ABSTRACT

Title of thesis: EXPLORING AMBIENT TO DISRUPTIVE HEALTH NOTIFICATIONS VIA SHAPE-CHANGING INTERFACES

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Ambient Information Systems have shown some success when used as a notification towards users' health-related activities. But in the actual busy lives of users, ambient notifications might be forgotten or even missed altogether, nullifying the original notification. When do people accept escalated levels of disruption for health notifications? In parallel, how could varying levels of health notifications be portrayed in shape-changing interfaces?

To investigate these questions, I took a Research through Design approach and created artifacts in the form of plant-mimicking Shape-Changing Interfaces (S-CIs), conducting interviews with ten participants who currently used a system to remind themselves to perform a health-related activity, to learn how they would react to the varying of motion types to achieve disruption. I report findings on scenarios where disrupting users for health-related activity purposes could be acceptable, how participants interpreted various aspects of the S-CIs and reasonings behind them, and how people envisioned using S-CIs within their physical environments. I also discuss avenues for future work in ambient-to-disruptive technology, and design suggestions for those working in health-related notification systems and shape-changing interfaces.

EXPLORING AMBIENT TO DISRUPTIVE HEALTH NOTIFICATIONS VIA SHAPE-CHANGING INTERFACES

by

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Chapter 1: Introduction

The health of the human body usually responds best to a balanced and consistent schedule. Sleep irregularity is linked to adolescent dysfunction, cardiometabolic diseases, and many other negative health factors [1, 32]. Metabolic health is affected when sedentary time is not regularly broken up by activity [36]. Regular liquid intake is important, as only a few hours of reduced hydration can result in body water deficits [9]. Many medications are prescribed to be taken on a daily timetable to maintain proper concentrations in the body. However, people are surrounded by distractions and often preoccupied with life demands, finding it difficult to maintain a regular schedule for their health. Because these health-related events are important but generally not critical immediately, people may temporarily deprioritize such activities when experiencing time-sensitive situations, resulting in the need to remember to perform the activity soon when they become free.

In response, several applications exist that attempt to remind users to perform an activity in a recurring manner for their health. For example, Fitbit allows users to set hourly reminders to encourage reaching step count sub-goals (e.g., move at least 250 steps every hour) throughout the day. Many medication reminder apps also use a time-based reminder when it is time to take a new dose [44]. However, this strategy falters if the user is not in a state to perform the requested action immediately. The same preoccupations that make it difficult for people to maintain their own schedule also thwart reacting to such alerts; someone receiving a Fitbit notification while recording themselves for a lecture would generally not wish to start pacing around the room to reach their step goals. Even if the user is

allowed to snooze the notification, this still demands immediate attention and a specific action, which may not be possible for someone deep in the middle of a task.

Another deficient scenario would be if the user fails to notice the notification. People are already bombarded with notifications emanating from their devices, vying for the same amount of attention from the user, regardless of their true priority. A user may misinterpret a health-oriented notification for another that does not need immediate attention, and the reminder is soon lost. Or, another action might coincidentally draw a person away from their device just as the notification arrives. Merely increasing the number of alerts to ensure acknowledgement would not be a suitable solution, as fatigue may set in from the overuse of messages, resulting in the user ignoring any future notifications [11]. To support users wanting to keep an eye on their health habits, we as researchers may need to look at emerging technologies to design a system, which provides notifications that reflect the urgency of the matter in a way that fits into the user's busy schedule.

To achieve non-overwhelming notifications, ambient information systems (AIS) can be leveraged, as they aim to portray non-critical information in a form factor that allows for receding in the background when unneeded [39]. Multiple notifications could be conveyed via an AIS at a calmer level than a repeating non-ambient alarm, affording systems more chances to remind the user without messaging fatigue. But, if a user lacks to respond after an ambient notification, it may place them past a health-risking threshold, making it reasonable to then use a more forceful, or even critical, alert. At those junctures, this system should act beyond its default ambient behavior and demand attention. However, very little work in AIS has investigated systems that aim to shift between varying levels of intrusiveness—and thereby attention demand—depending on the context and urgency of the notification.

To support this scenario, I introduce the concept of **ambruptive**, or ambient-to-disruptive technology, which can initially act as an AIS but contains the capacity to escalate its noti-

fication if the message becomes more critical, interrupting the user from their present task. However, before we can test the effectiveness of ambruptive technology in notifying users towards their health goals, we must first learn what makes for an effective system that can achieve both ends of the noticeability spectrum. To explore this concept, I created a set of shape-changing interfaces (S-CI) [12] artifacts, which are capable of performing different movements with various controllable parameters. By altering various motion settings, I could alter the look of the artifact and probe individuals' reactions to whether this form factor can meet the task of portraying a wide variety in notification levels. In my artifacts, I chose to mimic plants as a design motif. Plants are found in many interiors and their presence would not distract most, providing a naturally ambient platform to build from. And, just as living plants move during the day at rates imperceptible to humans, these artifacts aim for an ability to display data without being distracting to the user when such data is non-critical. However, when critical data must be communicated, the application of either "unnatural" shape-change or speeds may allow for a jarring experience that could provide the momentum needed to shift an ambient system into a disruptive one.

With these artifacts, I underwent an exploratory **Research through Design** (RtD) [50] study with ten individuals who were currently using a strategy to remind themselves to work on a health-related goal; more details on their strategies and goals may be found in Table 4.1. I wished to first learn about their current strategies, and then gather their reactions to my artifacts in an attempt to answer the following research questions:

(RQ1) When do people accept escalated levels of disruption for health notifications?

(RQ2) How could varying levels of health notifications be portrayed in shape-changing interfaces?

(RQ3) How do people envision using shape-changing interfaces within their environments?

In this thesis, I share my review on related work, artifact design considerations, information of the prototype implementation, and the results of my exploratory RtD study.

Chapter 2 analyzes the technologies and studies that precede my work.

Chapter 3 gives an example scenario to illustrate how ambruptive technology differs from general notifications, and explains the rationale behind various design choices made in my artifacts and study.

Chapter 4 recounts the efforts made towards this thesis: the creation of the artifacts, the infrastructure to aid online interviews, recruitment of participants, and analysis of the data.

Chapter 5 shares the results from the participant interviews, exploring both the answers to my research questions and revealing new insights and concepts that appeared from analyzing the data.

Chapter 6 explores possible areas in future research that stem from the findings of this study, as well as design considerations for additional products in this and related spaces.

Chapter 7 summarizes and concludes this thesis.

Chapter 2: Related Work

My artifacts sit at the intersection of ambient information systems (AIS) and shape-changing interfaces (S-CIs). Both of these areas in HCI fall within the paradigm of *ubiquitous computing*, as introduced by Weiser in 1991 [46], where computing becomes so ubiquitous that it disappears into one's environment. Although Weiser originally focused on screen-based peripherals, the concept represented the shift from dedicated and discernible "personal computers" to systems that interchange information without bringing the underlying computer into prominence.

2.1 Calm Technology and Ambient Information Systems

With this idea of computing being increasingly embedded into everyday life, Weiser & Brown later explored the concept of *calm technology*[47] as a preventative step, viewing the need for less obtrusive modes of communication in computing to compensate for the increased interaction between humans and computers. Described as technology that can move between the center and periphery of one's attention, it aimed to allow users to have awareness of more pieces of information by targeting the larger portion of our brain in charge of peripheral processing, and intended to give the user more control of what they wished to pay attention to. Later studies in this area described themselves as *ambient displays* and *peripheral displays*, but the term "Ambient Information System", or AIS, was coined in order to expand the concept to systems that use other modalities than vision, such

as sight and sound [39].

Pousman & Stasko created a taxonomy of AIS, defining the space as systems which:

1. *Display information that is important but not critical.*
2. *Can move from the periphery to the focus of attention and back again.*
3. *Focus on the tangible; representations in the environment.*
4. *Provide subtle changes to reflect updates in information (should not be distracting).*
5. *Are aesthetically pleasing and environmentally appropriate.*

Ambruptive technology extends slightly past these categories, namely in the additional ability to provide disruptive changes (expanding definition 4) which widens the range of information that can be portrayed: both important and critical (expanding definition 1). However, the remaining definitions still apply, and initially when not in a situation that requires escalated notification, an ambruptive system exists as an AIS.

However, while generally falling within the area of calm computing and designed to be unobtrusive, AIS taxonomies offer a full range of notification levels as a key dimension. Using the earlier term of *peripheral displays*, Matthews et al. proposed five levels of notification level, ranging from low to high (i.e., *ignore*, *change blind*, *make aware*, *interrupt*, and *demand attention*) [33], and Pousman & Stasko adopt the same levels with the exception of *ignore* being replaced by *user poll*. Thus, although AIS initially aim to reside in the periphery of users, they do not necessarily need to remain there. Little work has been done in designing systems which investigate multiple notification levels. Angelucci et al. proposed an interface which "distracts users only if the severity requires it" [2], assessing mockups which mapped colors to severity levels, in either a horizontal scrolling or tab-based interface. Their project differs from this work in display type (screen), context (telecommunication network fault notification), and study design.

2.2 Shape-changing Interfaces

As the seminal example of *calm technology*, the art piece *Dangling String*[47] classically paired AIS to a system that changed its shape as a notification. Designed to represent the amount of traffic flowing over the network, the piece twitched a dangling plastic string slightly when low amounts of data flowed through, but whirled and increased its motion if the network traffic was busy. This ability to change one's shape is the basis of Shape-Changing Interfaces (S-CIs)[12], which uses this modality as the interaction between human and computer. Rasmussen et al. surveyed the landscape of S-CIs and defined the space as systems that uses physical, self-actuated change of shape as input or output, and whose actuation method can be controlled to return the system "to its initial state and repeat the shape change." [40]

Although having a long history together, AIS and S-CIs do not need to coexist in the same system. As stated earlier, AIS is a broad term, which covers multiple sensory modalities. S-CIs can also exist without an objective to provide information in an ambient manner. Similarly, ambruptive technology is not limited to systems that use shape-change. However, exploring an abstract concept unfamiliar to the majority of users is a difficult endeavor both for researcher and participant. Therefore, I chose to create a system that I could use as a concrete example, in this instance a S-CI. Doing so would allow me to elicit reactions from users on which scenarios, if any, would warrant an ambient-to-disruptive escalation, and also whether S-CI could be a viable option for ambruptive technology.

As part of their review of the design space of S-CIs, Rasmussen et al. identified four factors of these systems. Here, I discuss how my artifacts fall within this categorization scheme.

- Interaction: does the S-CI offer input and/or output, and if output is offered, what triggers this action? My artifacts use *indirect interaction*, where data originating

from the user triggers a shape-change output, but such data is not transmitted through manipulation of the system.

- Purpose of shape change: what is the reason for changing shape in this interface? My artifacts use the most common purpose of *communicating information*, specifically, a notification for a user to perform a health-related activity.

- Types of change in shape: how does the S-CI alter itself? My artifacts change their *orientation* to communicate with the user, distorting their shape yet keeping their form.

- Types of transformation: in which manner does the S-CI perform its shape change? Here, my artifacts are able to use a variety of *velocity* and *path parameters*, with the purpose of finding which parameters users find best in ambruptive notification.

2.3 Ambient Notifications for Health

To further focus participants on the concept of ambruptive technology, I chose a specific context that users could already be familiar with: notifications for health-related activities. The rise of fitness trackers such as FitBit and Apple Watch meant that many in the general population would already be familiar with receiving notifications and reviewing data regarding their activity—in this instance one to aid their health. Such products have surely built off of prior work in health-related data for HCI.

The AIS space has been paired with a health-related context for multiple studies, a display-only example being Spark's use of informative art to visualize physical activity[14]. Additional studies have investigated further in the ability for AIS to actively promote healthy activity, e.g., Fish'n'Steps using an ambient display to link a cartoon fish's growth and demeanor with a users' footstep count[31], and Rogers et al. investigating three ambi-

ent displays intended to promote stairs use versus the elevator [43]. In other health-related avenues, García-Vázquez et al. created three AIS to encourage elders' medication compliance [17], and Wwall encouraged hydration through the use of a display wall [48]. While aimed at assisting similar health goals, these studies all focused on a single *notification level* and did not use notification escalation as this thesis does. MoveLamp was a study which touched on increasing notification level based on user activity, changing the color and brightness of a light display to promote physical activity [15]. However, it differs from this thesis both in the non S-CI aspect of the light display, its main focus on behavior modification, and in not focusing on when its participants wanted to be interrupted—instead using a predetermined formula for escalation.

AIS that specifically use shape-change have also been used as physical indicators for health-related systems throughout the years, from a physical avatar to alert users of eye fatigue [3], wall-like surfaces to portray biometric information [49], or sculptural elements encouraging good posture [20] and work breaks (Breakaway) [24]. Again, all share similarities to this thesis as they examine health-related scenarios, but none consider further behavior when a user fails to respond, and all remains solely on the calmer side of notification level dimension. Of note is the participant of Breakaway indicating that the system could be easily ignored if she was too busy—based one's situation, this could be a positive or negative trait.

Plant-like designs are also found in the health notifying S-CI arena: several studies alerted their users of bad posture [20, 22], and another used a set of flowers to aid in the reflection of sedentary behavior [4]. Non S-CI plants have also been used to represent user activity, whether altering the growth of a stylized representation of a garden [13], basing the foliage of a virtual tree on a user's hydration habit[28], or even affecting the health of living tomato plants by basing watering and nutrition schedules on Fitbit data [10]. These prior works in plant-based systems all similarly differ from this thesis, as they sought to

design ambient, non-interrupting interfaces—again not exploring a variation of notification levels in reaction to users' behaviors. These papers also generally investigated the workings of the displays and tracking mechanisms, focusing on measuring if users could correlate the various plant representations to the mapped data. Additionally, each used a single plant design, as compared to the selection of artifacts available in my thesis.

Chapter 3: Design Rationale

In this section, I clarify the concept of ambruptive technology by first describing an example usage scenario with current notification technology, and contrast that with the expected outcome of an ambruptive system. Then, I discuss the rationales between various design decisions made in the artifacts I created, as well as reviewing why the Research through Design method was used for this study.

3.1 Example Scenario

Chloe wishes to be reminded to take her medication, which is scheduled three times per day, or roughly every five hours. She loads a medication reminder app, and schedules reminder alarms at 9 AM, 2 PM, and 7 PM. At 9 AM, her device chimes with a notification, and she successfully takes her medication. However, at 2PM, she is in the middle of an important video call and does not hear the notification. As she immediately pivots to finishing an assignment from the call, she does not check her phone until hours later, and does not see the notification until time has passed the recommended dosage period.

In an alternate timeline, Chloe uses an ambruptive system that uses shape-change as a notification system, setting up the same thrice-daily schedule. At 2 PM, the S-CI subtly begins moving, but Chloe is again in an important video call and does not have the capacity to concentrate on anything else. At 2:05 PM, with no response from the user, the S-CI moves in a slightly more noticeable manner. Since Chloe is deep in working on her assignment,

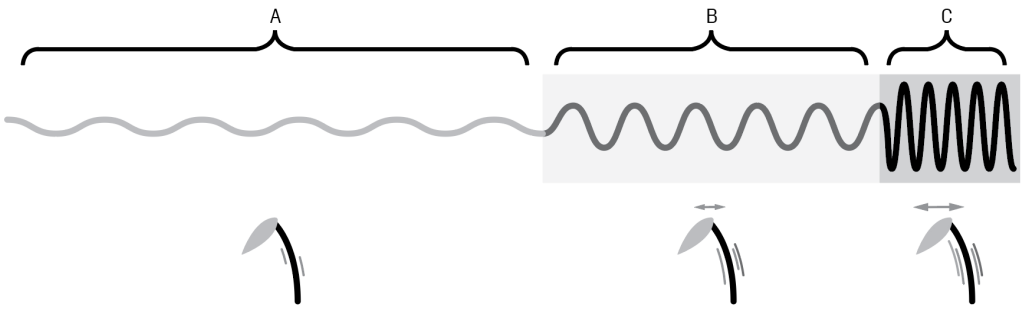

Figure 3.1: As time without user response grows, notification levels in a system that uses ambruptive technology can increase in turn. This variety increases the amount it shakes as notification levels rise. (A) initial, ambient notification suggests "action should be done soon"; (B) as period of inactivity continues, "make-aware" notification level is used to increase the urgency slightly; (C) user is now in danger of missing medication window, so "demand attention" notification level with higher intensity in shape-change is used.

she notices the alert peripherally, but completion of her task holds higher priority at the time, and she ignores the warning. A few minutes later, again with no user response, the S-CI now chooses a higher notification level and moves with a vibrant, distracting motion, forcing attention, as Chloe is now in danger of missing her medication time slot. Ambruptive technology offers the novelty of persistent alerting with appropriate shifting distraction levels. When health guidelines allow for flexibility, this system's subtle notification informs the user that their activity should be performed *soon*, but not necessarily immediately, allowing for the activity to fit into a user's busy schedule. As time lapses without activity, urgency increases, and a suitable higher level of notification is authorized to demand user action (see Figure 3.1). Furthermore, I envision that people can configure notifications' level of intrusiveness depending on the urgency or the importance of the target behavior.

3.2 Notifications for Wellbeing

To successfully design personal notifications that support the context of encouraging positive health behaviors—specifically promoting physical activity and medication adherence, we must examine the unique needs that each requires. Both contexts are important

but not initially critical; users are not required to act immediately in order to adhere to guidelines. For example, the length of time between medication dosages is given as a range, not an absolute number [23], so a person postponing their intake by ten minutes could still fulfill their medication requirements. Thus, a suitable notification system should allow this initial alert to be easily dismissed, both to accurately reflect its importance level and as to avoid notification fatigue. I chose to use an AIS platform to provide a notification that can easily be mentally dismissed. However, in this same example, as the user reaches the maximum duration for their dosage administration, the criticality of the notification increases. Designing a system that navigates different levels of importance must allow for differing presentation methods—thus my exploration into what characteristics portray this effectively.

3.3 Plants as an AIS for Personal Data

I determined phyto biomimicry to be appropriate for notifications of health-related activities, as humans have linked plants with health throughout history. Bamboo is a symbol of long life in Asian cultures, and the lotus was an Egyptian symbol of immortality [30]. The Popol Vuh describes plants that act as health indicators; these would shrivel and sprout in tandem with the condition of their owner's health [19]. Existing studies in plant-human interaction have investigated cognitive and emotional benefits received from caring for plants [25], the use of horticulture as therapy [41], and how the presence of even merely pictures of plants may provide positive mental benefits [5].

The use of plant emulation is also intended to aid in the ambient-ness of the devices by decreasing the intrusiveness of the interface. Today, plants can be readily found in homes and workspaces, and thus these artifacts could be integrated with the expected landscape of the interior. In the same way that camouflage mimics its natural surroundings to blend

in, the design choice of houseplant emulation is aimed to decrease the obtrusiveness of the interface. To aid in the familiarity of the artifacts, leaves from popular houseplants were replicated in the construction of each, such as Monstera deliciosa (Swiss cheese plant) and Strelitzia nicolai (giant bird of paradise). As the artifacts are sized to fit on a desk, the plants are proportioned as miniaturized versions.

However, the motion provided by the artifacts cannot be exactly found in nature, differing by the rate of change or even the actual movement type itself. I saw this greater control as an advantage, as different design parameters may be explored and adjusted easily in a synthetic entity, without being restricted by living growth boundaries. These "unnatural" motion types were meant to explore characteristics that increase the notification level of these interfaces.

3.4 Research Through Design

I chose to use a Research through Design (RtD) method, which uses design as a means to obtain new transferable information. The original concept was introduced by Frayling[16] in his examination of one of three ways research intersects with art and design practitioners; of most relevance was his subcategorization of RtD as "development work," depicted as "customizing a piece of technology to do something no one had considered before, and communicating the results"[16].

Zimmerman et al. [50] later applied this concept to the HCI community, stressing the creation of "artifacts intended to transform the world from the current state to a preferred state", which provides a concrete manifestation of a proposed solution, providing "the catalyst and subject matter for discourse in the community." These are especially useful for "wicked problems" [42], or problems with an "fundamental indeterminacy" that is present in most design problems [8]. In this thesis, the conflict between the desire to not overload

the user with notifications against the desire to ensure that an activity is ultimately performed for the user's health, the disparate requirements of individuals with different health goals and statuses, and the overall novelty of the ambruptive concept are all factors that make RtD a viable method.

Another important reason to use an RtD method for this study is to gain preliminary data to avoid harm, as we are dealing with the health of users. When working in this context, caution should be used to avoid unforeseen negative circumstances with emerging technologies. While other contexts offer a little more leeway—for example, affecting a user's productivity negatively is less damaging than affecting a user's health negatively—research that possibly interferes with the well-being of its participants must tread greater caution.

Finally, qualitative research of this sort is a practical choice when first reviewing emerging technologies, avoiding a resource-consuming study if feedback shows that initial presumptions were incorrect. Because very little data has been gathered about which scenarios make notification escalation acceptable, or what makes a system effectively communicate notification escalation, gathering initial user feedback is important before further in situ studies.

Chapter 4: Methodology

4.1 Initial Ideation

Using simple sketches, I iterated over different ways a plant-mimicking physical interface could be used to represent data, mainly focusing on S-CI applications. At this stage, feasibility was not prioritized, although ideas on how the mechanisms could be constructed were noted. This process led to the initial design of twenty-five different ideas, roughly categorized in five main categories: **shape**: a change in the overall structure of the plant itself; **orientation**: moving the plant body along different angles or axes; **plant state**: portrayal of different aspects in a plant's life-cycle, such as health state or fruiting phase; **external forces**: change to the plant caused by a foreign source, such as weather or a human; and **non-S-CI**: interfaces which used different modalities other than shape change, such as light or scent.

In parallel, I also experimented with designing different S-CI mechanisms capable of being printed using a fused deposition modeling (FDM) 3D printer. 3D printing technology was chosen for numerous reasons. The ability to alter my CAD model and manufacture the part immediately allowed for quick iterations of the mechanism until one meeting expectations was finalized. This quick manufacturing cycle also allowed for numerous iterations and technique experiments of the aesthetics of the artifact, as the shape and styling of the leaves could be designed independently of the working mechanisms, and unioned together in the final product. Additionally, the FDM material allowed for mechanisms that could

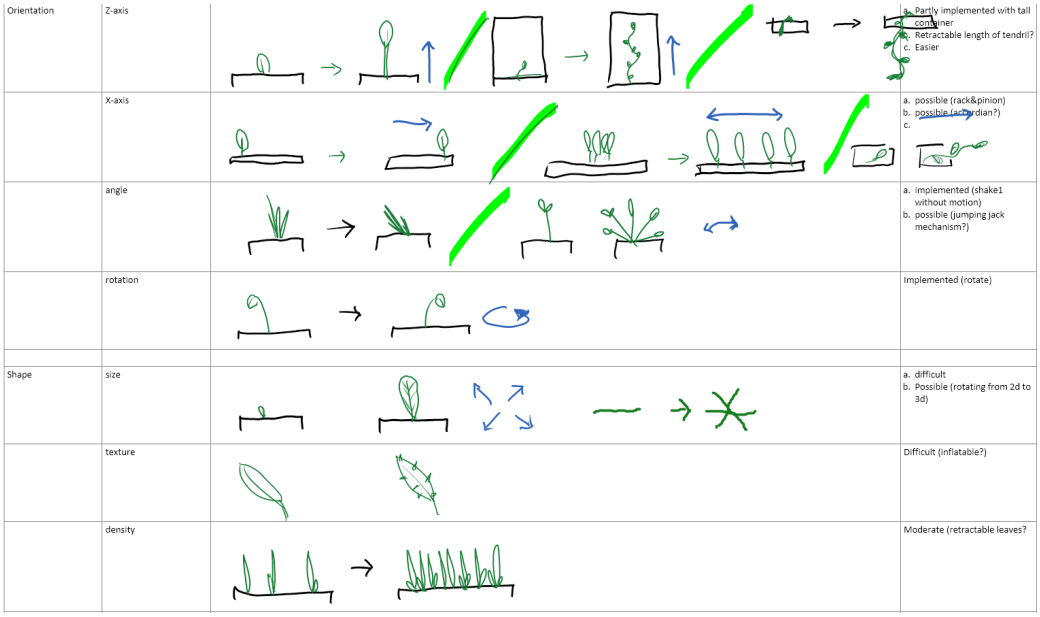

Figure 4.1: Example sketches from initial ideation work, imagining how plant changes could be used as a notification. This snippet shows two of the five categories: orientation and shape-change.

take advantage of its plasticity. Finally, 3D printing was chosen for its ability to quickly replicate multiple future artifacts without much manual work.

Due to my interest in notification, I explored which themes other researchers had used in their work in notification systems. Klauck et al. [26] experimented with varying the speed and size of movements and their effect on noticeability, and I planned to represent this in my own artifacts by varying the corresponding **speed and distance parameters**. In piloting my prototypes, I noticed that several people mentioned sad emotions from seeing the plant in particular positions, and I investigated further into **emotion portrayal** in shape-change. Lee et al. [29] rendered a 3D shape with various levels of bending and convexity/concavity and measured how such poses interacted with user emotional reactions. Strohmeier et al. [45] investigated the correlation with emotion specifically to various shape-changes. To gauge user reactions to the attempt to emote sadness in my artifacts, I decided to use shapes that have correlated to sad emotions: mainly concave poses in a downward position. Finally, I explored cognitive theories on bottom-up **saliency** models

mentioned within the psychology field [18, 27], but did not find many useful examples of what was considered salient; less so in the use of motion or shape-change. However, experimenting with various motion patterns led to the accidental discovery of particular motions which led to my uneasiness in watching the movement. Intrigued with the effect it had, I decided to investigate naturalness–unnaturalness as another axis which I could experiment along, as a possible look into the use of salient notification.

4.2 Artifact Construction

(a) shake-artifact (b) droop-artifact

Figure 4.2: The two artifacts used in the participant interviews. (a)shake-artifact's leaves shake, intended to portray wind naturally blowing through the plant. (b)droop-artifact's stems droop and rise at various speeds on command.

I designed my 3D printed parts in Autodesk Fusion 360, with some leaf shapes drawn in Adobe Illustrator and imported into the CAD drawing. The rack and pinion shapes were generated using gear-generation software. To get an aesthetic finish I was happy with, I modeled parts to both embed and avoid 3D printer build plate textures to create matte and shiny areas. This material contrast was used to draw the natural veins of a plant at a level of detail that could be lost with a standard print. I also fabricated a technique of post-print

re-sculpting, which allowed me to print flat parts and later sculpt them into naturalistic shapes with the help of a heat gun, leading to shapes that would not be possible at the same fidelity in 3D printing. Simple cube-like containers were made out of wood to hide the mechanisms and electronics.

The artifacts were controlled by an Arduino-compatible microcontroller board, specifically a Wemos-D1 clone using the ESP8266 chip. This platform was selected for its voltage compatibility with various motors, its small size, which allowed for integration in the artifact's container, and the ESP8266 chip, which provided built-in Wi-Fi capability on top of standard Arduino functionality. Each artifact used custom code specific to the mechanism and servo motors used within and were programmed to perform specific scripted actions on trigger. The artifacts were programmed with the ability to poll a remote server's web API and retrieve instructions on which action to perform, if any. However, due to the experiment's final needs, the artifact's motions were simply triggered over serial communication. A USB cable supplied both power to the microcontroller and a means of communication with my computer.

The first final artifact, $\mathrm{shake\text{-}artifact}$, uses a mechanism to shake the leaves of the device, intended to portray wind naturally blowing through the plant. A pinion driven by a motor linearly moves a rack connected to a comb that reaches through the stems of the plant. Moving the comb back and forth shakes the stems correspondingly. Control parameters for the $\mathrm{shake\text{-}artifact}$ were **distance**: the range of linear motion used by the artifact; **frequency**: how often a shake event occurred, and **speed**: how long the shaking motion's back and forth action should take. This artifact's leaves were modeled after Strelitzia nicolai, informally named the Giant Bird of Paradise plant. With the $\mathrm{shake\text{-}artifact}$, I chose a slower, $subtle\ shake$, and a much stronger $heavy\ shake$ motion as my two possible actions. Note: names used for the artifacts and motion types are only for clarity in this paper; the artifacts were not named during discussions with the participants in order to prevent bias.

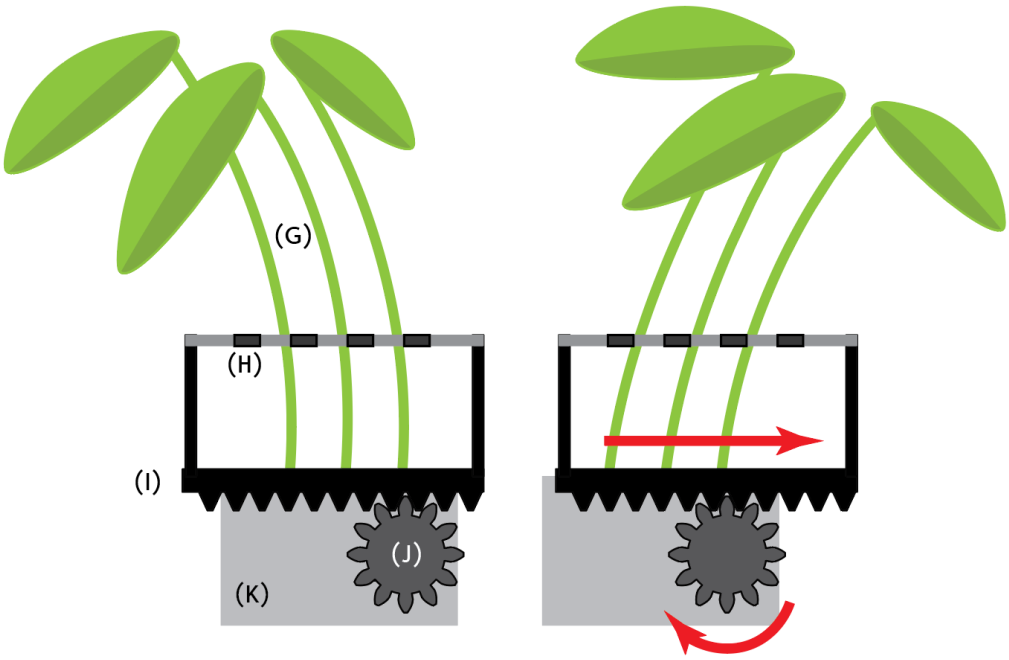

Figure 4.3: Shake-artifact mechanism. The artifact's plant stems (G) are pushed by a comb piece (H) attached to a rack (I). A pinion gear (J), driven by a motor (K), activates the rack. As the pinion gear rotates, it causes the comb piece to push stems in the opposite direction, and the motion is repeated.

The second final artifact, droop-artifact, uses a motor to pull monofilament passing through different nodes along a plant stem and attached to the top-most node. Pulling the thread curls the plant stem down, and releasing the thread allows the stem to straighten out to its original position, using a mechanism used by puppeteers for controlling fingers. Control parameters for the droop-artifact were: **distance**: the amount that the stems were pulled down or released up; **speed**: how slowly or quickly to take from one position to another; **direction**: whether the movement rose up or down; and **timing**: when to perform a move. This artifact's leaves were modeled after Monstera deliciosa, informally named the Swiss Cheese plant. Selected movements for this artifact included basic up and down actions at various speeds. I also included four additional scripted movements, meant to delve into different ways motion could be used as effective notifications. *Heartbeat* used

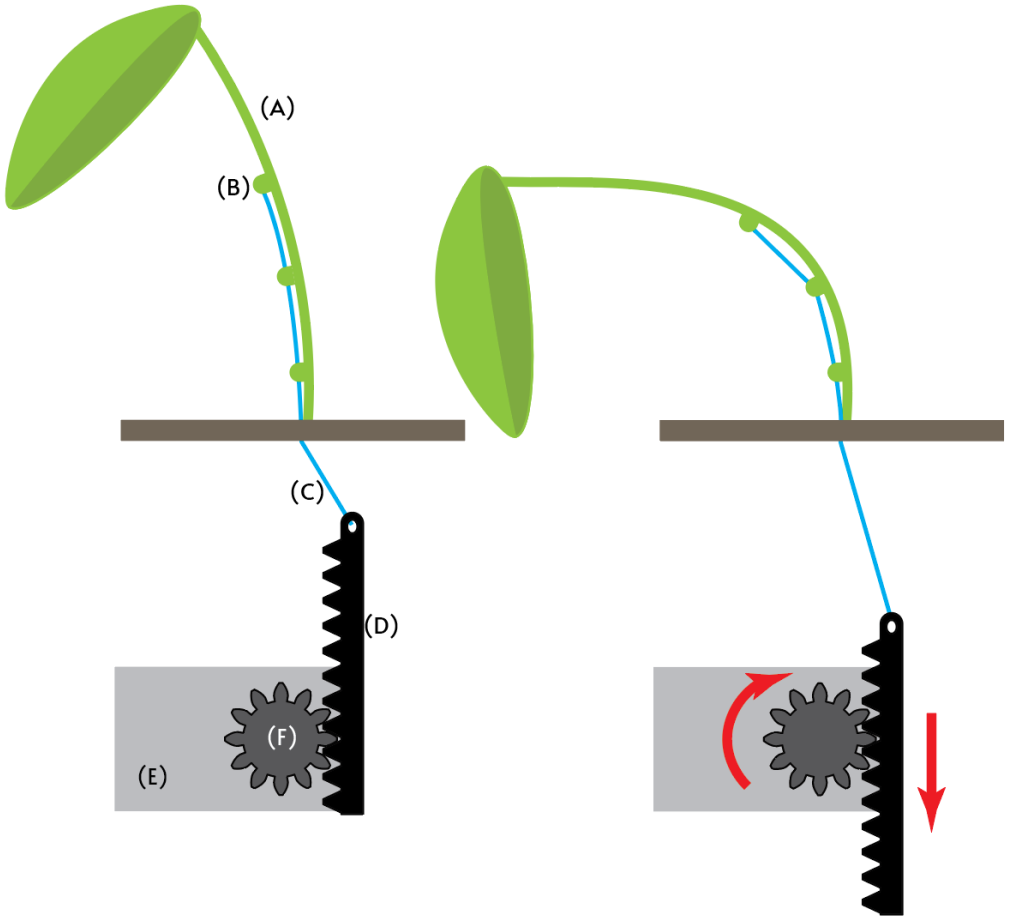

Figure 4.4: Droop-artifact mechanism. The artifact's plant stem (A) contains several channel nodes (B) which are connected to monofilament line (C). The line is tied to a rack (D), which is moved up and down by a motor (E) driving a pinion gear (F). As the pinion gear rotates, it pulls the rack down, in turn pulling the line down, also in turn pulling the stem down into a downward shape.

a duplicated abrupt start-stop motion to display a tick movement twice. *Hiccup* kept the plant in a down position but would pop up abruptly when trying to notify. *Lift* had the plant move its leaves downward so forcibly that it would lift itself slightly out of its own container. *Panting* used a smooth loop of undulating stems of the plant which was meant to look as if the plant were panting.

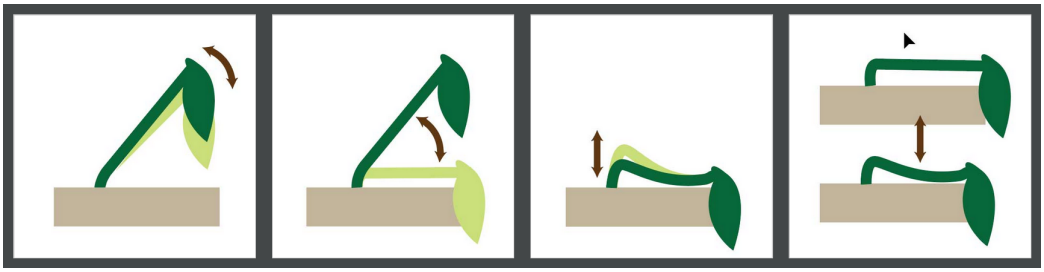

Figure 4.5: Thumbnails used to remind participants of the various motions used in droop-artifact's disruptive portion. From l-r, *heartbeat*, *hiccup*, *lift*, and *panting*.

4.3 Recruitment and Interviews

Due to the COVID-19 pandemic, I planned for interviews to be held virtually, over video chat. To support this, I took individual videos of a range of different motions from each artifact, which I could playback to each participant. To simplify the presentation of these videos during the interviews, I created a keyboard-driven web application where single keystrokes would load and display specific videos, with the ability to start and pause the playback. The specific keystrokes for each video were written into the protocol to make the interview and puppeteering of video selection easier. While some motions had relatedness to each other, (e.g., the *subtle shake* amplified into the *heavy shake* motion), some of the droop-artifact's notification motions were very disparate, and so thumbnails of each motion were also created and displayed alongside these particular videos.

4.3.1 Recruitment

A screening questionnaire, consent form, and sample interview were reviewed and approved by the University of Maryland's Institutional Review Board. Participants were recruited over social media (Facebook and Reddit), using iSchool-related mailing lists, and flyers across the University of Maryland College Park campus. The criteria for participation included *(with reasoning for each criterion in italics)*:

Figure 4.6: Web application display used during interviews to display video of artifacts to participants and situate them in a work-like situation.

- Be 18 years old or older. *(The intended population for this study was adults.)*
- Have normal or corrected-to-normal vision. *(Because I was holding interviews over video chat and presented the artifacts as a video clip, the individuals I would choose needed normal vision to participate.)*
- Have equipment capable of participating in a Zoom video chat (computer, internet access, webcam, microphone, Zoom software), and willing to participate with video and audio. *(I needed individuals to be able to use the video chat software effectively during the interview, and be willing to be recorded for transcription purposes.)*
- Work at least three days a week at a desk for 6+ hours per day. *(Because of the physical nature of the artifacts, I needed individuals who remained roughly in one location for an extended time per day, so that interactions would not be missed.)*
- Have a health-related goal, which requires acting on multiple times per day (e.g., taking medication regularly, step count goal, hydration goal, taking regular breaks during prolonged sitting, eating meals on a regular schedule). *(I wished to have user scenarios where they could be notified multiple times per day.)*

- Have prior experience with a strategy to aid in adherence to healthy activity goal (e.g., alarms and reminders, wearable devices like Fitbit, health apps, smart bottles, post-it notes, journals and calendars, pillboxes). *(I needed individuals already familiar with using a strategy so I could hear scenarios of current use, and compare / contrast with how they imagined they would use Ambruptives.)*

4.3.2 Selection

Potential participants were asked to fill out a survey held on Qualtrics; contents of the survey are found in Appendix B. The survey mainly followed the participation criteria, with a few extra questions about their health goals to allow me to choose individuals who differed from those I would have already interviewed. A total of 169 respondents took the qualification survey. 98 did not qualify due to their survey answers not meeting the initial criteria as specified in the ad. About one third of the remaining responses were suspicious, with repeated answers across participants, IP addresses shared across responses, or IP addresses originating from Virtual Private Networks. This suspicion was confirmed from a few interviews that were initiated with respondents in this group, where I did not proceed after the actual participant did not match the details of the initial respondent; the others in that group were flagged manually to be ignored. With the remaining respondents, I attempted to choose participants that would increase the diversity of age groups and health goals. Ten individuals were invited, asked to review and sign a consent form over Adobe Sign, and scheduled for a meeting over Zoom.

4.3.3 Interviews

For each participant, I held an hour-long video interview using a semi-structured interview process. Generally, I began by asking the participant to describe their health goals,

	Health goals	Strategies Used	Age Range	Location
P1	Increase exercise; Drink more water	Apple Watch; notes app, calendar reminders	18-24	USA
P2	Medication adherence; Track steps/activity; Track mood	Medisafe; Fitbit; Strava; Runkeeper; Daylio app for mood tracking	41-64	USA
P3	1000 kcal in activities per day; 10k steps a day; RHR below 55BPM	Heart rate chest strap; Garmin	25-40	Italy
P4	Stand up and stretch regularly; Medication adherence; Regular hydration	Pillbox; sticky notes for medication reminders	25-40	USA
P5	Drink 100 oz of water daily; 10k+ steps daily; Strength training 3x / week	FitBit; Garmin Watch; MyZone heartrate monitor; calendar to track miles run during training season	25-40	USA
P6	Regular work breaks to prevent RSI; Regular sight breaks; Hydration and meal regularity	RSI guard	25-40	Argentina
P7	Medication adherence; Monitoring weight and blood pressure	FitBit; automated email reminders	41-64	USA
P8	Closing rings on Apple Watch; Maintain or slightly lower weight; Gain muscle	Apple Watch	25-40	USA
P9	Maintaining hydration; Meal regularity; 10k+ steps a day	Calendar reminders for water, food, and multivitamins; Apple Health for steps and sleep	25-40	USA
P10	10k steps daily; Active 12 hours daily; Drink 32oz of water daily	FitBit; planner to track exercise and water intake	18-24	USA

Table 4.1: Details of participants interviewed for study.

then listened to the participant's accounts of what strategies they used to keep track of their health-related activities, multiple times per day. I then introduced the concept of ambient notification by showing the $gentle\ shake$ portion of the $\mathrm{shake\text{-}artifact}$, followed by the $strong\ shake$ motion to display how I would escalate notification. After hearing the participant's reactions to these, I switched to the $\mathrm{droop\text{-}artifact}$, and played the four escalated notification movements: $heartbeat$, $hiccup$, $lift$, and $panting$, asking the participant which movement best represents subtle and escalated notification, and why. The order of movement types shown was consistent across participants.

I then explored the plant's capacity of displaying state via shape-change rather than just a notification indicating the need for action. I showed various up and down movements and positions of the $\mathrm{droop\text{-}artifact}$, and then asked the participants what they felt was best to display their state in an S-CI. Finally, I followed up with general questions around how the participants imagined they would use the artifacts, such as location and size, and explored other features they wished to see. As participants shared more of their thoughts and reactions, I allowed the conversation to meander away from the script as needed, in an attempt to gather richer data. Each participant was compensated with a $20 Amazon gift card in appreciation of their time and for sharing their experiences and thoughts.

4.4 Analysis

All interviews were transcribed verbatim, with a light filtering of repeated words and vocalized pauses ("uhs" and "ums") when they did not alter the meaning of the sentence. I followed a reflexive thematic analysis approach [6, 7], starting with an inductive pass at coding on the first seven interviews. At this point, I began refining and clustering the codes that I had captured, generating broader themes from the data. Using new codes that represented these themes, I took a deductive coding pass against all interviews to continue

to build my outline of themes. Throughout this process, the codes and themes continued to be refined as I saw fit.

Chapter 5: Results

5.1 Interruption Etiquette

Although interruptions are necessary in a notification system, designing interruption that is considerate to one's mental state should be the default when considering a system meant for health-related activities. However, when considering ambruptive technology, this effort increases in complexity, as the designer must consider the balance between the ambient and disruptive states to maximize notification capabilities without annoying users. Current literature has not investigated much into ambruptive notification, especially in the context of notification for health-related activities. Thus, to learn more about the propriety of disruption, in my study I first investigated the question: **(RQ1) When do people accept escalated levels of disruption for health notifications?**

5.1.1 Tolerating Interruption for Health

The importance a user assigns to their health goals made a large difference in accepting interruption by the artifacts. P2 connected this type of acceptance to how medicines are tolerated due to their importance: *"You know, it's like medicine itself, you don't necessarily want to take it, it may taste bad, but it's kind of what you need to do. So, if that's what it takes to keep you on track and it's bad on me for not being better about it, so yeah, I can accept it."*

Two examples gave further insight into which characteristics cause some activities to

receive greater attention than others. P6 found interruption important when paired with her stretching health goal, which helped with her rotator cuff injury. When asked to discuss shake-artifact's escalated *heavy shake* movement, she attested about her past experience and the need to be interrupted:

> *. . . when you have an injury, like a rotator cuff, your shoulders, it's crucial, and I'm saying this word—to take breaks, to stretch, don't spend like eight hours a day and you know, you have to probably spend 2 hours, and stretch, therapy. It was [a] serious injury that I had. If it's about hydration, you know, . . . we'll have damage to our health, but it's not like a damage to our tendons [that] can lead to a break. So, if it's about hydration, I wouldn't create an object so dramatic to remind me to drink water.*

P6 assigned different levels of importance to her various health goals. The threat of a returning acute injury meant she was willing to prioritize those preventative activities above others. Although she acknowledged that maintaining hydration had importance to her health, her categorization of its importance meant that she did not want an escalated notification if merely a drinking opportunity was missed.

P7 contemplated several health goals and which ones he felt warranted disruption. He explains when disruption is welcomed, or when he felt the *subtle shake* movement was a better fit:

> *Well, I think I think a lot would depend on how important it was. So, for example, if it's a reminder to take my blood pressure, you know it's important that I take my blood pressure regularly. But if I miss today, it's not the end of the world. . . . On the other hand, like I said, if I'm taking a really time critical medicine, even if I went for this sort of subtle approach, I would want to get less and less subtle over time. . . . You know, if I'm being told,* 'take this pill or your risk of dying for AIDS is higher. Take it right now!' *Then this thing can*

wave all it wants, right? That's good. And if it's, you know, you need to weigh yourself at some point today, the initial thing blowing in the breeze is probably just right.

Here, the participant considers the time sensitivity of the health activity itself, comparing activities with a looser schedule to an imagined time-critical medication. The more important it is that the activity is done at a specific time, the higher his tolerance for a system which disrupts his life.

5.1.2 Low-Commitment Activities

One factor of disruption is the length of time a user is disrupted. If a user can easily and quickly recover mentally from the interruption, perhaps they may not register the disruption as substantial. In parallel, some health-related activities themselves may not register as taking noticeable amounts of time, as P8 describes one of his health goals: *"the standing up one is very easy to do, just have to stand up right? It literally takes no time out of the day."*

In the context of taking a hydration break, P2 described his reaction to the artifact: *"It also might make me think it's like I can take a break to go get a glass of water. You know, just to take care of that one thing real quick? It might might encourage me to do it."* The low time-cost of the activity, and the easy substitution for a natural break a user would have taken during their day made the interruption tolerable.

During the interviews, P1 reacted to the $hiccup$ motion alerting her towards her hydration goal: *"I feel like it's just telling me to get water. It's quick enough for me to not feel like it's annoying, you know."* The brief movement that $hiccup$ used reduced the annoyance she felt from other forms which used prolonged movement.

5.1.3 Circumstantial Notification

Unlike the previously mentioned health-related activities, which comprise of an immediate single action, some health goals require a larger commitment in both energy and time, such as a 30-minute exercise routine. Because these activities need to fit within one's schedule, the likeliness of it being delayed or even skipped in lieu of other activities is much bigger. Participants were aware of how their daily lives interfered with their health goals, and often, it was their health goals which took subservience.

P9 shared her reaction to a disruptive notification for her exercise goal, imagining two different scenarios and her varied reactions in both:

> *Based on my mood, if I have a lot to do, like a lot of tasks to do and I have no time for my exercise, this might annoy me a little bit. But on a normal day this won't annoy me, it will be pleasant and it will get my attention and probably motivate me.*

Although external forces cause the busy situation they are in, users may still target their negative reaction toward the system that gives the disruptive notification, even if they would normally welcome the message on a different day. Circumstance is an important factor in how the system is received, whether favorable or unfavorable.

P6 expanded on the negative views she held towards systems that issued strict commands without considering the user's situation. Although previously acknowledging that such disruption could be important for health, she did not want that decision to be made without context.

> *I personally don't like the apps that tell you when you need to do it, because they don't know you, like, why is an application telling you to do certain stuff without information?... The technology didn't [understand] the phenomenon. It was telling you go and move, go and move, you're lazy, you're... and that*

> *lack of understanding, and that lack of context of that similarly smart system generates frustration in satisfaction.*

P6 further details her anger towards health notification systems, which alert without situational awareness, recounting an app that locked her computer until her activity was performed:

> *The part I mentioned before, having like the technology begging you to do something without the context, and that's the part that triggers my anger, when I have technology telling me something inappropriate. And I'm thinking, it's probably something that can be controlled, as if you have the power button, you can turn on and turn off the plant, or tell the plant,* 'I couldn't, no'. *Like I'm in focus mode, I mean, I know or have levels like I have an acute injury or I have a medium injury, or I'm not injured.*

Here, she wished for the ability to provide feedback to the system, having it adjust its notification strategy to fit what she is doing and how she is feeling physically. Instead, her existing system simply doles its notification—portraying a command without a way for the user to debate its appropriateness, which leads to extreme frustration.

As a seasoned *quantified self* user, P3 additionally mentioned his physiological status as another form of feedback that could be used by the system. He explains a desired situation for the shake-artifact to escalate its notification based on this data:

> *. . . let's say [the plant] reads my data and then knows when it's best for me to work out. . . maybe track the heart rate variability and see that at five o'clock PM I'm ready. And the plant shakes and, I [say],* 'Oh the plant analyze[d] me and says I'm okay'*, so I'm going to work out.*

P3 later mentions his trust in health-optimizing algorithms, which he asserts as being better at calculating the optimal times his body would benefit from activity. Even if this could happen at a random point during the day, because he wishes to enhance the results of his

workout, P3 welcomes the interruption because it comes from a source he trusts more than his own mind.

But instead of the system calculating the best time to alert a user, P4 chose a different strategy for when notifications could be shown: *"I think the best way to show me, but this is just for me, is to like, when I'm looking at [it]."* P4 imagined that she would naturally glance over at her plant without prompting during the natural lulls in her day. If the system is able to take advantage of this user-initiated work-interruption to deliver a message, it could provide notification for a disruptive action but not break the flow of a user's work, keeping with P4's needs during work: *"...sometimes I'm in the middle of working, I just don't want to be interrupted."*

5.1.4 Overcoming Inertia

If interrupted while actively working on a separate task, one strategy users may take is choosing to delay their health-related activity to complete a portion of their task. However, when systems offer users the ability to delay, at a certain point the user may end up never doing the activity for that day. A couple of participants shared scenarios on why this deferment led to a missed activity, and when notification escalation could be useful.

P2 recounted a situation with his medication reminder app: *"I just hit snooze too many times, and it stops and then it's like: oh yeah, I totally should have gotten to that but forgot about it."* P2's app's snooze functionality did not infinitely push the notification to the future; it instead stopped notifications after some number of snooze requests. As a result, P2 missed a dose of his medication due to his main activity distracting him to the point of forgetfulness over his health goal. In comparison, when describing a scenario on how the artifacts could implement a snooze feature with the $heavy\ shake$ movement, he states:

Having a snooze function is always a good thing, except for when it isn't. But I

mean if it were doing, if it were a matter of accelerating—like if you are: here's the instant that the activity has been requested, here's 15 minutes later and you get a little more excited, and when it gets, you know, 30 minutes, an hour, where you're past due, it's getting very excited.

This notification escalation pattern would be useful where the user feels their health-related activity ultimately must not be skipped, but understands it lacks strict conditions and can tolerate some adjustability in timing. Notification escalation here can complement the flexibility of a snooze function.

P10 felt the artifacts should actively interrupt her after fifteen minutes of ambient notification about her exercise routine. She recollects the situation on days where she did not exercise to explain why she chose this length:

I will find that if I'm doing something that needs my attention and I know that I have to exercise at five, but I don't get to it. Usually, I'll wait and I'll be like, okay, just 15 more minutes of this task and then, you know, I'll get to it. If I get over 15 minutes, I notice that I usually don't end up exercising at all that night because it—just at that point, you know, it's almost 5:30 you know, it's getting closer to 5:30; that means dinner.

Due to their schedules, some users only have specific blocks of time that are available for their health-related activity. Here, the participant identifies a critical boundary in time that determines if she will be able to exercise for the day and wishes for notification escalation to increase the success of her health goal.

5.2 Shape as a Notification

The movements and postures of the artifacts do not impart a literal statement. They are abstract shapes, sans language, and must be actively interpreted by the user. In my

interviews, I purposely did not explain what each shape-change was supposed to communicate, leaving their definitions open to the participant's own reactions in order to investigate **(RQ2) How could varying levels of health notifications be portrayed in shape-changing interfaces?**

To avoid message fatigue, ambruptive systems should begin at an ambient state, and so I first needed to explore how the artifacts would be in conveying an ambient message. The artifacts did well in this area; participants considered shape change types with smaller motion ranges, smoother actions, and reduced motion altogether as suitable for ambient messaging, especially $subtle\ shake$. Conversely, for the most part users felt movements with larger sized actions, such as $hiccup$ with its broader up and down action, gave the best opportunity for a notification to be noticed as an escalated attempt. Participants also liked how the $subtle\ shake$ movement led into the $heavy\ shake$ when escalating—seen as an easily understandable progression from ambient to disruptive, as compared to some of the other varied motions that the $\mathrm{droop\text{-}artifact}$ was capable of. However, designing the artifacts to study participants' reactions around emotion and saliency ended up resulting in deeper discussion around the interpretation of abstract movements in a plant-like object.

5.2.1 The Human-Plant Relationship

The relationships between humans and plants cover a broad spectrum of living, whether the link between a farmer and the crops they grow for sustenance, or simply someone owning a houseplant for decorative purposes. These varied relationships were reflected in the ways the participants spoke about the plant-mimicking artifacts I presented. As humans learned how to domesticate plants and involve themselves in their life cycle over history, knowledge grew in understanding the effect of actions performed on the plants. This generalized knowledge was pulled from by various participants in their interpretations

of the artifacts' movement into health-related notifications.

P7 referred to the co-evolution of plants and humans in why an artifact's shape could easily be interpreted to indicate a user's health status. While discussing how droop-artifact's positioning could be used to represent his health, he explains why he chose the upward position to mean "healthy":

> *Healthy is what most looks most like a real plant, which is probably the up position, but it could easily involve the color, or perhaps, how saggy it looks, how plants get dehydrated or desiccated or whatever. So, I mean, I would... because we have evolved for millennia with plants, have a lot of intuitions about it.*

P10 also used her knowledge of plant health in interpreting the artifact's downward-to-upward motion to represent a gain in health: *"For me, I love starting down and then going up. I love that, especially with drinking water, it's so fitting because you know when you water plants they grow and they become unwilted."*

P1 liked droop-artifact's motion over shake-artifact: *"...this one's way better because it's using plants like how plants are usually used as, you know, when the sunlight comes, it goes to the sun, it's not, it goes down. It makes more sense, and I could better understand this..."* Her existing understanding of how plants react to light translated easily to the motion of the artifact and greatly influenced which motion she preferred.

5.2.1.1 Culpability as a Caretaker

In many cases, participants felt empathy towards the artifacts due to their interpretation of the shape and motion. Several of the droop-artifact motions consisted of the plant leaves being in a downward position, and participants interpreted this as if the plant were dying. As a result, many felt dismal emotions towards seeing plants in that state.

Figure 5.1: The downward position of the droop-artifact, interpreted by many as the plant "dying".

> *P2: the plant just looks so sad. . . . like having that on my desk would be not aesthetically pleasing. I'd be feeling like, oh God, I've killed it.*
>
> *P5: Because if I saw. . . wow, I didn't realize how I was like, sad to see it down. . . . Yeah, I'd be like, ugh.*
>
> *P4: like when those leaves are kind of like falling? It just [gives] that feeling that this plant is dying. So, I don't know if people will be willing to put a plant like that that's on their table.*

Indeed, many participants found the downward position so emotionally melancholy that they could not imagine themselves using it. Although participants did find it easy to correlate a dying plant with an unhealthy health situation, the emotions they felt overrode any usefulness of the natural metaphor to the point of an unwillingness to use such a system.

P4: I mean if this is the default gesture like it's having then, like the first thought I'm having is that I will probably replace it... So, I would probably just [turn it off] or like I just stop using it because I feel depressed.

P9: A plant is supposed to grow upwards in a normal species. And it's... I associate plants with liveliness and happiness and greens, and if they're dropped like this, they would perhaps look dead to me, and I won't be happy about it. I won't be happy looking at it... Yeah, I won't use it if it looks like that.

When asked if an abstract, non-plant-like system would elicit the same negative reaction in a downward position, P6 noted that the same shape with different aesthetics would be fine. *"Because that thing won't be dead for me, right. It won't look dead."* The plant-like form factor holds importance in how the shape-change data is perceived in users.

Why would an object hold such an emotional pull with users? Some reflected on their current relationship with plants to explain why the downward position would not work, such as P10:

As someone who has a lot of plants, at the sight of like wilting leaves,... it makes me kind of upset, because I take care of my plants and like I hate when they look like that because that, you know, they're not doing well.

P5 also related how her own personal results with plant caretaking affects the strong emotions over them:

I own plants, but I'm not the best plant mom. So, they look sad, and I think they're dying because they're wilting. So, this already, I'm like, oh, it just looks sad and reminds me of like a dying plant, and I don't want to look at dying plants personally.

The caretaking role that participants held in the past with plants extends towards the plant-like artifacts, perhaps heightening any reactions they may have towards these S-CIs.

These emotions were not limited to the motions that gave the artifact a look of a dying

plant. P6 found the shake-artifact's movement worrisome due to the agitated motion on a plant with thin stems: *"I would think that the plant will have pain. So, I will stand up, because I see the plant moving, that might be, it might be painful for the plant to shake like this. So, I would stand up and do whatever to make the plant stop [breaking]."* Although her emotions did motivate her towards her health activity, she also mentioned she *"immediately feel[s] manipulated by the plant"* and questioned the ethics of using empathy to prompt action. This feeling of manipulation extended to the droop-artifact, as she indicated, *"I mean it's too much manipulation, in one piece. It's like saying,* 'I'm dying, I'm dying, go and'*... I mean, I feel weird."*

Figure 5.2: A progression of the droop-artifact from upward to downward positions.

Attempting to motivate users by eliciting emotion was not limited to time based notifications. During discussion on how the droop-artifact could use its level of droop to indicate the state of a user's health goal progress, some participants also referred to a threshold for which a plant's shape could continue to motivate them to do any action. If the system used a restoration motif, i.e., health-related actions raising the plant from a downward state to an upright state; even with the knowledge that their actions could restore the plant back to an upright position, P2 imagined not finding the motivation to try, *"If I need to do a ton of stuff, and it's already dead then, yeah, it's sort of like, oh well, try again tomorrow."* A similar downward position from the artifact had him mention, *"this gives me no hope that I can ever make it feel better again."*

In summary, people's prior knowledge of horticulture plays a part in the innate inter-

pretation of the plant's status, leading towards a diagnosis of unwellness for the plant with downward shapes. Although easily interpreted by the user, personal caretaking responsibilities with plants give users the subsequent feeling of personal defeat and becomes a situation that is unwelcomed by the user, defeating any gains in noticeability or motivation.

5.2.1.2 Expectations of Naturalness

Designers often represent a product's "natural" quality with a portrayal of a plant, such as a leaf icon indicating a beauty product's organic and natural ingredients. Many participants reflected an obvious relationship between naturalness and a plant form, such as P5 noting *"But I also like [how] this looks somewhat natural, like a plant."* But with my plant-mimicking artifacts, I also found an inverted expectation from participants: wanting something looking like a plant to have natural characteristics, i.e., a natural seeming movement. When asked if naturalness of the movement was an important factor, P9 declared: *"Since it's a plant? Yes."*

P1 found some movement types to be negatively affecting desire for the artifact: *"It seems a little robotic. It doesn't seem natural for a plant to move like that . . . there has to be some element of like natural, naturalness, if I'm going to get it."* To P1, naturalness in motion was a requirement in using something that looked like a plant.

The elasticity of the artifact's plastic parts sometimes led to unintended resonant movements, such as a leaf continuing to wobble after its actuating motor had stopped. This too was described in negative terms such as *"unnatural because it kind of had a jerky movement"* (P8), *"Yeah, they seem really unnatural. Especially especially [the hiccup movement]. Yeah, I don't know why, I think it's just the jerkiness of it"* (P10) and *"I don't like the little, short movements, because it's like someone's poking me."* (P1) Here, the lack of precision in the movements resulted in distracting wavering movements, which perhaps

over accentuated the movement the plant-like artifacts were meant to perform. Although some plants do have visible motion in nature, like a Venus flytrap closing on its prey, such natural motions are smooth and measured, unlike the artifacts. In the same way poor audio fidelity can easily be perceived as abnormal, poor movement fidelity can also give an unnatural quality—a detriment especially for a device that users expect to act "naturally."

5.2.1.3 Uncanny Xylum

Interestingly, some artifact motions were met with even stronger negative reactions than the general moroseness over the artifacts' state. The *lift* motion gave P8 a sense of weirdness: *"you know the plant going up. It just seems weird to me I guess... I wouldn't expect a plant to go up."* P6 felt discomfort over seeing the shake-artifact move gently: *"It makes me nervous? There's something not right, it creates some tension."* Although unable to pinpoint why the movement brought upon these emotions, she had a clear opinion on what she would do if directed by her employer to use such an artifact: *"Well, if they forced me, I'd have two options. Hide the plant, or send my resignation note."*

Even more so, the *panting* motion caused several participants to mention feelings similar to the discomfort stemming from the uncanny valley, but here towards a non-human figure.

> *P5: Oh! I kind of got a creepy vibe on that one.*
>
> *P4: So, yeah, I feel like it's similar to like human's movement, but it's not. So, it will somehow give me that kind of like scary feeling.*

P7 explained his reasoning for discomfort in detail: *"It's shaped like a plant but it's not acting like a plant. So, it's violating my mental model of what plants do, well, looking like a plant that just makes it... I think that's what I mean when I say it's creepy."* These uncanny reactions seem to stem from a **representational dissonance**, that is, the discom-

fort from the inconsistency in how a user expects an object to act based on its appearance, compared to what they are actually perceiving. In this case the participants' expectations of a plant-like object clashes with how I had programmed it to actually move, and thus unease occurred.

However, such unnatural and uncanny movements still may show utility in demanding one's attention. P7 noted the effectiveness of creepiness of this motion to garnering attention, with some caution:

> *. . . it would be creepy. Which you can use? I mean, the more urgent something is, the more useful creepiness is. You know, this is going to get your attention. I just I think it's a bad state for when it's just sort of* 'ehh, eventually you got to do something'*, you don't want to creep [the user] out.*

While possibly effective, again designers will need to consider the accompanying emotions that could be delivered along with salient style notifications.

However, it should be noted that although very strong feelings were evoked with the artifacts, these were not universally held reactions. For instance, even though P1 also saw anthropomorphic qualities in the $panting$ motion, she instead described it as *"like you're getting a massage"* and it not exuding creepiness, but *"relax time. Like, you know, it's time to focus on yourself."* She later spoke of how allowing customization of the artifact could further solidify the meaning of the $panting$ motion:

> *. . . you could have it like take on a personal approach, like maybe a motion you do with your shoulders, like I said, it looks like a massage. . . I could attach emotions and give it my own meanings. Because it reminds me of a motion I already do.*

The personal history and experiences of each user could greatly modify how each motion is perceived, in the same way a Rothko causes some to weep and others to dismiss it as a boring painting. Allowing users to configure which motions are used by the artifacts seems

like a necessity.

5.2.2 Configuring Abstraction

Full customization of the abstract movements was requested by several of the participants for several different reasons. Besides discussions about wanting options to avoid a movement they did not like, some participants also saw the need to tweak the motion settings as their understanding of their own reactions to the artifact increased. P7 disclosed: *"And I always try to get these things just right. So, for me, it would help with my health goals because I could really customize it."* P2 mentions that customization *"would be the sort of thing that I would like the most. If I could just tell it: here's what this trigger is, here's the acceleration and the reminder points. And then for a different trigger thing it could be totally different pattern.... part of the thing is you're trying to customize your goals to meet your needs."* Both felt that adjustments in a system could change their own success of health goal adherence, and so wished for this option so they could tailor them.

Some referred to their goals changing over time, such as P1 noting *"things that I would do in the summer I'm not going to do in the winter, obviously."* Correspondingly, participants brought up configuration as a means of expanding their health goals as they progressed through others. When asked if she would prefer a single motion, P10 considered: *"But if you're able to change the functionality, I think that's really great as well. If I was like,* 'you know what I've been really good at drinking water'*, I want to make this into more of the shaking, you know, for a goal like exercising."* Repurposing of the artifact would allow users to transfer their understanding of how to interact with the artifact's notifications, to other goals they may have in mind.

Another reaction to being asked if the artifact should keep one motion over a long period of time was whether the motion would still be noticed after a period of time.

P9: But a week later I won't [notice the artifact] because it will just become part of my surroundings.

P6: what happens with this ornament, is you pay attention [for] a certain time, and then it becomes transparent.

To combat this, P9 wished to be able to change the *"kind of movement and being able to control it and change it maybe every few days."* Allowing for changes to support visual novelty may be important to maintaining usability over a longer period of time.

5.2.3 Imprecise Interpretation

When presented with how the $droop\text{-}artifact$ can be used to represent state by the interpretation of its leaves' posture, several participants mentioned concern with being able to read its data with the accuracy they desired for their health goals. For example, one of P4's medications is dependent on her menstruation cycle, with a complicated schedule: twenty days after her period, she takes a pill twice-daily for the following ten days. She mentioned concern with the "data accuracy" of the artifact if paired with this medication schedule, explaining:

[my medication] requires you to take [it at] a different time, or a different date and that's something related with numbers. But the movement of the plant just can't show like the change of numbers... Like for example if the plant started at the very—started at the up pose, and then for example, say I need to take my medication at the 20th day. So, when the plant is probably at it's like middle pose. So, I don't know. How do you show when do I need to take those medications just from this plant?

Here, she imagines the shape range of the $\mathrm{droop\text{-}artifact}$ needing to represent a month of time, and cannot envision this mode independently giving her the information she needs

to act upon her goal. However, she also mentions pairing with a separate app: *"But if the plant can kind of like have a way to like link with my app and I think yeah, it will be just better than just having an app."* These artifacts do not need to exist only as a standalone system; they can be paired with another app and serve as a form of **meta-notification**, that is, a notification that informs a user to check elsewhere for more precise notifications.

In P8's case, his concerns were due to his preference for numeric statistics rather than broad indicators. He illustrates his concerns with the mere approximation offered by the artifact's state-representation by describing how he has switched from the popular "rings" UI on the Apple Watch to:

> *...these little dots that you know, you get a dot for every hour. If you miss it, it's like a gray dot, if you hit it, it's a blue dot, right? And I can see exactly how many hours I've hit, you can count them, but in the ring it's just like, I need to figure out the angle of like the arc and calculate it from there, which is, you know: I want the number... Like I want to be able to know exactly where I am. This would tell me roughly what I am.*

When questioned about his desire for precision, he explains the practical reasons he needs direct numbers:

> *The critical thing is usually if I've been lazy in the morning, I need enough hours in the day to complete my goal. If there's, you know, if there's five hours left and I need to complete six more hours, I'm not gonna be able to hit it, so I need to stay ahead of that at all times. Like I need to make sure that there's enough hours in the day before I get too lazy.*

P8's stand goal is defined by Apple as *"getting up and moving around for at least 1 minute during 12 different hours in the day"*. Health goals bound to meeting a requirement for a percentage of predefined divisions in the day have the side-effect of being untenable after a given point in time. As his day passes, the display of what P8 has *already* accomplished

transforms into a mental burden: he now has to perform math to figure out the effort level needed to accomplish his goal, and also whether or not he has enough hours to do so. Using a display like Apple's rings or the artifact's shape-change state-representation adds even further to that burden, as an additional visual estimation step is needed to obtain his first variable, and so usability suffers as a result.

5.3 Existing in the Physical World

As S-CIs, the physical aspect of the artifacts I created led to various discussions on how such devices could work in the lives of our participants. Although S-CIs have existed in literature for decades, they are still an uncommon sight in most homes. However, newer devices have populated the home in the form of voice assistants, such as Alexa and Google Home, and users are now familiar with interacting with computing without looking at a screen and placing a standalone physical device in one's environment. These interviews provide a current look at users' reactions in the post voice-assistant world to answer **(RQ3) How do people envision using shape-changing interfaces within their environments?**

Physical space is a finite restriction in everyone's home or office. A device that constantly takes up valuable physical space has different deciding factors than the thought process in choosing one's desktop wallpaper, for instance. As an example of the strong rules that users choose for their physical environment, P9 noted that because she needed her work area empty, she would need the artifacts *"a little further because I need the space around my monitor to be empty and I need like proper clean space with nothing, not even a diary or a notebook to work. I design and I like white blank spaces around me."*

5.3.1 One Space, Many Roles

One theme throughout the interviews was the desire for the device to have multiple purposes. P1 firmly set this as a requirement before use: *"You want something that is multi-functional... I would want all in one. I wouldn't buy it if it was just doing one thing."* P10 described some of the characteristics that would be ideal in an artifact: *"And if you want to like have less clutter and everything, it's nicer if one plant can do all those different functionalities. And then in terms of like money, like buying, you know."* The weighing of several costs, both in physical space and in finance, led to her preference for a multi-functional artifact that could accomplish more than one thing.

When asked if multiple artifacts would be usable, several participants noted the additional mental cost of having to remember which plant would represent which health goal, such as P4: *"So, if I'm having multiple plant[s] then there's another problem. So I need to remember which plant is for which medication. Yeah. And also, I think that will be a little bit hard to memorize."* Outside of some natural pairings such as medications and the plants they originate from, not all health goals have a corresponding plant that all users can unmistakably identify as a representative.

Due to the aforementioned costs, participants suggested expanding the functionality of devices by portraying multiple health statuses in one plant. P9 described how she would design a system providing a summarized state glanceable display of her progress:

> *Maybe one leaf would represent one health goal. One leaf can be a number of steps. The second one can be calories. The third one can be intermittent fasting, all of those things. And based on what I do, the leaf can rise, for example, that 5000 steps a day, only one of the leaf can be halfway up, and that way by the end of the day, I can realize that I did not make my day, like I did not complete my goals and hence the leaves did not rise.*

P7 suggested a conglomerate notification artifact similar to P9, but expanded how he would use it as a pre-indicator—a way of letting him know that he should look further into his health status:

> *I like the idea of a something that looks like a healthy plant, meaning basically everything's fine. And the more something droops or changes color, if you have that option right, the less it looks like a healthy plant, the more I'm inclined to say,* 'why is that?' *Is it worried about my heart rate, is worried about I haven't eaten in so long?*

In P7's configuration, individual health factors are not shown as distinct pieces of data. Instead, they are treated as a whole, and the prior concept of **meta-notification** applies, as the artifact acts as a nudge to look into a supplementary system that would have its own set of notifications with more details. As a S-CI, the system can transmit this simplified notification without the user needing to bring up a screen.

However, expanding the number of notifications was not the only way that participants categorized artifacts as being multi-functional. The aesthetics of the item were also considered a secondary use, such as P5 designation of the artifact being a "triple win":

> *It gives me greenery, and it's also a bonus round telling me to do something. Because people around me, well before the pandemic, had plants for aesthetics. So, this is like, it looks nice, and it will tell me what to do or notify me subtly, and that notification helps me for my health goals. That's like a triple win.*

P5 enjoys the idea of a plant artifact adding to her decor yet improving her health goals. This aesthetic value of the artifacts could also lead to prolonged usage of the notification system. P5 compared the artifacts with current health devices and noted how its aesthetics could sustain the device staying in the environment.

> *Yeah. I think it's just pleasant to look at, right? Like, I would want to put this on my desk versus like putting it, I don't know... like hiding it away. Because*

that's one of the challenges with all these trackers, right? Like you could buy them but never use them and it would be in a drawer... So, it would make me want to have it in a prominent spot because it like makes the space look nice.

Because the decorative aspect of the artifact holds utility, i.e., making the area more pleasant, P5 feels she would find herself continuing to display them, unlike other health tracking aids that she has hidden away after disuse. P9 also refers to this additional aesthetic purpose when she speaks about tempering her reliance on technology for her health. She conveyed that she would probably turn off the artifact at times to exercise *"my memory and my discipline"*. Nonetheless, similar to P5, disuse does not mean the artifact is stored away, as she offered: *"Also on days that I don't want to rely on this, I would treat this as a plant instead of as something that reminds me to do stuff"*. With dual purposes, when a user's interest in one aspect of the artifact wanes, its secondary aspect can provide a reason to continue to dedicate physical space to the system, and vice versa as the user's focus changes over time.

5.3.2 Fitting into the Environment

However, as aesthetics can be very subjective, the look of the artifact was an important factor for interviewees. Participants seemed keen on having an object that united into the existing aesthetics of the room. For instance, several participants chose design characteristics such as size and shape to match houseplants that were already in their environment. A positive reaction to the artifact was attributed to the artifact looking like a realistic plant, similar to the other houseplants already in their spaces.

The simple choice of choosing to style the artifacts made a difference in its reception. Multiple participants indicated that its aesthetics would be an important decision point for them. When asked if an unstyled device such as a simple flag was used for the artifact in conjunction with the existing movement, P3 rejected the idea altogether: *"If it's something*

like a flag or like a flag, just saying, I will not put on my desk." P3 required some form of design aesthetic in order to be worthy of a spot on the desk.

P10 detailed how physical items need to match the location they reside in:

> *I think at home I go with more colorful things, like I'm fine with that. But if it were at work where I have less clutter on my desk, I would probably not want something that's too bright in color, or something that has a lot of pattern. Because it's fine for at home, you know because I like color, but at work like it doesn't really go with the environment, if that makes sense... Yeah, because it's very clean medical center and the whole design of it is clean and there's like accent walls, like a dark accent wall, there's already kind of that color pop there. So, like you know, bringing in something that's like bright red for example would be kind of distracting.*

An artifact placed at home would likely have a different styling than one in the office, based on the interior scheme of both environments. As the office is a shared environment whose decor needs to work with multiple people, and the home can portray a more personal design style, different colors and shapes may work in one but be too boring or gaudy in another.

Size was another element where participants made choices based on the environment they would place the artifacts into. P6 noted how she would pick vastly different sizes for the home and for the office: *"I mean, now I'm working from home, which the challenge is the size. If I was at the office, I'd pick a big one. I'd like to have a nice plant. If I'm home, I want a small plant."* P6 wishes to maximize the size of her artifact but understands the personal space limitations in each location.

In discussing optimal sizes for the artifacts, P2 states: *"I don't think it would have to be any bigger than like a 3" pot. it could be that you know, even a little 1" pot might suffice. That might be easier to fit in. I mean my desk is kind of a mess... "* P2 chose a very small size for the artifacts, noting that the existing contents on his current desk meant the

artifact needed to be under three inches to fit. S-CIs compete with other physical objects in a limited location, but if dealing with a large space, one must also size the artifact correctly, as P7 conveys:

> *My living room is very large, and I'm a fair distance from the TV and I watch TV in there. Having a rather large plant off in the corner, waving like this, I would notice it. Whereas a small plant that was on the other side of the room, I might never notice it. On the other hand, it's a smaller room you don't want a plant that overwhelms the room.*

P7 noted how a room's size and his usual position in the room related together when considering the size of an artifact. S-CIs with visual components need to balance both the environment and the recipient in order to be effective.

Placement is very important to S-CIs, as these devices are dependent on visual awareness. For instance, P6 shared how much attention one of her real houseplants gets when she's working due to its placement behind her back: *"It has to be in your sight. When I'm focused. I don't see, I don't care what happens to my plant [points to plant behind her] If there's a bug eating my plant, I don't know, I'm working."* Although users' screens are by default placed in the optimal position to be seen in a workspace, S-CIs generally do not hold the same importance and are set off to the side. Due to humans' predatory-based forward-facing eyes, we are limited in our field of vision, and so the viable locations for a S-CI with notification capabilities is also limited.

P2 also mentions focus as a detriment to non-screen notifications: *"If I'm particularly if I'm focused in on a task, I'm not gonna be glancing over to see how it's doing."* The choice of motion could likewise be some form of detriment for an S-CI being in the farther areas of a user's peripheral view. P3 noted how a subtle movement would work for his office, but he would need to choose a different motion at home as *"because at home, maybe I don't see it."*

5.3.2.1 Environmental Interference

With the gentle version of the $shake$ mechanism, modeled to look like a slight breeze passing through the plant, participants noted how the environment itself might interfere with the interpretation of the artifact.

> *P2: If I just sort of at the corner of my eye started moving, I wonder if there's a draft or something.*
>
> *P4: So, I usually work with my fan on. So, I don't know if that will like influence the less shaking of the plant.*
>
> *P5: So, like if someone walked by and I saw it move: was it moving because I need to move? Or because someone walked past fast enough to move it*

Because air currents are actually part of the environment these artifacts would live in, this naturalistic movement might have been **too** naturalistic, having users wonder if the movement was caused by the system itself, or by some other external force common to the space they were in.

5.3.3 When Everyone Sees Your Notification

The workplace was imagined as an ideal location for the artifacts by many participants. However, some noted how a shared environment leads to a personal notification turning into a broadcast notification, as anyone within sight of an artifact could notice its movement. P1 explains how she would react to the artifact activating in front of others: *"I would probably have to tell them, like, they're going to be like, did your plant just move, and I'd tell them,* 'Yeah, it's a moving plant'*, and give them an idea of why it moves."* She and others had no concern with informing others of such a device and its purpose. The artifact might provide a conversation piece or a way to share their health goals with others, if they choose.

Conversely, P2 described discomfort with an elevated notification being visible to others:

> *If I'm in a meeting, it's a little different than if I'm just like zoned in on, you know, editing something... Obviously [if] we're in an office and that's happening with somebody sitting across the desk from me, that [could] get weird fast.*

However, P2 indicates how the knowledge of notification escalation could be a form of impetus itself: *"I think if you've got somebody in the room with you and starts it, probably more likely to also react to it sooner because you know, what could be coming."* Here, the more subtle notifications insinuate a second message beyond a reminder of one's health goal: a possibly embarrassing escalation or a situation that could annoy others if one does not act. Publicized notifications allow for the leveraging of social etiquette, if the user feels it is personally effective.

Despite the artifacts effectively sending its notification to all within sight, the abstract nature of the shape-changing artifacts provided some users with a feeling of privacy from others who may be in the same room as them. Here, a few participants discuss the abstract nature of the plant and what it communicates:

> *P8: But this just seems more: who's gonna know what that means. It's moving. I know that means "stand up" but other people probably don't know.*
>
> *P9: No, I don't mind people saying because 1: they won't know what represents what in the plant and what is the plant doing until I tell them and I'll only tell them if I want to tell and second even if they know, I don't mind.*

Having a non-literal indicator as a notification means they are able to decide who they wish to share the meaning with, and when. P5 detailed her personal approach on not sharing health goals with others, and how the non-literal artifacts complement it:

> *So, this is nice because it's for me, like I don't need like a banner saying like*

> *you need to do this and everyone else needs to know. . . . I feel like fitness is a personal journey for folks and sometimes people love to share because that motivates them, but I also know for others, it's so personal to them that maybe they don't want to share. So this, I feel like it's a nice way to have like their own thing.*

P5 enjoyed how the artifact could keep her personal fitness goals personal, yet still be effective in reinforcing her adherence. As shown in these examples, the S-CI format of the artifacts is flexible to support both those wanting to actively share their health goals, due to shared notifications, as well as those keeping their health goals personal, due to their abstract nature.

5.3.4 Reinforcing Locations

Location, by itself, can provide a reminder to people about their health goals. For instance, P1 explained how entering her kitchen was all that was needed to prompt herself on her hydration goal: *"I basically have [to] tell myself to drink water because I'm doing so much things at once, and I don't carry around my water bottle, so, whenever I'm downstairs in the kitchen, I just kinda remind myself: drink water."* As the artifacts were physical items unencumbered by the confines of a screen, they innately have the ability to be placed where they can accentuate these cases of "locations as a reminder" when standard screen-based notifications would be restricted to the main personal computer.

A natural pairing is to place the artifacts in areas where the health-related activity is actually done, e.g., inside the home gym. For instance, P1 imagined the owner of a home gym using the artifacts to measure their activity: *"if you have like a gym, and you're trying to use it for like exercise, how long you should exercise."*

Because food routines are commonly paired with health-related activities (e.g., med-

ication, diet maintenance), the dining table was noted as a location where these artifacts would enhance health goal adherence.

> *P4: Like stick on my table to kind of remind me when I should take pills?*
>
> *P7: I mean, with the right sensors, fast forward 20, 50 years, I can imagine getting up for breakfast to go to the table and noticing from the state of the plant on the table that I probably ought to have some citrus fruit or something.*

Participants also considered placing the artifacts in areas where one was known to lapse from their health goals. P8 chose his desk as a suitable location, as *"because I'll be sitting at my desk and that's when I miss my stand up goals."*

P7 imagined the disruption of binge-watching by the use of an artifact next to the television itself:

> *And you know, if you want to be reminded, for example, not to watch TV for too long without getting up and moving around—which is not a problem for me, it just came to mind—you might put something like this up next to the television, and you know, you zone out and you're watching show after show. It just starts waving more and more. Eventually you're gonna get up and do something.*

Instead of a system prompting users towards an action, P7 conceptualizes the placement of the artifact to disrupt the ability to continue with a specific activity. Here, we deal with the bingeable show: a format designed specifically to maintain your attention, with no regard to the health of its user. Using a system that can combat this via its own attention-seeking disruption may be a natural and effective pairing, and the freedom of a S-CI allows users to locate the system in the most effective area spot.

Chapter 6: Discussion and Future Work

6.1 Notification

6.1.1 Limitations and Future Work in Ambruptive Technology

This research aimed to explore the initial reactions of users to ambruptive technology in the context of notification for health-related activities. This was an initial look with a limited set of participants who were already familiar with using systems to notify them regarding their health-related goals. Future research could broaden the participant pool and look into if the scenarios identified as being worthy of an interruption also apply to other health goals or people with no experience in health-goal notification. It can be assumed that many in the world's population do not use systems for their health-goals notifications or may even have health goals at all. Viewing how users who are new to health-goal notification or tracking and investigating their reactions to ambruptive technology will help the community understand how prior experience in such systems affects one's reaction.

Additionally, the participants in this study did not have disabilities, severe illnesses, or age-related disorders, but interviewing those populations or possibly their caretakers would be worthwhile to learn how ambruptive technology could work in their situations. Would users have different positions on when notification escalation is warranted if they had other disabilities or illnesses? For caretakers, when health-related notifications are not for you, but for someone in your care, how would that change how notification escalation is re-

ceived? Ambruptive technology could reduce the mental overload of monitoring a patient by the initial use of ambient notification, while providing a safety measure in the notification escalation ability if an ongoing situation reaches a critical state, so these situations are well worth the effort.

Another extension of this research could be to continue with an in situ study, observing how participants act when using ambruptive technology in their daily life. Gathering quantitative data about the use of ambruptive technology could show if users' expectations of this new technology actually matches their actual usage and results. A prolonged in situ study could give insight into how users adapt to the technology over time, and how this alters their health goal success.

As a piece of exploratory work investigating several emerging technologies, practicality forced some aspects in the design of this study to be fixed, such as the specific shape change types used by the artifacts. However, ambruptive technology is a much broader area than what these artifacts cover. Further work could also look into decoupling or remixing the various design elements and technological areas in these artifacts, and investigating any resultant changes in user reaction. For example, if the S-CI aspect of an artifact was removed, how would users react to a screen-based ambruptive system with plant-like design? Or, how much would abstract sculptural design rather than plants change user reactions?

While perhaps any actions people perform today could have some effect on mental state, thus placing the majority of activities under the context of health, it would be worthwhile to explore the idea of ambruptive technology in other avenues. Although AIS are not a common sight in most environments, future research could analyze when do users benefit and accept the escalation of an ambient notification to a disruptive state for other purposes? Would similar themes around what makes acceptable disruption be found in other contexts, or, for example, does "overcoming inertia" only apply in a health context and not in a business productivity situation?

6.1.2 Feedback context

Circumstantial notification was a topic broadly discussed by participants, where systems would analyze various types of data to determine the best times to provide an escalated notification. Although the community is making great progress in areas like just-in-time adaptive interventions (JITAIs) [21], improving both on input devices and the algorithms to decipher them will be a great aid in allowing systems to identify these disruption-worthy events.

One example that developed from a participant's comment was giving notification information only when it detected she was already looking at it. Exploring systems that can slipstream information within a period of self-induced distraction may be an interesting area of future research. Although a few JITAIs used users' data to infer present condition, no known projects in this area have performed this at a needed level of granularity for microbreak detection, using sub-second precision. However, systems exist which identify when someone has broken attention using gaze recognition, altering content based on that state [38], so similar technology could be used to determine real-time attention status suitable for escalated notification.

6.2 Abstract Interpretation

6.2.1 Roots of Negativity

One interesting finding was the strong negative reactions to various motions and poses in my artifacts. This ranged from the sadness felt upon seeing the droop-artifact in the downward position, to the unsettled feelings when viewing movements that caused **representational dissonance**.

These negative reactions show how designers must consider more than mere inter-

pretability in notification systems. Although the poses of the droop-artifact could successfully be interpreted by participants as representations of their state, the emotions and feelings that resulted from this interpretation caused them to reject the use of the system. This reflects how users avoided Fish'n'Steps if their activity led to a sad fish display [31]. While this study uncovered that some of these feelings stem from the caretaking relationship between humans and plants and possibly would not be found in a non-living representation, future work could look into when an object crosses the boundary of "things that are cared for," where changing its look results in empathetic reactions from a user, versus an independent object that does not rouse any empathy. Finding out more in this area could reduce the cases where participants discontinue use of systems because of the adverse emotions that originate from their design.

Furthermore, although others have looked into creepiness and HCI, especially in the case of humanoid robots and the infamous uncanny valley[34], to my knowledge this is the first work that found uncanny effects in a non-zoological representing entity. Future work could explore the precise factors of these artifacts that caused this discomfort, as this study was not focused on exploring the root causes of these emotions or measuring the effects of parameter changes. Nonetheless, using plant-like artifacts to explore uncanny reactions may be useful in future experiments where removing the zoomorphological factors could help isolate such factors. Related, could research continue with the distancing away from humanoid representations and find objects that represent non-lifeforms that also invoke uncanny reactions?

It is unknown how the reactions I found relate to those stemming from the uncanny valley theory. As the uncanny valley explores the axis of realism, it would be interesting to see if adjusting the realism of my artifacts affected the uncanny reactions. I designed the artifacts with realism in mind, but would the presentation of a more realistic, less realistic, or even cartoonish plant change users' reactions? Due to the COVID-19 pandemic, all in-

terviews were given virtually, and the artifacts were presented via 2d video. As I personally felt the *panting* movement was odd when viewing it in real life, I do not feel that video portrayal changed much in the reaction of the participants, but it would be a valid test to eliminate anything in the presentation chain having an effect to user response.

Additionally, not all users found the same revulsion towards the *panting* movement, and few even reacted favorably towards it. Another avenue of exploration would be into which prior experiences cause some users to react positively to artifacts that normally invoke feelings of the uncanny to others. Similar to the change-blindness that participants predicted might occur from repeated exposure of the same motion, could increased exposure of something change the response of users who initially feel some revulsion to a movement? Extending on this idea, would it be more worthwhile to learn how to nullify the the uncanny valley reaction rather than traverse the steep levels of achieving true realism in robotics?

6.2.2 Effective, but Healthy?

In investigating three avenues of notification: speed and distance parameters, emotion portrayal, and salience, I found that all three had at least one movement type that was described as effective in prompting the user to act. However, as the previous section discusses, some prompts were coupled with discomfort. As designers, if we solely look at the analytic results, we might miss these negative emotions that arise from the product due to the user still reaching the end result we aimed for. But is this **healthy** for the user? Are guilt trips, uncanny unease, and morose reactions worth it if the user still acts towards their health goal, or could this be more damaging to them mentally, nullifying any gains from their activity? Especially in the health-oriented sector, I feel this question of what additional mental effects could emerge must continually be reviewed when investigating new tech-

nologies and techniques, such as Owens & Cribb's investigation into personal autonomy with wearable technologies [37].

Long term negative effects of technological aids must also continue to be studied, if we are concerned with the complete health of users. For instance, we know that literal crutches aid in the prevention of further damage to a user's leg, but over time may cause shoulder injuries with prolonged use [35]. What are the long-term effects of using technological crutches to aid users in remembering their health activities? For instance, P9 mentioned wanting the ability to turn off the artifact because she did not want to become reliant upon it. Is reliance on technology a gain or loss in the overall health of a user? Again, future work should look into this area to ensure we are net positive in the health of our users.

6.2.3 Reducing Notification Burden

In some cases, the artifacts' abstract movements were fairly disconnected from each other thematically, e.g., the $hiccup$ movement has no direct connection to the $lift$ movement; one does not necessarily follow another. Some participants cautioned on the burden of understanding which movement meant which message, which is especially important with ambruptive technology, with its multiple notification levels. This study did not investigate deeply in this matter, so future work could investigate further the relationship between various movements to learn how users associate or compare multiple types with each other.

In another facet regarding burden, P8's shared how various Apple Watch displays created burdens for him in calculating the viability of his stand goal from the data captured on his state. Both the rings and dots displays assigned burden on the user when "read"—some more than others—but this burden could perhaps be reduced further by designing with the goal in consideration, rather than simply a record of the captured data. Further research

could look into other combinations of state representation and their attached goals to see if this problem occurs in other situations, and investigate the viability of new display motifs which target the aid of goal completion.

However, one interesting observation was the deferred notification burden in cases of **meta-notification**. Users seemed willing to perform a lengthier action of checking another system for notifications if a preceding notification reduced the overall burden by only notifying them in specific situations. Burden thus exists with different levels of acceptability, and future work could investigate which situations cause users to consent to additional burdens and why, or perhaps which techniques could be used to reduce the perceived cost of necessary burdens.

6.3 Designing for Shape-Change

6.3.1 Designing for New Locations

Although the interviews revealed interesting use cases for S-CIs in location enhancing notification, it must be noted that the current design of the artifacts would not work well for some situations. For instance, although the dining table is a spot where many health-related activities occur, it is not a location conducive to a device which requires wires of any sort—cable management is not a consideration for most dining table designers. Designers of S-CIs that plan to be used in new locations could benefit from additional engineering to ensure that the devices elegantly fit within one's space, whether this means having a completely cable-free device using wireless power transmission, or perhaps introducing electronic furniture standards which provide inductive power on their surfaces.

6.3.2 Materials and Motion

The interviews also revealed interesting reactions on the material and design of the S-CI artifacts. I chose to use thin plant stems on my artifacts both aesthetically, to match the look of real plants, and practically, to limit the torque needed in the motors I had used. However, this led to a number of problems: unwanted movement when the flexible stems wobbled after the direct actuation stopped; users questioning if any movement was intended because it looked as if air currents in the environment could move it; and users apprehensive that continued motion would break the artifact itself.

Future designers should consider designing S-CIs with unambiguous motion as a goal; designing not only how an interface moves, but also how it stops moving. The users should be certain that any shape-change was intended by the systems. Solving this problem could be an exploration of different materials, changing the mechanism away from one that relies on material plasticity, or just having a sturdier visual look to the item itself to give the proper expectation.

Several participants expressed concern that their use of the artifacts would be damaging to the item itself, due to how they interpreted the form and materiality of the stems. Exploring how fragility and damage prevention discourages usage might also be an interesting area to explore in HCI. For instance, designers add weight to physical products to make them seem more durable—is there an equivalent in UI, and would that encourage use of a widget? In a broader take, could a pristine empty state UI actually be repelling users from performing actions because it could "damage" the balance of the screen once data is represented?

6.3.3 Aesthetic Tastes

Participants noted the need for the artifacts to suit the environment it would be placed in. However, S-CIs obviously cannot change their look as effortlessly as something in a digital format. Future designers may want to look into how some screen-based applications prepare for different look-and-feels by structuring a "skinnable" interface and convert that into the physical format. As an example, prior iterations of my artifacts included ways to reuse the same mechanisms with different plant styles by being designed with slots which could accept different leaf types. Designing for aesthetic modularity and making the styling of a S-CI more easily updated could result in better adoption by users.

Aesthetics were also considered a secondary use of the artifacts that some imagined would keep these systems in their environment, even if not using them for their notification ability, as its decorative nature provided enough utility. This differs from systems that do not offer any secondary usage and may be "put away" when use is discontinued. Beautifying the environment allows these systems to inhabit valuable physical space that keeps these objects in sight by their owners, which has several advantages. Remaining conspicuous alone could act as a passive reminder of one's health goal, even if active notification is not occurring, as a user could be reminded of the original reason of the object whenever it was seen. It also continues to occupy a spot in users' environments that makes re-continuation of the system convenient for the user. Thus, the aesthetic utility of the object can act as a buffer against temporary disinterest, and thus extend the overall lifetime of the system. This concept of **disinterest buffering** may be another area that could be investigated further both in the context of health and outside of it, and may be a useful design strategy when dealing with activities that are known to have cycles of use and disuse.

Chapter 7: Conclusion

In this thesis, I aimed to explore the concept of ambruptive technology, or systems that can escalate from ambient to disruptive notifications. To accomplish this, I created a set of shape-changing interface artifacts that took on the appearance of plants in order to blend with users' environments, aiding with their initial ambient nature. These artifacts were mainly 3D printed mechanisms coupled with motors driven by a microcontroller board, and designed to explore three themes in notification strategies, **speed and distance parameters**, **emotion portrayal**, and **saliency**. The first, shake-artifact had leaves that shook at differing intensities, *gentle shake* and *heavy shake*. The second, droop-artifact had leaves that could arise and droop at different speeds and timings, along with multiple scripted movements, *heartbeat*, *hiccup*, *lift*, and *panting*.

I used a Research through Design methodology to present these artifacts to ten participants individually in an hour-long interview, and gathered their reactions and thoughts on the use of ambruptive technology in use for notification towards their health-related activity goals. With these interviews, I hoped to answer three research questions:

(RQ1) When do people accept escalated levels of disruption for health notifications? There were multiple scenarios where participants found notification escalation acceptable. The importance of one's health goal influenced whether the participants would accept such escalation, for instance activities meant to prevent acute injury or those that had a time criticality. Health activities that were deemed less important were not considered suitable for notification escalation and would be an annoyance to the users. But if

an activity was one with low-commitment, such as a goal to stand up briefly every hour, this succinct interruption reduced the disruptive nature and was acceptable. Several participants wished for notification to be circumstantial and contextual to their ongoing life. This could be as broad as considering one's overall activity importance for the day, it could be as qualitative as identifying when the user's body was best prepared for exercise, or it could be as precise as identifying when a user was taking a natural break from their work and taking advantage of this lull. Finally, in scenarios where users suspected inertia could overtake the ability to accomplish their goals, such as an unlimited snooze, participants were comfortable with increasingly disruptive notification to combat the situation.

(RQ2) How could varying levels of health notifications be portrayed in shape-changing interfaces? The artifacts were introduced to the participants without interpretation of their motions, allowing each interviewee to construe the meanings portrayed by each motion. Generally, larger motions were seen as more disruptive than smaller motions, and increasing motion speed was interpreted by most as a more disruptive notification. However, generally participants indicated a desire to have configuration control of the artifacts, for reasons such as goals changing over time, to overcome ignoring the motion if it loses novelty, or simply to tune the notification to fit their needs.

Using the pose of the artifact to indicate a users' state was too imprecise for certain cases, such as meeting Apple's stand goal of moving during twelve different hours in the day—being too difficult to judge where exactly one was towards this goal. This point raises the consideration of burden for users when designing notification, displaying not simply what data was recorded but instead portraying what is needed for success towards a goal.

The plant-like design of the artifacts allowed participants to use their prior knowledge of horticulture to interpret meaning from the abstract movements. But this choice of plant-like design also resulted in participants preferring movements they felt were naturalistic.

When the artifacts moved in a way that did not match how some participants expected plants to move, such as the *panting* motion, it led to feelings of uncanniness, seemingly a result of of **representational dissonance**, or the discomfort from the inconsistency in how a user expects an object to act based on its appearance, compared to what they are actually perceiving. This is perhaps the first known case of uncanniness from a non-zoological object, and it raises ideas on how to investigate the uncanny valley. However, some participants did not have this same uncanny reaction, which could be studied further to see why this was the case, and if this could be used to reduce the uncanny valley effect without having to further the degree of human likeness in robots.

Another negative reaction stemmed again from horticulture knowledge: in the motions meant to elicit emotion, such as the downward position of the droop-artifact, the pose made the plant look dead, which was so depressing to participants that several indicated they would not likely use it at all. Some participants felt these feelings were due to the dead-looking pose reminding them of their own lack of success in plant caretaking, and others felt that a dying plant portrayed a situation past a recovery point, and thus this halted any motivation for working towards their goal. These negative reactions show how designers must consider more than mere interpretability in notification systems. Although participants were able to interpret these poses, the emotions and feelings that resulted from this interpretation caused them to dismiss the use of the system.

(RQ3) How do people envision using shape-changing interfaces within their environments? Due to the standalone nature of the artifacts—unconnected from a typical computer—these systems provide different interaction opportunities with their users. However, before these interactions can occur, users must want the device in their environment. Participants mentioned their desire for the artifacts to have multiple purposes, whether as notification for several reminders, or simply to be both functional and decorative. These multiple utilities could be used to buffer the natural cycle of disinterest in devices, when

users keep the device around due to their secondary use as disinterest in the first use occurs, and vice versa. During the interviews, the plant-like looks of the artifacts were admired, leading to discussions on how S-CIs should fit into their environments aesthetically. Since aesthetic tastes and environments differ greatly, designers may wish to incorporate ways to interchange aesthetic styles while keeping the same shape-change mechanism, similar to how screen-based applications allow for "skins" to change their look. However, choosing a notification indicator that does not blend with the environment is also needed, as participants mentioned that the $gentle\ shake$ motion could be misconstrued as something in the environment affecting the plant's shape rather than an intended motion. Because these devices are often out in the open, the notifications they emit are essentially broadcast to everyone in the area. Participants gave varied reactions, whether nonchalance over others viewing and interpreting their notification, to embarrassment over others seeing a notification, to the degree of it being an impetus to perform one's action before the notification. However, the abstract nature of S-CIs allows for some concealment over the actual message, which helps allay its public nature. Finally, the ability for S-CIs to be placed in non-standard areas allows for the reinforcement of reminders connected to a location, such as continuing to perform a healthy action at the dinner table or preventing binge watching in the media room.

Appendix A: Recruitment Copy

Subject line: **Invitation to Participate in a Research Study on Health-related Goal Notification Systems**

Have you ever used a system to remind yourself to work on a health-related goal? Some examples of this could be using a Fitbit to track your steps, writing post-it notes to remind yourself to drink water, or organizing a pillbox to keep track of your medication doses. If so, we would like to invite you to participate in a research study at the University of Maryland, to talk about your experiences and to share your opinions. The purpose of our study is to understand how different people use systems to notify themselves about their health-related goals, how effective the systems work during a busy day, and to get your feedback on a new type of technology that aims to help in notifying you towards your goal.

The study includes an online screening questionnaire and an interview held over Zoom. During the interview, we will ask you about your daily schedule, how you currently schedule healthy activities, and your feedback on our design prototypes. The duration of the interview may last up to an hour, and the sessions will be recorded. To participate in the study, you must meet all the following criteria:

- be 18 years old or older
- have normal or corrected-to-normal vision
- have equipment capable of participating in a Zoom video chat (computer, internet access, webcam, microphone, Zoom software), and willing to participate with video

and audio

- work at least three days a week at a desk for 6+ hours per day
- have a health-related goal, which requires acting on multiple times per day (e.g., taking medication regularly, step count goal, hydration goal, taking regular breaks during prolonged sitting, eating meals on a regular schedule)
- have prior experience with a system to aid in adherence to healthy activity goal (e.g., alarms and reminders, wearable devices like Fitbit, health apps, smart bottles, post-it notes, journals and calendars, pillboxes)

As a thank you for completing the interview, you will receive a $20 Amazon gift card.

If you are interested, please fill out a screening questionnaire at the following link: [qualtrics link]

If you have any questions or simply want to learn more, please contact Jarrett Lee at jgwl@umd.edu.

Appendix B: Screening Questionnaire

1. Do you have normal or corrected-to-normal vision?

    - Yes
    - No (reject)

2. What is your age range?

    - 0-12 (reject)
    - 13-17 (reject)
    - 18-24
    - 25-40
    - 41-64
    - 65-90
    - 91+

3. How many hours per day do you work at a desk during your normal workweek?

    - 0 (reject)
    - 1 (reject)
    - 2 (reject)
    - 3 (reject)
    - 4 (reject)
    - 5 (reject)
    - 6
    - 7
    - 8
    - 9
    - 10 and up

4. How many days per week is your normal workweek? [numeric]

    - 1 (reject)
    - 2 (reject)
    - 3
    - 4
    - 5
    - 6
    - 7

5. Currently, do you: (check all that apply)

    - Work at home
    - Commute to office

6. Do you have the following equipment available to use? (check all that apply)

    - Computer (Desktop / Notebook / Laptop)
    - Webcam
    - Microphone
    - High-speed internet access
    - Zoom software

    (less than 5 selected: reject)

7. We are seeking individuals who try to maintain a health-related goal. This could be any activity related to your health, such as taking your medication regularly, reaching a number of steps per day, taking regular breaks during work, or drinking 8 ounces of water per day. Please fill up to your top three health goals and how long you've had each goal.

	Name of health-related goal	How long have you had this goal?
Most important		
2nd most important		
3rd most important		

For questions 8-10, please answer these on the health-related goal you listed as most important in question 7.

8. How many times per day do you usually plan on performing an action for your most important health-related goal?

    - Once per day (reject)
    - Twice per day
    - 3+ times per day

9. Do you use a system to keep track of when to work towards your goal? Please briefly describe all systems you have tried. (examples: alarms and reminders, wearable devices like Fitbit, health apps, smart bottles, post-it notes, journals and calendars, pillboxes)

10. How successful would you rate yourself in in keeping your most important health-related goal?

    - Unsuccessful
    - Somewhat unsuccessful
    - Okay / Neutral
    - Somewhat successful
    - Very successful

Appendix C: Consent Form

Project Title	Examining Ambient to Disruptive Personal Health Notifications via Shape-changing Interfaces
Purpose of the Study	This research is being conducted by Jarrett Lee at the University of Maryland, College Park. We are inviting you to participate in this research project because you expressed your interest in our study about personal health notifications. The purpose of this research project is to examine new ways of notifying individuals to act on their health-related goals (such as: medication dosing times, activity reminders, drinking water) throughout the day.
Procedures	You will be interviewed over video chat (Zoom) where you will be asked questions around your daily schedule, how you currently schedule healthy activities, and your feedback on our design prototypes. The duration of the interview may last up to an hour. The sessions will be recorded.
Potential Risks and Discomforts	There is no more than minimal risk associated with participating in this study.
Potential Benefits	There are no direct benefits from participating in this research. However, a possible benefit could be understanding which factors and strategies may help you maintain a schedule of healthy behaviors throughout your day.
Confidentiality	Your confidentiality will be protected in all circumstances. Only researchers on this project will have access to the data, and the data will be de-identified: personal identifiers will be replaced with a non-identifiable participant number. Your participant number will be linked to your identity via an identification key that will be stored separately from data. To minimize any potential loss of confidentiality, we will store data in password-protected computers/servers and in UMD Box, an encrypted and secured cloud storage service.

Medical Treatment	The University of Maryland does not provide any medical, hospitalization or other insurance for participants in this research study, nor will the University of Maryland provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.
Compensation	By completing the session, you will be compensated with a $20 Amazon gift card. Note: if you no longer meet eligibility requirements, or you are otherwise unable or unwilling to participate in the study sessions, or your data is unusable for any reason, you may be dismissed from the study.
Right to Withdraw and Questions	Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. If you are an employee or student at UMD, your employability, grades, or academic standing will not be positively or negatively affected by your participation or non-participation in this study. If you decide to stop taking part in the study, if you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the investigator: Jarrett Lee 2117F Hornbake Building, South Wing, University of Maryland, College Park, MD 20742 jgwl@umd.edu
Participant Rights	If you have questions about your rights as a research participant or wish to report a research-related injury, please contact: University of Maryland College Park Institutional Review Board Office 1204 Marie Mount Hall College Park, Maryland, 20742 E-mail: irb@umd.edu Telephone: 301-405-0678 This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.

Statement of Consent	Your signature indicates that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction and you voluntarily agree to participate in this research study. You will receive a copy of this signed consent form. If you agree to participate, please sign your name below.
	_____

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