumers in the App Store and Play Store. We will also discuss non-digital programs or interventions for PSU which are nonetheless conceptually related to our study.

There are many tools available for consumers to help them manage their smartphone usage. Both Apple and Google, the companies developing the two most widely used mobile operating systems, have built (and keep building) lots of tools into the Android and iOS operating systems to help users maintain focus, including focus modes and do-not-disturb settings. Google's collection of digital wellbeing experiments includes a handful of applications that aim to help users find a balance between their lives and their use of technologies [64]. One of these experiments was the *Unlock Clock* which counts the number of times you unlock your phone and displays this on the phone wallpaper. Another similar one was *Activity Bubbles* which has been removed from the Play Store at the time of this writing. *ScreenHive* displays the amount of time you have been using your phone as an overlay on the screen. *PostBox* holds the smartphone user's notifications until a time specified by the user. *Potential* [161] is another app for Android and iOS that seeks to help users develop "intentionality". These interventions often interfere to various extents in what would be the normal daily activities of the user like in *PostBox* which removes immediate access to notifications and *ScreenHive* which has a persistent timer overlaid on the screen.

The Wellpaper application by OnePlus [141] offers a selection of live wallpapers that represent the user's screen time and app usage statistics. Headspace [72] has a mindfulness wallpaper, but it is focused on getting the user to remember to breathe each time they look at the wallpaper using an animation. There are also other static or live wallpapers on the internet that are designed for mindfulness such as those

with a message to focus, or those with cute images intended to remind the user to smile.

Finally, several psychology-based programs have been developed to tackle the same problem. These interventions consist of education [67], peer education [16], cognitive behavioral therapy [76, 92, 117], and family or group therapy [114, 78] programs. In this review, we have focused on digital interventions; for comprehensive reviews of psychological interventions for PSU, refer to Augner et al. [15], Liu et al. [113] and Malinauskas and Malinauskiene [121].

2.5 Stages of Behavior Change

The Transtheoretical Model (TTM) of behavior change [164] describes behavior change as an intentional process that occurs in stages over time. In this model, an individual's stage of change (SoC) with respect to a particular behavior represents the extent to which they have gone to change some behavior. The stages of change are not linear: an individual may move back and forth between the stages.

The stages of change in the TTM include **Precontemplation**, **Contemplation**, **Preparation**, **Action**, and **Maintenance**. Table 2.4 contains a description of each stage of change.

Table 2.4: TTM Stages of Behavior Change

Stage	Name	Description
Stage 1	Precontemplation	No intention to change behavior in the next 6 months
Stage 2	Contemplation	Intention to change behavior in the next 6 months
Stage 3	Preparation	Intention to change behavior in the next 30 days
Stage 4	Action	Behavior change for less than 6 months
Stage 5	Maintenance	Behavior change for more than 6 months

This model is widely used in the context of health behavior change. In persuasive computing studies, the TTM is used to identify the needs of individuals at various stages of change, as well as tailor interventions to specific user groups [149].

A few previous studies have applied the TTM to the design or evaluation of PSU interventions. Some studies used the TTM stages of change to target their

interventions at smartphone users at specific stages of change for PSU [154, 95, 96, 89]. In Haliburton et al. [68] participants are categorized by whether they had a high or low predisposition for absent-minded smartphone use, but this classification was not linked to the TTM stages of change. The results showed that absent-minded use was reduced for users with high predisposition after the intervention while it had no significant effect on users with low predisposition.

2.6 Summary

To sum up the related works, there is evidence to show that PSU is linked with a lower quality of life, making it a relevant and important challenge for HCI researchers to focus on. Following a systematic process of search and data extraction, we reviewed 25 studies that evaluated digital interventions for PSU. The studies incorporated theoretical principles like persuasive systems design, mindfulness, and digital nudging. They are deployed both on the smartphone itself and on off-device platforms. Our review also identified the evaluation methods for these interventions.

The results from the literature suggest that the quality of the interaction between the user and the smartphone is more important than the quantity [180, 25]. This places more focus on the subjective markers around smartphone use, such as self-efficacy [86], mindfulness [169] and lack of subsequent regrets [33], with less emphasis on objective measures of smartphone use such as screen time or number of unlocks. Absent-minded use is an important challenge to overcome to ensure that people use their devices more intentionally, regardless of the intensity or duration of use.

There have, however, been only very few digital interventions specifically designed and evaluated for absent-minded use. This led us to develop an intervention that combines some of the best-performing strategies for PSU and to evaluate it for its effectiveness to reduce absent-minded smartphone use.

Chapter 3

Chai Wallpaper Design and Development

In this chapter, we describe in detail the design and development process of the Chai wallpaper intervention as well as the principles that went into consideration for the final design.

For an overview, we have developed a wallpaper application named Chai (pronounced *kai*) based on the live wallpaper feature which has been a feature of the Android [59] operating system since Android Eclair (Android 2.1) was released in 2010 [65]. The wallpaper contains a semi-abstract representation of a tree. The leaves of the tree change according to the user's usage behavior in the following ways:

1. A leaf from the tree drops each time the user unlocks their phone.

2. The leaves change color as the user spends more time on their phone.

3. The leaves can be regrown when the user engages in an alternative real-world activity instead of spending time on the phone, in this case, physical activity which is detected via the smartphone's in-built accelerometer.

In addition to the wallpaper, the application also contains features to help users monitor their smartphone use as well as customize the wallpaper. The goal of the application is to help users achieve awareness about smartphone usage behavior and to adopt healthy smartphone use behavior.

In the following sections, we describe the conceptualization, design, and development process for the intervention, deferring to the frameworks that guided these processes, including Fogg's 8-Step Design Process [54] and the User-Centered Design Approach [2], as well as design principles such as the Persuasive Systems Design (PSD) model [135] and mindfulness. These frameworks have been widely used to design and evaluate previous interventions.

3.1 Fogg's 8-Step Design Process

To conceptualize the design, we followed an approach that is comparable to the best practices suggested by Fogg [54] for creating persuasive technologies. The 8-Step Design Process consists of the following steps:

Step 1: Choosing a simple behavior to target The first step in the design process is to choose a simple behavior to target. Fogg makes the case that the focus of the intervention should be small and simple. While the overall problem we were targeting was problematic smartphone usage, it has many components as we have already discussed in Chapter 2. Hence, we chose to focus on the behavior of absent-minded smartphone use. This is because we believe that absent-minded smartphone use is a behavior that can more precisely be targeted. It is also a behavior that is easy to operationalize using already-established measures like the absent-minded smartphone use questionnaire [124].

Step 2: Choosing a receptive audience PSU is a problem that affects a wide range of people. Based on several statistics, a good number of young smartphone users have voiced concerns about their screen time and wish that they could use their phones less than they did [80, 42]. This makes them a good target for the intervention.

Step 3: Finding what prevents the target behavior In this step, we identified that the main factors preventing more mindful use of the smartphone are a combination of a lack of motivation and a lack of a well-timed trigger. People are usually more motivated to moderate their smartphone use at certain times than at others, for example when they have upcoming exams versus an unexciting holiday evening. Our goal is to give the users a motivation to curtail absent-minded smartphone use, as well as provide a trigger to deter this behavior before it is started.

Step 4: Choosing a familiar technology channel Like we have pointed out in the background chapter, there are various platforms on which interventions for PSU are deployed. There are also opinions that these interventions should not be

deployed on the smartphone itself. In this case, Fogg [54] has advocated for deploying persuasive interventions on platforms that the target audience are already using citing the difficulty of training people to learn a new channel while hoping they adopt a new behavior at the same time. We chose to deploy our intervention on the smartphone because we believe that the smartphone is the most accessible and sustainable technology channel for the target audience. It is also the channel that does not require the user to learn a new technology since the smartphone is a technology that practically all our target audience already use.

Step 5: Finding relevant examples of persuasive technology At this step, we looked for digital interventions that have been successfully used for problematic smartphone use. We found that there were examples of interventions that have been deployed on the smartphone and these have been reviewed in detail in Chapter 2, where we showed that many of the existing interventions showed positive or partially positive results for reducing PSU. A closely related mindfulness-based intervention, MindPhone [190], was successful in reducing absent-minded smartphone use.

Step 6: Imitating successful examples In this step, we took the best practices from the examples we found and incorporated them into our design. For instance, a key finding from the MindPhone intervention was that drawing the attention of the user to the real world was important for reducing absent-minded smartphone use [190]. This provided inspiration for how we could use elements from the real world/nature in our design. We also found that the use of strategies from the PSD model such as goal-setting and rewards were effective in the design of several of the interventions [75, 155, 95, 100]. We, therefore, decided to incorporate these into our design.

Step 7: Testing and iterating quickly More details about how we iterated using the user-centered design approach are described in section 3.2.

Step 8: Expanding on success At this point, we evaluated the effectiveness of the intervention with a user study to find more ways to improve it.

3.2 User-Centered Design Approach

We followed an iterative user-centered approach to the design and development of the Chai wallpaper. The stages in this design process starting from the initial conceptualization to the final design used in the study evaluation are shown in the flowchart in Figure 3.1. In the following subsections, we describe each of these stages in more detail.

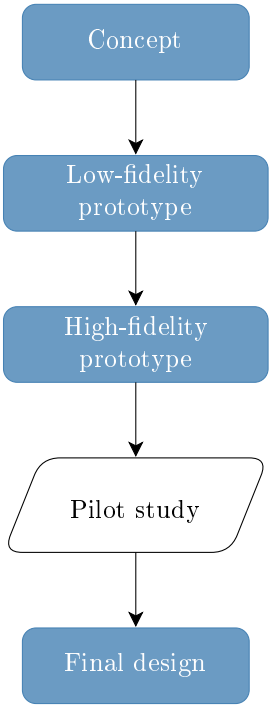

Figure 3.1: Iterative design stages

3.2.1 Low-Fidelity Prototype

We drew rough sketches of the concept using paper and pencil. These prototypes were not formally evaluated because it would be difficult to present the prototypes as possible wallpapers to participants without the essential interactions and changes in the wallpaper. We got some positive feedback on the concept from some colleagues, and then we moved on to develop a working prototype.

3.2.2 High-Fidelity Prototype

Figure 3.2: Screenshots of the high fidelity prototype. A leaf drops each time the phone is unlocked, and as screen time increased, the leaves changed color to black as shown in the third image.

We developed a working version of the application (some screenshots in Figure 3.2), and to get feedback on it, we conducted a pilot study before we continued the development. The findings from the pilot study are published in Nwagu and Orji [133] and also presented in Chapter 4. Overall, the app was well-received during the pilot study. However, we did receive suggestions for improvement, the major ones of which include:

1. The app was not informative enough on its own. Users would not know what the app was about and how to use it without the researchers being on hand to explain.

2. The app did not have a dark theme. Some of the participants used their phones in dark mode and wanted their wallpaper to be in dark mode as well.

3. The color change of the leaves was not inclusive enough. There was only one

color change available in this version: from all other colors to black. Users wanted to be able to choose from a variety of color changes.

4. We added the Google Fit integration as a way for users to regrow dropped leaves while staying physically active.

3.2.3 Final Design

The design of the final version[1] was made based on feedback from the pilot study. Some of the changes we made based on the pilot evaluation feedback included:

Onboarding One of the feedback from the pilot study was that the app was not informative enough. So in the latest version, using a series of animations, we added an initial onboarding section that explains the purpose of the app and how to use it (see Figure 3.3). We also added just-in-time information in various sections within the app to explain how they work.

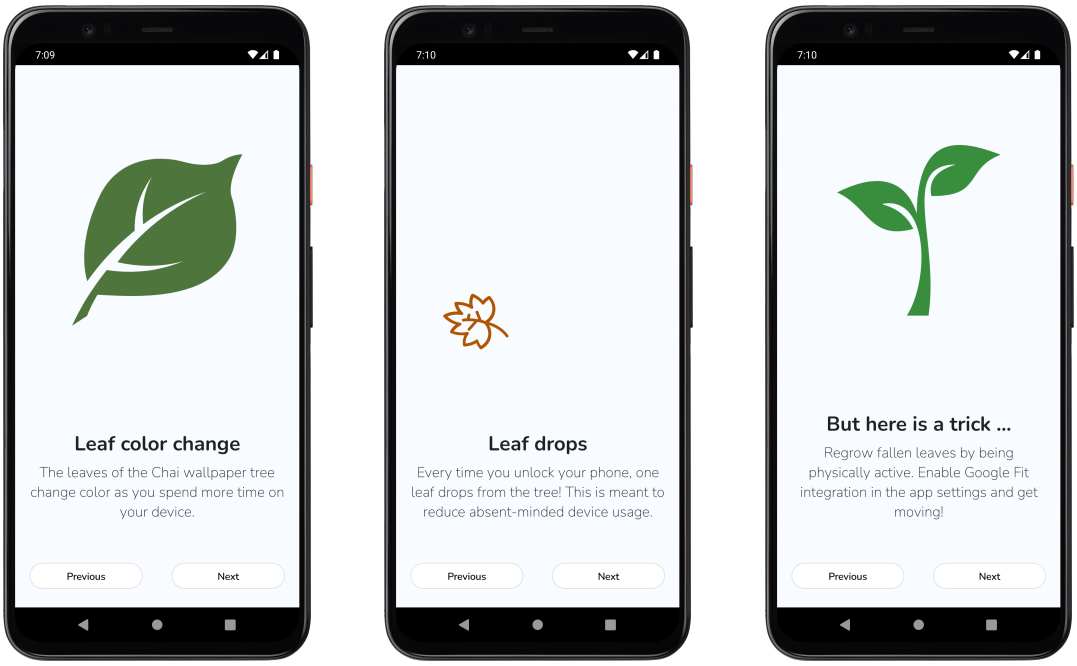

Figure 3.3: Some of the informative animated screens in the onboarding flow provide information about how the app works.

[1] version used for the user evaluation reported in this thesis

Physical activity We integrated the Google Fit API to collect data about users' physical activity (step count) and use it to update the wallpaper visualization using a reward mechanism. This is a strategy to encourage users to engage in real-world activities as opposed to using the smartphone, and this has been found to be effective in reducing PSU in previous studies [190, 119]. While being physically active is not the only healthy alternative activity one can engage in, we chose it specifically because it is easy and seamless to track using smartphone sensors.

Leaf color change update We allowed room for users to customize the color changes of the leaf by choosing from a set of color changes provided in the app.

Themes We included the option to select a dark theme or to change the app and wallpaper theme based on system-wide settings.

Logging The pilot study did not log objective smartphone usage data. We added this feature after the pilot. More details about this can be found in section 4.3.3.

3.3 Mindfulness in the Design of the Chai Wallpaper

Mindfulness can be a very ambiguous term as we have already noted in the background chapter. Hence, we make use of the framework by Terzimehić et al. [191] to identify exactly what we mean by mindfulness and how our work compares to other work in the field (Figure 2.9). We identify the mindfulness aspect of the present study as informal mindful reflection (Figure 3.4) used as a mediator for smartphone usage and physical activity behavior awareness and change. Since the behavior change we are targeting is not temporary, we are focused on the trait mindfulness of the individual.

Design-wise, we aimed to achieve a subtle and dynamic image that evolves as the individual uses their phone, and does not make any judgment about the user's smartphone use behavior or make the user feel guilty. The main goal is to keep users aware of how they use their smartphones. We used symbols from nature, specifically the color change and fall of leaves in autumn, to make the changes in the wallpaper feel natural, like a cycle that matches the user's smartphone use behavior [214].

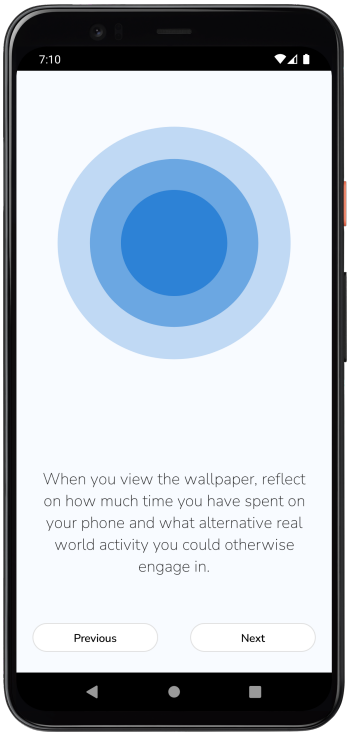

Figure 3.4: A screenshot of the animation encouraging mindful reflection when the wallpaper is viewed. This is shown in the onboarding flow and is also available within the app settings.

The absence of notifications or reminder strategies in the app was also due to the mindfulness aspect of the design. We hoped that users would learn to be observant of the wallpaper and accept it as a reflection of their smartphone use behavior and not as a tool actively trying to make them disengage.

Nature and nature symbols are very common in mindfulness practice, including in digital mindfulness interventions [214]. Hence the use of a tree is expected to be appreciated by many users. The tree is also meant to remind the user of the real world by linking their physical activity in the real world to the growth of the leaves of the tree.

3.4 Persuasive Systems Design in the Chai Wallpaper

In this present work, we use the PSD model to guide the design and evaluation of the Chai Wallpaper. We use this model because it is a well-known and widely applied model. It is also a comprehensive model that covers a wide range of persuasive

strategies.

Based on the Persuasive Systems Design (PSD) model, the persuasive strategies that we implemented include self-monitoring, personalization, customization, rewards, authority, and liking. We refrained from using strategies such as reminders and social comparison so that the intervention does not contribute to increasing smartphone use.

Self-monitoring

The application contains a self-monitoring feature that allows users to view their screen time and the number of leaves dropped as shown in Figure 3.5. The screen time is also broken down into a graph showing the number of minutes spent on the phone per hour of the day for more fine-grained monitoring. The current screentime is compared with the user's target screentime in a progress bar to show them how much of their target screentime has been spent already.

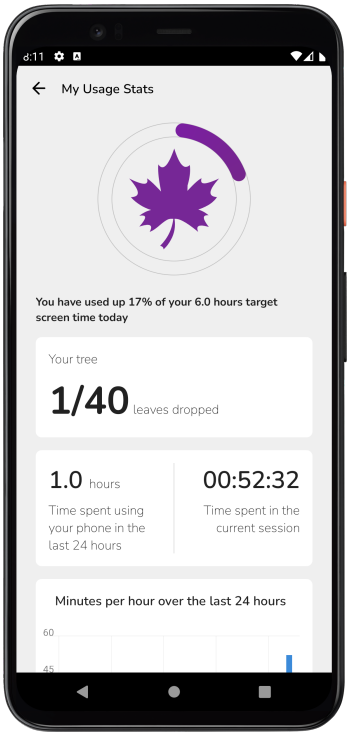

Figure 3.5: Screen depicting self-monitoring in the form of user stats for screen time and number of leaves dropped.

Customization

Customization was an important aspect of the design process because different people have wide-ranging preferences for colors and other visual aspects. As the intervention was a wallpaper, it was important that users could personalize it to match their taste as well as their device settings (see Figure 3.6). Hence we used the customization strategy which gave users the ability to make changes to the wallpaper to fit their preferences [145].

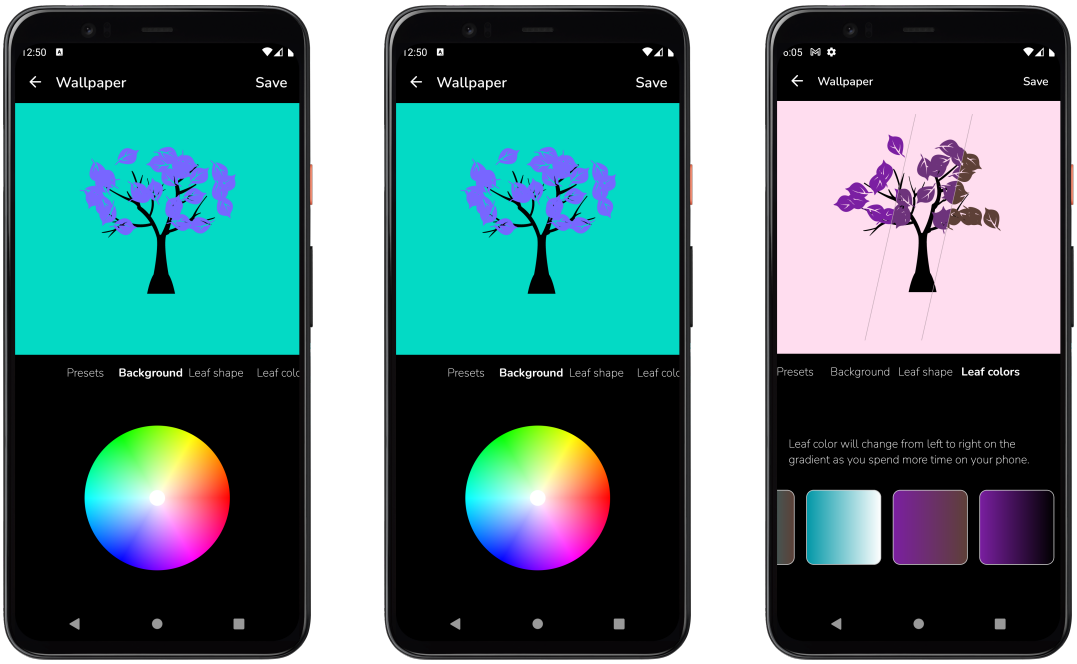

Figure 3.6: Users can personalize the wallpaper by changing the background color and the color of the leaves on the tree. The color change of the leaves can also be personalized.

According to data from various sources reported by DataReportal [88], the average internet user in 2022 spent above five hours using mobile phones daily, with the average person checking their phone 58 times per day. We used these statistics to set the default wallpaper settings. However, users could customize the wallpaper settings to their liking (Figure 3.7). The number of leaves could be set to between 25 to 45, while the target screentime could also be changed to any value between 1 to 5 hours. Users can also change the theme of the wallpaper and the app to either light or dark mode or to match the system settings.

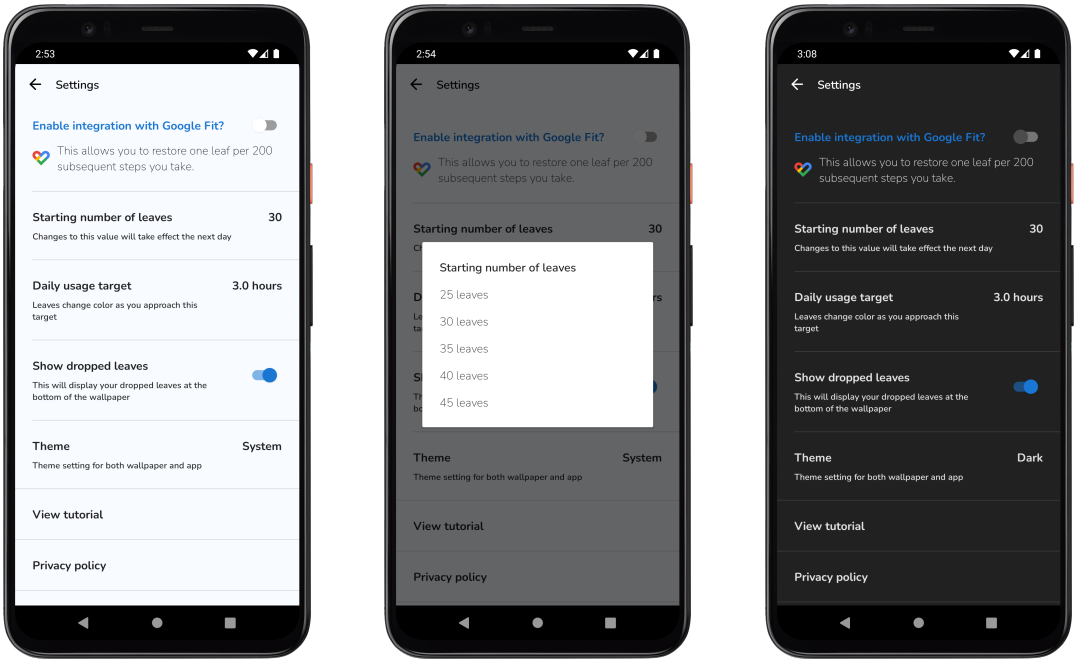

Figure 3.7: App settings.

Rewards

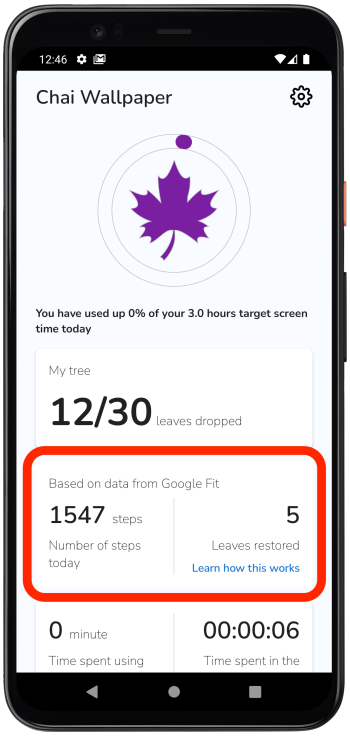

Figure 3.8: Showing the reward offered to the user in the form of regrown leaves when they engage in physical activity.

Physical activity as an alternative to smartphone use is potentially an effective strategy to reduce absent-minded use [190]. We used a reward mechanism to encourage users to be more physically active. Specifically, users are rewarded with a leafier tree when they spend time engaged in physical activity. The step count is retrieved from Google Fit and the number of leaves on the tree is increased by one for every 200 steps taken. The reward is shown in the screenshot in Figure 3.8.

Liking

The user interface of the application was designed to be visually appealing for most users to increase their liking for it. We ensured that the wallpaper looked neat and the animations were smoothly rendered. We also made sure that the application features were intuitive and easy to navigate. All these was to make sure that the user had a positive experience while using the app.

3.5 Development

In this section, we describe the details of the development of the app. We used Android Studio [60] (Electric Eel 2022.1.1) for the development of the application. We used Git and GitHub for version control. The app was developed to be compatible with Android 5 (API level 21) and above.

3.5.1 Application Architecture

The app was developed with the Kotlin programming language, and with Jetpack Compose as the UI toolkit. The recommended Android Architecture Guide, or Modern App Architecture [62], was adopted in the code to provide proper separation of concerns as shown in Figure 3.9. This architecture distinguishes between the user interface (UI) layer which displays the application data on the screen, the optional domain layer, and the data layer which contains the business logic of the application. Data flows from the data layer to the UI layer while user interaction events flow from the UI layer to the data layer. The Android ViewModel class is used to manage state for the UI layer. The View component observes ViewModel stateflows and is updated when the values of those stateflows change. The viewmodels are persistent

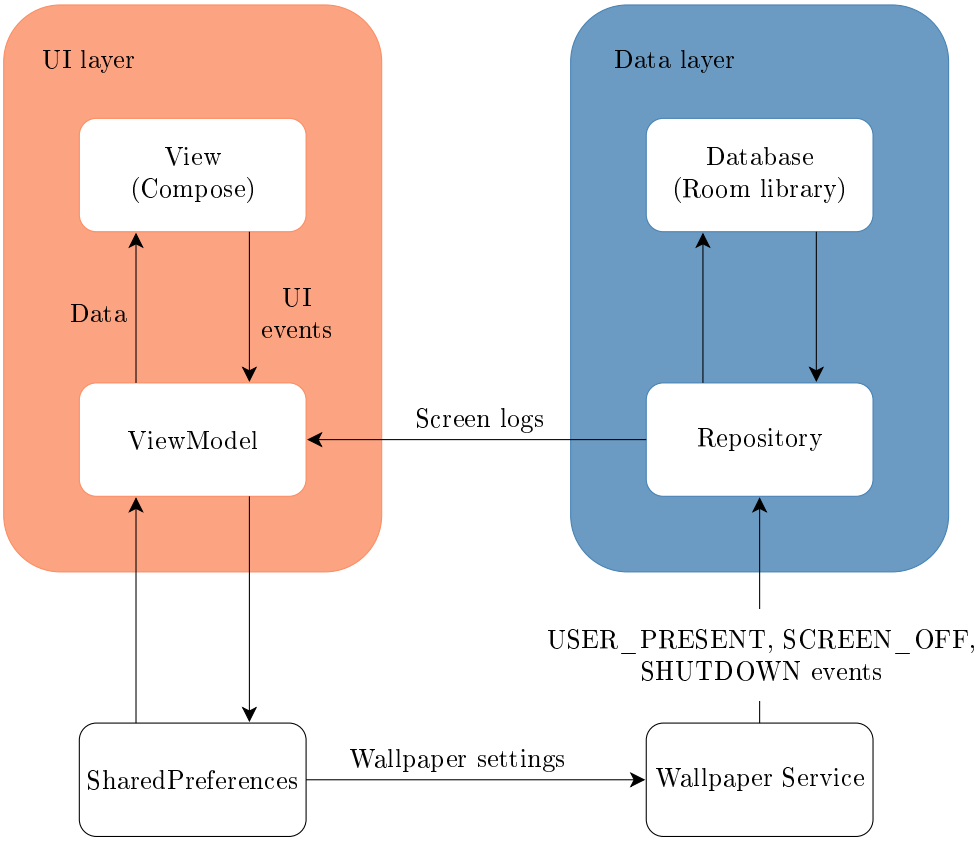

Figure 3.9: Architecture of the app

throughout the lifecycle of the view.

3.5.2 The Live Wallpaper

To make sure that the wallpaper was not too power-hungry and could be used sustainably for most devices, we developed it using the native Canvas API from Android to ensure that we had good control of the animations. We used random Bézier curves for the falling leaf animations. We ensured that the animations and color changes were displayed only when the wallpaper was visible as recommended in the Android documentation.

No participant complained of excessive battery drain. Our tests during development did not reveal any noticeable increase in battery usage when the wallpaper is set. However, we did not measure the effect of the wallpaper on the battery.

3.5.3 Screentime and Unlock Count

In Android, the permission to get screentime is a sensitive permission. It also grants the developer access to fine-grained information about how often users use each app, not the aggregated data. In order to get the screen time without requesting this sensitive permission, we leveraged the fact that when the wallpaper is set, our application can register to receive system actions broadcast such as `ACTION_USER_PRESENT`, `ACTION_SCREEN_OFF` and `ACTION_SHUTDOWN`. Using these actions, we developed an algorithm to calculate the screen time by keeping track of the time between user login and screen off or device shut down. Each occurrence of these actions is logged in a local database on the user's device, accessible only by the Chai application. When the screentime is needed, it is calculated as described in the pseudocode below, by first retrieving the logs for the required time period containing user 'login's (`ACTION_USER_PRESENT`) and 'logout's (`ACTION_SCREEN_OFF` or `ACTION_SHUTDOWN`). Similar methods for tracking smartphone use on Android have been used in prior work [180, 57].

Algorithm 1 Pseudocode for the calculation of screentime

Require: *logs* login and logout events within the time period

```
userSessions ← split logs into pairs of consecutive login and logout events
screenTime ← 0
for session in userSessions do
    screenTime ← screenTime + session.end − session.start
end for
```

This approach worked fine during the pilot study. However, it led to unexpected behavior for a couple of participants during the main study. These participants had the screen time going up when they were using the device passively such as listening to YouTube Music with the screen off. This is discussed in more detail in the results section. Given the open-source nature of Android, and how manufacturers are free to customize their Android builds, we believe that this issue might have been caused by some device model-specific settings. Further investigation is needed to properly scope the problem and ensure that it is fixed in future versions of the app.

3.5.4 Physical Activity Tracking

We used Google Fit API [61] to track the step count of the user. This is an optional feature of the app so permission for physical activity data and access to the user's Fit data is requested when the user opts for the feature. The app then subscribes to step count data and periodically updates the wallpaper as already described in a previous section.

3.5.5 Remote Logging

Firebase Realtime Database was used for the logging. Logs were sent three times a day for each participant's device. Our implementation of this feature ensured that even if the device was not online when the log was supposed to be sent, the log parameters were collected and logging was re-attempted when the device is connected to the Internet. Further details about the parameters we logged are available in section 4.3.3.

3.6 Summary

We have outlined the design principles that guided the design of the Chai wallpaper application and reported the development process. We summarize with the following points that highlight how our intervention is different from existing interventions:

i) Unlike previous self-monitoring interventions that are only mobile applications in the traditional sense, our designed Chai wallpaper when used on the lock screen has the potential to proactively nudge the user away from taking an action (unlocking their device); hence it is not just a way to monitor past behavior.

ii) Unlike other existing restrictive interventions that seek to block users from their smartphones, this present intervention does not obstruct the usability of the device. It is so integrated into the smartphone that users can choose to ignore the wallpaper and continue to unlock the device if they so wish. In this way, the intervention acts more like digital nudges that subtly promote behavior change and hence is more sustainable than solutions with hard restrictions.

iii) Unlike other interventions that reward users for disengaging with their devices, the Chai wallpaper rewards users for engaging in alternative real-world physical activities.

Chapter 4

Evaluation

In this chapter, we describe the methodology adopted to evaluate the Chai wallpaper app. We conducted both a pilot study and a full study and both evaluations are described below. Ethics approval from the Dalhousie ethics committee was sought and received[1] prior to the commencement of the evaluation.

4.1 Research Questions and Hypotheses

The research questions that guided the evaluation of the Chai wallpaper app are listed below:

RQ1 How usable is the Chai application?

RQ2 How effective is the Chai wallpaper with respect to reducing absent-minded smartphone use?

RQ3 Are there differences in effectiveness across user groups based on stages of behavior change and demographics?

RQ4 How persuasive is the Chai application to motivate smartphone use behavior change?

RQ5 Are there differences in persuasiveness across user groups based on stages of behavior change and demographics?

RQ6 Does perceived persuasiveness of the application correlate with behavior change?

Based on our literature review (Chapter 2) and the design of the intervention (Chapter 3), we formulated the following six hypotheses to correspond with each of the research questions:

[1] REB No. 2023-6462. See in Appendix G

H1 The Chai wallpaper application will be perceived as usable by the participants.

H2 The Chai wallpaper application will be effective in reducing absent-minded smartphone use overall.

H3 There will be no difference in effectiveness for reducing absent-minded smartphone use based on demographics. However, users at earlier stages of behavior change will show more change in absent-minded use than users at later stages of behavior change who are supposed to already be monitoring and regulating their smartphone use.

H4 The app features will be found to be persuasive by the participants.

H5 There will be no difference in perceived persuasiveness based on gender or stage of change.

H6 Perceived persuasiveness of the application will be negatively correlated with change in absent-minded smartphone use ($post - pre$). In other words, persuasiveness will be positively correlated with a decrease in absent-minded use. This is expected because the more persuasive the system, the more likely it is to reduce the user's absent-minded use.

4.2 Pilot Study

Prior to a full study, we conducted a pilot study. The findings from the pilot study are published in Nwagu and Orji [133]. In the following subsections, we summarize the design and results of the pilot study.

4.2.1 Pilot Study Participants

The pilot study was evaluated by 9 participants who were all members of the Persuasive Computing Lab at Dalhousie University.

4.2.2 Pilot Study Design

The study consisted of a pre-intervention survey, an intervention period of 7 days during which the participants installed and used the wallpaper on both their home

and lock screens, a post-intervention survey and an optional interview. Five participants joined in the interview. In both the pre and post-intervention surveys, we measured absent-minded smartphone use with the Smartphone Use Questionnaire-Absent-Minded (SUQ-A) questionnaire [124]. We also measured the usability of the application using the System Usability Scale (SUS) [27] and the perceived persuasiveness of the various features of the application using the Perceived Persuasiveness Test (PPT) [43].

4.2.3 Pilot Study Results

The SUS score for the application was 78.75 indicating that it had above average usability. Figure 4.1 shows a slope plot of the pre and post-intervention SUQ-A scores for all the participants. Overall, there was no significant decrease in absent-minded use after the one-week intervention.

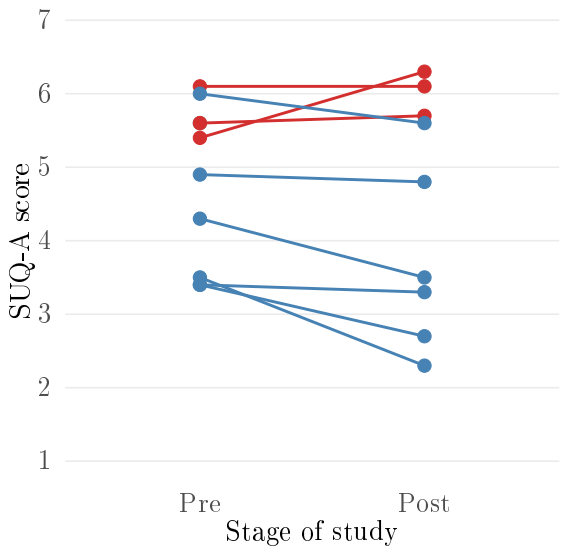

Figure 4.1: Intra-individual SUQ-A score changes for pilot study participants. Higher SUQ-A scores indicate more absent-minded smartphone use. The reds are participants who had either increased or unchanged scores post-intervention.

We conducted thematic analysis on the interview responses and came up with 4 themes: 1. *Increased Awareness* about smartphone use behavior as reported by the participants; 2. *Behavior Change* representing the changes in behavior reported by the participants which included refraining from unlocking the phone, batching

tasks together to get more done once the phone is unlocked, and using a desktop instead of the smartphone; 3. *Accessibility and Inclusion* representing the feedback we got about the features of the app that users wanted to be more inclusive and customizable; and 4. *Feature Suggestions* for made by the participants.

These results and feedback were used to improve the application and design of the main study as described in the following section.

4.3 Main Study

After the pilot study, we conducted a full study consisting of a pre-intervention survey, an intervention period of two weeks during which the participants used the Chai wallpaper on their home and lock screens, a post-intervention survey and an optional interview.

4.3.1 Participant Recruitment

Participants were sourced from various avenues including University mailing lists, social media, and word of mouth. Recruitment ran from 22nd February to 17th April 2023 with participants taking the study in staggered timelines. The participants were required to own an Android smartphone and be willing to change their wallpaper. The recruitment poster is shown in Appendix B. The participants were included in a prize draw for 15 x $15 Amazon gift cards as compensation.

4.3.2 Task

An overview of the study design is shown in Figure 4.2. When a participant followed the link in the recruitment notice, they are led to the consent form (Appendix C) on Opinio. If they accept to participate after reading the consent form, they are led to the pre-intervention survey (Appendix D). The pre-intervention survey included a demographic questionnaire, the Smartphone Use Questionnaire-Absent-Minded (SUQ-A), and the stages of change questionnaires for both smartphone use and physical activity. After completing the pre-intervention survey, the participants receive a link to download the Chai wallpaper application from the Google Play Store. A follow-up email was also sent to the participants' email upon submitting the pre-intervention

survey, containing the link to the application in case they missed it.

The participants were asked to use the application with the wallpaper set on their lock and home screens for at least two weeks. We chose this amount of time because it is the same amount of intervention time used in previous similar studies [75, 190, 96, 68, 171]. When the wallpaper was set, the participants did not have to do any task or interact with the application. This was to ensure that the participants used their smartphones as they would normally do except for the presence of the wallpaper. Using the various features of the app asides the wallpaper was optional and left to the participant's discretion.

After 2 weeks, we sent an email to the participant containing the link to the post-intervention survey on Opinio (Appendix E). The post-intervention survey included the Smartphone Use Questionnaire-Absent-Minded (SUQ-A), the System Usability Scale (SUS), the Perceived Usefulness Test (PUT), and the Perceived Persuasiveness Test (PPT) questionnaires for various features of the app. The participants were also asked to indicate if they were interested in participating in an optional interview. The interviews were conducted over Microsoft Teams and lasted between 15 and 30 minutes. The interviews were semi-structured and the participants were asked about the usability of the application, their thoughts on the effectiveness of the application, and any suggestions for improvement. The interview questions are available in Appendix F.

More details about each scale used in the study are provided in the following section.

4.3.3 Measures

In addition to collecting demographic information of the participants, we measured constructs relevant to our research questions as described below.

Absent-Minded Smartphone Use

In both the pre and post-intervention surveys, we measured absent-minded smartphone use using the Smartphone Use Questionnaire-Absent-Minded (SUQ-A) scale [124] (see section D.4). This scale has been used in similar related work to evaluate interventions targeting absent-minded smartphone use [190, 68].

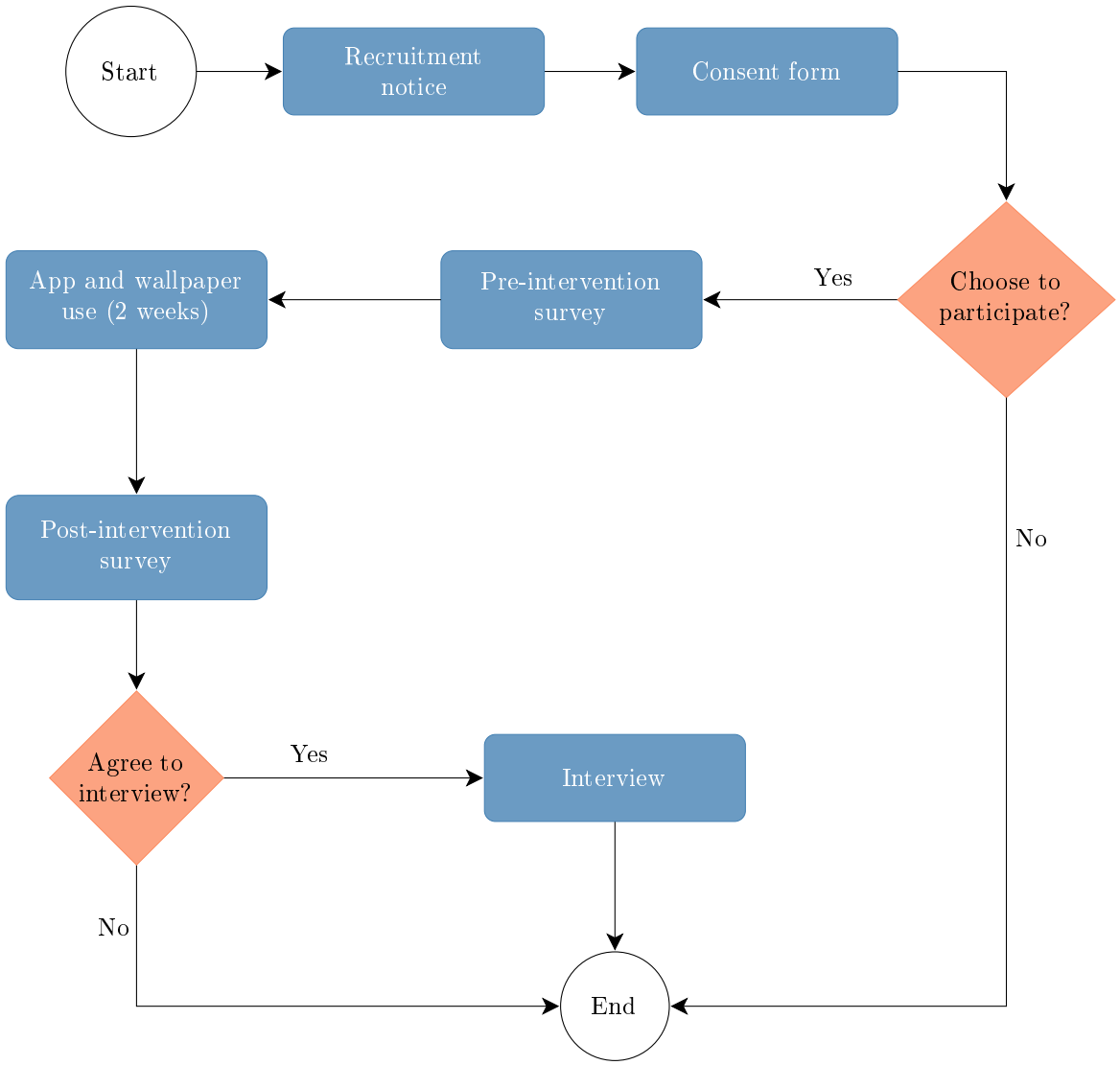

Figure 4.2: Flow chart showing the study procedure

The essence of this scale is to measure the extent to which the intervention affected the participants' absent-minded smartphone use. The scale consists of 10 items or questions asking how often participants have certain experiences that are typical of absent-minded smartphone use. The participants are asked to rate each item by how frequently they experience it on a typical day on a scale from "Never" to "All the time".

Usability of the Application

We measured the usability of the application using the System Usability Scale (SUS) [27] (see section E.2). This is a very common way to test the usability of systems. We used this scale to get feedback about how usable the intervention was and to quantitatively answer **RQ1**.

Usefulness of the Application

We measured the perceived usefulness of the application using the Perceived Usefulness Test [41], with the questions modified to refer to the Chai wallpaper application (see section E.3). This case was used to supplement the SUS scale, and to get further insight into how useful the participants found the intervention.

Perceived Persuasiveness

The perceived persuasiveness of the various features of the application was measured using an adapted Perceived Persuasiveness Test [43, 146, 192]. In this questionnaire, the participants are asked to select how much they agree or disagree with statements about the persuasiveness of the feature on a scale of 1 to 5 with 1 being "Strongly disagree" and 5 being "Strongly agree". We adapted this scale to our needs by changing the questions to reflect motivation awareness and regulation of smartphone use behavior. For each of the features (falling leaf animation, leaf color change, number of leaves settings, wallpaper customization, dropped leaves summary, usage summary and chart, and Google Fit integration), a relevant screenshot was shown to ensure they know what feature was being referred to, as shown in Figure 4.3.

In addition to the standard Likert scale responses to the PPT questionnaire, we also asked the participants to optionally provide a reason for their ratings of each

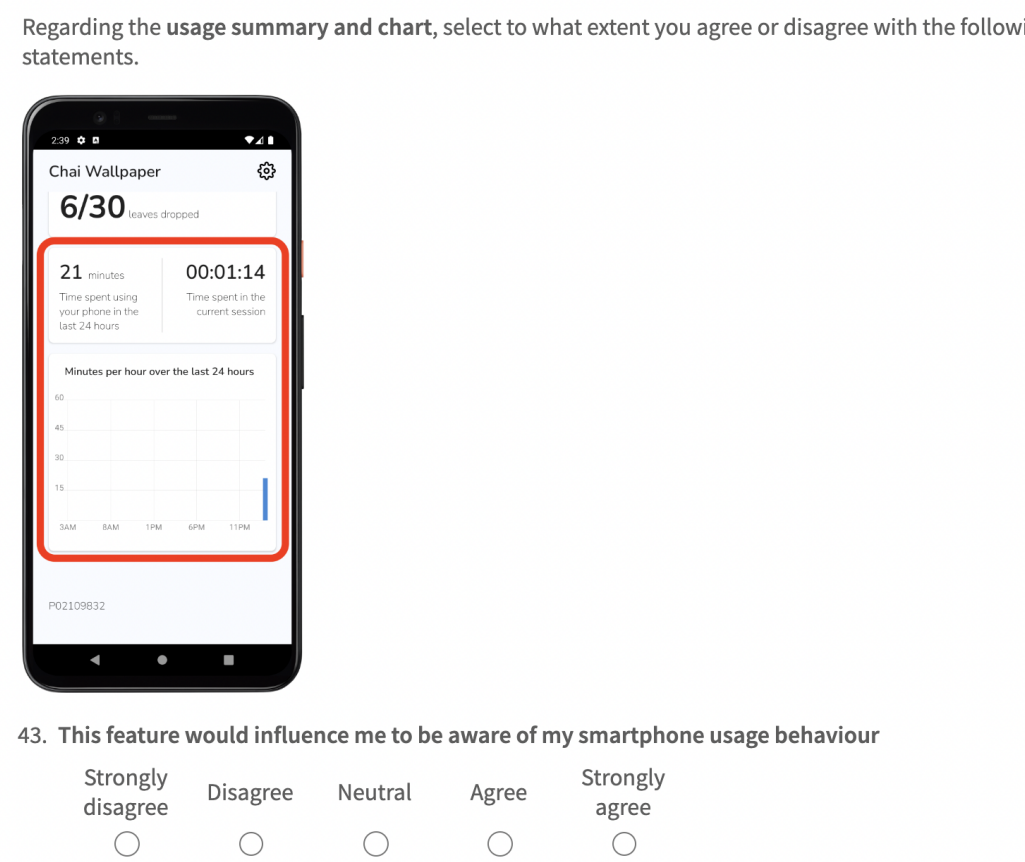

Figure 4.3: Sample PPT question on Opinio including the relevant screenshot for the feature being rated.

feature using an open-ended comment box that allowed text entry. This was done to gain a richer understanding of the reasons behind the ratings.

Stage of Change Smartphone Use

In this study, we also collected the stage of change of the participants using the Health Behavior and Stages of Change Questionnaire (HBSCQ) [58] adapted for smartphone usage behavior by modifying the questions to refer to awareness and regulation of smartphone use (see section D.2). This is based on the Transtheoretical Model of behavior change [164]. This was useful for answering **RQ3** and determining the groups of users for whom the intervention is most effective. Table 4.1 summarizes the stages of change in the context of smartphone use.

Table 4.1: Stages of change for smartphone use

Stage	Name	Description
Stage 1	Precontemplation	No intention to change behavior with regards to smartphone use in the next 6 months
Stage 2	Contemplation	Intends to moderate smartphone use in the next 6 months
Stage 3	Preparation	Intends to moderate smartphone use in the next 30 days
Stage 4	Action	Moderating smartphone use for less than 6 months
Stage 5	Maintenance	Consistently moderating smartphone use for more than 6 months

Table 4.2: Stages of change for physical activity

Stage	Name	Description
Stage 1	Precontemplation	No intention to engage in regular physical activity in the next 6 months
Stage 2	Contemplation	Intends to engage in regular physical activity in the next 6 months
Stage 3	Preparation	Intends to engage in regular physical activity in the next 30 days
Stage 4	Action	Engaging in regular physical activity for less than 6 months
Stage 5	Maintenance	Engaging in regular physical activity for more than 6 months

Stage of Change Physical Activity

The stage of change for physical activity was measured using the TTM-based scale by Marcus et al. [122] (see section D.3). This was useful for answering **RQ3**. Table 4.2 summarizes the stages of change in the context of physical activity.

Objective Smartphone Use Logging

Logs were sent from the application to Firebase Realtime Database thrice a day. The logs were used to gauge compliance with the study instructions. The following are

the data that were logged:

1. A random participant id (`pid`) generated for each participant as soon as the wallpaper was set for the first time. Asides being used to identify the participant with their logs, the `pid` also serves to let us know at what time the participant set the wallpaper. The first four characters of the `pid` after the `P` is the date when the id was generated (when the wallpaper was set) in the format `MMDD`, while the last five characters are random characters. For instance, the `pid P02215673` tells us that the participant set the wallpaper on the 21st of February. This `pid` is saved in the device's shared preferences and is included in all the logs.

2. Number of leaves dropped or unlock count

3. Screen time (both current screen time and screen time for the previous day)

4. Whether or not the wallpaper was set at the time of logging. This is to ensure that the participants had the wallpaper set throughout the intervention period.

5. Whether or not Google Fit integration was enabled at the time of logging

4.3.4 Differences Between the Pilot and Main Study

Some of the changes made to the application based on the pilot study feedback are listed below:

i) The pilot study intervention lasted one week, while the main study was for two weeks. Similar studies have also used intervention periods of two weeks [139, 75, 190, 96, 68, 100, 94].

ii) The pilot study did not include a way to either record logs for usage behavior or read already existing usage data from the device to determine objectively whether there was any change in behavior due to the intervention.

iii) In the main study, the effect of the individual's stage of behavior change on the persuasiveness of mindfulness strategies using the Transtheoretical model [164] is explored.

iv) The pilot study did not include the integration with Google Fit to draw the users more toward the real world and promote physical activity.

v) The main study intervention included several improvements suggested during the pilot study as already outlined in Chapter 3.

4.3.5 Analysis

In this section, we describe the data preparation, cleaning and analysis processes carried out on the collected data.

Data preparation

The process of data preparation involved merging participant responses from the pre-intervention and post-intervention surveys based on email addresses, and then linking this to their logs by participant id.

We wrote a Python script to convert the Firebase Realtime Database json log files to a CSV file where each row constitutes a log entry. From this data, we then determined the screen time for each participant for each day of the intervention period and converted this into two values: the average screen time for the first and the second week of the intervention period.

Next, we removed incomplete and invalid responses, including:

i) Participant who started but did not complete the pre-intervention survey ($n = 69$). 197 participants completed the pre-intervention survey.

ii) Participant who did not complete the post-intervention survey ($n = 76$). This represents a 38% attrition rate. The dropout was a result of several factors including technical reasons. Some participants were unable to install the application because live wallpapers were not supported on their Android device models. Others could not set the wallpaper on the lock screen, only on the home screen. In all, 122 participants completed the post-intervention survey.

iii) We further excluded one response in the post-intervention survey because the email address was invalid and did not match any of the email addresses in the pre-intervention survey.

In the end, the total number of participants whose data were used for analyses was 121.

Study Compliance We examined participants' compliance with the study instructions during the two-week intervention period by analyzing the collected application logs. Some participants had varying time differences of up to three days between when they submitted the pre-intervention survey and when they set up the wallpaper. This was because those participants did not immediately install the app after submitting the survey but only after receiving the follow-up email. Further, the logs showed that the participants set the wallpaper and left it on once set, indicating that they complied with the study instructions.

Quantitative Data Analysis

We used `R` [166] (version 4.2.1) and the RStudio IDE (Version 2023.03.0+386) to analyze the quantitative data. SPSS (Version 28.0.1.1 (14)) [77] was employed for ANOVA tests. All analyses were conducted with a significance level of 0.05.

We first conducted a power analysis to determine the suitability of our data. The `pwr` package [30] for `R` implements power analysis as outlined by Cohen [40]. Using its `pwr.t.test()` function, we conducted power analyses to check the power of our t-test for fairly small effect sizes. We determined that our sample size of 121 participants would be sufficient to detect an effect of size d = -0.25 with a power of 0.8 and at a significance level of 0.05.

We used the ggplot2 package [203] to generate descriptive visualizations of the data, followed by inferential statistics. A summary of the analyses conducted is presented below.

i) To determine the perceived usability and usefulness of the Chai application (**RQ1**), we computed the overall average score of the SUS and PUT scales. We then conducted one-sample t-tests to test whether these mean scores were significantly different from the respective neutral scores for both scales.

ii) To determine the effect of the intervention on absent-minded smartphone use (**RQ2**), we computed the SUQ-A score for each participant before and after the

intervention. We then conducted a paired samples t-test to determine whether there was a significant difference overall in mean SUQ-A scores before and after the intervention.

iii) To answer **RQ3**, we conducted a repeated measures analysis of variance (RM-ANOVA) test (after validating for ANOVA assumptions) with gender and stages of change as between-subject factors and the SUQ-A scores before and after the intervention as within-subject factors. We also conducted a series of post hoc tests with Bonferroni correction to determine which groups were significantly different from each other. This approach is useful to investigate potential differences in the effectiveness of the intervention among different subgroups.

iv) To determine how persuasive the intervention was (**RQ4**), we computed the average persuasiveness score for each implemented feature based on a 5-point scale. We then conducted one-sample t-tests to test whether the average persuasiveness score for each strategy was significantly different from the neutral score. To test whether any feature was more or less persuasive than others, we conducted a repeated measures analysis of variance (RM-ANOVA) test with features as within-subject factor (after validating for ANOVA assumptions).

v) To answer **RQ5**, after validating for ANOVA assumptions, we conducted an RM-ANOVA test with gender and stages of change as between-subject factors and the PPT scores for all the features as within-subject factors.

vi) To answer **RQ6**, we used a linear model with a covariate (also known as analysis of covariance, ANCOVA) to examine the association between perceived persuasiveness and the change in absent-minded smartphone use from pre to post, while removing the effect of the baseline (pre-intervention) score as recommended by Clifton and Clifton [39].

Qualitative Data Analysis

15 participants joined the optional interview. We also had additional qualitative data from the open-ended post-intervention survey questions.

To analyze the qualitative data, we first transcribed all the interviews. Then we conducted inductive thematic analysis [26] on all the textual data using Taguette [167]. This is a process of clustering comments addressing similar issues together to extract themes iteratively. We started by going through this qualitative data to get a general overview of it. We systematically assigned codes to snippets/comments within the data, and then grouped codes that shared similar concepts. This process of grouping and refining the codes was done iteratively until we formed them into coherent and meaningful themes. Finally, we analyzed the content of each theme in light of our research questions. The thematic analysis was conducted by one researcher, and the themes are presented in Chapter 5

Chapter 5

Results

"This very good to people misusing their phone"

– P113

In this chapter, we present the results of the study. In the first two sections, we give a descriptive overview of the participant demographics and stages of change. In later sections, we focus on statistical tests and making inferences to answer our stated research questions. And then in the final section, we report the results of the qualitative analysis of interview data.

5.1 Participant Demographics

A total of 121 participant responses were included in the analyses. This included 66 (54.55%) men, 52 (42.98%) women, and 3 (2.48%) participants who either self-described or chose not to specify their gender. See Figure 5.1.

The age distribution of the participants is shown in Figure 5.2. There were 87 (71.9%) participants aged 18 - 25 years, 23 (19.01%) aged 26 - 35 years, 9 (7.44%) aged 36 - 45 years, and 1 (0.83%) aged 46 or over. 1 (0.83%) participant preferred not to answer the age range question.

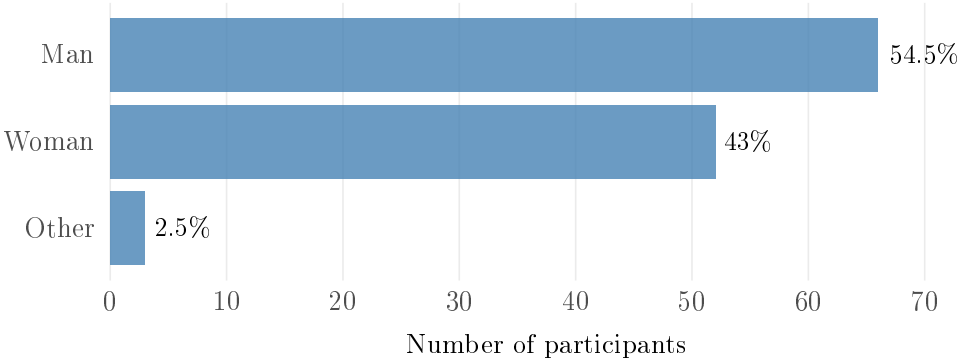

Figure 5.1: Gender distribution of participants

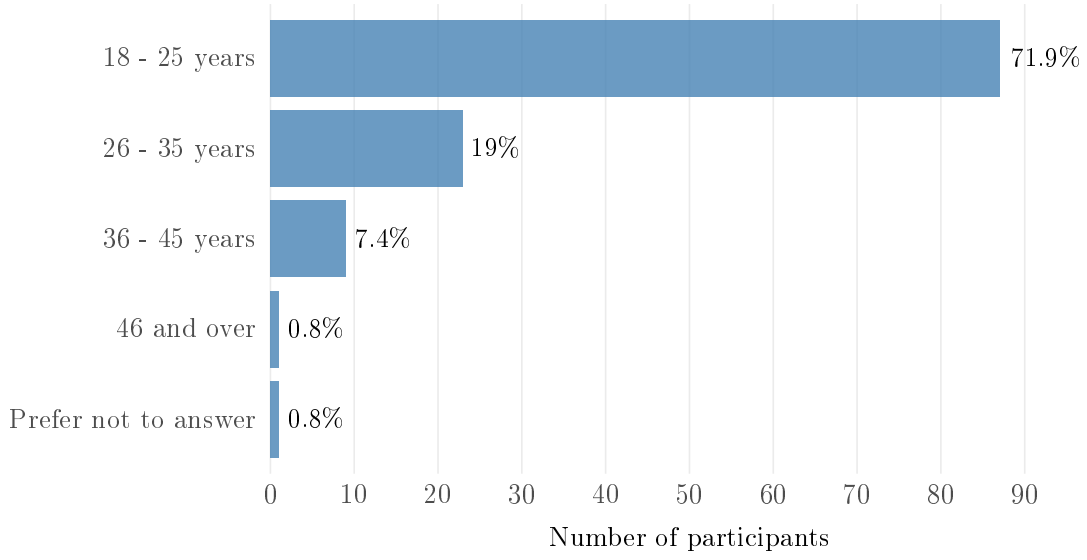

Figure 5.2: Age distribution of participants

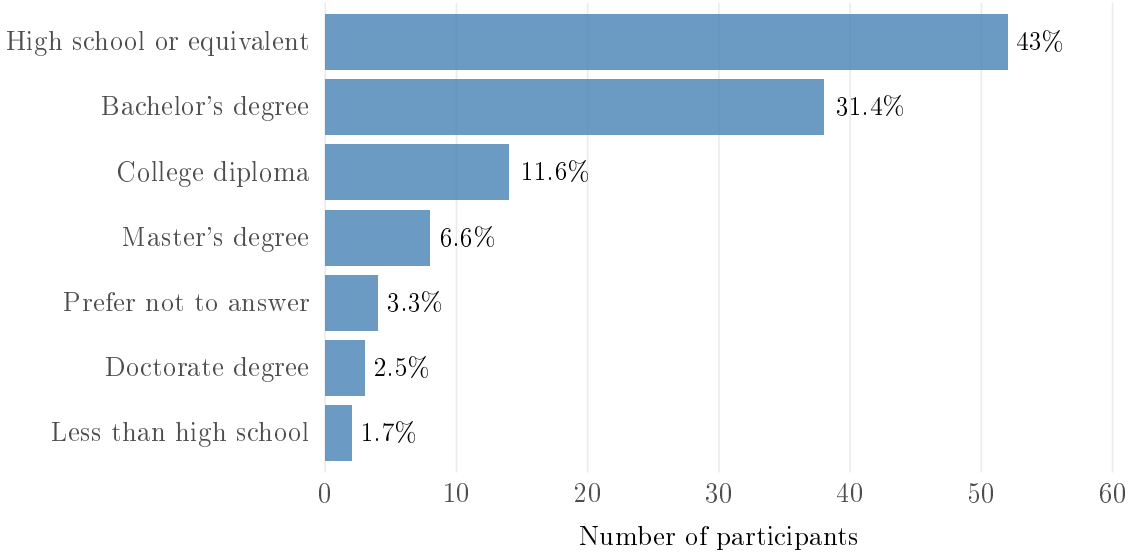

Figure 5.3: Distribution of participants by level of education completed

The education level distribution of the participants is shown in Figure 5.3. The education level most commonly completed by the participants was high school or equivalent ($n = 52$, 42.98%), followed by bachelor's degree ($n = 38$, 31.4%), college diploma ($n = 14$, 11.57%), master's degree ($n = 8$, 6.61%), doctorate degree ($n = 3$, 2.48%). 2 (1.65%) participants had completed less than high school education, while

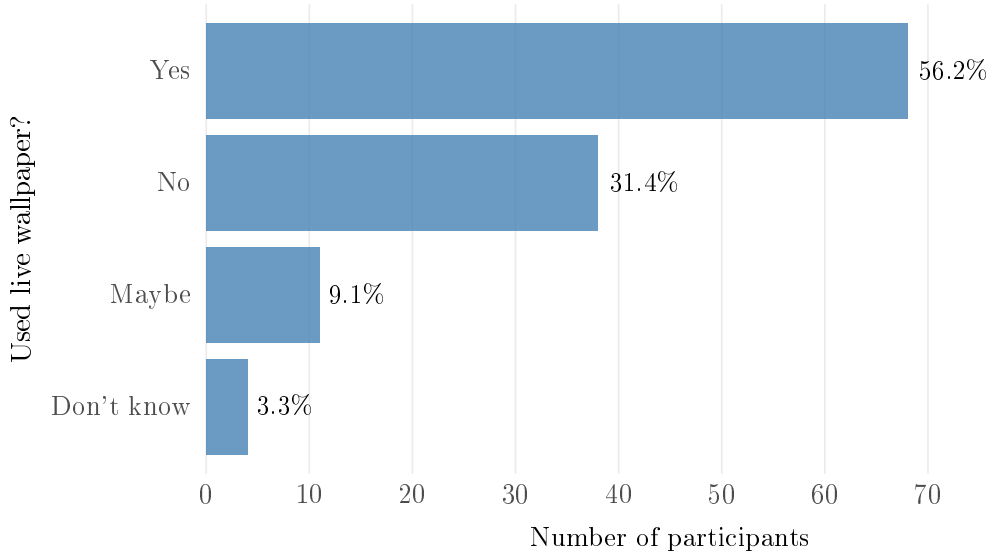

Figure 5.4: Distribution of participants by whether they had used Android live wallpapers before the study

4 (3.31%) participants preferred not to answer the education level question.

68 (56.2%) participants had used Android live wallpapers before the study, 38 (31.4%) had not, while 15 (12.4%) participants were not sure (Figure 5.4).

Hence, broadly speaking, the most common demographic of participants in the study was young people between 18 and 25 who have a high school or bachelor's degree. This sounds good because this is the demographic that is most likely to be affected by absent-minded smartphone use.

We asked participants whether the Android device with which they participated in the study was their primary device. 102 (84.3%) participants answered "Yes", while 19 (15.7%) participants answered "No" (Figure 5.5). This shows that a majority of them participated in the study with their primary devices, while the rest, in addition to their Android device, own some other device, perhaps an iPhone, which serves as their main device.

We also asked participants to select three tasks they use their devices for from a list of *Social media*, *Education*, *Tools*, *Entertainment*, *Games*, *Lifestyle* and *Other*. The result is presented in Figure 5.6 indicating that social media was what the majority of the participants agreed that they use their devices for, followed by education, productivity and entertainment.

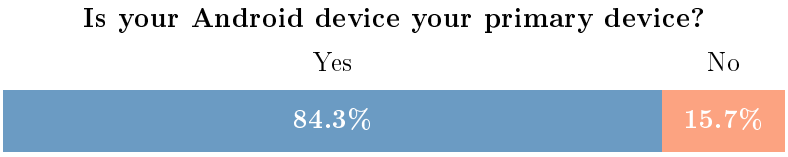

Figure 5.5: Distribution of participants by whether or not their Android device was their primary device

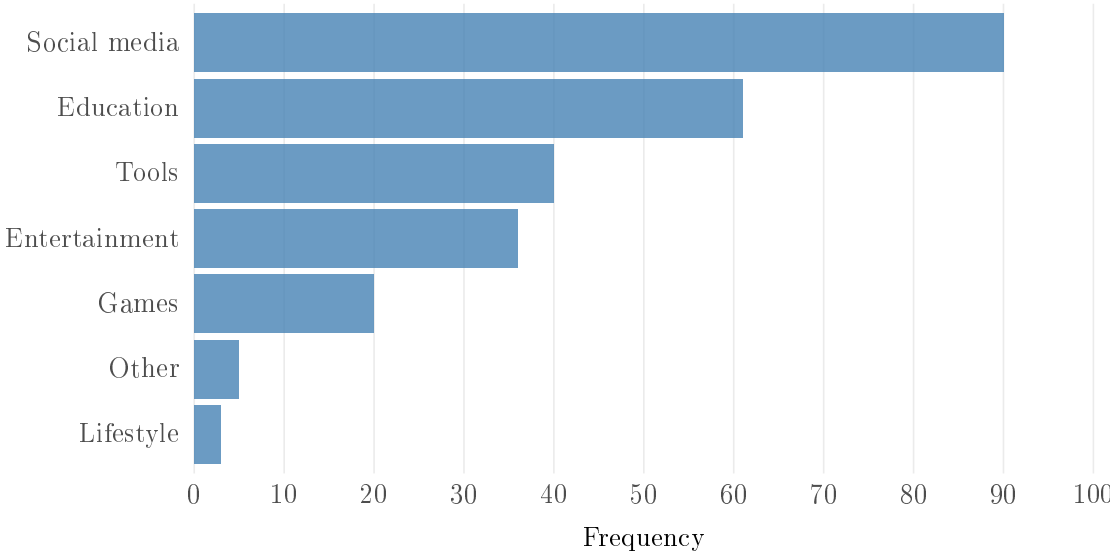

Figure 5.6: Distribution of tasks participants use their devices for

5.2 Distribution of Stages of Change

5.2.1 Stages of Change for Smartphone Use

For the stages of change for smartphone use, 45 (37.19%) participants were at stage 1 (precontemplation), 34 (28.1%) participants were at stage 2 (contemplation), 33 (27.27%) participants were at stage 3 (preparation). There was only one participant at stage 4 (action) and 8 at stage 5 (maintenance). Because of this low number of participants at stages 4 and 5, and to ease the analyses, we merged stages 4 and 5 into one stage: "action/maintenance". This group, therefore, contains 9 participants representing 7.44% of the total participants. See Figure 5.7.

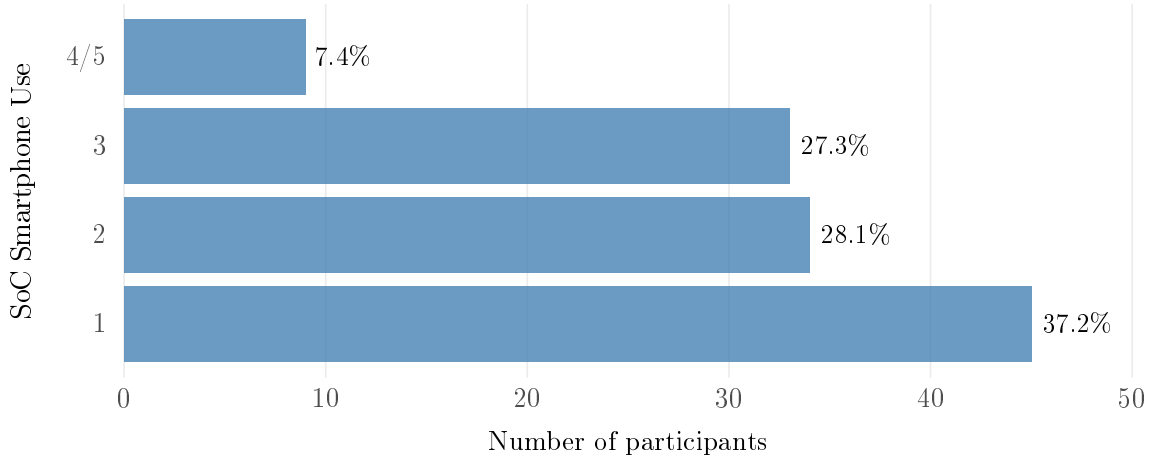

Figure 5.7: Distribution of participants by stage of change for smartphone use. The numbers on the vertical axis represent the stages of change according to the TTM.

5.2.2 Stages of Change for Physical Activity

For the stages of change for physical activity, 11 (9.09%) participants were at stage 1 (precontemplation), 12 (9.92%) participants were at stage 2 (contemplation), 27 (22.31%) participants were at stage 3 (preparation), 12 (9.92%) participants were at stage 4 (action), and 59 (48.76%) participants were at stage 5 (maintenance). See Figure 5.8.

Figure 5.9 shows the overlap of stages of change for smartphone use and physical activity. This shows that our study sample is made up to a large extent of individuals at later stages of change for physical activity, but at earlier stages for smartphone use.

5.3 Analysis of Perceived Usability and Usefulness

We analyzed the SUS scores and the PUT scores to answer **RQ1**.

The SUS is a 10-item scale with possible SUS scores ranging from 0 to 100. We assume a neutral score of 50 since by most interpretations of the scale, this score lies between “poor” and “ok” or “grade F” and “grade D” [18, 176].

The overall mean SUS score for the application was 63.76 (SD = 13.58). We conducted a one-sample t-test to determine if this average is significantly different

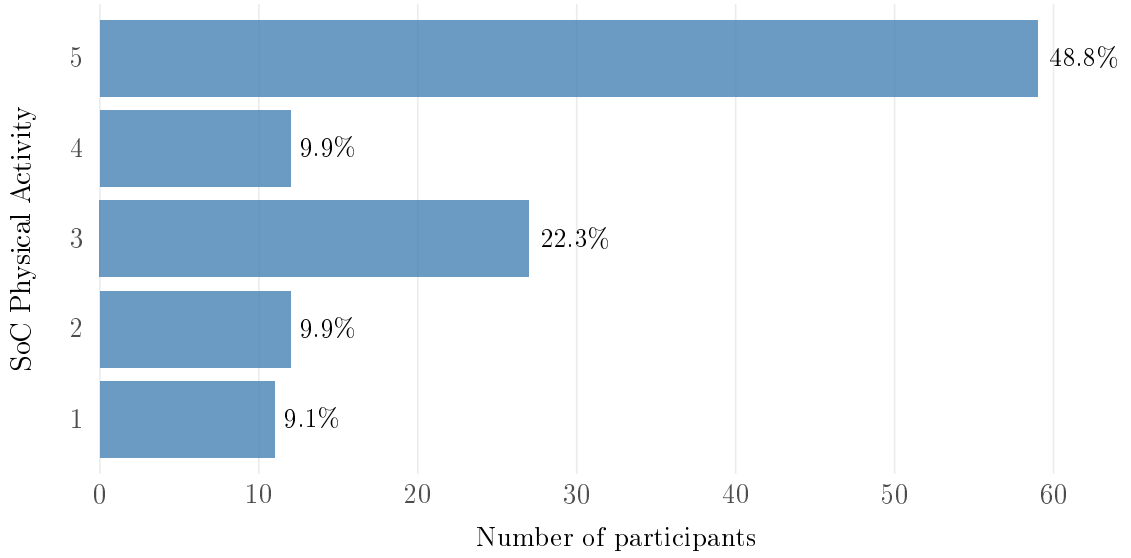

Figure 5.8: Distribution of participants by stage of change for physical activity. The numbers on the vertical axis represent the stages of change according to the TTM.

from the neutral score of 50. The result of the test shows that the average SUS score is significantly higher than the neutral score (Table 5.1). This suggests that the participants perceived the app as usable but with some room for improvement.

The PUT scale as we adapted it consists of 5 items assessing usefulness each of which has 5 possible options ranging from "Strongly disagree" to "Strongly agree". The overall mean PUT score for the application was 3.82 (SD = 0.52). We conducted a one-sample t-test to determine if this average is significantly different from a neutral score of 3.0. The result of the test shows that the average PUT score is significantly higher than the neutral score (Table 5.1). This suggests that the participants perceived the app as useful.

Table 5.1 shows the mean and standard deviation for the SUS and PUT scores alongside their one-sample t-test statistics and significance.

5.4 Analysis of SUQ-A Scores

The Smartphone Use Questionnaire (absent-minded) was used to measure absent-minded smartphone use before and after the intervention. This helped us measure the effectiveness of the intervention in terms of reducing absent-minded smartphone

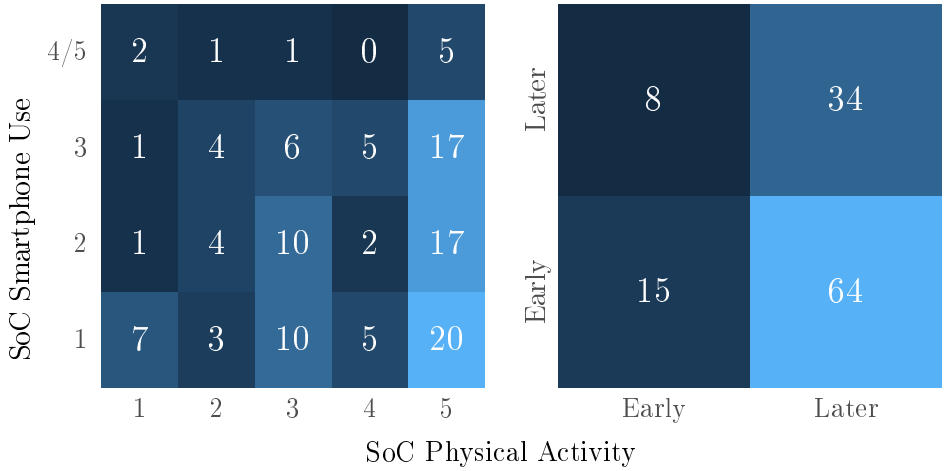

Figure 5.9: Heat map of participant count in various stages of change for smartphone use and physical activity. In the second image, the stages of change are grouped into early and later stages.

Table 5.1: The mean scores for the SUS and PUT scales. The t standard score and p-values indicate how significant the mean scores are compared with the neutral scores of 50 and 3.0

Scale	n	Mean	SD	t	p
System Usability Scale	121	63.76	13.583	11.144	$<$0.0001
Perceived Usefulness Test	121	3.818	0.52	17.299	$<$0.0001

use. The SUQ-A scores are on a scale of 1 to 7, with 1 indicating low absent-minded smartphone use and 7 indicating high absent-minded smartphone use.

In the pre-intervention survey, the average SUQ-A score was 4.38 (median = 4.4) and in the post-intervention survey, the average SUQ-A score was 4.1 (median = 4.2). Hence, the average change in SUQ-A score across the board was -0.29 (SD = 1.12).

A slope plot of the pre and post-intervention SUQ-A scores for all the participants is shown in Figure 5.10. Every participant in the study is represented by a line going from their pre-score to their post-score. The scores for 71 participants decreased post-intervention (shown in blue in Figure 5.10), while the scores for 50 participants increased or remained the same post-intervention (shown in red in Figure 5.10).

In order to analyze the significance of the difference in SUQ-A scores pre to post, we first determined the normality of the differences. A normal distribution will

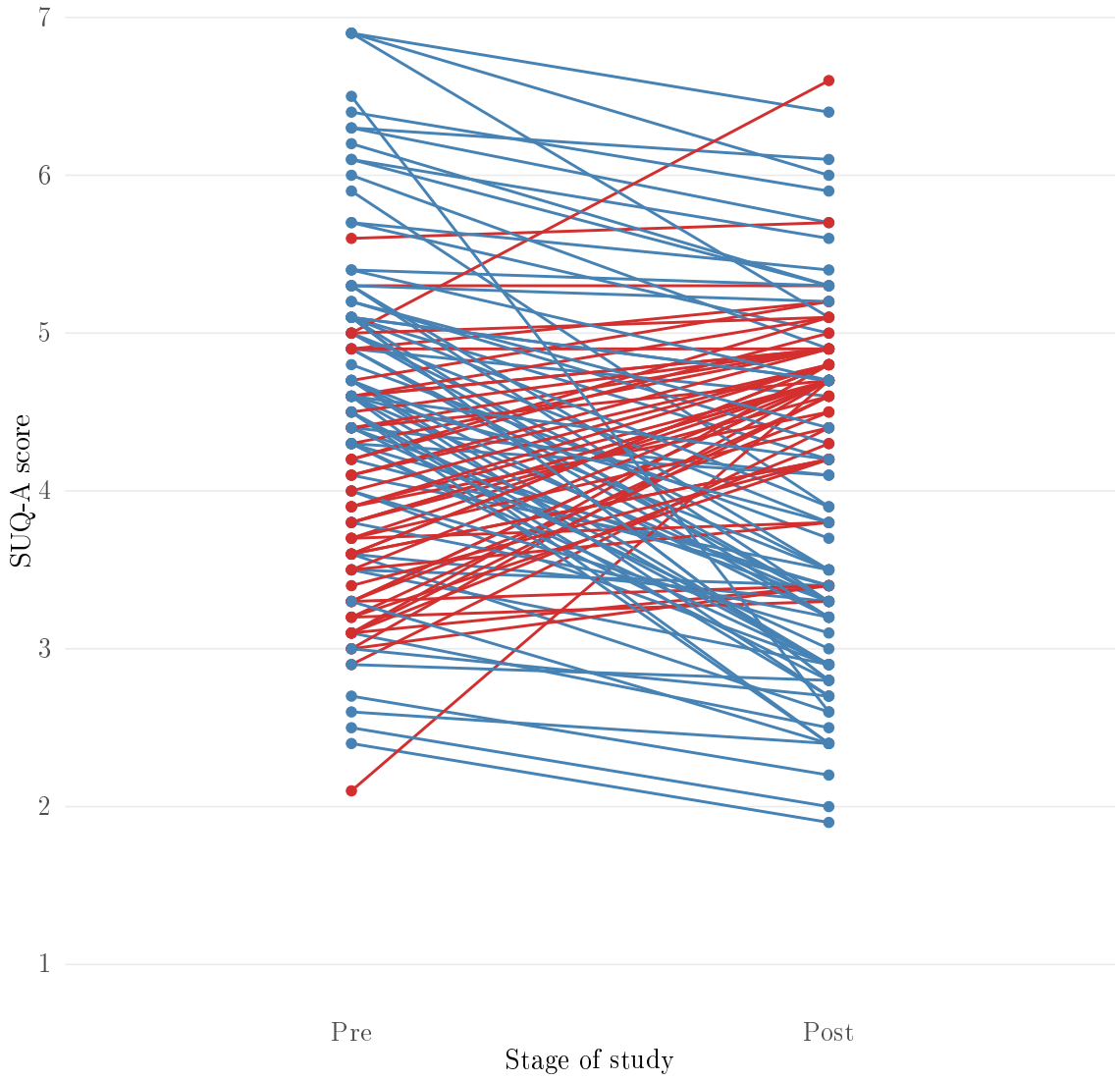

Figure 5.10: Intra-individual SUQ-A score changes for all the participants. Higher SUQ-A scores indicate more absent-minded smartphone use. The reds are participants who had either increased or unchanged scores post-intervention.

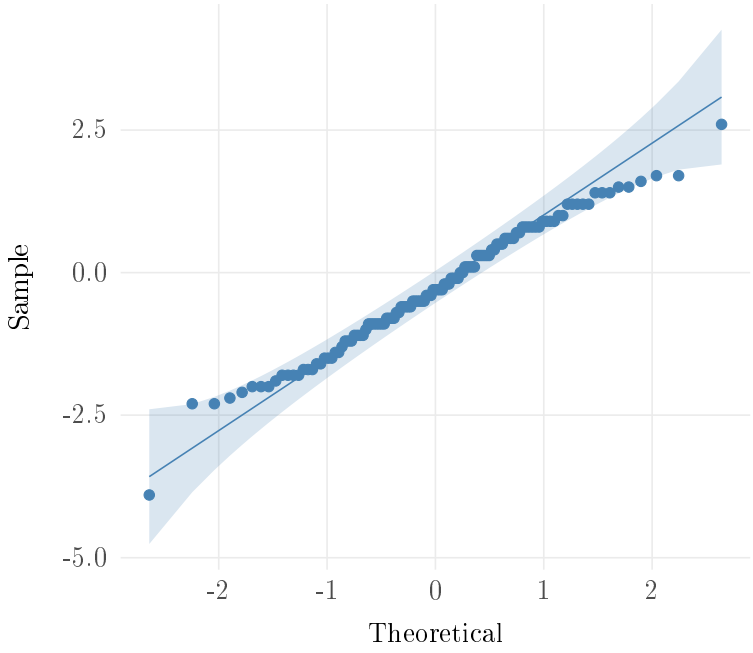

Figure 5.11: Q-Q plot of the change in SUQ-A scores pre to post. Visual inspection of this plot indicates that the change in SUQ-A scores is normally distributed.

fulfill one of the assumptions of the paired samples t-test. The central limit theorem tells us that provided the sample size is sufficiently large ($n > 30$), regardless of the population distribution, the sampling distribution tends to be approximately normal. Even though our sample size is larger than 30, we went ahead to check the normality, visually and using the Shapiro-Wilk test. The Q-Q plot of the SUQ-A changes (Figure 5.11) shows that the differences in the pre and post-scores for SUQ-A are approximately normally distributed. The Shapiro-Wilk test confirms this with a non-significant p-value indicating normality ($W = 0.99$, $p = 0.38$).

5.4.1 Change in SUQ-A Scores for all Participants

The change in SUQ-A scores for all participants is visually represented in the box plot in Figure 5.12.

To answer **RQ2**, we conducted a paired samples t-test to test the significance of the difference in SUQ-A scores pre and post. The test indicated that the difference in SUQ-A scores pre and post was significant: difference = -0.29, 95% CI [-Inf, -0.12], $t(120) = -2.8358$, $p = 0.0027$. However, the effect size was small: Cohen's

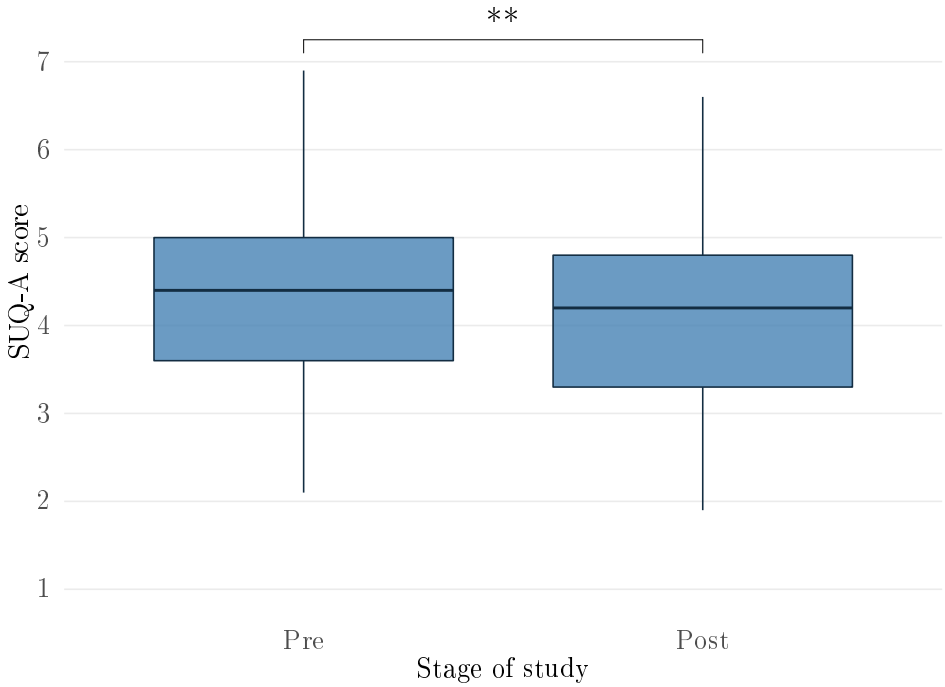

Figure 5.12: Box plot of pre- and post-intervention SUQ-A scores for all participants. Overall, the change in absent-minded use was small and significant.

d = -0.278, 95% CI [-0.081, -0.475]. This suggests that, overall, the intervention significantly reduced absent-minded smartphone use, albeit to a small extent.

5.4.2 Change in SUQ-A Scores for Participant Groups

To further explore how the SUQ-A scores might have changed for participant subgroups, we first examined the means and standard deviations for groups by gender, stage of change for physical activity, and stage of change for smartphone use. The results are shown in Table 5.2.

Then we conducted a repeated measures analysis of variance (RM-ANOVA) test with a between-subjects factor (after testing for the assumptions of RM-ANOVA) to determine whether any change in score was the result of interaction between gender and time, or stage of change and time. In other words, we tested whether the effectiveness of the intervention was different based on gender or stage of change.

There was no significant interaction between gender and time ($F(2) = 1.563$, p = 0.215, $\eta^2(partial) = 0.034$), nor between stage of change for physical activity and

Table 5.2: Mean and standard deviations of pre, post and difference scores across various groups

		Pre SUQ-A score		Post SUQ-A score		SUQ-A change	
Group	n	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Gender							
Man	66	4.415	1.103	4.139	1.028	-0.276	1.104
Woman	52	4.365	0.971	4.035	1.063	-0.331	1.151
Other	3	3.967	0.252	4.167	0.971	0.200	0.954
SoC Smartphone Use							
Stage 1	45	4.509	1.148	4.016	1.081	-0.493	1.079
Stage 2	34	4.547	0.986	4.224	1.115	-0.324	1.039
Stage 3	33	4.076	0.960	4.230	0.902	0.155	1.128
Stage 4/5	9	4.256	0.648	3.511	0.831	-0.744	1.197
SoC Physical Activity							
Stage 1	11	4.282	1.015	4.300	0.888	0.018	1.403
Stage 2	12	4.442	1.010	3.950	1.024	-0.491	1.239
Stage 3	27	4.500	1.125	4.304	1.103	-0.196	1.083
Stage 4	12	4.000	0.751	3.650	0.871	-0.350	1.137
Stage 5	59	4.414	1.058	4.081	1.058	-0.332	1.068

time ($F(4) = 0.733$, $p = 0.572$, $\eta^2(partial) = 0.032$). So we do not further explore those differences within those groups.

There was however a significant and medium interaction between stage of change for smartphone use and time ($F(3) = 2.966$, $p = 0.036$, $\eta^2(partial) = 0.092$). This suggests that the effectiveness of the intervention was different based on the stage of change for smartphone use. We explore this result further in the next section.

Change in SUQ-A scores by stage of change for smartphone use.

A visual inspection of the SUQ-A score changes for participants in different stages of change (Figure 5.13) reveals some interesting patterns. A large percentage of participants at stage 3 (preparation) had increased scores post-intervention compared with participants in other stages. This is even clearer from the box plots in Figure 5.14 which show that the mean SUQ-A score increased for participants at stage

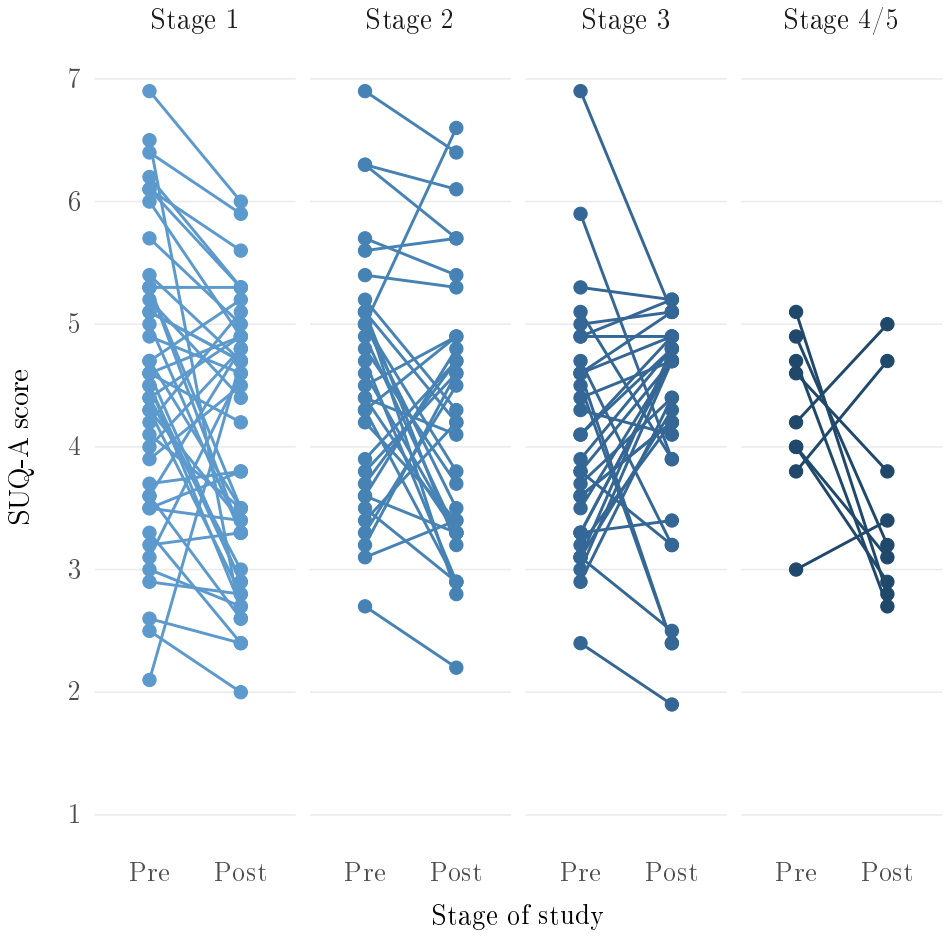

Figure 5.13: Intra-individual SUQ-A score changes for participants grouped by stage of change for smartphone use. Compared to other stages, we observe that a large percentage of participants at stage 3 (preparation) had increased scores post-intervention.

3 of smartphone use behavior change, while decreasing significantly for participants at other stages of change.

As already reported in the previous section, the results of RM-ANOVA showed a significant interaction between time and stage of change for smartphone use. We went further to conduct post hoc pairwise comparisons for the smartphone use stages of change using Bonferroni correction. However, the results of the post hoc test were contradictory to that of the ANOVA and revealed no significant difference between any of the stages of change. The reason for this contradictory result could be the weakly significant main effect from the RM-ANOVA.

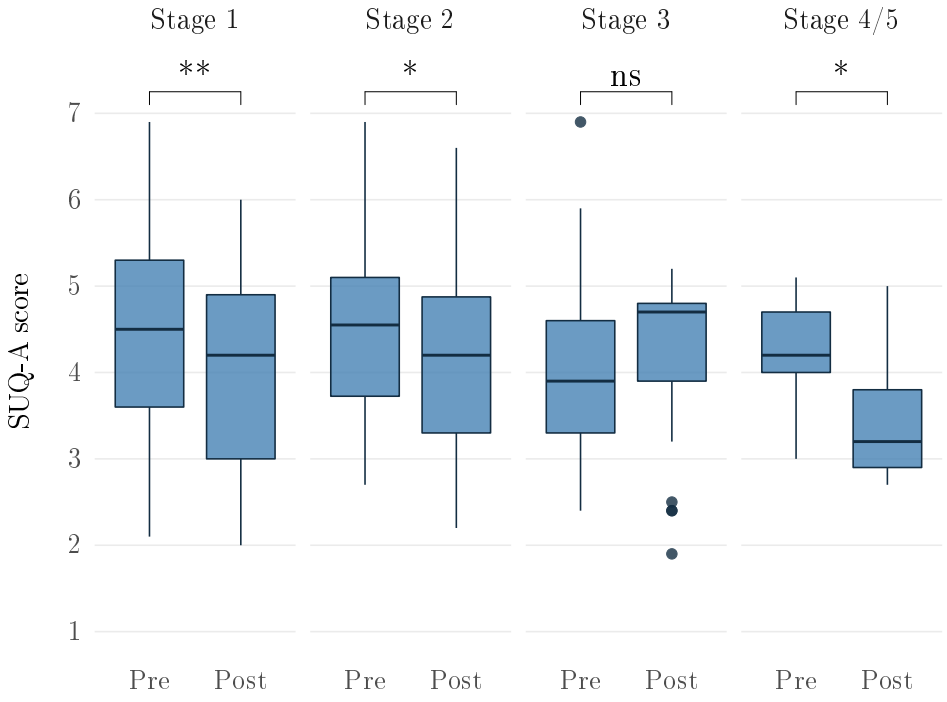

Figure 5.14: Box plots of pre- and post-intervention SUQ-A scores grouped by stages of change for smartphone use. We see that the mean SUQ-A score for participants at stage 3 (preparation) increased post-intervention.

In order words, and in answer to **RQ3**, the mean change in absent-minded smartphone use was not significantly different for users at different stages of change for smartphone use.

5.5 Perceived Persuasiveness

5.5.1 The Persuasiveness of the Application Features

To start the analysis of the persuasiveness of the implemented features, we first plotted the mean persuasiveness of the various features (see Figure 5.15). This plot reveals that the mean persuasiveness scores of the various features are all above the neutral score, and hence suggest that all the features were found to be persuasive by the participants.

We further conducted one-sample t-tests to check whether the mean persuasiveness scores of the various features are significantly different from the neutral score of

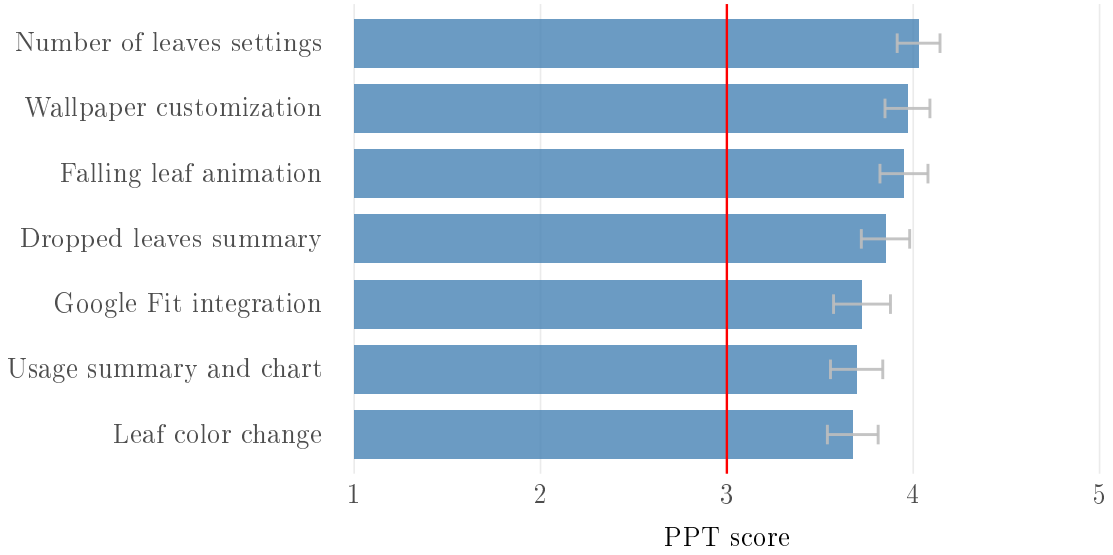

Figure 5.15: Plot of perceived persuasiveness scores for various features of the app. The error bars depict 95% confidence intervals associated with each of the feature score means. The red vertical line indicates the neutral score of 3.

3. The result of the one-sample t-tests shows that the persuasiveness scores of the various features are all significantly higher than the neutral score of 3 (Table 5.3). This means that indeed our participants perceived the individual features as persuasive in terms of their ability to motivate behavior change.

The customization strategy of the number of leaves settings was perceived as the most persuasive (mean = 4.03, SD = 0.638), followed by the wallpaper customization feature (mean = 3.97, SD = 0.67), and the falling leaf animation (mean = 3.95, SD = 0.716). The leaf color change was perceived as the least persuasive among all the features overall (mean = 3.68, SD = 0.757).

5.5.2 Comparing Perceived Persuasiveness of the Different Features

By examining the means of the perceived persuasiveness for the various features as presented in the previous subsection, we can tell that the features are perceived to be persuasive to different degrees (Figure 5.15). However, to check if those between-feature differences are significant, we conducted an RM-ANOVA to examine the effect of feature on perceived persuasiveness for all participants. The sphericity assumption of RM-ANOVA was first tested using Mauchly's test, and it was significant, $\chi^2(6) =$

Table 5.3: The mean persuasiveness of the app features. The p-values indicate how significant the mean PPT scores for the features are compared with the neutral score of 3.0 using one-sample t-tests

		n = **121**		
Feature	**Strategy**	**Mean**	**SD**	p
Dropped leaves summary	Self-monitoring	3.851	0.721	<0.0001
Falling leaf animation	Mindfulness	3.950	0.716	<0.0001
Google Fit integration	Rewards	3.725	0.848	<0.0001
Leaf color change	Mindfulness	3.676	0.757	<0.0001
Number of leaves settings	Customization	4.029	0.638	<0.0001
Usage summary and chart	Self-monitoring	3.696	0.779	<0.0001
Wallpaper customization	Customization	3.969	0.670	<0.0001

0.596, $p < 0.001$. This meant that the sphericity assumption was violated. Therefore, the degrees of freedom were corrected using the Greenhouse-Geisser method, $\epsilon = .84$.

The RM-ANOVA result suggests that the main effect of feature is statistically significant and medium ($F(5.04, 605.2) = 7.81$, $p < .001$; $\eta^2(partial) = 0.06$, 95% CI [0.03, 1.00]). In other words, there is a significant difference between features/strategies with respect to their persuasiveness.

We went further to conduct Bonferroni-corrected pairwise comparisons. The results are shown in tabular form in Table 5.4. Using the results from the pairwise comparisons, as well as the means of the individual strategies, we can make inferences about the relative persuasiveness of each feature. In the following subsections, we discuss the results of the pairwise comparisons and use qualitative feedback from participant interviews to support the findings.

5.5.3 Falling Leaf Animation

The results of the pairwise comparison show that the falling leaf animation is perceived as significantly more persuasive than the usage summary and chart ($p = .022$). This is an important finding since it suggests that the wallpaper animation was potentially more effective than the traditional in-app self-monitoring strategies for reducing PSU using charts and other visualizations, as employed in applications

Table 5.4: p-values from the post hoc pairwise comparison of the persuasiveness of features.

	Falling leaf animation	Leaf color change	Dropped leaves summary	Usage summary and chart	Wallpaper customization	Number of leaves settings
Leaf color change	**0.001**					
Dropped leaves summary	1.000	0.208				
Usage summary and chart	**0.022**	1.000	1.000			
Wallpaper customization	1.000	**0.005**	1.000	**0.030**		
Number of leaves settings	1.000	**0.000**	1.000	**0.002**	1.000	
Google Fit integration	0.186	1.000	1.000	1.000	0.105	**0.005**

like Digital Wellbeing and Apple Screen Time.

This can equally be attributed to the fact that the wallpaper is a just-in-time intervention, as opposed to the after-the-fact nature of the in-app self-monitoring strategies. Hence, with the wallpaper on the lock screen, users can reflect on their usage behavior before they unlock their phones.

The results show that the falling leaf animation is perceived as significantly more persuasive than the leaf color change ($p = .001$). *"I found myself noticing the change in leaf density however the change in colour was less relevant."*[1] [P36].

Other comments made by participants to support their ratings for this feature include: *"First thing I love about the app is the screen saver, then secondly the falling leaves, it's very artistic. These past few weeks the app has taught me that I use my phone more than necessary <smile emoji>, my leaves finish before 12 hours, I hope to improve."* [P100]; *"It's perfectly designed and makes you very conscious of your phone usage habit, you cannot but see the leaves falling."* [P120]; *"The falling leaf animation is smoothly rendered and looks naturalistic. Feels like fall season has begun."* [P42]; *"Natural"* [P24].

[1]Snippets from the interviews and open-ended survey responses are presented with only minimal spelling or grammatical corrections to make them understandable.

5.5.4 Leaf Color Change

The results show that leaf color change is significantly less persuasive than the falling leaf animation ($p = 0.001$). This is in spite of the fact that both features are part of the wallpaper, not in-app. Leaf color change was also significantly less persuasive than wallpaper customization ($p = .005$) and number of leaves settings ($p < .001$). This means that the ability to personalize the wallpaper and change the settings was found to be more persuasive than the color change feature. There could be several reasons contributing to the relatively low persuasiveness of the color change feature.

One of these is that compared with the animation of the falling leaves, the color change is very subtle. It is easier to miss especially for users who are not very observant. This is supported by participant comments: *"The colours were quite similar. I would almost prefer an unrealistic color set for each hour of use i.e purple, red, blue. I believe the slow gradient scale was hardly noticeable."* [P36]; *"The colour effect is not appeasing. I would rather suggest colour gradient or lighter colours"* [P43].

Other comments to support the perceived persuasiveness rating for leaf color change are presented below. The comments address how relatable this feature is to real life and how effective it is for behavior change.

"I believe the colour change is a good feature as I don't have to look at the same type of tree. But this would not help me in mindfulness for phone usage." [P40]; *"Makes it relatable to real life, would have loved the default leaves to be green though so it turns brown instead"* [P49]; *"It make me to know when I have overused my phone"* [P106]; *"This very Good to people misusing their phone"* [P113]; *"It notifies me on how long I have spent on my phone and it makes me to withdraw immediately and engage myself in other activities"* [P111]; *"This is second most important feature for me. I personally used a black background with orange leaves that went brown if screen is used a lot. If the leaves went too dark, I knew I needed to cut down."* [P27].

5.5.5 Dropped Leaves Summary

This is a self-monitoring feature. This feature's persuasiveness is not significantly different from any other feature. This feature was found by the participants to be useful for planning and tracking smartphone use: *"Makes me plan ahead next time*

on how I will use the phone" [P49]

However, this feature and the other self-monitoring feature implemented in the app (usage summary and chart) were deemed to be less accessible by some participants compared with the wallpaper features. This supports the earlier finding that the wallpaper is potentially a more effective way to keep users aware of their device usage. *"Features hidden behind a layer like an app, are seldom used by users. Too much friction to open them. Perhaps a 'screen time warning' and 'Screen time exceeded' notification when approaching the goal, would be more appropriate"* [P30]; *"I checked this feature probably once or twice over the period."* [P36].

5.5.6 Usage Summary and Chart

This is another self-monitoring strategy like the dropped leaves summary. It shares similar qualitative feedback as the dropped leaves summary, including being useful for tracking and planning, but also the 'friction' to access them.

"The summary and chart help me track my phone usage habits and this way I can try and change them to whichever extent I want. So, I liked this feature." [P40]; *"It makes the information from the app more clear to me"* [P104]; *"It serves as a timer that helps me to be conscious on how long I spend on my phone"* [P111]; *"The timing of very good features I have seen in this app. Time is everything. One can as well monitor their children phone usage using this feature of the app"* [P37]; *"again, I rarely come in here, but this is a nice graph. I think maybe the tree was enough and I didn't really need to come in here for a more extensive overview of my usage."* [P121].

5.5.7 Wallpaper Customization

This is a customization strategy. It was the second most persuasive feature in the app, significantly more persuasive than the leaf color change ($p = 0.005$) and the usage summary and chart ($p = 0.030$). Some of the comments made by participants to support their ratings for this feature include:

"Customizing wallpaper and the leaf colour gives me a feeling of agency and ownership of the tree." [P42]; *"This was my no 1 favourite feature. I'm glad I was able to tweak the tree to match my phone and my preferred color. One thing I loved about*

is how it turns dark during the night!" [P28]; *"I mean, to me it is a personalization thing. If I was stuck with something static, I probably won't have used it for as long as I did. Am a bit picky about my wallpaper"* [P27]

5.5.8 Number of Leaves Settings

This feature also implements the customization strategy. With this feature, participants are able to change the number of leaves on the wallpaper tree as well as the time it took for the color change. It is also the feature perceived as the most persuasive overall in this study. In comparison with other strategies, it was significantly more persuasive than the leaf color change ($p = 0.0001$), the usage summary and chart ($p = 0.002$), and the Google Fit integration ($p = 0.005$).

Some of the comments made by participants to support their ratings for this feature include: *"I did not change anything, but I can see how I might like to change things another time, but I was happy with the default"* [P121]; *"I mean, it let's me modify it a bit according to my personality so that's a plus "* [P27]; *"The ability to set the number of leaves and my goal for smartphone usage is a good feature. This would help me reduce my phone usage."* [P40].

5.5.9 Google Fit Integration

This is our implementation of the reward strategy. The Google Fit integration was one of the features that had a relatively low persuasiveness score. However, in spite of the low persuasiveness score of this feature by observation, it was only significantly less persuasive than the number of leaves settings ($p = .0005$), possibly suggesting that there were participants who found it to be very useful. This can be seen in the positive opinions about its usefulness: *"This may be my best feature of the APP, always encouraging me to walk."* [P49]; *"I like the idea of how the new leaves can be replenished with walking."* [P22].

It should be noted that the low persuasiveness of the Google Fit integration may be because some of the participants could not make use of the feature because it required installing the Google Fit app. This is supported by comments like: *"I wish this feature worked on my phone but it did not. I personally like this feature on this app"* [P43]; *"It never worked on my smartphone so I don't have much to say about*

that" [P119].

5.5.10 Comparing the Persuasiveness by Gender and Stages of Change (Smartphone and Physical Activity)

We conducted an RM-ANOVA with 3 between-subjects factors to check if there are differences in the perceived persuasiveness of the app features between the various stages of change for smartphone use and physical activity, and also for gender. The sphericity assumption was tested using Mauchly's test, which was significant, $\chi^2(20) = 0.538$, $p < 0.001$. Therefore, the degrees of freedom were corrected using the Greenhouse-Geisser method, $\epsilon = .83$.

The RM-ANOVA results did not indicate any significant interaction of feature with either gender ($F(9.95) = 1.66$, $p = .089$; $\eta^2(partial) = 0.04$) or the stages of change for smartphone use ($F(14.92) = 0.552$, $p = .910$; $\eta^2(partial) = 0.02$), or the stages of change for physical activity ($F(19.89) = 0.527$, $p = .955$; $\eta^2(partial) = 0.02$).

Hence, we did not explore this analysis further. In answer to **RQ5**, the mean difference in perceived persuasiveness of the various implemented features was not significantly different across gender or stage of change for either smartphone use or physical activity. In other words, when considering the means, all participant groups perceived the features to be persuasive to the same extent.

5.5.11 Checking Correlation between Perceived Persuasiveness and Change in SUQ-A Scores

To answer **RQ6**, we fitted a linear model (estimated using ordinary least squares) to predict change in SUQ-A score with the perceived persuasiveness of each of the app features while accounting for the pre-intervention score. The formula for the linear model is given below:

$$\text{Change in SUQ-A} \sim \text{PPT} + \text{Pre SUQ-A}$$

Note that this is equivalent to conducting an Analysis of Covariance (ANCOVA) using the pre-intervention score as a covariate as recommended by Clifton and Clifton

[39]. So we first checked for the linearity assumption by visually inspecting the relationship between the pre-SUQ-A score (covariate) and the change in score (dependent variable). The correlation plot (Figure 5.16) shows that the correlation is linear. This

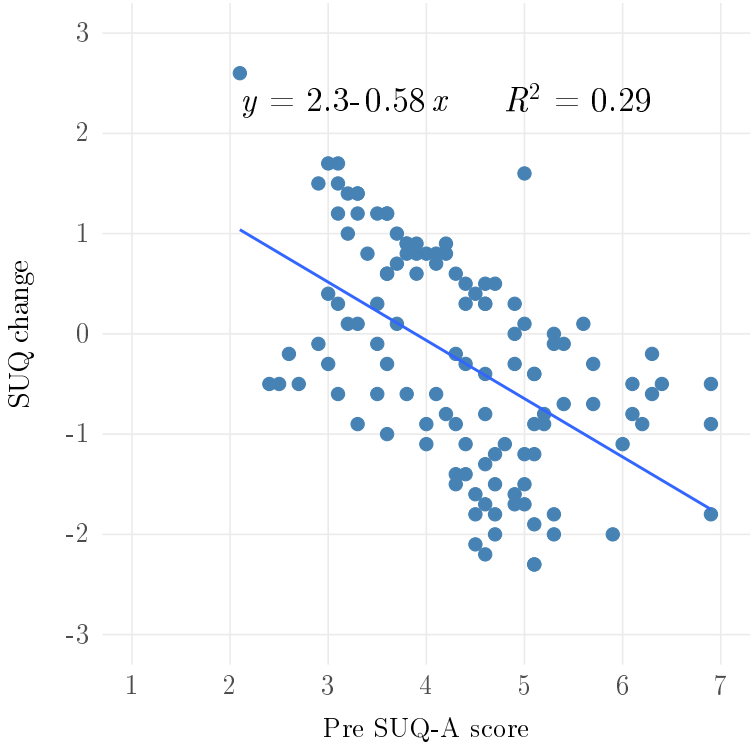

Figure 5.16: Correlation plot of the pre-intervention SUQ-A score and the change in SUQ-A score. Visual inspection of this plot indicates that the correlation satisfies the linearity assumption.

is confirmed by the linear model where the effect of the pre-SUQ-A score on change in SUQ-A is statistically significant and negative (β = -0.58, 95% CI [-0.75, -0.41], $t(118)$ = -6.74, $p < .001$). The linear model explains a statistically significant and substantial proportion of variance ($R^2 = 0.29$, $F(2, 118) = 24.00$, $p < .001$, adj. $R^2 = 0.28$).

Within this model, the effects of the perceived persuasiveness of all the app features were weak and non-significant (see Table 5.5). Even the test that comes close to rejecting the null hypothesis (the *wallpaper customization* feature, with a p value of 0.07) had a positive coefficient ($\beta = 0.24$). This is counter to our alternative hypothesis **H6** where we stated that higher perceived persuasiveness will correlate with a larger drop in absent-minded use (negative coefficient).

Table 5.5: Partial correlation of persuasiveness with change in SUQ-A scores while removing the effect of baseline scores. β is the regression coefficient of the effect of the perceived persuasiveness of the corresponding feature on change in SUQ-A scores.

Feature	β	**Std. error**	t	p
Dropped leaves summary	0.0380	0.1220	0.312	0.756
Falling leaf animation	-0.0035	0.1242	-0.028	0.978
Google Fit integration	0.0774	0.1024	0.756	0.451
Leaf color change	0.0013	0.1153	0.011	0.991
Number of leaves settings	0.1583	0.1399	1.132	0.260
Usage summary and chart	-0.0420	0.1112	-0.378	0.706
Wallpaper customization	0.2389	0.1314	1.818	0.072

We conclude therefore (in answer to **RQ6**) that the perceived persuasiveness of the features was not associated with change in absent-minded smartphone use. The intervention period of two weeks should be taken into consideration while interpreting this result since it might be argued that this time period was not long enough to fully capture behavior changes that might occur due to the persuasiveness of the app features. This also suggests that the perceived persuasiveness does not reflect the actual persuasiveness of the features. We discuss this in more detail in Chapter 6.

5.6 Qualitative Results

We conducted a thematic analysis of the interview transcripts for 15 participants and the responses to the open-ended post-intervention survey questions. We started by going through this qualitative data to get a general overview of it. We systematically assigned codes to snippets/comments within the data, and then grouped codes that shared similar concepts. This process of grouping and refining the codes was done iteratively until we formed them into coherent and meaningful themes. The emergent themes are described below.

5.6.1 Visual Appeal

Many participants found the application and its features to be visually appealing, especially the wallpaper features. A few of the comments about the visual appeal of the app are presented below.

*"It's **beautiful**"* [P25].

*"It's **appealing**"* [P13].

*"I **love the green leaf color change** to brown. ..."* [P119, about the leaf color change feature].

*"I **liked the concept** of the application because the tree is something that I really like."* [P21].

This is a positive result as the wallpaper is the first thing the user sees when they look at their phones, so it must be visually appealing.

5.6.2 Ease of Use

The participants appreciated how easy to use and well-integrated the wallpaper-based intervention was.

*"I like that **it is simple** too. It's **not too complicated** to use."* [P121].

*"It **nicely integrates** with the rest of your life."* [P121].

*"It's **pretty easy to set up** and it's **pretty easy to use** ... I guess every youngster that owns a phone would be able to use it pretty easily."* [P11].

*"I had tried installing couple of apps from Google Play Store but everything was like more of explicit. I had to put in all the details and you know, like what was my goal and what is the problem? It was more of like explicit thing and based on my inputs it was giving me suggestions and things like that. But this app is like **more intuitive** and I would say **more unobtrusive**. ... It was kind of like someone behind me who is reminding me of my smartphone usage practices."* [P21].

*"it's **very easy** to be installed. It doesn't need so much of Google assistance or any assistance anywhere. You just install it and set it up and you're good to go."* [P21].

We can conclude that the simple design and easy setup process of the app was a usability strength as evidenced in these comments.

5.6.3 Raised Awareness About Smartphone Use

This theme was present in all the conversations with the interviewed participants, showing that the wallpaper was particularly effective at raising awareness about usage behavior.

"The falling leaf wallpaper animation ***made me to be conscious*** *on how long I engage [with] my phone"* [P111, about the falling leaf animation feature].

"the application and the falling leaf in particular normally like ***activates my conscience and makes me more aware.****"* [P14].

"It helps one to be ***time conscious*** *and control pressing of your phones unconsciously and mindful of time"* [P118, about the falling leaf animation feature].

"the dropping leaves function definitely, you know, ***creates an awareness****, even if subconsciously in my mind"* [P11].

This is also an important result because it relates to the main purpose of the intervention, to increase awareness and reduce absent-minded use.

5.6.4 Evoked Strong Emotions

Some participants expressed a variety of emotions that the wallpaper caused them to feel. This ranged from glowing to scared to guilt.

"it ***breaks my heart*** *each time the leaves fall. I love it"* [P49, about the falling leaf animation feature].

"The leaf colour change ***makes me feel guilty*** *of using my phone for no good reason."* [P42, about the leaf color change feature].

"I think the leafs should change color alone instead of falling down. Because I don't always feel comfortable seeing those leafs fall. I might be forced to delete the app since ***it scares the life out of me as though my life is being shortened*** *each time the leaf falls down."* [P37, about the leaf color change feature].

"sometimes I'm ***scared*** *to open my phone so that my flower will not drop ..."* [P106].

"my flowers falling down, that one was like ***the scary part*** *... "* [P106].

One participant went into details about how their feelings about the app changed over the course of the intervention: *"... at first I thought that I was not getting a lot of positive vibes because like the leaves start falling off every time I use my phone for*

like no reason and it felt like I was being forced to like not use my phone, but as I got off of that addiction of like opening my phone for like no obvious reason, I started to realize that ... it was like quiet positive reinforcement." [P7].

This result is mixed because we designed the application to persuade without causing feelings of guilt. Further investigation is required to determine the effect of these emotions in the long term and the best way to mitigate the unexpected emotions.

5.6.5 Useful for Self-Regulation

One of the ways that participants found the wallpaper useful was for monitoring and regulating their smartphone usage.

"The [self-monitoring chart] is always ***giving me the time*** *I used my phone most ... mostly around 9pm"* [P106].

"Yea, it really affected the way I used my phone. It actually ***minimized my screen time.****"* [P29].

"I mean [leaf color change] definitely ***helped me regulate*** *a lot of my usage."* [P7].

"Each time I see the leaf drop, it makes me think maybe I should ***take a little break.****"* [P25].

The participants also expressed that they have made efforts to keep the tree from becoming completely bare:

"It does create an impression on me, and I ***try to avoid [dropping leaves]*** *as much as I can"* [P11].

"But right now I'm ***trying to minimize the way I [turn] on my phone****. So the app is trying for me."* [P106].

"to prevent a leaf from falling, I did try to ***use my phone a bit less*** *than I'm used to."* [P121].

5.6.6 "I have things to do"

This theme represents the tension that participants felt when they had to use their phone for something important but also knew that a leaf was going to drop if they unlocked the phone.

"most time if I'm using my phone, it's not like I'm not occupied or I'm lazy or I don't ***have things I'm working on****."* [P14]

"... each time I have to use my phone, it's mostly when ***it's of importance****"* [P14].

"I ***have to do important tasks*** *that require longer screen time and I cannot consider the changing colour of the leaf."* [P42, about the leaf color change feature].

Some participants added that the intervention works to keep them from overusing their phone when they are bored but not when they have work to do: *"I have to still use [my phone] for calling or any other work. But [because of the wallpaper] I use it less when I'm bored. So I don't use it mindlessly, you know, just because I'm bored."* [P11].

Further to this, one participant suggested fitting the intervention to their context: *"So I don't know if it could fit a little bit more around my context ... Like if I just wanna check something or reply to a message very quick then I probably don't want it to bother me at all because I know it's for only a quick second and then I return to my main task whether it's cooking, or doing something ..."* [P121].

5.6.7 Level of Engagement

The idea behind this theme was that participants had opinions about how lively versus undisturbing the wallpaper or application was. On the one hand, some participants liked how the wallpaper was quiet and undisturbing:

"So that's the good thing that I really like about it because it's ***not constantly trying to get my attention****."* [P121].

"I like the way it is because it's in the background, so it's ***not like always disturbing me****."* [P14].

"What I really liked about the application is the ***non-intrusiveness****."* [P21].

On the other hand, there were suggestions to make the application more active and engaging. Some participants suggested making the wallpaper more lively by using emojis or incorporating sounds so that it would be more difficult to ignore. Others suggested adding reminders that can be used to notify themselves when going over the limit:

"It's easy to forget because it is just a wallpaper, there is no sound per se, but

maybe if there was a ***sound like to jolt you*** *up ... Something more alerting maybe. The tree is* ***too silent.****"* [P111].

"But as I got through the days, it became much easier to keep using my phone normally." [P40].

Firstly, this result suggests a need for tailoring the intervention based on user personality. But it also points to a tension that has been highlighted in previous research by Terzimehić et al. [191] about the level of engagement with mindfulness technology. This is discussed further in Chapter 6.

5.6.8 Suggestions for Improvement

There was no shortage of diverse suggestions and feature requests to improve the application. The suggestions ranged from how to improve the current 'tree-and-leaves' wallpaper:

"I think the leaves should be able shake as if it's alive." [P114].

"I think the leaf colors should be changing anytime ten leaves falls." [P114, about the leaf color change feature].

"The time taken for a leaf to fall should also be calculated, thanks." [P114, about the dropped leaves summary feature].

"Instead of just being people who invariably kill the tree, can we get the chance to water it by staying off our phones longer or by using our phones for shorter periods each session ... And then as we water the tree, it should get greener" [P57, about the leaf color change feature].

To suggestions for wallpapers based on new kinds of visualizations:

"Just other different metaphors that I can probably explore, like I may get bored of the tree after two months and I might want to switch to a different plant or a different, I don't know, village. I don't know. Or ocean of fish." [P121]

"Right now it's just a tree with different color leaves. So if you can maybe add a little more wallpaper options, like kind of a pie chart I would imagine ..." [P11].

"Maybe not only just tree. Maybe every day can be a different thing." [P111].

One reason a participant gave for wanting new visualizations was that they shared the app with other people in their home and now *"we are actually using the same app ... a kind of* ***mix up somewhere trying to identify your phone from your***

screen. *"* [P30].

Other features suggested include a lockout feature to prevent themselves from getting distracted: *"it would really help if, uh, let's say I can, you know, lock my phone for a certain period of time, let's say when I'm studying, trying to study, I get distracted and use my phone. So during that time, if I can just lock my phone so I can use any social media apps like Insta or whatever."* [11]

There were also a couple of bug reports related to the calculation of screen time:

"Not sure if this is a bug but when I'm listening to music, the leaves would still go brown and fall down. This happened when I playing game too and I understand that scenario but the music app seemed like a bug." [P28].

"One suggestion would be to count out features like background music playback as I am not technically using my screen. Maybe a change on scale? Otherwise, the second most important feature for me. Works perfectly in combination with the first feature" [P27, about the leaf color change feature].

All the suggestions are rich feedback that will definitely help in improving future versions of the application.

5.6.9 Continued Use of the Intervention

We also highlighted comments related to the continued use of the Chai app after the intervention. Some participants said they still have the wallpaper set even after completion of the study and some have shared the app with others such as friends and family. One participant even asked for the best way to share the app because the popular Xender sharing app did not work for them.

"Like I have already shared the app with my friends." [P24].

"It's a very nice app, I still have it installed." [P72].

"it is a very recommendable app that everybody who has addiction to fiddling of phones and even their computer device devices should have." [P29].

This theme is important because the sustainability of the use of the application was a priority at the design stage of the intervention. This ensures that users can have enough time to develop mindfulness about smartphone use.

In the interview, we asked participants in the interviews whether they missed their previous wallpaper during the intervention period. Many did not, citing that prior to

the study they did not really mind what they had as their wallpaper; however, a few participants did miss their previous wallpapers, especially those who had pictures of family or loved ones before the intervention.

5.7 Summary of Findings

In summary:

1. The app was found to be usable and useful, with room for improvement.
2. After the two weeks of intervention, self-reported absent-minded smartphone use was significantly reduced by a small amount.
3. There was no significant difference in the effectiveness of the app for participants when grouped by gender or stage of behavior change.
4. The various features within the app were all perceived to be persuasive, with some more persuasive than others. Notably, the settings for number of leaves in the wallpaper was found to be the most persuasive, followed by the ability to customize the wallpaper and the falling leaf animation of the wallpaper. The leaf color change was rated as the least persuasive feature.
5. There was no significant difference in the persuasiveness of the app features for participants when grouped by gender or stage of behavior change.
6. The perceived persuasiveness of the app features did not predict or correlate with behavior change in terms of change in self-reported absent-minded smartphone use.

The qualitative data provides deeper insights into the results and how the participants perceived the intervention and feedback for further improvements.

Chapter 6

Discussion

In this chapter, we discuss some of the insights from the results of our evaluation of the Chai application. Specifically, we discuss the implications of the results for further development of the intervention, as well as for the development of future interventions in this field. We end the chapter by making recommendations for future research in this area.

6.1 Usability and Usefulness of the Application

Based on the calculation of the mean score on the SUS scale, the application was rated to be usable at a score of 63.76. Compared with the mean SUS score obtained in the pilot study, which was 78.75 [133], this is quite a significant drop. This can be attributed to the addition of more features, especially the Google Fit integration, which required additional steps from most participants to get set up. The drop can also be attributed to the larger and more diverse participant sample used for the main study evaluation compared to that of the pilot study. On the other hand, the application was found to be useful with an above-average score of 3.82 on the PUT scale.

The qualitative results provide some insights into these scores and the areas where there is room for improvement. Firstly, we found that most of the participants appreciated the simplicity of the design. They specifically liked how easy it was to set up the wallpaper, access their device usage information and how it nicely fits in with their smartphone use patterns with minimal disruptions. During the interview, some participants reported having experienced no usability challenges at all. However, some participants desired that the wallpaper be more engaging. Some suggestions for making it more engaging included incorporating sounds and animations. A good way to do this based on the PSD model would be to make elements of the wallpaper play a social role for the user, for instance, a pet that needs to be taken care of, or

a friendly personal assistant.

Furthermore, as some of the participants suggested, alternative visualizations apart from the tree could be designed and developed to further increase personalization and give users more options. These could be inspired by various aspects of nature that can be appreciated by most people and will be developed iteratively while evaluating with target users at each step to ensure their effectiveness.

The key takeaways from the results about usability and usefulness include: (1) Extra effort should be put in to make the step count-based rewards mechanism easier and more seamless to setup for all participants, regardless of whether they already had Google Fit installed or not; (2) There were reports of a bug in the screen time calculation which affected a couple of participants, and this should be fixed in future updates; (3) To make the wallpaper more useful to the users, it would be worth considering making it a bit less passive without being overly obstructive.

6.2 Effectiveness of the Intervention

In this section, we discuss the effectiveness of the intervention to reduce absent-minded smartphone use.

6.2.1 Overall Effectiveness

Overall, the intervention significantly reduced absent-minded smartphone use as measured using the SUQ-A scale. This is a positive result that implies that the intervention was relevant and effective for its purpose. It validates future efforts to develop and put out improved versions of the application.

The reduction in absent-minded use due to this intervention was small overall: a drop of -0.29 on the SUQ-A scale and an effect size of -0.278. While this might be attributed to the duration of the intervention which was two weeks, it also means there is much room to improve the effectiveness of the app. This current result will serve as an adequate baseline to compare future evaluations. The effectiveness can be improved by boosting the usability of the app as outlined in the previous section, but also by tailoring the strategies to user personality, occupation, or stage of change for smartphone use.

6.2.2 Impact of User Stage of Change on the Effectiveness of the Intervention

A previous study by Haliburton et al. [68] using an intervention for absent-minded use grouped the participants into high and low-predisposition groups. The study found that absent-minded use was reduced significantly for users with high predisposition, but not for those with low predisposition. Our results using TTM-based stages of change for smartphone use contain more details, showing among other things that the intervention was in fact effective for users at higher stages (action/maintenance).

Specifically, we checked if the stage of change of the participant for smartphone use was associated with the effectiveness of the intervention for reducing absent-minded use. Our RM-ANOVA test indicated a significant interaction effect, but this interaction was not significant in the post hoc test. However, paired samples t-tests conducted groupwise for stage of change (Figure 5.14) show that absent-minded use was reduced significantly for participants at stages 1 (Precontemplation), 2 (Contemplation) and 4/5 (action/maintenance), but not for participants at stage 3 (Preparation).

A significant proportion of the participants at stage 3 (preparation) had increased scores going from pre to post. These increased scores might be a result of the participants being more aware of their smartphone usage after the intervention. This is because the SUQ-A test is a self-reported test, and the participants might have been made more aware of their smartphone usage during the period of the intervention. The reason why this increase is more significant in this stage than in other stages might be because the participants are in a transition stage. Stage 3 is characterized by the intention to act in the immediate future, usually measured as the next 30 days. Hence participants in this stage, after this intervention, might have been made more aware of periods of absent-minded use as they prepare to take action.

However, the inability of our data to reveal any statistically significant evidence of difference in the change in absent-minded use for participants in the different stages necessitates further studies in this area. Results that identify differences in response between participant groups will inform the design of interventions that are tailored to each group to ensure maximum effectiveness and usefulness for the user.

6.3 Persuasiveness of the Intervention

In this section, we discuss the findings about the persuasiveness of the app features.

6.3.1 Persuasiveness of the Chai Application Features

We have shown that the implemented application features were all found to be persuasive by the participants. We also showed that some features were perceived to be more persuasive than others. For instance, the settings for number of leaves in the wallpaper was found to be the most persuasive, followed by the ability to customize the wallpaper and the falling leaf animation of the wallpaper. The leaf color change was rated the least persuasive feature.

This result suggests the assignment of priorities to various features for future development or maintenance of the application. For instance, because the leaf color change feature was not perceived to be as persuasive as the other features of the app for motivating users to moderate their smartphone use, future developments on the app would either de-prioritize this feature or redesign to make it more obvious. The two most persuasive strategies were both related to customization. This means that the ability to customize the intervention was very important to the participants and should be a priority in future developments.

Our analysis did not reveal any significant difference in how users at different stages of change perceive the persuasiveness of the various strategies. The goal of this research question was to identify the particular needs and preferences of participants at different stages of change for smartphone use. Thus this result necessitates further studies which will provide the evidence to inform the tailoring of future interventions.

6.3.2 Persuasiveness and Behavior Change

Our results also show that perceived persuasiveness was not correlated with behavior change as measured using the self-reported SUQ-A scale. This suggests that the actual persuasiveness and hence effectiveness of the intervention might be different from the self-reported persuasiveness. The direct implication of this for the Chai application is that perceived persuasiveness must not be assumed to mean effectiveness. Specifically, the intervention could potentially be effective for users who think

it is not persuasive enough; on the other hand, the intervention might not be very effective for other users even if they perceive that it is highly persuasive.

Broadly speaking, this result also reveals a research gap in the literature on persuasive technologies. Several persuasive technology studies measure the perceived persuasiveness of the interventions. There is however very little empirical research showing how perceived persuasiveness translates to actual persuasiveness and behavior change for the users. A good starting point in this direction might be a systematic review and meta-analysis of studies that measured both perceived persuasiveness and change in behavior over time.

Further, there could be other variables involved in the relationship between persuasiveness and behavior change such as ability, or the presence or absence of triggers, as suggested by Fogg's behavior model [53]. Hence future research might well consider the variables that moderate the relationship between perceived persuasiveness and behavior change. For instance, in our own case where we seek to reduce absent-minded use, would delaying and batching notifications from social media apps (reducing triggers [55]) significantly change the relationship between persuasiveness and change in absent-minded use? Is ease of access to the device such as unlocking using face id versus manually typing in passwords (representing various levels of ability) a moderator of the relationship? Answering these questions would contribute to an empirical understanding of how persuasive interventions lead to behavior change.

6.4 Mindfulness and Persuasive Technologies

In our intervention, we combined mindfulness design principles (creating awareness without judgment) and persuasive systems design strategies (self-monitoring, rewards, liking, and customization). In this section, we discuss insights related to this combination as discovered during our evaluation (primarily from the qualitative data) and relate these to what has been reported in previous studies.

The applications of mindfulness for behavior change have received some attention in previous works: Schuman-Olivier et al. [177] noted that mindfulness-based interventions (MBIs) do lead to behavior change in areas such as substance abuse, eating disorders, emotion regulation, and chronic disease self-management. However, there is little knowledge on how best mindfulness practice using digital technologies can be

integrated with persuasive designs which have been widely studied and implemented for behavior change. Crucially, the relationship between mindfulness and persuasive designs in the literature so far is not entirely cordial. It has been termed 'paradoxical' in a recent study conducted with mindfulness practitioners which revealed that some persuasive design patterns (such as notifications and streaks) create friction with the practice of mindfulness and tend to be perceived as stressful [85]. Terzimehić et al. [191] have also pointed out some important conflicts between mindfulness principles and commonly accepted design principles in HCI, for example, user control in HCI versus acceptance in mindfulness, richness versus minimalism, and level of engagement with technology. We did observe some of these conflicts in our study as further discussed below.

6.4.1 Level of Engagement

As we highlighted in one of the themes from the thematic analysis, there were comments regarding how engaging the intervention should be. While some participants liked the undisturbing nature of the wallpaper, others wished it could be more lively. For example, some participants wanted the wallpaper to have sounds and others suggested adding emojis. These would make the intervention more interactive. However, for fostering mindful awareness, these must be implemented carefully to ensure that the goal of the intervention is not defeated.

6.4.2 Acceptance vs Control

Some suggestions for improvement made by the participants, such as the addition of reminders to notify them when they were using their phones beyond some set time, or a feature to lock them out when they needed to focus, point to the need for control. Reminders are also a common strategy in persuasive interventions. On the other hand, however, mindfulness encourages the cultivation of deliberate awareness and acceptance without the need for such tools, and for this reason, we did not implement reminders. It is, therefore, necessary to further investigate acceptance versus user control to determine whether reduced control will result in reduced efficacy or user rejection of the intervention [191].

6.4.3 Richness vs Minimalism

One participant in the interview complained that there were not so many features within the app (not wallpaper), and they only remembered to check the in-app features of the Chai app "once or twice a week". This implies an assumption that the goal of the application was to keep users engaged with the app. Checking the application (not the wallpaper) only a few times weekly was just perfect in our opinion as the developers. We designed the app to integrate into users' daily lives, without adding to the amount of smartphone use by frequent checking of the app features. Karlsson et al. [85] used the 'productivity imperative' put forward by Gregg [66] to explain this response. In this case, the desire for more features could be because the participants were used to applications having loads of features to help the user be more productive or engaged and then found that this app has very few of those features. This tension can also be framed in terms of richness versus minimalism as highlighted in [191].

Overall, tools for restricting one's unproductive use of technology have manifested great benefits. Mindfulness on the other hand is a deliberate effort that does not require a tool. It is like sitting outside in a garden and being aware of the sights, sounds and smells, versus thinking about for example how to make the experience of sitting in the garden even more pleasant perhaps by weeding or hedging. Both pursuits have their uses and perhaps what is needed in the face of these contrasting needs is deliberate communication through the design about what the focus of the intervention is.

6.5 Recommendations for Future Research

For future researchers who may consider designing mindfulness-based digital interventions for problematic smartphone use, some of the lessons that might be drawn from this work include the following.

6.5.1 Integrate with Already Existing and Widely Used Systems

It is important for persuasive interventions to be available to participants in a way that they do not need to learn or get used to a new platform while using the intervention [54]. This need for integration is also part of the design qualities of digital mindfulness 4.0 as outlined in Zhu et al. [214]. It essentially aims to become a way of life for the individual. The importance of this point is evident in the literature where the behavior change of the participants did not persist after withdrawal of intervention [138]. In this case, well-integrated interventions are also more sustainable since users could use them for extended periods without disruptions and hence consolidate the gained behavior change.

This is what we aimed to achieve with the wallpaper in our intervention. Many participants appreciated the lack of friction in our wallpaper implementation. Our results show that the falling leaves animation of the wallpaper was more persuasive than the in-app self-monitoring features.

Future interventions could, as much as possible, take a leaf out of this book[1]. An example would be to make a plugin for an existing and widely used application or system instead of building a new standalone app. However, proper integration would depend on understanding the particular situation and the existing user behavior.

6.5.2 Make it Dynamic

While it is important that the user is deliberate about being mindful of their environment, it is easy for mindfulness-based interventions to fade into the background and become part of the furniture so to speak. In our case, we see this effect from the different persuasiveness scores of the falling leaf animation and the color change as well as the qualitative comments that participants made about the two features. The falling leaf animation was more obvious and hence more persuasive, while the more subtle color change feature was sometimes not noticed by some participants. A possible direction in situations like this could be to make use of dynamic features that are engaging and not always predictable.

[1] pun intended!

6.5.3 Personalization is Key

Smartphones are personal technology that people use for a wide variety of things. People also use their smartphones differently. As we have seen from our qualitative results and the discussion so far, sometimes what works for one participant is an area for improvement for others. Hence the saying that one size does not fit all. We, therefore, argue that future interventions would benefit from extensive personalization.

The importance of personalization is also evident in our results which show that the customization strategies were perceived to be very persuasive by the participants. While customization is a user-controlled adaptation, personalization can also be system-controlled and both approaches have their strengths and weaknesses [145]. Lots of features can be personalized in an intervention like this, but also importantly, personalization can help when navigating the balance between acceptance and control, richness and minimalism, and the level of engagement of the intervention.

6.5.4 Combining Mindfulness and Persuasive Strategies

The primary task support category of strategies in the Persuasive System Design (PSD) model [135] includes both self-monitoring and simulation. Self-monitoring allows a user to observe themselves as they work towards a goal, while simulation allows the user to observe the cause-effect relationship between behavior and outcome. Both strategies cause the user to look inwards and reflect on their behaviors and they can be highly personalized especially when simulation is directly related to the individual. Some recent works in persuasive computing are focused on tailoring persuasive interventions to an individual's personality [144] and stage of change [149]. This direction towards more personalization has been shown to be effective, especially for health-based persuasive interventions. These strategies and research directions may be the starting point to create experiences where the user is led to learn about themselves and encouraged to capitalize on this self-awareness to adopt and consolidate healthy behavior. The use of more passive persuasive strategies like this can be a starting point for researchers who hope to combine persuasive technologies with mindfulness.

Furthermore, we suggest that the role of persuasive technology (or technology

in general) in mindfulness-based interventions should be to create a reflective environment that will spur users to adopt mindful practices in their everyday lives. This environment should provide the means for the user to pay attention to their behavior and get feedback on the actions that they take, probably nudging them towards healthier behavior. This role of technology in the environment rather than a tool has been touched on in both mindfulness-focused [214] and HCI-focused studies [68]. In the work done by Zhu et al. [214], this meant capturing the experience that makes nature so suitable for practicing mindfulness, but also including elements that are not found in nature that enhance the experience of being mindful. This can be interpreted in various other ways when designing for different platforms.

6.6 Limitations and Future Work

The limitations of this intervention and study are listed below together with how we plan to address them in future work:

i) The platform on which we based our intervention (Android smartphones) is a limitation of the study since we cannot reliably generalize our results to all smartphone users. This limitation is unfortunately prevalent in the literature as the majority of related interventions that we reviewed were also focused solely on the Android platform. This is most probably caused by the more restrictive nature of the iOS platform for developers compared to Android. Future work on the Chai intervention will explore the best ways to bring this intervention to iOS users.

ii) Even further, while our intervention is mobile-only (and understandably so, given that we are dealing with PSU), smartphones are not the only digital devices that people use and misuse. There is also the TV, laptops, smartwatches, and extended reality headsets. This can also be seen as a limitation of this work, since, for example, people who do not own TVs would likely use their smartphones to watch movies/news while TV owners would not register such time as smartphone use. As we reported in our results, some participants in our study admitted that when they wanted to use their smartphone but did not want the leaves to drop, they moved to their desktop or laptop instead. Other

participants expressed the desire to have a similar system for the desktop too which will be in sync with the mobile.

There has already been some work done on systems that span both mobile and desktop [94, 171]. Future efforts will also consider ways to bring this solution to non-mobile platforms for a more holistic moderation of digital technology use. This could target the wallpaper of desktops. Virtual and augmented reality systems present even richer avenues to implement mindfulness-based interventions for moderating digital technology use [133].

iii) The Chai wallpaper only responds to smartphone use that happens after users unlock their devices. However, a significant amount of smartphone use, like checking for and reading notifications, could happen on the lock screen [74]. This is an area that we might explore in the future.

iv) Future evaluations of the interventions will include control groups taking the study at the same time to ensure there are no confounds. A longitudinal study over a longer period would also be important to explore how the intervention affects smartphone use behavior in the long term.

Chapter 7

Conclusion

PROBLEMATIC smartphone use occurs when compulsive misuse of the smartphone negatively affects the daily life and activities of the user. It has been linked to various issues like poor sleep, lower academic performance, and lower quality of life, making it an important problem in HCI research.

Multiple interventions targeting PSU have been developed, including digital interventions deployed both on-device and off-device. In this thesis, we reviewed the existing interventions for PSU. We found research gaps, such as the relatively lower number of interventions for PSU available for iOS users than for Android users. In addition, evidence in the literature suggests that more emphasis should be placed on developing the individual's mindfulness and self-efficacy about smartphone use than on reducing use. Our review showed that there needs to be more research into reducing absent-minded use of smartphones compared with the research focused on reducing use.

Hence, we developed the Chai wallpaper application, a novel intervention for absent-minded smartphone use. We evaluated this intervention over two weeks and with 121 participants at different stages of behavior change for smartphone use and physical activity.

Our results show that the intervention successfully reduced absent-minded smartphone use. Our analysis also suggests that the intervention reduces absent-minded use for individuals at other stages of change but not for those in the Preparation stage. However, this was not supported by subsequent post hoc tests. Participants also found the app's various features to be persuasive to various degrees. The perceived persuasiveness was not determined significantly by gender or stage of change of the participant. The perceived persuasiveness was also not associated with the change in absent-minded smartphone use.

This study's results will help further improve the Chai wallpaper application to

make it even more relevant and valuable to people. Our results also leave open questions that prompt further research into the different needs of people at various stages of change for PSU, which will guide the tailoring of other future interventions to meet these specific needs. Further studies that link the perceived persuasiveness of interventions like this to actual behavior change are called for.

My Publications

[1] **Chukwuemeka Nwagu**, Alaa Alslaity, and Rita Orji. EEG-Based Brain-Computer Interactions in Immersive Virtual and Augmented Reality: A Systematic Review. *Proceedings of the ACM on Human-Computer Interaction*, 7(EICS):Article 174, 2023.

[2] **Chukwuemeka Nwagu** and Rita Orji. Chai Wallpaper: A Mindfulness-Based Persuasive Intervention for Absent-Minded Smartphone Usage. In *Adjunct Proceedings of the 31st ACM Conference on User Modeling, Adaptation and Personalization*, pages 16–21, Limassol Cyprus, 2023. ACM.

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Appendix A

Literature Review Corpus

Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
Zimmermann & Sobolev [217]	2023	Participants switched phone display to grayscale and used the Screen Time app for **self-monitoring**.	iOS	RCT	Both	7 to 25 days	112	P
TypeOut Xu et al. [207]	2022	Just-in-time interventions on target app launch that require users to **type out messages** based on the **self-affirmation** theory.	Android	Longitudinal	Both	10 weeks	54	P
MindPhone Terzimehić et al. [190]	2022	A **mindfulness**-based intervention that prompts users to answer (type out or reflect upon) a question when they unlock their phone, to reduce absent-minded use.	Android	Pre - Post	Both	2 weeks	28	p
Haliburton et al. [68]	2022	A study with a box as a **physical barrier** between the user and their device to regulate bedtime usage.	A physical box	Pre - Post	Subj.	3 weeks	10	p
Ochs & Sauer [134]	2022	One of two design changes is applied to participant phones: grayscale display, or move apps into folders a few pages removed from the main home screen.	iOS	Pre - Post	Both	1 week	97	p

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Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
Olson et al. [139]	2022	Various intervention strategies including reducing phone brightness, turning off notification sounds, disabling touch/face id, leaving phone at home, etc.	iOS	Pre - Post	Both	2 weeks	51	P
Lyons et al. [120]	2022	Interruption-based service that allows users to select applications and set time periods within which they wish to use those applications.	Android	Survey	N/A	Not clear	9	N/A
Myers et al. [129]	2022	Various intervention strategies including changing phone display to **greyscale**, turning off social media notifications, removing social media icons from the home screen, etc.	Android & iOS	Qualitative survey	Subj.	3 weeks	274	p
MindsCare Lee et al. [108]	2022	"... when the target time is exceeded or if it is predicted to be problematic, the smartphone's alarm announces that usage time is being managed." [108, p. 3]	Android	Longitudinal	Obj.	13 weeks	342	P
GoldenTime Park et al. [155]	2021	An app that **rewards users with virtual gold coins** followed the time limit rule that they set for themselves, as well as sends them **reminders** when they exceed or are near the time limit.	Android	Pre - Post	Obj.	4 weeks	210	P

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Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
FeelHabits Roffarello & De Russis [171]	2021	A system with which users can set **limits of use on applications** on both smartphone and PC browsers. Users either get **notified** when the time limit is crossed or **access to the app is blocked**.	Android	Pre - Post	Obj.	2 weeks	7	p
Not Less But Better Keller et al. [86]	2021	An intervention in the form of a series of exercises to promote psychological resources for **goal-directed smartphone use**.	iOS	RCT	Both	20 days	110	p
Holdable devices Tiersen & Calvo [194]	2021	"Biofeedback-based tangible interfaces that sense when smartphones are used inattentively or compulsively from the motion of the hand behind the phone and gently alert users to regain **mindfulness** through haptic feedback and abstract visualization." [194, p. 1]	Tangible interface	Interview	Subj.	12 hours +	10	P
Phone Life Balance Kent et al. [89]	2021	Timed messages delivered to the participants' smartphones. The contents of the messages were **personalized** based on the **users' set goals**.	Android	Pre - Post	Both	3 weeks	10	p
Potapova et al. [160]	2020	An application to **visualize smartphone usage** and **block distracting apps**.	Android	Reviews	N/A	N/A	14	N/A
Throuvala et al. [193]	2020	An evaluation of the effectiveness of 3 consumer apps for reducing distraction from smartphones. The apps offered **mindfulness**, **self-monitoring**, and **mood-tracking** features.	Android & iOS	RCT	Subj.	10 days	143	p

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Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
GoalKeeper Kim et al. [95]	2019	A smartphone intervention app that **locks the user into self-defined daily use times** with restrictive intervention mechanisms.	Android	Pre - Post	Both	4 weeks	36	p
LocknType Kim et al. [96]	2019	An intervention that makes the user **type in some digits** with varying workloads when they try to launch any of some previously selected apps.	Android	Pre - Post	Obj.	3 weeks	40	P
Lu & Lo [118]	2019	A **popup reminder** or blank screen that is shown on the user's smartphone when walking is detected to remind them not to use their phone while walking. Push notifications are also hidden.	Android	Observation	Both	90 minutes	10	N
Pinder et al. [159]	2019	Push away smartphones on a bedside table and pull toward the user a book.	Tabletop	Pre - Post	Subj.	Not clear	40	N
GoodVibrations Okeke et al. [138]	2018	An intervention that uses **haptic feedback** to remind users that they have exceeded their set time limit.	Android	Pre - Post	Obj.	3 weeks	50	p
Interaction Restraint Park et al. [156]	2018	**Mandatory cognitive tasks** that users have to complete before launching selected applications.	Android	Pre - Post	Obj.	4 days	7	P
Let's FOCUS Kim et al. [93]	2017	Location-based virtual rooms when a user is in one of them, they are not able to launch certain applications, and **notifications from those apps are also muted**.	Android & iOS	Observation & Interview	Obj.	6 weeks	379	P

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Table A.0 – continued from previous page

Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
SCAN Park et al. [153]	2017	A social context-aware smart notification system for breakpoint-based notification management.	Android	Observation & Interview	Obj.	45 minutes	30	p
PomodoLock Kim et al. [94]	2017	Based on Pomodoro technique principles, users can **block out interruptions** from multiple devices for specific periods of time during which they intend to focus.	Android	Interview	Obj.	3 weeks	40	p
MyTime Hiniker et al. [75]	2016	A system that pops up a dismissible "Time's Up!" dialog when the user-defined time limit for selected apps has elapsed. Also, a timer in the notification and **daily aspiration prompts**.	Android	Observation	Obj.	2 weeks	23	P
MindsCare Lee et al. [107]	2016	A PC app used for **visualization and self-monitoring** of smartphone usage.	Android	Observation	Obj.	7 days	96	N/A
LockDoll Choi et al. [35]	2016	A tangible cat-shaped doll that reminds users to not be distracted by their devices when in a group.	A physical doll	Observation & Interview	Subj.	20 minutes	7	p
PreventDark Ruan et al. [173]	2016	An Android app that can automatically detect and send a **warning message** when the user is using the smartphone in a dark environment.	Android	Observation	N/A	N/A	3	N/A
NUGU Ko et al. [100]	2015	An app for self-regulation of smartphone use through leveraging **social support**: groups of people limit their use together by sharing their limiting information.	Android	Pre - Post	Both	3 weeks	62	P

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Table A.0 – continued from previous page

Name & Author(s)	Year	Brief description	Platform	Study type	Measure*	Duration	N	Result§
Park & Gweon [154]	2015	A **decisional balance exercise** used to resolve the ambivalence of smartphone users by making them aware of the pros and cons of PSU.	PC	Pre - Post	Both	3 weeks	26	p
Eddie et al. [45]	2015	"...a series of **discouragement messages** that become steadily more intrusive as the user continues using their phones." [45, p. 3]	Android	Surveys	Obj.	2 weeks	8	p
Lock n' LoL Ko et al. [99]	2015	An app that allows the creation of virtual rooms in which smartphone use is limited by **locking the screen and the usage of other apps**, as well as **muting notifications**.	Android	Interview	Subj.	Not clear	20	p
ATLAS Lubans et al. [119]	2014	An app that accompanies a non-digital intervention. Mostly for **self-monitoring**.	Android & iOS	Focus groups	Subj.	42 to 58 minutes	361	p
AppDetox Löchtefeld et al. [115]	2013	An application for creating rules for **restricting access to selected apps** on the user's device.	Android	Observation	Obj.	Variable	11,700	p

* Measure used for PSU: Subj. = subjective or self-reported; Obj. = Objective logs.

§ Categorization of result: P = Positive, p = partial positive, N = Neutral/No effect. (see further description in subsection 2.2.6)

RCT = Randomized Control Trial

Appendix B

Recruitment Poster

Appendix C

Consent Form

Project title: Chai Mindfulness Wallpaper: A Persuasive and Mindfulness-Based Intervention for Smartphone Usage Behavior Awareness and Change

Lead researcher: Chukwuemeka Nwagu, Faculty of Computer Science, Dalhousie University

Academic supervisor: Dr. Rita Orji, Faculty of Computer Science, Dalhousie University

Contact person: Chukwuemeka Nwagu, Email: cnwagu@dal.ca

Introduction You are invited to participate in our research study. Your participation in this research study is voluntary. The study details are described below. The description summarizes about what is involved in the research and the nature of your participation: what you will be asked to do and about any benefit, risk, inconvenience, or discomfort you might experience. You can withdraw from the study at any time without penalty simply by emailing the lead researcher (cnwagu@dal.ca) to inform that you would like to withdraw. If you have any other questions about this study, please contact Chukwuemeka Nwagu (cnwagu@dal.ca).

Purpose and Outline of the Research Study The purpose of this research is to evaluate the effectiveness of an Android live wallpaper application called Chai designed to encourage smartphone usage behavior awareness and change using persuasive and mindfulness-based strategies.

Who can take part in this study You should be 18 years or older and have access to an Android device running Android 5.0 or later to be able to participate in this study. The survey has been developed in English, so you should be able to read and understand the English language.

What you will be asked to do If you choose to participate in this research, you will be asked to fill out a pre-intervention survey, after which you will be given access to the Chai wallpaper application. You will be asked to set the Chai wallpaper as your home and lock screen wallpaper for 2 weeks. After 2 weeks, you will be asked to fill out a post-intervention survey. Both surveys take around 10 minutes each to complete. You can also choose to be part of an optional interview session to give more feedback on your experience will the app. The interview will last between fifteen and thirty minutes.

Possible benefits, risks and discomforts As mentioned earlier, this study requires participants to temporarily change their device wallpaper, and this may be discomforting to individuals who have wallpapers that they are attached to or that hold some significance to them. You must consider these risks before agreeing to participate in the study. Your participation will mean that you are aware of the risks involved and have agreed to participate regardless of the risks. Also remember that you can stop participating at any time by sending us an email at cnwagu@dal.ca. There is no direct benefit for participating in this study, however, you may learn about mindfulness and how it applies to smartphone use. Moreover, the research might contribute to new knowledge on using persuasive and mindfulness-based interventions to create smartphone usage behavior awareness.

Compensation / Reimbursement Your email address will be entered into a draw to win a C$15 gift card (15 winners). You will be entered in the draw even if you withdraw from the study or do not complete it. If you win, the lead research will email you a C$15 gift card.

How your information will be protected Your email address will be collected as part of the pre-intervention survey in order to contact you for the post-intervention

survey and optional interview; hence your data will be identifiable but protected and confidential and will only be accessible to the researchers including the lead researcher Chukwuemeka Nwagu and supervisor Dr. Rita Orji. All survey responses will be stored securely on Dalhousie server and password-protected computers. Logs from the application including daily screen time, and step count from Google Fit integration (if you opt in) are collected and securely transmitted to Google Firebase servers in an anonymized form and can only be identified by the lead researcher using your participant id which is included in the logs. In addition, data transfer is fully encrypted (using Secured Socket Layer Certificate) to prevent unauthorized access while collecting and storing data. The optional interview will be conducted using Microsoft Teams. The researchers will use their Dalhousie University credentials for the Microsoft Teams meeting, which will ensure that the Teams meeting recordings are securely stored in Canada. During the live Teams meeting, audio and video content is routed through the United States, and therefore may be subject to monitoring without notice, under the provisions of the US Patriot Act while the meeting is in progress. After the meeting is complete, meeting recordings made by Dalhousie are stored in Canada and are inaccessible to US authorities.

We will describe and share general findings of this research in the lead researcher's master's thesis and possibly through publications in conferences and journals. Direct quotes from your responses in this study may be used in publications and these will be anonymized so they cannot be linked to you. We will destroy all data 5 years after completing/reporting the results.

If you decide to stop participating Your participation in this research is entirely your choice, and you are welcome to stop participating in the study at any time if you no longer want to participate. However, you can only withdraw your data only if the data are yet to be analyzed and results published. Specifically, withdrawal will not be possible after 2 months of participating in the study. If you intend to withdraw, please contact the lead researcher at cnwagu@dal.ca. We will not include any incomplete responses in our analyses.

You should discuss any questions you have about this study with Chukwuemeka or Dr. Rita. Please ask as many questions as you like before or after participating.

My contact information is cnwagu@dal.ca.

If you have any ethical concerns about your participation in this research, you may contact Research Ethics, Dalhousie University at (902) 494-3423, or email ethics@dal.ca (and reference REB file # 2023-6462)."

If you agree to participate in this study, please click "Start" to continue.

Appendix D

Pre-Intervention Questions

D.1 Demographics Questionnaire

Please choose your age range

1 Less than 18 years

2 18 - 25 years

3 26 - 35 years

4 36 - 45 years

5 Over 46 years

6 Prefer not to answer

Please choose your gender

1 Man

2 Woman

3 Prefer to self-describe

4 Prefer not to answer

What is the highest level of education you have completed?

1 Less than high school

2 High school or equivalent

3 College diploma

4 Bachelor's degree

5 Master's degree

6 Doctorate degree

7 Prefer not to answer

8 Other:

Is your Android phone (to be used for this study) your primary mobile device? (Answer "Yes" if you split your time equally between the device and any other smartphone)

1 Yes

2 No

3 Prefer not to answer

Have you used live wallpapers on Android before?

1 Yes

2 No

3 Maybe

4 Don't know

What do you most frequently use your Android smartphone for? (Select up to 3 options)

1 Tools/Productivity

2 Games

3 Entertainment

4 Social media

5 Education

6 Lifestyle

7 Other

D.2 Stage of Change for Smartphone Use

Below is a group of phrases related to different behaviours. Please select the option that most closely matches what you do.

1 Using my smartphone is a core part of my job and I have not thought about cutting down on screen time.

2 I don't monitor my screen time and I have not thought about starting.

3 I think about cutting down on my screen time.

4 I am planning to start monitoring and managing my screen time.

5 In the last 6 months I started monitoring and managing my screen time.

6 More than 6 months ago I started monitoring and managing my screen time.

7 I try to manage my screen time, but sometimes I am not consistent.

8 For several years I have monitored and managed my screen time consistently, it is part of my lifestyle.

D.3 Stage of Change for Physical Activity

For each of the following questions, please select Yes or No. Be sure to follow the instructions carefully.

Physical activity or exercise includes activities such as walking briskly, jogging, bicycling, swimming, or any other activity in which the exertion is at least as intense as these activities.

I am currently physically active.

1 No

2 Yes

I intend to become more physically active in the next six months.

1 No

2 Yes

For activity to be regular, it must add up to a total of 30 minutes or more per day and be done at least five days per week. For example, you could take one 30-minute walk or take three 10-minute walks for a total of 30 minutes.

I currently engage in *regular* physical activity.

1 No

2 Yes

I have been *regularly* physically active for the past six months.

1 No

2 Yes

D.4 Smartphone Use Questionnaire (Absent-minded)

Please indicate how frequently or infrequently you have these experiences on a typical day. Never - Sometimes - All the time

1 How often do you open your phone to do one thing and wind up doing something else without realizing it?

2 How often do you check your phone while interacting with other people (i.e. during conversation)?

3 How often do you find yourself checking your phone “for no good reason”?

4 How often do you automatically check your phone without a purpose?

5 How often do you check your phone out of habit?

6 How often do you find yourself checking your phone without realizing why you did it?

7 How often have you realized you checked your phone only after you have already been using it?

8 How often do you find yourself using your phone absent-mindedly?

9 How often do you wind up using your phone for longer than you intended to?

10 How often do you lose track of time while using your phone?

Appendix E

Post-Intervention Questions

E.1 Smartphone Use Questionnaire (Absent-minded)

Same as section D.4

E.2 System Usability Scale (SUS)

Please select to what extent you agree or disagree with the following statements about the app Strongly Agree - Agree - Neutral - Disagree - Strongly Disagree

1 I think that I would like to use this app frequently

2 I found the app unnecessarily complex

3 I thought the app was easy to use

4 I think that I would need the support of a technical person to be able to use this app

5 I found the various functions in this app were well integrated

6 I thought there was too much inconsistency in this app

7 I would imagine that most people would learn to use this app very quickly

8 I found the app very cumbersome to use

9 I felt very confident using the app

10 I needed to learn a lot of things before I could get going with this app

E.3 Perceived Usefulness

Please select to what extent you agree or disagree with the following statements about the app Strongly Agree - Agree - Neutral - Disagree - Strongly Disagree

1 The wallpaper interface is aesthetically pleasing

2 The app user interface is professionally designed

3 I will use the app for monitoring my smartphone usage in the future

4 In addition to future use, I would actively take necessary steps to be aware of my smartphone usage

5 I would suggest to others to use this app

E.4 Perceived Persuasiveness Test

Regarding the [feature], select to what extent you agree or disagree with the following statements. [screenshot]

Strongly Agree - Agree - Neutral - Disagree - Strongly Disagree

1 This feature would influence me to be aware of my smartphone usage behavior

2 This feature would convince me to adopt healthy smartphone usage habits

3 This feature would be personally relevant to me

4 This feature would make me reconsider my current smartphone usage behavior

Please provide comments to justify your rating for [insert feature]

Appendix F

Interview Questions

Function-related questions:

1 Did the application affect your level of awareness about how you use your phone? If so, how?

2 Did the system influence how often you use your smartphone phone? If so, please explain.

3 Is there anything you would like to change about how you use your phone? If so, how do you think an application like this can help you achieve such change?

Usability questions:

1 What did you like about the application?

2 What did you not like about the application? Bad user experience (unclear labels, ambiguous icons, any confusing features)? Technical challenges?

3 Do you have any other feedback about the application or general suggestion to improve the application?

4 What do you usually use as your Android phone wallpaper? Did you miss your former wallpaper while using this application?

Appendix G

Research Ethics Board Approval Letter

REB # 2023-6462 Letter of Approval

ethics@dal.ca <ethics@dal.ca>
Tue 21-Feb-23 11:10 AM
To: Emeka Nwagu <ch436566@dal.ca>
Cc: Rita Orji <rt924119@dal.ca>;Research Ethics <ethics@dal.ca>

DALHOUSIE UNIVERSITY

Social Sciences & Humanities Research Ethics Board
Letter of Approval

February 21, 2023
Chukwuemeka Nwagu
Computer Science\Computer Science

Dear Chukwuemeka,

REB #: 2023-6462
Project Title: Chai Mindfulness Wallpaper: A Persuasive and Mindfulness-Based Intervention for Smartphone Usage Behavior Awareness and Change

Effective Date: February 21, 2023
Expiry Date: February 21, 2024

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans*. This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Megan Bailey
Chair, Social Sciences and Humanities Research Ethics Board
Dalhousie University

Post REB Approval: On-going Responsibilities of Researchers

After receiving ethical approval for the conduct of research involving humans, there are several ongoing responsibilities that researchers must meet to remain in compliance with University and Tri-Council policies.

1. Additional Research Ethics approval

Appendix H

Permission to Use

In presenting this thesis in partial fulfilment of the requirements for the master's in computer science degree from Dalhousie University, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Dalhousie University in any scholarly use which may be made of any material in my thesis.

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Dalhousie University,

Halifax, Nova Scotia, Canada B3H 1W5