Designing for Long-Term Human-Robot Interaction and Application to Weight Loss

by

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S.M., Massachusetts Institute of Technology (2003)
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Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
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Abstract

Human-robot interaction is now well enough understood to allow us to build useful systems that can function outside of the laboratory. This thesis defines sociable robot system in the context of long-term interaction, proposes guidelines for creating and evaluating such systems, and describes the implementation of a robot that has been designed to help individuals effect behavior change while dieting. The implemented system is a robotic weight loss coach, which is compared to a standalone computer and to a traditional paper log in a controlled study. A current challenge in weight loss is in getting individuals to keep off weight that is lost. The results of our study show that participants track their calorie consumption and exercise for nearly twice as long when using the robot than with the other methods and develop a closer relationship with the robot. Both of these are indicators of longer-term success at weight loss and maintenance.

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The Media Lab here at MIT has been a truly great community to be a part of. It has been very exciting for me to be able to be a part of this renowned institution for several years. I have made many friends among the faculty, administration, and staff. Among those who have been a great help during my time here are John Maeda, Pattie Maes, Frank Moss, Chris Csikszentmihalyi, Polly Guggenheim, Amna Carreiro, Lisa Lieberson, Aileen Kawabe, Sarah Page, Ken Goldsmith, Stacie Slotnick, Paula Aguilera, Walter Bender, Kevin Davis, Cornelle King, John DiFrancesco, Will Glesnes, Tom Lutz, Hugh Herr, Henry Holtzman, Kent Larson, Nicholas Negroponte, Gigi Shafer, Brian Wallenmeyer, and Hiroshi Ishii. I am certainly omitting others, as it can be difficult to complete a list like this after six and a half years in the lab.

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Part I

Theory and Background

Chapter 1

Introduction

This thesis describes the design, development, and study of sociable robot systems intended for long-term use. The field of human-robot interaction (HRI) has recently reached the point where such a system can be feasibly built and studied.

1.1 Why long-term interaction?

Humans have been interacting with robots and other automata for many years. In the past decade, the methodical, scientific study of this interplay between man and machine has matured into the field of human-robot interaction. Much of the work thus far has looked at aspects of development and learning (e.g. Breazeal's Ph.D. thesis and subsequent work [19]); human perceptions of various portions of a robot's appearance, personality, and behaviors (work in Dautenhahn's lab [121] or Carnegie Mellon University's HCII group [40, 67, 68], for example); or short-term interactions in laboratory-based settings (such as previous work carried out by myself and colleagues using a variety of robots [59, 62, 98, 105] and others at CMU on robots following people [39], the University of Washington on young children interacting with robots[58], and the University of Hertfordshire in the UK on how comfortable people may be near a robot [70]).

The vision of the field of HRI, however, has been to create and study robots that exist in our everyday lives. These robots are envisioned to be the realization of the science-fiction fantasies from Carl Căpek's original robot workers in *Rossum's Universal Robots* (for which he coined the word "robot") [27] through Rosie the Robot [93], the domestic robotic helper of the 1960s *The Jetsons* television cartoon series, to the current depictions of robots in movies like *Bicentennial Man* or *AI: Artificial Intelligence*. The objective shared by many currently practicing researchers is to build the robots that will enter our everyday lives and assist us in anything from the mundane tasks of cooking and cleaning to the more intellectual and social endeavors of entertainment and caregiving. The enormous challenges presented in surmounting the scientific, engineering, and interaction difficulties has kept the field from creating systems capable of autonomous, sustained interaction in the real world, leaving us to build systems and study the resulting interactions in the microcosm of the laboratory.

It is rapidly becoming possible to build a wider variety of robots that could enter our everyday lives. We see simple examples on the shelves of our local discount store. The two most notable ones are iRobot's Roomba vacuum cleaner robot and the RoboSapien from WowWee. These two robots showcase two ways to bring robots into our homes without overcoming this full set of challenges. The first, Roomba, is a pre-programmed, single-purpose robot. To be successfully deployed, it need only do one task and have extremely limited interaction with its human owner, namely being turned on and off. The RoboSapien, on the other hand, has a more complex interaction. So complex that it comes with a twenty-one button remote control where most buttons have 2 or more functions. While one can interact with it, the social aspects of interaction are notably lacking. With existing home robots at the extremes of complexity, we have much work to do to reach a useful middle ground.

As the software, hardware, and interaction capabilities of robots progress, we will begin to realize the science fiction visions of useful robots in our everyday lives. One of the challenges unique to this ambition is understanding the relationship between people and these robots. The nature of this relationship is drastically different from that between a person and their computer or their household appliances – once this entity starts looking at them and responding in social ways a person is immediately drawn into the interaction in ways distinct from what is seen when people are interacting with a computer. When comparing this to human-computer interaction, a well-studied field from which we can draw data and experiences, robots have the potential to provide a more powerful experience – either much better or much worse. It us up to us, as robot designers and HRI researchers, to understand how to make this experience a positive, engaging, and useful one.

Most people have experienced frustration with their computer. What happens when this computer becomes something that is experienced as a social, lifelike entity that shares their physical space? If we're not careful, it could become an ongoing annoyance that we find difficult to escape. If we better understand how to create these long-term relationships, however, they can be useful and even enjoyable tools in our everyday lives. This quality of relationship is important beyond simply the satisfaction of the user. It is well-known that for some types of tasks, the relationship quality is correlated with outcome. Two examples are learning (see Brophy's book for a discussion of earlier literature on the topic of learning and relationships [20]) and healthcare (see Kearley, et al. [55] and Stewart, et al. [103], for treatments of the benefits of having a positive relationship with a physician as well as Beckman, et al. [9] for some analysis of the reasons for negative outcomes in physician-patient relationships).

In order to grasp the concepts of successful HRI, it is necessary to create and study interactive robotic systems in our everyday environments. A great deal of knowledge about human-robot interaction has been gleaned from laboratory-based experiments, but it is difficult to understand how these interactions evolve into a relationship from these short experiments. If we want to understand how a sociable robot will impact an individual's life over time, we must build systems that people can interact with on a daily basis and develop techniques for measuring those interactions over a longer duration than the HRI studies that have been conducted in the past.

1.2 The problem domain: weight loss

My approach in finding a suitable application for a sociable robot system that will allow for the study of long-term interaction has been to identify a real-world need where the creation of such a system might make a practical difference. Overweight and obesity are currently significant problems in the United States. They are increasing and estimates of the cost to the US economy for obesity-related health problems range from US 75 to 125 billion dollars per year as of 2004.

In the United States, the National Center for Health Statistics at the Centers for Disease Control and Prevention report that 65% of the adult population is overweight or obese (31% obese and 34% overweight, calculated using the body mass index, or BMI) [37]. According to the World Health Organization, this is an international problem, with over 1 billion of the world's adult population overweight, with 300 million of these considered obese [130], and they state that "almost all countries (high-income and low-income alike) are experiencing an obesity epidemic" [131]. It is also known that of those who do lose weight, 90 to 95% are unable to keep the weight off long-term [42]. The length of time looked at in studies of weight regain varies, but is commonly between six months and one year.

Obesity is a problem that is being addressed in many ways. Most current work relates to new pharmaceuticals, diets, bariatric surgery, or other treatment regimes. Some of the most popular ways to attempt to lose weight include fad diets like Atkins or South Beach as well as joining programs such as Weight Watchers™or Jenny Craig (see [111] for an overview of commercial and self-help programs and [129] for the description of a clinical trial conducted with one commercial program). Some clinical research in the last decade has looked at new interventions that are focused on creating behavior change and leading to long-term weight loss (for example, see Tate, et al. [107] or van Gils, et al. [113] as examples of studies conducted for new interventions and Anderson, et al. [6] for a meta-analysis of the long-term success of several weight loss programs).

The design and study of novel and potentially more successful means to effect behavior change is a promising direction in recent bariatrics work. Some of these include internet-based interventions using either text- or character-based interfaces. With earlier results showing how a robot can be seen as more credible and informative than a character on the screen, there is reason to believe that a robot may be a more effective mechanism for conveying the behavior change message. Results showing that a robot can be more engaging than an animated character lends itself to the possibility of creating a set of interactions, or a relationship, that is longer-lasting than previous techniques and therefore also more likely to have the opportunity to create long-term behavior change.

1.3 Sociable robots

A sociable robot is one that is "capable of engaging humans in natural social exchanges" ([19], page 40), according to Breazeal's 2000 thesis, which was one of the early uses of the term. There is a psychological grounding for this concept described in the introductory chapter of her thesis that relates to Reeves and Nass' 1996 popular book on social aspects of human-computer interaction [94]. They posit that as a result of evolutionary behaviors the more social cues a piece of technology exhibits, the more human-like people will find it. While their work dealt mainly with traditional computer interfaces, Breazeal's work extends this theory to humanoid robots and states that using social cues in interactions between people and robots offers an attractive alternative to traditional methods of communicating with robots. Further explanation of sociable robots are described in Section 2.1 and of relevant previous work in Chapter 3.

In the next chapter, I discuss the extension of Breazeal's sociable robots to sociable robot *systems*, for which the definition encompasses not only the robots, but also the other people, devices, and social conventions involved in the set of interactions. The design principles described in a later chapter have been devised and discovered in the process of building one such sociable robot system.

1.4 The robots: Autom

In setting out to study long-term HRI, the initial intent was to use an existing robotic platform and design a study or series of studies around the chosen robots. As the available robots were explored, it was discovered that nearly every existing robot fell into one of two categories. The first are the robots built by researchers in academic or corporate laboratories that include the necessary capabilities for interacting with humans, processing power for handling interactions, and a platform for programming the kinds of interactions desired. The major limitation of this group of robots is that most of them have been built by hand and there is only one or maybe a few in existence. Robots like our group's Leonardo [17, 18], Breazeal's Kismet [15], Ishiguro's humanoid creations [49, 54], or Sony's QRIO [106, 125] all fall into this category. Because of this limitation and the fragile nature of most of these robots, it would be very difficult and time-consuming to create an ongoing set of interactions that could take place in the daily lives of even a small set of people.

The other group of robots are those that are mass-produced. The big advantage of this group is that there are many robots available; they can be purchased off the shelf, often at reasonable prices; and they are reasonably durable for use in everyday interactions. The three main examples of robots in this category are Sony's now-discontinued AIBO robot dog [124], WowWee's Robosapien remote controlled toy [75], and iRobot's Roomba vacuum cleaner [48]. The challenge with using any of these robots is the limitations on their programmability. The Sony AIBO is the most flexible of the three, but after several months of exploration, we determined that creating a great enough variety of interactions for an extended study of HRI would be difficult at best.

As a result of this analysis of existing robots, I decided that it would be necessary to create a new robot that would be capable of serving as the centerpiece of a long-term HRI study. This new robot would need to be capable of some understanding of the world around it, be programmable so that interactions could vary over the duration of the study period, and most importantly of exhibiting interactive behavior to those using it. An extended discussion of the necessary capabilities appears in Chapter 4.

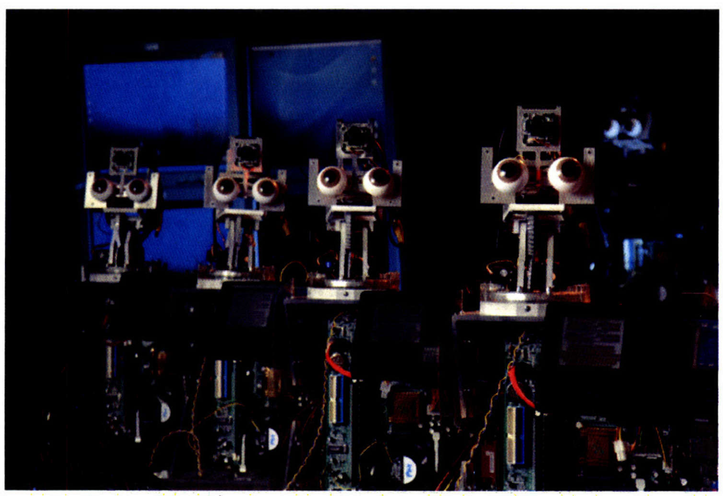

Figure 1-1: The set of robots built for the long-term HRI study.

There are several key features that are desirable for robots to be used in a long-term study of HRI. The ability to look at the user (or appear to do so) is important for drawing a person into the interaction. A robot in which the software that controls the human interaction is easily modifiable is vital, as many aspects of the interaction will need to be adjusted as user tests are conducted. Some set of features that enable social interaction (e.g. eye contact; look-at behaviors; head, arm, and hand gestures;

speech; and speech recognition) are needed, but the exact set depends on the type of interactions expected. A more complete discussion of design requirements for a robot is found in Chapter 4.

A subset of the seventeen robots that we created are depicted in Figure 1-1. It is a four degree of freedom robot based on easily available PC components, motors, and motor controllers. It has a moving head and eyes, a camera for vision, and a full-color touch screen display for user input. Details of the hardware are given in Chapter 7 and the software is described in Chapter 8. The set of interactions that it can perform with the user are talked about in detail in Chapter 6.

The robot is designed to have a once- or twice-daily interaction with the user with each interaction lasting approximately five minutes. The nature of the interaction is helping an individual track information related to their weight loss program, which is described in Chapter 6. The robot talks to the person and guides them through the interaction, making small talk along the way. The discussion is varied, changing with each interaction based on variables including time of day, estimated state of the relationship between the robot and person, time since last interaction, and data that the user has input in recent days.

1.5 Contributions

There are three main contributions of this thesis. Two are theoretical contributions to the field of human-robot interaction allowing for the design and study of robotics intended for long-term use. The third is the construction of a system based on these principles and the evaluation of the system using the proposed techniques and measures.

- I propose a set of design principles to be used in creating sociable robot systems. These principles depend on aspects of human-robot interaction and ubiquitous computing, take into account the social network of people in a given situation, and consider aspects of the particular domain within which the sociable robot system will be situated. The relational model that has been developed supports long-term interaction with the robot as part of a network of heterogeneous devices and as part of the users social network. (Chapter 12.)

- I have developed a set of techniques and measures for evaluating a sociable robot system in long-term use (periods of at least a few weeks to several months). The evaluation metrics include specific measures for any sociable robot system as well as guidelines for choosing domain-specific metrics appropriate for the particular SRS implementation. (Chapter 13.)

- Finally, I have built a specific system that has allowed for the evaluation of aspects of long-term human-robot interaction in a context appropriate to its use where user benefit can be measured in a concrete way. A six-week controlled study with 45 participants was conducted and results showing that people use a robot for longer than the computer or paper log control groups and develop a closer alliance with the robot are presented herein. (Part II.)

Chapter 2

Sociable Robot Systems

2.1 Definition

Kismet, a personable robot with large eyes and ears developed by Breazeal and colleagues in the late 1990s (seen in Figure 2-1) [19], is often considered the first sociable robot. Breazeal defines a sociable robot as a robot that participates in social interactions with people in order to satisfy some internal goal or motivation. She notes that sociable robots rely on cues garnered from interactions with humans in order to function. Indeed, the videos of people interacting with Kismet for the first time demonstrate that the robot is picking up on some of the verbal and non-verbal cues exhibited in the exchanges and is using these cues to modulate its behavior. What is not evident, however, at this early stage of research is an end goal of these exchanges beyond simply the act of conversational give and take, for Kismet was developed to explore basic questions of human-robot interaction by eliciting and responding to emotional behaviors and not to delve into the longer-term usability or usefulness that such a robot might provide.

The outcomes of the construction of this creature and the variety of interactions that were carried out with it include some of the first integrated theories concerning the appearance, movement, perception, and social feedback of a social robot. It is on top of these theories that we build our current work.

In this thesis, we further the idea of the sociable robot (discussed in Section 1.3) to encompass more than simply the robot and its software. A *sociable robot system* is a set of technological artifacts that can communicate with one another, a robot that engages people in a social manner, the means of interaction, and the network of people involved in the interaction. The design of such a system embeds a sociable robot and other technology into an existing social system. The intent of this type of work is to augment current means of addressing problems rather than replacing them with purely technological systems. These components are summarized in Figure 2-2.

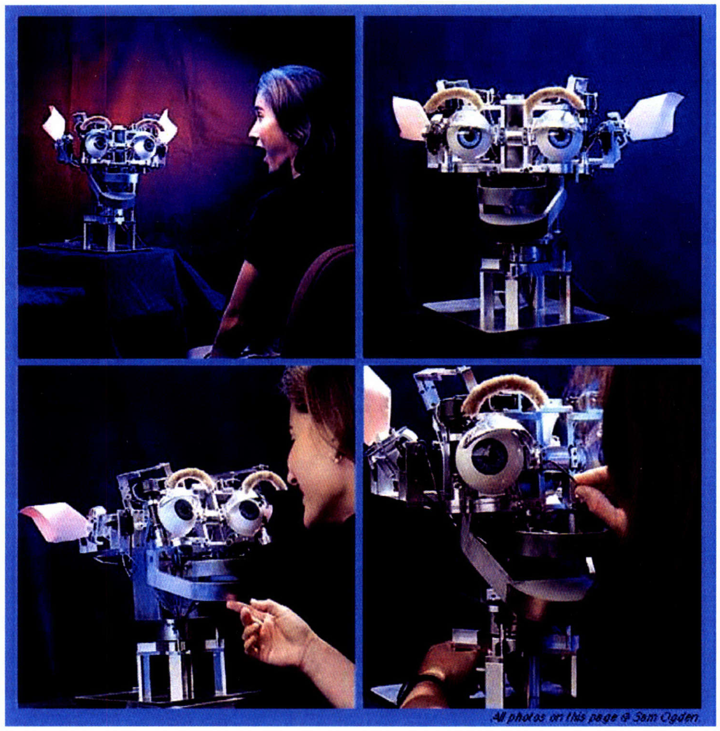

Figure 2-1: Kismet, an early sociable robot.

We posit that these sociable robot systems will use their interactions to fulfill a particular purpose. The purpose varies depending on the system being developed, but each implementation will be designed so that the robot (and the entire system) has a purpose that requires a social level of interaction with the user.

A robot that engages people in a social manner

The central piece of the system is a robot that is capable of integrating all of the other portions of the sociable robot system and is the visible, social face of the system to a user. The robot must be capable of understanding social cues from the world around it using its sensing abilities. In the other direction, it has to be able to convey information to the user, often through multiple modalities such as speech, gesture, or a graphical interface. It must encompass a theory of interaction that takes into account the desired goals that it is meant to achieve with a user as well as the factors that could vary within and between interactions. Finally, it must integrate these pieces to carry out successful, seamless interactions with the user. Details on the design requirements for sociable robot systems and for the system that has been constructed for our long-term test are in Chapter 4.

Components of a Sociable Robot System	
Component	**Influential Disciplines**
Robot	Engineering, HRI
Technological Artifacts	Engineering, Computer Science
Means of Interaction	HRI, UbiComp, Psychology, Affective Computing, HCI
Network of People	Social Psychology, Practice Area

Figure 2-2: The components that make up a sociable robot system and the main disciplines of influence.

Set of technological artifacts

A sociable robot system comprises several pieces of technology that are appropriate to a given application, such as sensors or other devices on the person, in the environment, or on the robot. This is a necessarily vague description, as this set of items will be tailored to each application of a robot. In a health care-related application, they might include sensors for heart rate, blood pressure, or blood sugar level. A home security-based system might network with sensors on all doors and windows in a home, a thermostat control, and kitchen appliances. A drug delivery system in a hospital might have access to drug portions of medical charts, current maps of where each patient's room is, and biometric data for medical staff to confirm requests and deliveries. The set of components used in the weight loss coach sociable robot system is delineated in Section 6.1.

Means of interaction

The most important aspect of developing the sociable robot in this system will be creating the means of interaction. The *means of interaction* encompasses what the robot knows (i.e., the information that it has access to or can gather with its own sensors), how it can process that information to present to the user or affect its interactions with the user, and what strategies it uses to create and maintain a relationship with the user over time. Much of the work from the field of human-robot interaction discussed in the next chapter surrounds these issues and they are perhaps some of the most complicated portions of creating a sociable robot system, as they integrate the psychology of the user, the hardware and software capabilities of the robot, and the goals of the system.

Network of people involved in the interaction

In addition to the technological components of the system, most sociable robot systems will fit into an existing or new ecology of people. These systems should not be developed in isolation from human networks of support for the issues that they are addressing, rather they should be integrated into contemporary organizations. In the context of the weight loss system, I discuss how the system augments current accepted methods of weight loss in Chapter 4. This may be the ideal way to have a robotic system accepted for use: integrate and extend an existing model such that the user can easily comprehend and see the benefits of adopting the system.

2.2 Experimental foundation

The development of a theory of sociable robot systems has grown out of a series of experiments to better understand what happens when people interact with robots. I began my exploration of human-robot interaction with two vaguely-formed ideas. The first came from watching the videos of people interacting with Kismet, most for the first time; from reading Cynthia's thesis and subsequent book; and from numerous discussions with Cynthia about her experiences in building and using Kismet for a variety of interactions and the possibilities for creating and studying new robots. The second idea was that I wanted to take this new technology and the promise swirling around it and create useful, helpful, and interesting robots that would be used over the long term in our everyday lives. I wanted to move from robots being curiosities in labs and museums (a still-recent improvement over existing only in science fiction!) to things that we use in our homes, offices, schools, and other spaces where we will interact with them on a regular basis.

From these early discussions, papers, and videos on Kismet, it was clear that there was something happening in these interactions between people and this robot that could look, babble, and move a little. But the questions for me were *What was happening? Would this happen if it weren't this novel robot? What's different than interacting with a person? Or with a character on a computer screen?* So I set out to design and run experiments to test theories that were being developed in the HRI field and to attempt to create new theories to explain this interaction.

Initial differences between a robot and animated character

The first experiment I designed looked at how the physical presence of a robot, as compared with a similar-looking animated character, might impact the ability of a person to understand what it was trying to communicate through gesture. It also measured how similar to an interaction with a person that subjects found interactions with a robot or an animated character to be. The setup (depicted in Figure 2-3) had the subject interacting with all three characters, one at a time. Each would give a set of requests spoken in a pre-recorded human voice that asked the experiment participant to manipulate a set of blocks that were on the table between the participant and the character (a view of the setup from the perspective of the participant is shown in Figure 2-4).

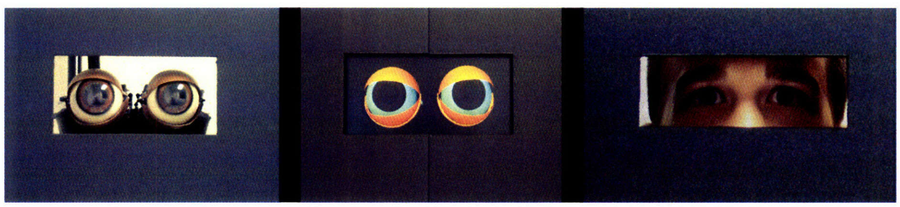

Figure 2-3: Three characters used in first HRI experiment: physical robot, computer-animated, and live human.

There were two types of measures in the experiment: physical and behavioral responses that were measured during each interaction as well as questionnaire-based psychological measures that were gathered upon completing the interactions. A main data point gathered during the interaction was response time when a character uttered a phrase such as "Pick up that block" while looking at one of the three colored blocks on the table. While the behavioral responses to the robot were initially significantly faster from the response to the animated character (and quite similar to response time with a human), these evened out after only a few trials as the person acclimated to the animated character and were better able to read its gaze direction. In measures of social presence (how much like interacting with a human the experience is), the robot consistently scored significantly higher than the animated character.

As a result of this experiment, we wanted to better understand the reasons for the difference in perception between the robot and the animated character. We hypothesized that it was either the fact that one was a physical thing immediately in front of the person or the fact that it was seen as a real thing while the animated character was imaginary. A second experiment was designed to test whether the physical presence of the robot was the root of the impact.

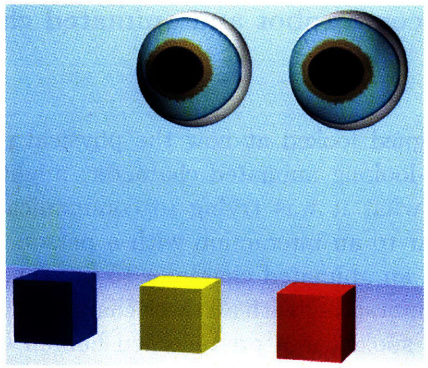

Figure 2-4: The setup for first experiment had a set of three colored blocks between the participant and the robot, animated character, or human.

Better understanding the nature of responses to a robot

In the second study setup, all participants interacted with a simple robot that was capable of moving its "head" left and right, up and down, and towards or away from the person seated across from it. The robot is depicted in Figure 2-5 and as can be seen, it used the eyes from the first experiment with the addition of a paper face and degrees of freedom allowing it to move forward or back, left and right, as well as up and down. Half of the participants were seated directly across the table from the robot and had it respond to things that they did on the computer screen such as moving items around or getting information from the robot. The other half were seated across from a television monitor with the robot in the next room, although participants were not told the location of the robot. This allowed us to test the impact of the immediate physical presence of a robot versus a real, physical robot that is not immediately present.

What we discovered is that it is not the immediacy of the robot that makes a difference, rather it is the fact that there is a real, physical robot. This shows us that by using a robot in an interaction, there is a different psychological response than is seen with an animated character on a screen. Across these two studies, differences were noted in measures of credibility (how believable information from the character seems), informativeness (how useful to the person the information is), engagement (how drawn into the interaction the person was), and social presence (how much like interacting with a human the experience is); in all measures, the robot was scored significantly higher than the animated character by participants. More details on this study can be found in Kidd's S.M. thesis [59].

Although we were not measuring what subjects believed about the robot's perceptual capabilities, there was an indication that people were not able to make accurate attributions of its abilities even after being told what the robot could or could not do. In the study, the robot's motions were preprogrammed; it had a set of motions

Figure 2-5: The robot used in the second experiment.

that it randomly chose from to make it appear that it was moving about while interacting with the person. There was no knowledge of where the person actually was, but the participants' chair was placed directly across from the robot to start the study so that they would be roughly in line with its "gaze." Although participants were told that the robot had no camera with which to see them and no sense as to how they were moving, many of the participants shared the belief that the robot was indeed looking at them and following them during the interaction. The mistaken perceptions were surprising at first, but become more predictable by the end of this experiment and reinforced through the following two experimental interactions.

Using natural gestures

In the next study, I collaborated with researchers at Mitsubishi Electric Research Labs (MERL) using their robot Mel, a penguin depicted in Figure 2-6. Mel was capable of using conversational language to give a demonstration of another research project at MERL. The robot would attempt to engage a visitor, show off the project, explain how it worked, get the visitor to try the demo, and direct them to appropriate people to answer further questions. The robot was fairly simple, with degrees of freedom for its beak, which was programmed to move roughly in time with its speech; its head, which was capable of moving up/down and left/right; and its "wings" that could simply move up and down from about 90 degrees straight out to approximately 45 degrees down.

In the study, participants interacted with the robot in one of two modes. For

Figure 2-6: Mel, the robotic penguin, used in studies at Mitsubishi Electric Research Labs.

everyone, the robot moved its beak while talking. In the first experimental condition, it used gestures meant to encourage engagement, such as looking at the person using its face tracking software, gesturing on natural beats in conversation, and turning to and gesturing to the objects it was talking about. In the second condition, it made none of the engagement gestures while interacting with the person to whom it was giving a demo, moving only its beak.

In both cases, we found that if we asked people whether the robot had used some of these gestures they believed that the robot had indeed gestured. This was an interesting finding because when both cases were seen one after the other, the difference in activity was striking. The robot appeared to be very staid and uninteresting in the non-gesturing case when both were seen, but without the contrast, this was not noticed. We also asked about participants' perceptions of the interactions, asking how much they enjoyed interacting with the robot and how appropriately the robot performed during the interaction. When asked about these aspects of their experience, the same people who could not consciously tell us whether the robot moved or not reported a significant difference, with the gesturing version of the robot rating much more highly on these scales. We also observed that in the gesturing case, participants also directed their attention more towards the robot at appropriate times, indicating that they found this to be a more natural, human-like interaction. The full details of the study are reported in our journal article [98] and earlier conference papers [97, 99].

Continued social interaction

The next experiment was conducted with Leonardo, our very expressive sociable robot shown in Figure 2-7. The purpose of this experiment was to better understand the use of what we called subtle expressions. In interactions with Leo, these included perking his ears and turning his gaze to indicate that he was paying attention, shrugging his shoulders and using his face to convey confusion, and blinking his eyes and shifting his gaze to give the appearance of "aliveness." Similar to the experiment conducted with Mel, there were two conditions: one group of participants saw all of these behaviors activated at appropriate times while interacting with the robot and the other group did not experience these behaviors during their interactions. In both cases, participants were asked to teach Leo a series of tasks that required making gestures, speaking to the robot, and testing the robot's understanding.

Figure 2-7: Leo, an expressive sociable robot in our lab at MIT.

The vision and speech recognition systems that we used are fairly robust, but there were still errors throughout every interaction. Our hypothesis was that the use of these subtle expressions would smooth the interaction, making it seem more natural for a participant to complete. The reasoning is that when an error occurs in the condition where the robot is not continuously presenting subtle feedback to a user, it may take some time before the error is realized. At that point, it may be difficult to determine when the error occurred ("Did it misunderstand the last command?" "Did it misinterpret a label I assigned a minute ago?" "Did it never hear anything I said?"), in which case the participant might have to fumble around repeating several utterances before figuring out the problem, often becoming frustrated while this is happening. Alternatively, we hypothesized that the use of subtle expressions would confirm when the robot understood (or at least followed) what was happening or indicate a problem in recognition, understanding, or parsing as soon as it occurred. This would allow the user to make a quick correction, much like humans do in everyday interactions with others – repeating words, clarifying gestures, or restating a point.

The results of this experiment showed that indeed the use of these subtle gestures during the interaction does have a positive effect on people being able to understand what the robot was doing, on the speed with which participants could complete the assigned teaching task, and on how well they could recover from the inevitable errors that arise during complex human-robot collaborations. Through both behavioral and questionnaire-based measures, we saw the impact of subtle expressions on making the experience of teaching the robot more enjoyable and efficient. Further details of the experimental design and analysis are in a published conference paper [18].

Beginning long-term studies

From this point, I began to look to longer-term studies. If our goal is to ultimately build robots that we interact with in our everyday lives, then we must study them in that environment. Initial effects will wear off. Reactions will change after people become familiar with a robot. The nature of interactions will evolve as a relationship develops. We can not fully understand how we will react to robots that we talk with, listen to, or maneuver around in short-term laboratory experiments.

To start looking at long-term interaction, we set up an experiment to study novelty effects. In psychology studies, novelty effects are those reactions that are seen initially but change or disappear after a subject acclimates to a novel situation or stimulus. To test this with a robot, we used a commercially available robot called the Paro. Paro, depicted in Figure 2-8, is a robot from researchers in Japan that is sold as a companion for elderly people living in nursing homes. While it is envisioned for one-on-one interaction, our study used it in a group setting, with the goal being to encourage social interaction among residents of the two homes that we visited.

Figure 2-8: The Paro robot used in our first ongoing studies with the same group of individuals.

Our design had us returning to the same homes and interacting with the same groups of residents and caregivers every two weeks for several months. We saw a striking affinity for the robot among some of the participants in the study while others paid it little attention. Among the groups of individuals, however, we noted that the small movements and squeals from the robot were enough to elicit conversation.

Where conversation sometimes lagged in our groups with a robot at the table, these stimuli were enough to get people talking again, often not even about the robot or what it had done. In the control groups (robot off or no robot present), an impetus to restart conversation was more infrequent. Tellingly, this behavior did not seem to disappear over time, rather it held fairly consistent for the duration of the study. More details of the study setup and findings are discussed in an early conference paper [105] and a description of the relational behaviors between participants who were observed and the robot are in a later journal article by Turkle, et al. [112].

2.3 Summary

The series of experiments described here have led from an initial understanding of how people perceive robots in both a physical and psychological sense to the development of theories of both short- and long-term interaction. Early studies showed the importance of the physical robot in an interaction and led to ideas about where these differences – in engagement and believability – might be important for longer-term interaction. We showed the importance of using human-like social cues for helping to complete an interaction.

Through this set of studies, we have been able to make recommendations for future experimental HRI work. Several of the measures we have used have proven useful in these types of experiments as well as the experimental designs themselves. Details about each experiment are in the papers referenced in the respective sections and a brief summary of the lessons learned were published in a conference paper [62].

The most interesting part regarding the studies exploring perceptions that people had of a robot using human-like social gestures was that although participants in our studies were not consciously aware of whether or not the robot used these gestures, the impact that it had on their perceptions of the interaction was quite clear. This indicates that people are not cuing in to particular gestures or sets of behaviors, rather they seem to be judging the interaction on how naturally their partner behaves. If the robot uses the appropriate set of social cues for a given interaction, everything is okay. If something is missing or if the wrong thing is present, people will not necessarily be able to pinpoint what is not right, but they clearly will not be as satisfied with the interaction.

It appears that these perceptions are not necessarily tied to task outcome either. In short-term experiments, an individual may be able to complete an assigned task with a robot just as well with or without these behaviors. But if we hope to have these robots become a part of everyday life, it is likely that the initial ambivalence or dislike towards the robot and its capabilities will only grow into frustration over time.

Our first attempt at looking at the longer-term effects came in the nursing home-based studies with the Paro. The level of social interaction between the robot and people was limited because of the design and capabilities of the robot. Therefore the next challenge for us was to create a robot and entire system that would allow for the study of longer-term study of human-robot interaction in a real-world setting. The remainder of this thesis describes the construction, experimental design, deployment, and results from our first long-term, large-scale study of a socially interactive robot in people's everyday lives.

Chapter 3

Related Work

The endeavor of creating sociable robot systems draws heavily on the fields of human-robot interaction and ubiquitous computing, but important influences also come from psychology, social psychology, computer science, human-computer interaction (HCI), affective computing, and artificial intelligence (AI). In the application to a weight loss system, we also draw from work done in the fields of bariatrics, nutrition, and behavior change.

Each of these fields has something to add to the study of HRI. Psychology contributes an understanding of human reactions to various situations, concepts of human motivations, and ways to measure these factors. From social psychology, we draw information on how people react to social stimuli, which guides the creation of a robot's behaviors and even its construction. Tenets of traditional computer science guide the creation of the software systems that control the interactions that a robot carries out with its human interlocutors. There is a rich body of experimental practice in HCI that has guided the creation and subsequent development of many of the computer interfaces that we use today and many of the theoretical concepts that have been developed are useful in HRI. Algorithmic techniques from AI underly a system's ability to learn about human behavior, process environmental cues, and determine what action to take at a given instant in an interaction.

The strength of existing work in HRI is the knowledge that has been gained about how to create an interactive robot that has an internal model of itself, the world, and its interaction partner; has the ability to interact with people by reading and expressing human (or human-like) conversational gestures; and can express some of its state to the users with which it is interacting.

In this chapter, I elucidate what is drawn from each of these domains in the creation of a sociable robot system.

3.1 Why a robot?

An initial question or criticism about much work in applying human-robot interaction to real-world problems is "Why use a robot when you can use a character on a mobile phone, PDA, or computer screen?" While many of the effects that are important in the interactions described here can be achieved using an on-screen character, they have been shown to be easier to achieve and more effective in interactions with a robot. The presence of a real, physical robot sharing space with a user has a marked effect on the impressions that the user has of the interaction. For the kinds of applications that are envisioned for sociable robot systems, these differences are important to the potential success of such a system. Further details of research related to this question were discussed in the previous chapter (see Section 2.2).

The series of experiments we have conducted over the last six years has led to the desire to explore long-term human-robot interaction as well as helped to develop the reasoning as to why a robot has shown to be a more effective interaction partner in certain settings. Taken together, they showed the power of a robot in conducting an effective interaction and the stronger responses that the set of robots we have used elicited from many study participants.

3.2 Human-robot interaction

Sociable robots were defined by Breazeal as those robots which

> are socially participative "creatures" with their own internal goals and motivations. They pro-actively engage people in a social manner not only to benefit the person (e.g., to help perform a task, to facilitate interaction with the robot, etc.), but also to benefit itself (e.g., to promote its survival, to improve its own performance, to learn from the human, etc.) (Breazeal [16], p. 169).

While this domain comprises a relatively new field of scientific inquiry, there are results that encourage us that the development of the kind of human-supportive application proposed here is a promising and appropriate use of sociable robotic technology. The context in which the field has been discussed since its inception is the desire to create robots that will interact with people in their daily lives. Because of the enormous challenges in achieving that goal, most work thus far has looked at more circumscribed interactions. Some examples of work that attempts to create and study this longer-term ideal are described here.

In interactions between robots and people ranging from school children to the elderly, benefits have been shown for employing social interaction. A group of researchers at the ATR Intelligent Robotics and Communication Laboratories in Japan has carried out a series of experiments showing positive outcomes from interactions between school children and robots. The work of Kanda and others [53] presents lessons learned from a robot interacting with children for several weeks and includes suggestions for creating affinities between a robot and a person interacting with it, while an earlier paper [52] discusses successful communication between children and a robot where the objective is to improve the (Japanese-speaking) children's English abilities. Researchers at Japan's National Institute of Advanced Industrial Science and Technology (AIST) have completed a series of studies with their Paro robot interacting with the elderly in nursing homes and assisted living facilities. They report measuring psychological, physiological, and social benefits to the people who interact with their robot [114, 115]. Similar studies that we have carried out confirm some of the interaction patterns that they see in an American nursing home [105] and other environments [112].

The Pearl project at Carnegie Mellon University, the University of Pittsburgh, and the University of Michigan has sought to build a mobile robot to assist the elderly [92]. This is one of the only projects that has robots interacting with people in a health care-related scenario. The goals of the Pearl/Nursebot project are quite different from those in the present work. However, one lesson that can be learned from their work comes from seeing videos of people interacting with the system. It would seem that much effort was put into the functional aspects of the system, but little work was done on crafting the interaction between the person and the robot. The result is interactions that seem to perplex or even frighten the elderly people with whom the robot is supposed to be interacting (videos depicting these interactions can be seen at the project web site [1]). Creating more successful interactions must be a high priority in these systems so that people will actually want to use and continue to use them over extended periods.

In-home studies

The most closely related work in long-term human-robot interaction work may be that of Forlizzi and colleagues at Carnegie Mellon University. In a recent conference paper, she reports on studying families' reactions to having a robot in their homes for a period of one year by conducting interviews with the families at three month intervals [38]. The study was designed as a controlled experiment, where a family was given either a robotic Roomba vacuum cleaner or a Hoover upright vacuum cleaner. During these interviews, study participants were asked about their liking of the product that they had been given as well as their use of it. The results showed that the robotic vacuum cleaner had a much stronger impact on habits of participants than the traditional vacuum cleaner.

One of the major outcomes of this work is the development of a "product ecology" that describes how a given product fits into the lives' of its users. According to

Forlizzi, this ecology, which is similar in purpose to our "sociable robot system" that was described in Chapter 2,

> describes the social experience of use of a product, as well as how mutual adaptation occurs between the people and the product in the ecology. Within the product ecology, the environment is defined as a place containing products that shape roles, social norms, human behavior, and how other products are used at the same time. The environment affects how products are used; in turn, product use changes the user(s) and the context of use as a result.

In evaluating how people talked about the product that they had been given for the study, five dimensions were used: function, aesthetics, symbolism, emotion, and social attributions. This set of factors comprises the ways in which people make sense of their reactions to an object over time. In the analysis of interviews, they note that most cleaning products are discussed only in relation to functionality and that the cleaning process is talked about in terms of the symbolic, social, and emotional meanings. Notably, however, the Roomba robotic vacuum cleaner was talked about using all five categories. This is seen to be indicative of the how the robotic product is more readily accepted by users.

Forlizzi concludes her analysis by noting that "when simple social attributes are part of the design of robotic products and systems, people may adopt them more readily and find them less stigmatizing." This is interesting in that it indicates that it is not only the functionality of the product that is interesting, rather the social interaction plays a large part. When taking into account the extremely limited socially interactive abilities of the Roomba vacuum cleaner, we might expect that a system that is designed with richer social interaction capabilities could be even more effective at being adopted into and integrated with its users' lives.

Applicability to health-care applications

We have written about the application of sociable robots to real-world problems in recent years as we have begun exploring the design and construction of such systems. Early thoughts about applications were included in a 2003 conference paper that was published in a book several years later [60]. A discussion of healthcare applications of robots comprised the concluding section of that paper. An earlier discussion on the important factors in creating a relationship [63] noted three factors that are most important: engagement of the user, trust of the system, and motivation to use the system. An exploration of the extension of the robot's capabilities by adding other devices into the system is discussed in a workshop paper [64]. An early design of the system that has been built is presented in a conference paper [65] that shows many of the theoretical design decisions that underly the system that has been constructed and tested and is described in this thesis.

A related area of research, affective computing, also provides support for using engaging robotic interfaces to health-related systems. While not speaking specifically about robots, Picard discusses the important of creating machines that have some emotional intelligence, both being able to sense something about the emotional state of a user as well as possessing the ability to use emotional displays to convey something about the state of the machine back to the user [89]. Much of the work in the affective computing field looks at the estimation of emotions using a variety of sensing technologies, including computer vision, speech analysis, and a variety of physiological sensors. Applications that have been built include health assessment [74] and helping patients interact with their caregivers [90], and those envisioned include long-term behavior change such as drug rehabilitation [91].

There is clear promise in these ideas and implementations for extending interfaces beyond traditional input and output to include an understanding the emotional aspects of interaction. Bringing these into our interactive robots in an intelligent fashion would provide for a richer and more useful experience in the kinds of applications that we propose building.

3.3 Conversational agents

For over a decade there has been interesting work conducted in creating similar types of interactions that we discuss with robots using animated on-screen agents. This work has shown the benefits of using characters on the screen referred to as *embodied conversational agents* (ECAs) and much of the focus has been in creating systems that are capable of the *conversational* portion: the ability to both analyze and generate appropriate interactions.

These kinds of interactions have been presented in a variety of scenarios. The work of Cassell, credited with creating this area of inquiry, focused for a time on creating a real estate agent named Rea that was designed to interact with people. Rea was depicted on a screen and carried out "face-to-face" interactions with human interlocutors (see [29] for an overview of the system). What was shown is that using these interactive gestural and conversational behaviors in interactions led to a more engaging interaction than with a character that did not use these cues; Cassell [28] discusses these findings in an article. (An overview of earlier agent-based research that describes many of the potential benefits of using animated agents, as well as cautions on how far claims can go based on empirical research that has been conducted, can be found in Dehn's review article [32].)

In a subsequent paper, Cassell, et al. describe the BEAT system, which is a toolkit for animating an ECA [30]. This software can take a passage that the programmer would like the character to utter and turn it into a set of gestures, other non-verbal behaviors, and computer-generated speech. One of the challenges in creating an interactive character that has enough range in its interactions to be interesting to a user over time is the generation and choreographing of content. The BEAT work addresses the second half of that problem – once there is a spoken utterance that the character should use, this toolkit can handle the work of coordinating the various degrees of freedom and social cues that are necessary for creating a believable and sustainable level of interaction.

In later follow-on work, Bickmore shows the value of using on-screen agents in his FitTrack system for behavior modification in a 30-day intervention in his study [10]. His system was one of the first to show the power of using these types of engaging traits in a system designed to elicit behavior change in a user over time. A central argument in his thesis regards the creation of a relationship between a conversational system and a person [11, 12, 13]. He argues that relationships are built over time through face-to-face conversations, which are implemented in an animated conversational interface that he named Laura.

Comparison to a robotic interface

There is a growing body of work that compares animated agents to physical robots and shows the consistent benefits of robots over on-screen agents for certain types of interactions. Our previous work has shown that the values of using a physical robot over that of an animated character include greater trust in and engagement with the interactive system (experimental design and results detailed in M.S. thesis [59]; brief results reported in a conference paper [61]). These were short-duration studies and the question of long-term effects were still open and are addressed in the current work. Reeves and colleagues also report greater liking of a robot over an animated character, higher judgments of credibility (for women), improved memory on a task (for men), and less concern that the character was passing judgment on the users [95]. Taken together, this set of studies indicates that using robots for certain types of application creates a greater likelihood of success than using an on-screen agent. In particular, these are applications where the creation of a long-term, collaborative, and trusting relationship is seen as important.

3.4 Psychology

There is a rich history of psychological theories and experimentation that inform us about many aspects and types of human relationships. Work that is most relevant to the types of systems that we are concerned with building are presented here.

Gaze and eye contact

The rôle of eye gaze in a two-person interaction has been extensively studied by a number of researchers. In his 1990 book on behavior patterns during human interaction, Kendon devotes a chapter to summarizing previous research and presenting his own findings [57]. Most notably, he discusses the use of eye contact to indicate a willingness for commencement of conversation and the maintenance of that gaze as an indicator of continued interest in a conversation. (This discussion draws largely on the earlier work on the importance of gaze by Goffman [41].)

Kendon finds in his work that one of the important functions of gaze in regulating interaction is for one interlocutor to assess the state of her conversational partner (e.g. being attentive, wanting to take the floor, or desiring to end the conversation). While human gaze patterns are rather nuanced, the maintenance of eye contact throughout an interaction is a basic way to regulate an interaction. There are two uses of eye contact that are useful to our application of sociable robots. During a conversation, the maintenance of eye contact indicates to a partner that they are making progress towards any goals that they are trying to achieve by indicating that attention is being paid to them. This is one of the primary uses of gaze in interaction. The second is that as one individual completes a speaking turn, looking at their conversational partner lets them know that a reply is expected.

Phases of relationships

An important development in this work over previous HRI systems is the idea of creating a long-term relationship between a user and the robot. In order to do this, we must have some model of the relationship, a way of measuring and estimating the state of the relationship, and a method for trying to change the relational state. Theories for each of these three components can be found in the literature on human psychology and relationships. The outlines for our system were drawn from several sources.

In *Close Relationships*, Levinger describes the trajectory of a "typical" relationship ([56], p. 321). There are five stages in this model: (1) acquaintance, a phase of getting to know one another that may last indefinitely; (2) the buildup of an ongoing relationship, when two partners learn more about one another; (3) mutual commitment to a long-term relationship, a lasting phase in which each partner is comfortable with the commitment of the other; (4) a deterioration phase where connections break down; (5) and an ending. We are concerned here with the first three phases – initiation through commitment – and theories related to their occurrence and evolution. (Levinger does note that not every relationship evolves through this set of 5 stages, but does posit that it is a good framework within which to think about the creation and possible dissolution of relationships.)

In our model, we explicitly attempt to guide the user's relationship with the robot from stage one through to stage three. While some users pass through stage four to stage five, we try to repair the relationship if we believe it reaches stage four (a decline) and build it up again using techniques discussed subsequently. Stage five, the dissolution of the relationship, is not yet modeled for the set of interactions that

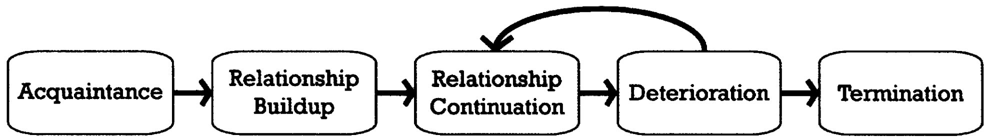

Figure 3-1: Five phases of relationships from Levinger [56] with recovery added.

we have created, as we had imagined the use of the systems to be indefinite. This model is depicted in Figure 3-1 along with an arrow indicating the repair phase that we have added based on other theories.

Levinger's model does not take into account one important aspect of relationships, that of recovery when things go wrong or the relationship has suffered some kind of downturn. In Duck's 1998 book, *Human Relationships* [34], he covers the type of breakdowns possible in relationships. Figure 3-2 summarizes the stages of dissolution of a relationship as well as how the relationship might be repaired at that stage. It is beyond the scope of our work to address all of these phases of ending relationships, but we do address the first two stages and partially address the third phase. Our detection of relationship dissolution is minimal, but when a breakdown or decline in relational state is detected, the sociable robot system employs strategies suggested by the third column in the figure from Duck. In an earlier book, he suggests some additional strategies that can be employed conversationally at each of these stages and have been adopted in our system [33]. For example, in the *intrapsychic phase*, where one partner in a relationship is aggrieved, but not necessarily sharing the reasons with the other member of the dyad, the strategy suggested is to use meta-relational discussions to clarify the goals of the relationship and draw the disaffected party back into the relationship.

Conversational tactics

Closely related to the attempt at manipulating the phases of a relationship are the linguistic strategies that can be employed to convey a particular meaning or relational state to an interaction partner. In *Politeness: Some universals in language* [22], Brown and Levinson discuss a multitude of tactics that can also be employed in a sociable robot system.

They devote much of their discussion to *positive politeness*, or addressing the "desire that [a person's] wants should be thought of as desirable." They discuss fifteen strategies for achieving this goal and we employ many of them in this work. A summary of the tactics that we have used follows:

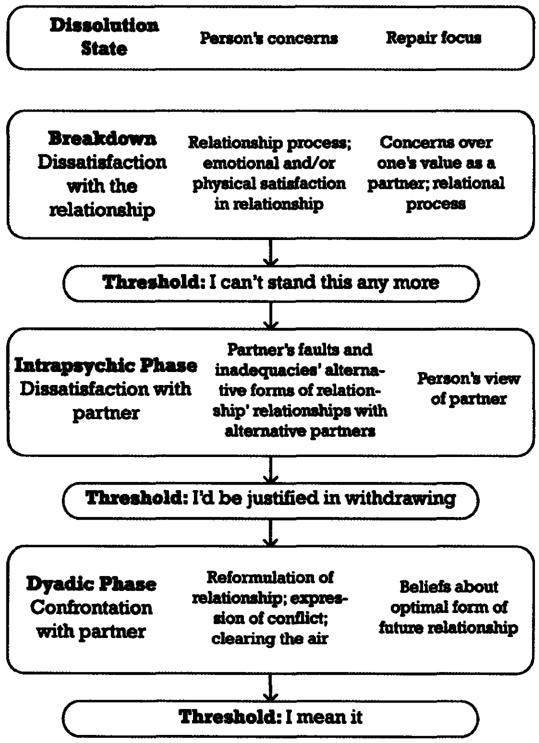

Figure 3-2: Three of Duck's relationship dissolution phases with threshold for moving to next stage.

- Notice and attend to a partner. For example, find things that may have changed since the last interaction or simply inquire about something that is expected to be relevant to them. Our robot points out changes in behavior over time and sometimes introduces questions with assumptions about activity (e.g. "Since it's afternoon, you've probably been able to get some exercise in so far today, right?")

- Intensify interest in the partner. This includes things like making clear that the other person's interest are one's own interests as well. Our system clarifies on occasion that its purpose is to work toward the goals of the user.

- Seek agreement. Find ways in which you can agree with the other person. This includes using small talk that is expected to be agreeable to most people. Discussion of the weather, a commonly used conversational tactic, is an example of this strategy. The robot uses these types of topics in small talk to find common ground with the user.

- Presuppose, raise, or assert common ground. Similar to the previous strategy, this is a way to create discussion for no purpose other than carrying on interaction with another and establishing agreement on any topic. Our robot discusses the goal of weight loss and maintenance to establish that as a point of shared interest.

- Joke. The use of humor is a common way to draw to people together. The robot makes jokes about a variety of topics in an attempt to appeal to users.
- Assert knowledge of and/or concern for the partner's wants and desires. Our system is designed around a particular goal that the partner has, so it is relatively straightforward to employ this strategy by discussing those goals.
- Be optimistic. The robot continuously monitors the user's progress and offers upbeat analyses of their situation. Much like the caregivers were seen to do in our observational work, the robot offers positive accounts when progress has been made and helpful suggestions of things that can be improved that are phrased in a positive way.
- Include both partners in an activity. While the system is not capable of shared physical activities, it does use the aspect of this strategy that has to do with employing inclusive language. Statements are made with "we" when possible instead of "you" or "I."

These eight methods for creating a closer relationship are those that are most appropriate for a robotic system to use in the kinds of interactions that we have designed. Others could be used (e.g. "give gifts" or "show reciprocity"), but it becomes more of a challenge to make them seem plausible within the current set of interactions.

Technology as a social actor

In their 1996 book describing years of studies on human interaction with technology, Reeves and Nass bring together a series of studies and theories on human interpersonal behavior to better understand how people respond to technology [94]. Their main target of study is a computer that exhibits some social cues to a user; often something as simple as using natural language or doing a task that a human would usually ascribe to another human, such as teaching. What their studies show is that when a computer exhibits social cues to a user, the user responds in a social way, as though the computer is another person.

An example is a study in which subjects were brought into a room and given a short lesson on a variety of topics that was presented on a computer screen using plain text. Each person was then quizzed by the computer on what they were taught. Finally, subjects were asked to rate how good of a job the computer did as a teacher. For this part, half of the participants in the study were asked to respond to these questions on the same computer that they had just used and the other half were to use another computer in the same small room for this rating. The results clearly showed that people did not want to hurt the feelings of the computer and consistently gave the teaching computer a higher rating when they responded to the final questionnaire on that same computer. This is a result that would be expected in a similar situation when asking people about a human teacher or conversational partner – most individuals would not want to hurt the feelings of an interaction partner and would be more likely to answer more positively to that person about their performance than if asked by someone else about their partner. This politeness that we exhibit to other people was clearly shown to carry over to our interactions with social machines.

Reeves and Nass call their theory *computers as social actors*, meaning that people interpret the actions of many modern technological artifacts as though they are social actors in a given situation. Before our initial experiments (presented in Section 2.2, we discussed these theories with Nass and hypothesized that these reactions would be at least as strong when people were interacting with computers. Our earlier experiments showed this to be the case and led to the reasoning for the development of systems that could take advantage of these responses over time, our sociable robot systems.

3.5 Social support

Social support is something that most people intuit to be useful in many situations where individuals are trying to cope with some problem, improve themselves, or simply deal with daily life. The term "social support" has been interpreted in somewhat different ways, but we use Cobb's definition which describes social support as knowledge that leads to a person feeling that they are cared for, that they are loved and thought highly of, and that they are a part of a social network that will reciprocate their feelings and actions ([31]). It is clearly important that the person both give to and receive benefit from their social support network for this to be effective. The kind of interaction implemented in this and other work on sociable robots (e.g. Breazeal's work on Kismet [16]) leads to a robot that is capable of providing elements of this social support. A central rationale for including a sociable robot as a part of the weight loss support system is that it provides social support to the user, a key aspect of the overall system.

The benefits of social support are clear and have been demonstrated for a variety of situations, such as higher cognitive functioning in the elderly [133], general cardiovascular performance [51], and general daily functioning [71]. The kinds of social support that can be provided include emotional support, network support (being a part of a helping group), esteem support (increasing belief in the self to provide help), functional support (in our system, the actual physical task that the robot or system performs), informational support (for the type of system we have created, assistance in working towards the health care goal), and the chance to help another (which could be providing some regular service to the robot to feel needed as a part of the system).

A study conducted by Wing and Jeffery looked at the benefits of social support in weight loss and maintenance [128], the domain we have tested these theories in. The participants in their study were enrolled in a weight loss program and they proceeded to vary the apparent provision of social support using two methods. The first was by recruiting participants either alone or along with one or more friends who would participate with them and the second was by assigning half of the participants into "teams" that were designed to create an impromptu social support network. They found that both of these social support manipulations had a positive impact on weight loss and maintenance. Regardless of the way in which they attempted to increase an individual's feeling as though they had more support in their weight loss endeavors, it led to a great increase in the number of participants who completed the study, lost weight, and maintained that loss over time. It is clear that the provision of some form of social support makes a person more likely to be successful at weight loss and maintenance goals.

3.6 Behavior change systems

Programs for behavior change, including those using a technological implementation and more traditional methods and theories, inform the way that we have gone about creating our sociable robot system. There has been a great deal of work on understanding behavior change and creating methods for bringing it about, including in the area of obesity, although we find no work in using a robot in a behavior change application. The most closely related work in this domain is that of Tate, who has studied online-based behavior counseling for obese patients trying to lose weight [107, 108].

Tate's work has found that a technology-based system for providing ongoing support *in addition to* typical interaction with a health care provider is a functional means of helping people who are attempting to lose weight. The work of Picard and Bickmore also shows a successful implementation of a behavior change system, this one using an on-screen agent to encourage people to change their exercise habits [13]. Their system, FitTrack, used an embodied conversational agent in the form of a female exercise trainer that attempted to build a relationship with a person using techniques from social psychology, sociolinguistics, and communications. This did not include interaction with a human trainer or health care provider, but did show that the system was capable of building and maintaining a relationship with the user over time.

What both of these systems show is that people are willing to repeatedly return to a non-human system for information about and encouragement for their behavior change goals. A main difference between them is that Bickmore and Picard's system concentrates more on creating the relationship between the user and the system, which we believe to be an integral part of the long-term success of a technologically-based system. Tate's system, on the other hand, included regular, albeit mediated, interaction with a human caregiver. Both the human interaction and the relationship with the system have influenced the design of our system for weight loss.

A discussion of the factors that contribute to the global obesity epidemic and how individuals can control their weight makes recommendations on what are the factors which are potentially the most amenable [88]. Peters, et al. suggest that the use of cognitive aids are a key to successful weight loss and management. It is "the knowledge, cognitive skills and incentives for controlling body weight ... [that] allow better management of body weight." Indeed, three-fourths of individuals who are *successful* at weight management weigh themselves more than once a week and half continue counting calories after completing weight loss, according to a review of patients in the National Weight Control Registry [69]. The kind of knowledge and skills discussed by Peters include understanding the importance of and extent of participation in physical activity and the knowledge and awareness of food consumption habits. They claim that individuals who have been successful at weight loss "have done so, in effect, by institutionalizing cognitive management of their eating and physical activity behaviours into their lives." Currently this takes "substantial cognitive effort," but systems such as the one we have designed and built could serve to reduce the taxing effort and potentially allow others to succeed.

Taken together, the work cited in this section helps us to understand what the potential applicability of a robotic coach might be as well as how we might approach the creation of such a system. Work from weight loss researchers leads to an understanding of what the effective supports for a person attempting weight loss and weight maintenance are. Tate, Picard, and Bickmore give us an understanding of how we might create technological systems that are capable of creating a relationship with a person and providing effective help over time.

3.7 Ubiquitous computing

The term *ubiquitous computing* (or ubicomp) was defined by Mark Weiser to encompass technologies that "integrat[e] computers seamlessly into the world" [123]. The systems that have been constructed in this vein in the succeeding decade and a half of work have been designed for a variety of domains such as the classroom [21], the office [122], and the home [66]. A more general overview of a variety of ubicomp work, techniques, and research directions can be found in an overview article by Abowd and Mynatt [4]. There are several ideas that most of these systems have in common. Two that I draw on in my work are the use of design techniques that allow the systems to be accessible to as many people as possible and the use of technology at any time and in any place.

3.7.1 Universal design

The first of the two ideas that are drawn from ubiquitous computing in this work is the encompassing of the ideals of accessibility to a large population. This is referred to as universal design in some communities (or "user-interface design for the disabled and elderly" by Marcus [77]) , or the "approach to the design of products, services and environments to be as usable as possible by as many people as possible regardless of age, ability or situation" [126]. When creating a complex technical system that is intended to be used by many different people, it is vital that it be easily accessible to non-technical users. Much of the focus of creating a ubicomp system is in understanding the range of potential users and their capabilities. We have approached this through our clinical observation, discussions with caregivers, and conversations with potential users.

3.7.2 Always-on infrastructure

The second relevant concept we utilize is the augmentation of people's activities and spaces with computing technology that provides assistance upon request. A design tenet of sociable robot systems is that they should allow people to more easily accomplish the relevant task (or set of tasks) than could be done without the system. The ideal version of this means giving users anytime, anywhere access to relevant information with lightweight, simple, and powerful interfaces. In their work on the Digital Family Portrait, Mynatt el al. use the term *environmental supports* to describe an always-on, supportive technological infrastructure [78]. They discuss a particular system in their work that is designed to support an elderly person in the home, but they draw general lessons that are applicable in a variety of situations. Key criteria of a successful system are "creat[ing] a continuously present interface for the home that reflects and supports daily activity and ... are aware of the [people] and their needs, both on the long and the short term" [78].

3.7.3 Long-term interaction

Ubiquitous computing researchers have begun to run experimental studies to look at the effects of long-term interaction with their systems. Researchers in the house_n project at MIT have written about lessons they have learned in conducting long-term monitoring studies using real-world participants [8]. Their suggestions can be broken into two areas, technological and social. Relevant lessons about the technology and its installation include recommending the redundancy of information capture methods to ensure that more data is gathered for real-time or post-hoc analysis, spending more time before experimental deployment to coördinate and synchronize assorted data sources to save time and effort after the experiment's completion, and that methods for labeling data be built into the system so that labeling is not an extensive endeavor when analyzing the data. Their social-related suggestions are that "participants need to feel that the research team is respectful of their homes and their time," that issues of privacy can be very complex, and that there is no such thing as "normal" that can be assumed when it comes to monitoring real-world behavior.

Researchers working on the aforementioned Digital Family Portrait, an ambient display supported by ubiquitous sensing technology, ran a one-year study with a pair of participants. (The Portrait is discussed in Mynatt, et al. [79] and the study in Rowan, et al. [96].) Some of their conclusions are relevant to the proposed work. One promising note is that their users continued to regularly use the system after an entire year of having it in their home. In contrast to the work of Beaudin, et al. [8], they claim that regularity in patterns can be discerned over time. As neither present the data to back up their arguments, it is difficult to determine which is a more accurate statement or how it depends on particular aspects of the experimental setting. They also note that the study participants used the technology in unanticipated social ways. They state that the two users felt a social connection through the system.

There are few studies of medical-related behavioral interventions that can arguably be considered long-term ubicomp work. The work of Tate, et al. [107] used an Internet-based system to support individuals trying to lose weight for 1 year. They found that this technologically-assisted intervention was successful in increasing weight loss. It is important to note the conditions of their study: all participants (n=92) had access to the Internet-based weight loss program; only half of the participants also received e-mail support. Thus they show that the social support aspect of the intervention is a critical accoutrement to the technological component.

The *DiaBetNet* project by Kumar [72] addressed the treatment of diabetes in children (age 8 to 18) with the ongoing monitoring of their blood glucose levels. A study using the system was carried out for 4 weeks, arguably long enough for novelty effects to dissipate. Participants in the study (n=40) were divided into *game* and *control* groups. The *game* group had access to more information about how their recent measurements and activities (e.g. blood glucose, insulin doses, and carbohydrate intake) might affect their blood glucose level in the near future. Results showed that the *game* group improved on all measures related to diabetes monitoring and treatment. (In this study, the measures were frequency of blood glucose monitoring, frequency of hyperglycemia, lower HbA1C values, and increased knowledge about managing diabetes.) These results are quite possibly a result of the system providing greater access to and showing the interrelationship among factors contributing to diabetes.

3.8 Summary

There is a rich history of work that informs our current construction and evaluation of a sociable robot system. The ability of technological artifacts to elicit responses that are nominally thought to be directed towards a human as well us the understanding of how to create and measure a relationship over time give us the foundation for creating systems that are intended for interaction over longer periods than previous interactive robots. We draw broadly on work in psychology to explain human interactions and relationships and look to ubiquitous computing for examples of systems that have been created for people to use and rely on on a daily basis. In part from these, we have created our theory of sociable robot systems and designed a first system that has been deployed and studied.

Part II

Implementing Sociable Robot Systems

Chapter 4

Design Requirements

One of the contributions of this work is to suggest a set of design principles that can be used in creating future sociable robot systems.

The design of a sociable robot system entails the incorporation of many different criteria. There are four main areas that are addressed:

- The creation of the *sociable robot system* as an integrated set of components. This includes the construction and integration of the robot itself as well as other components that make up the system.

- *Interactions* with the user. To create successful interactions, the robot needs sensors to understand appropriate input, enough intelligence to understand and manage the input that is received in a way that is appropriate, and the ability to vary the interactions over time.

- The *relationship* between the system and the user. A comprehension of how relationships develop and evolve, as well as how this can be measured and affected is necessary for a successful system.

- Needs of the *target audience*. Each application will have a different target audience. Their needs for input, synthesis, and output may vary greatly, so an understanding of how it affects the creation of the system is important.

Each of these four sets of requirements is discussed in this chapter as they would apply to creating most any sociable robot system. The next chapter presents concrete examples of how they are considered and implemented when building a specific system, our weight loss coach.

4.1 Sociable Robot System Requirements

Robot

A key component of this system is the robot that the user interacts with. The robot is important both in the short-term as the face of the system, but also for long-term relationship purposes. There are several factors that are important when considering what robot can be used for such interactions. The main three are the ability to express state to the user, integrate into the other parts of the system including both technology and people, and be programmable. A fourth factor is ready availability of the system. More detail on each of these follows.

Expressing state to the user is the most critical factor for a robot used in this system. As previous work has shown (that mentioned in Section 3.2 and in particular our recent study showing the utility of expression in interaction discussed in a conference publication [18]), interaction with a robot in general is greatly enhanced when the robot conveys its internal state. In some types of applications, the robot's main purpose may be to express state to the user. There are several modalities through which a robot can be expressive, including speech (generated or recorded), non-verbal auditory communication, and physical action. There is currently no simple way to determine *a priori* whether a particular robot has sufficient expressive abilities. The best method is to test behaviors on a user for a robot about which we are unsure.

The *ability to be integrated into a larger system* is another important factor for any robot used in a sociable robot system such as this one. While the capabilities of the robot itself determine whether it can be useful in isolation, its ability to interact with the human and other technological portions of the larger system make it useful in the context of the system. Generally this means the ability to communicate with the system (most efficiently through standard wired or wireless communications protocols) and the ability to modify its behavior based on system input.

The degree of flexibility in the *programmability of the robot* determines how easily it can be made to meet the first two requirements when it is technically capable of doing so. A given robot that is capable of expression and integration becomes much more useful when there is a straightforward method of controlling it. In general, this limits the sociable robot system designer to robots that have been created for third-party programming or those that have been developed expressly for the system.

Finally, the *availability of the system* is an important factor when trying to get a system built in order to conduct research. The interesting research done with the sociable robot system described in the next chapter (and likely with others that might be constructed) has to do with questions of interaction and long-term use. Thus the number of person-hours that it would take to design, implement, and integrate a new robot for a particular sociable robot system detracts from many sociable robot system designers' goals. Thus a commercially available robot might be a desirable choice for a system if it meets each of the three previous requirements.

Technological artifacts

The term *technological artifacts* is a broad generalization for the many other devices and systems that we may want to have communicate with or through the robot. There are two main reasons for connecting a robot to other devices: the robot needs more information for a particular set of interactions or the robot is being used as a sociable interface for communicating with a user.

A particular sociable robot system may need more input from the user or the environment than the robot itself is capable of gathering. For example, a home helper robot may want to know the state of appliances in the kitchen and the thermostat in the den. These devices can provide information directly rather than the robot trying to read them as a human would. There may be existing or new technologies that are more appropriate for getting a particular type of data. For many healthcare applications, an array of biometric indicators are useful. There are many devices available to gather this kind of data that would make sense to use when putting together a system that needs that kind of information. In either of these cases, the robot is the centerpiece of the system and is gathering data that it can store and use when interacting with a user.

One advantage of using a robot as an interface are the social cues that it can provide to ease the burden of interacting with technology for many users (reasons for this are discussed in Section 3.1). When using a robot as an interface, it is not necessarily the core component of the system, but is being used for its interface capabilities. An example might be an intelligent home system that stores and analyzes data about the environment and its occupants and needs some way of communicating with users. A sociable robot interface might be employed to interact with the user and pass inputs back to the main system. In these cases, the robot's inherent advantages can be utilized to provide intuitive interactive capabilities that a system would not otherwise possess.

Means of interaction

The *means of interaction* are the set of visual, audio, and tactile experiences provided by the system to the user of a robot. In terms of traditional HCI, this might be the set of interfaces shown in a graphical user interface. With a robot, the set of interaction capabilities is much more diverse. The potential benefits to utilizing this rich set of cues is great, but the challenges in creating an appropriate interaction are also more difficult. One thing that a robot interaction designer must overcome is the tendency of humans to occasionally note when something is wrong with an interaction, but more frequently to simply have a poor experience without being able to say exactly what was wrong. As discussed in Section 2.2, we have seen that when we take away cues from a robotic interaction, most people don't notice what changed. They do, however, find that the robot is not as good in carrying out the interaction. Thus, while users will have a poor interactive experience, it may be difficult to tell what the root cause of the problem is.

The particular set of interactive capabilities will vary greatly depending on the particular robot used and its capabilities as well as the goal of the application being created and its requirements. We have two main considerations in creating this set of interactions. The first is understanding what a human would do in that situation: what cues do they use from the world, what information are they gathering, and how do they react to or interact with the person that we will consider our user. The second is iterative prototyping. There are as of yet few rules about what is the right thing to do in a given situation, but with careful prototyping and experimentation, we can quickly hone in on the good and bad behaviors. Our approach to this for the system we have built is discussed in the next chapter.

Network of people

Looking beyond the individual user of the system to their social support network and considering the aggregation of these resources when designing a sociable robot system is a central concern of this work. We believe that for these systems to be successful, they must look at the larger context of their placement and interactions. For health-related applications, for example, previous work has shown that the social support of peers is clearly helpful for achieving positive outcomes (refer to section 3.5 in Chapter 3 for more of the background research in this area). Thus a central design goal is to create methods of interaction to allow the robot to interact both in a heterogeneous network of devices as well as the social network of the user.

There are three ways that we consider interaction beyond the direct user-robot interaction. Each of these can be considered individually and supported in a particular social robot system design. Typically, other methods of interactions will need to be created to support any of these, as the goals and interaction patters will differ for any of these peripheral types of interactions.

The first of these additional types of interaction is that between the system and another person who is a part of one of the user's social support networks. An example of this might be a robot that conveys information directly to another user about its interaction with the main user or gathers information from others in support of the user. To implement this method of interaction, the current interlocutor must be known, as well as their rôle in relation to the main user.

The second interaction that may be supported is that between the robot and a group of users that includes the main user. Examples of this may be the user sharing information that the sociable robot system stores with other people in their social network, using the robot to mediate communication, or demonstrating the features of the system to someone else. To support this type of interaction, the system must be able to reasonably handle interactions among multiple users at the same time. At a basic level, the interaction techniques that we draw from the psychology and social psychology of human interactions that are used when interacting with multiple people differ from those used when interacting with a single person. Depending on the type of interaction desired, an understanding of human expectations for the type of interaction is necessary.

A third interaction type that a sociable robot system may support is between the user and one or more other people but that does not explicitly include the robot itself. Returning to the benefits discussed previously that have been seen for social support, a system may simply encourage the user to interact with others who might provide some of these advantages. To accomplish this, an understanding of the psychology of the situation and how the system might create circumstances under which the user may increase their interactions with others in their social support network is crucial.

The next chapter discusses an example of how we implemented each of these interactions in our system.

These design goals bring up challenges that must be addressed as well. These include the privacy issues that will arise when such a system collects or has access to information about the user and the user's interactions. Depending on the goals of a particular system, this data could be more or less extensive and more or less personal. It will be important to consider not only the safety of and access to this data, but also how the system presents the information to the user in some cases.

Ideally, by presenting the parameters of the system clearly to a user when they are considering the use of a sociable robot system or begin using such a system, we could expect that they would understand and be comfortable with the bounds of the systems capabilities and how it handles their information. The reality is that a few users will remain cognizant of the actual capabilities of the system. Most, however, will rapidly begin to project their ideas of the systems capabilities and actions onto the sociable robot, many of these projections having to do with how their data will be shared with others in their network. We have found it important to create modes of interaction that can be carried out with the sociable robot system that can be accomplished without direct access to any user data.

4.2 Interaction Requirements

There are three factors that are most important when trying to create and maintain the kind of helpful, long-term relationship between a person and a sociable robot system that will be useful in sociable robot systems. The robot must be able to **engage** the user so that they will begin to interact with the system in the first place and then **motivate** the user to carry out particular actions once they are engaged. The system must also be worthy of the **trust** of the user, meaning that it can carry out the actions that it has "promised" – implicitly or explicitly – that it can do.

Engagement

Engagement is the manner in which two or more parties begin, carry out, and end an interaction in which they recognize some connection to one another. In humans, we see this in any conversational encounter when two people attract each other's attention, begin and carry on a discussion, and then disengage. (This happens in other types of encounters and with multiple people as well; the dyadic conversation is given as an illustrative example.) The ability to draw a person into an interaction and to successfully negotiate that interaction is of great importance for a sociable robot system. Without the ability to create and maintain engagement, no other aspect of the system will be relevant. In order to carry out any other abilities of the system, the user must be willing to carry on regular interactions with the robot.

There is work focusing on different aspects of how to extend this concept of engagement beyond human-human interactions. The work of Bickmore and Picard in the MIT FitTrack system (described in [13], along with their theoretical background) shows a good example of a model for drawing a human into repeated interactions with an animated agent and continuing these interactions over time. They discuss the relationship literature from the social sciences and explain how strategies that have been identified in interpersonal relationships can be applied to human-computer relationships. They then show how these theories can be applied to human-computer interaction in their implementation of a health-related behavior change application. This work shows some of the necessary aspects of long-term interaction that must be considered and tracked over time. Sidner and others [98] describe our work on the concept of engagement between a human and a robot along with experimental methods which were used to measure engagement in a human-robot interaction.

We have seen through a series of studies that have observed people interacting with a variety of robots that the appearance of robot appears to be a factor for only a minority of people, either for initial attraction or long-term engagement. What has been seen observationally is that a person's general stance towards technology makes them more likely to initially try a system or be hesitant to interact with it. This is a factor that is challenging for a sociable robot system to overcome on its own. Rather, the promise of the system and the benefits which it can provide are the way to get users interested in trying it out. Once the user is initially engaged, the patterns of interactions and perceived ongoing usefulness are the ways to maintain engagement over time.

The robot's ability to draw the user into repeated interactions and get them to commit to using the system are factors that determine the long-term perceived usefulness of the system to an individual. Methods to get the user to commit to continued use of the system, such as doing something for the robot to show their commitment, are key ways to get the user to continue interactions over time if the application is one in which their attention may wane on occasion. Providing regular feedback and benefits to the user is a good way to maintain their level of interest in using the system. Even if the intended benefits of using the system are long-term, ways to show progress along the way and allow the user insights or observations into the process are important.

Motivation

Many of the issues that must be considered for successful use of the sociable robot system are concerned with the user playing an active part in the regular use of the system. In order to do that, the user must be motivated to take part.

There is work in understanding how to motivate a person for changing their behavior, for example that in smoking cessation or weight loss. Little work in applying this to technological systems has been done; the work of Bickmore and Picard discussed above in a journal article [13] is one of the only examples we know of. However, no work in applying this to sociable robots has been done previously.

A precursor to providing motivation to the user is goal-setting. During early interactions, long-term goals should be communicated between the user and the system. These goals should be updated as necessary during later interactions – when initial goals have been met, if they no longer make sense, or if they need to be updated for other reasons. To reach the next step in encouragement requires a reasonable goal that the user believes that they might be able to attain.

Providing encouragement to the user is a successful way to motivate them through their use of the system. Encouragement can be given regularly throughout an interaction by suggesting next steps or actions a user might take or simple and subtle feedback on things that they have done. It can also be accomplished by showing a user how they are doing in terms of progress towards reaching longer-term goals of the interaction. When there are goals that are set, regular feedback on how the user is doing in progressing towards those goals can keep them motivated to continue using the system over time. Achieving a feeling of making progress can be a strong motivator to want to take advantage of using the sociable robot system.

Trust

As a person becomes engaged with the system, they must initially believe that the system is going to work and then continue to believe that over the course of their relationship with the system in order for it to be effective in its weight loss aims. Thus the system must make its capabilities clear initially (the implicit promise of what it can do) and subsequently follow through on this commitment over time. We do not want to develop systems in which users falsely place their trust, expecting it to do something of which it is not capable. The system must be dependable and reliable for those functions which the user expects.

The concept of trust encompasses a number of factors, such as reliability and credibility, which concern the function of the system over time and the quality of information and feedback that the user receives from the system. Reliability relates to the system performing in the same way each time the user interacts with it and the user's belief that this is the case. For these systems to be effective in conducting long-term research, we must go beyond laboratory prototypes that function most of the time; they must be completely reliable in order for a person to develop trust in them over time. Even a short-term problem can destroy credibility that has been built up with a user.

Credibility has more to do with the information and feedback coming from the system. The robot must be seen as presenting correct information to the user, whether this is outside information (i.e. something it is programmed to have knowledge about) or data about the user or their interactions with the robot (health data that the system has observed over time, for example).

4.3 Relationship Requirements

Researchers in several fields have begun to explore longer-term relationships with interactive technology. We referred to work in home-based technology and health care technology studies in the long-term interaction section previously (section 3.7.3) as well as work in behavior-modification agents (near the end of section 3.2) that both suggest possible design elements for sociable robot systems. While none of this work has utilized robots, there has been more study and analysis of long-term behavior and relationships that is proving useful in our design process. More specifically, none of this work has studied the effect of physical embodiment and colocation of the helping system as this work does.

Relationship model

Developing a model for creating a relationship between a user and the sociable robot system is one of the most challenging aspects of creating a sociable robot system. Here we outline what is available for creating the relationship, what the relationship should be like, and some of the necessary features of the model.

Based on psychological theories discussed in Section 3.4, there are three relationship phases that must be developed for the interactions with a sociable robot system. These are the initial relationship building phase, the ongoing action/interaction phase, and a "reacquaintence" phase for users who discontinue and then resume use of a SRS. (As we noted in the earlier chapter, we are not currently modeling a dissolution phase of a relationship in our work.)

The initial phase of relationship building must focus on developing the user's understanding of how the system works and what it can do. The system must also engender in the user an appropriate sense of trust. *Appropriate* trust means getting the user to trust that the system can and will do the things that it is actually capable of doing for or with them. Just as importantly, it means ensuring that the user does not have too high expectations for the system. Expectations that are set too high mean that the user will often end up being disappointed by the system when it does not live up to these ideals.

Relationship creation

In order to create the kind of relationship we describe here, we draw on what is known about interactions among people and how this knowledge has been translated into other agent-based systems. The best examples of this are in Bickmore's description of the Rea real estate agent and the more sophisticated Laura exercise advisor (both described in [12]). These systems encode the factors that need to be tracked when creating and manipulating a relationship over time. Important variables to be tracked include trust and the working alliance inventory, a measure commonly used in therapy and other helping relationships that tracks trust and belief in a common goal of helping that the therapist and patient have for one another (as described by Horvath and Leslie [47]).

We have seen that to be successful along any of these measures, a system must be explicit and clear on what benefits it can potentially provide to the user. When a sociable robot system is introduced to a prospective user, the workings of the system, the requirements expected of the user, how it is a part of a new or existing social network, and most importantly what it offers to the user all must be made clear as soon as is practical. This is analogous to the beginning of a relationship between people or transition points in the relationship when they negotiate what the nature of the relationship is (friends, student/teacher, lovers), what is expected of each partner, and other aspects of their interaction (discussed previously regarding Duck's work [34]). Only when a user has a clear understanding of what the system is and what it can be expected to provide can there be an opportunity for the system to fulfill those expectations.

Long-term relationship maintenance

A very important, but little understood, aspect of the kind of relationships that are important in creating a successful ongoing interaction with a sociable robot system is the long-term nature of the relationship. In the literature on human-human relationships, this is referred to as relationship maintenance (again from Duck [34]), but there has been little work on either implementing relationship maintenance techniques or measuring aspects of ongoing relationships between a person and a sociable robot.

The main factor that we must be concerned with is whether the system is keeping the user engaged and maintaining (or building) trust over time. Based on the human relationship literature, this largely has to do with the system fulfilling the promises it has made to the user and being enjoyable to interact with. This means that the system must be able to carry through on the contract established between it and the user. It must also have means of expressing what it believes that it is accomplishing and getting feedback from the user so that a common understanding may be established.

In order to maintain the relationship over time and repair it when necessary, the system must have some way of measuring the state of the relationship in order to know where the current relationship state fits into the working model of the overall relationship. The measurement techniques will vary depending on the nature of the desired relationship, but can often be gleaned from techniques used to measure human relationships in a similar situation. In our work, discussed in the next chapter, we use tools developed in the domain of psychology that were designed for analyzing human to human interaction. Previous work by ourselves and others has shown the validity of many of these types of measure in HRI. For other types of sociable robot systems, means of measurement might be derived directly from the interaction. For example, frequency of interaction, emotional state of the user, or ways of using the system might lead to an understanding of the relationship state depending on the model used.

When necessary, techniques to improve or repair the relationship may need to be employed. Tactics such as meta-relational conversation, restatement of goals, or clarifying the abilities of the system versus expectations of the user are all methods we have considered for implementations of relationship repair. Again, we can draw on knowledge of human interactions to understand what kinds of actions should be taken in such a situation.

4.4 Target Audience Requirements

When designing any sociable robot system, it is imperative that the designer understand how the system will fit into the lives of its users. In this section, three aspects of appropriateness for target users are discussed: what requirements are necessary for the robot itself, how the separate components of the system should be integrated with one another, and the usability needs of the overall system. The next chapter gives concrete details about how each of these was implemented in our system.

Robot requirements

Based on in-home experience, one thing that is necessary of the robot is that it not be seen as too "robotic" looking, at least when designing for a general, non-technical population. When conducting long-term, in-situ studies with robots, a very refined prototype is necessary. Robots with cables hanging out, software and hardware glitches, or unfinished components clearly detract from the user's experience. In some cases, it can even prevent potential users from being willing to work with the system at all. The robot must also look good enough to fit in with whatever environment it is designed to be a part of. When conducting long-term studies, not every individual is willing to have something that clearly looks as though it belongs in a research laboratory in their everyday lives. Understanding what is appropriate in the intended environment should be accomplished at an early stage of the design process.

There are also considerations of the target population that must be taken into account: What is their visual acuity? Can they manipulate parts of the robot that must be used? Will they understand technical metaphors employed by the system? Many of these things can be difficult for the designer to realize might be a challenge for their users. A process of iterative prototyping is very important when designing for general users. Much like recommendations for HCI, we recommend building even basic mockups or early functional prototypes and getting feedback both from others who may know the target population well and from potential users themselves.

Integration of components

The ability to integrate all of the components of a system together is not trivial. As discussed previously, a sociable robot system may comprise several components in addition to the robot. The designer must ensure ease of use for the end user and an integrated experience when interacting with the system. The use of multiple components should be done in such a way that it places minimal or no technical requirements on the user. Everything required for passing data from one component to another should be done behind the scenes, leaving the user free to concentrate on the purpose of the system and not on making it work.

Usability requirements

A sociable robot system should be easy to use for any population. This includes interaction with the physical robot, with any graphical user interface, and with any other component that is a part of the system. In our work, we considered as a potential user someone who was not familiar with computers as our minimum design standard. Understanding how such a user might interact with computer vision, speech recognition, computer-generated speech, or even robotic motion is important to understanding how the overall system might be perceived.

Overcoming this challenge is one of the clear benefits of using a robot in an interaction. As was discussed in Section 2.2, the ability to both read and utilize social cues in a robot eases the burden of interaction for all users, as well as simplifying the learning process for novice users. What is required of the designer in this case is a clear understanding of what are the cues that might be used in the types of interactions that the system is being designed for. As with experimenting with how a user will accept or use a particular robot design, iterative prototyping is a powerful method for integrating social cues into a set of interactions that are being designed for a sociable robot system.

Chapter 5

Weight Loss and Maintenance

In this chapter, we discuss background research and theories on weight loss and weight maintenance as an introduction to the problem domain that will be discussed in the next chapter. These ideas were developed during a period of clinical observation at the Nutrition and Weight Management Center at Boston University Medical Center; through discussions with physicians, dietitians, and nutritionists who provide care for people trying to lose weight or maintain weight they have lost; and in conversations with individuals who are trying to lose weight or who have done so in the past. Research in recent years has shown promising new directions in the treatment of overweight and obese individuals, but there is not currently a method of treatment that is successful at helping individuals to lose weight and keep it off indefinitely. The recidivism rate of those who lose weight is extremely high, reported to be 90% to 95% in some meta studies.

5.1 Overweight and obesity

Increasing rates of overweight and obesity in recent years has brought us to the point where nearly two-thirds of our adult population falls into one of these categories. The National Health and Nutrition Survey, NHANES, in 2002 shows 65% of the adult population in these categories, with 30% obese and 35% overweight [37], with similar trends seen in children and adolescents [86]. (Overweight is defined as a body mass index (BMI) of 25 up to 30 kg/m^2 and obese as greater than 30 kg/m^2.) Much of this increase is seen as the result of a trend towards higher-calorie foods and more sedentary lifestyles [14, 84].

This excess weight leads to a significant increase in many comorbid conditions including type 2 diabetes mellitus, heart disease, high blood pressure, and some cancers among others [85]. It is noted that a reduction of even 5% to 10% of initial body weight can lead to a significant reduction in risk to these concomitant conditions [100].

5.2 Current treatment methods

There is a long history of treatments trying to effect weight loss in patients. For much of this history, overweight or obese patients were given instructions or short-term treatment and expected to lose weight and then maintain that loss independently. Only in recent years has the medical community developed an understanding of obesity as a chronic condition that must be managed on an ongoing basis [119]. Current practice uses treatments including behavioral therapy [120], lifestyle modification [35], pharmacotherapy [85], and surgical interventions [24], as well as combinations of these methods [117, 118].

There are currently a wide variety of methods for weight loss, including popular diets such as the Atkins or South Beach diets, more organized programs such as Weight Watchers™, behavior therapy programs that concentrate on healthier eating with registered dietitians, pharmacotherapy regimens coördinated with physicians, and several forms of bariatric surgery. The National Heart Lung, and Blood Institute at the National Institutes of Health (NHLBI) has written a guide for health care practitioners that describe each of these therapies, the factors that influence them, and their likelihood of *long term* success [76]. Table 5.1 summarizes current weight loss practices and outcomes. For methods that have been reported on in the obesity literature, a reported weight loss and long-term outcome is also given. The final column gives sources for this information.

A recent study looked at the efficacy of some of the commercial programs and found that there was no clinical evidence of success for most of them [110, 111]. The exception was one study (of three commissioned by the company) of participants in Weight Watchers showing significant weight loss (5.3% of starting weight) and weight maintenance (3.2% at two years, as compared to 1.5% loss and 0% maintenance with participants in self-help interventions during the same period). In general, Tsai et al. conclude that there is little support for the long-term success of most commercial weight loss programs.

5.3 Weight regain

The above-stated improvements in health and reduction in risk is lost when an individual regains lost weight. Unfortunately, nearly everyone who loses weight using current treatments gradually regains at least all of the weight that was lost during the subsequent months and years [132]. Nearly every study following up on weight loss shows the gradual regain of weight after the cessation of an intervention. An exception is the group of people who are a part of the National Weight Control Registry, a database of over 5,000 people who have lost at least 30 pounds and kept it off for over a year [127, 46]. While the methods of weight loss and maintenance vary across this group, some common factors among those successful at maintaining

Category	Method	Recommended For	Reported Loss	Long Term Outcome	Source
Dietary Management	Low Calorie Diets	any	5 - 6.5 kg	2 kg below initial weight at 5 years	[7], [6]
	Very Low Calorie Diet	any	17 kg	7 kg below initial weight at 5 years	[6]
Pharmacotherapy	Central Nervous System	BMI $>$ 30 with no comorbidity or BMI $>$ 27 with comorbid factors	6-12 kg in 12 mos.		[101]
	Gastrointestinal	BMI $>$ 30 with no comorbidity or BMI $>$ 27 with comorbid factors			
Surgical	Gastric Banding	BMI $>$ 40 with no comorbidity or BMI $>$ 35 with comorbid factors			
	Gastric Bypass (Roux-en-Y)	BMI $>$ 40 with no comorbidity or BMI $>$ 35 with comorbid factors			
Other	Calorie Counting	any			
	Weight Loss with No Treatment	study on post-menopausal women, age $\bar{X} = 59$	loss for all participants $\geq 10kg; \bar{X} = 12.5kg$	1 year: regain 42%; 4 year: regain 87%	[45]

Table 5.1: Current weight loss methods and their target population.

their weight loss is a modification of their food intake, daily exercise, and consistent self-monitoring [127].

Other studies have shown that continuing care after weight loss helps to prevent regain of the lost weight [87]. Despite these successful outcomes, it is clear that long-term weight maintenance is still an enormous challenge for most of our population. Finding new and successful ways to address this issue is an important area of work if we are to succeed at helping people to achieve a healthy weight.

While any of the aforementioned therapies can be successful at shedding pounds, reported estimates of the number of people who regain the lost weight range from a low of 80% [76] to a high of 95% [42]. The NHLBI guidelines state that

> therapy must be continued indefinitely; otherwise, excess weight will likely be regained. Numerous strategies are available for motivating the patient; all of these require that the practitioner continue to communicate frequently with the patient.

We have seen in clinical observations that most patients do not continue regular contact with their health care practitioner; most lose motivation and discontinue the practices that helped them to lose the weight to begin with.

A particular example of a weight loss system's failure that has been studied is that of eDiets.com [2]. Womble, et al. compared two groups of people trying to lose weight, one using eDiets.com (as of February 2001 through September 2002) versus a group using a dieting manual, the *LEARN Program for Weight Control 2000* [129]. The results of their study showed that participants using the dieting manual lost significantly more weight than participants in the eDiets.com condition. They posit that the two reasons for this difference are that participants did not actually log on to the eDiets.com site frequently (participants logged on an average of 17.7 times in the first 16 weeks of the study) and that the eDiets.com plan was not structured. They do note that those who logged on more did lose significantly more weight than those in the low log-on group, although the more frequent users still used the system less than they predicted for the mean usage of the entire group. We can learn from this that an impetus for using the system may need to be considered to be as important as the actual makeup of the system.

Shape Up America!'s guidelines for the treatment of obesity lists long-term prognoses for several different weight loss methods [5]. They note that for behavior change, 52% of patients maintain partial weight loss for 4 years but less than 3% maintain total weight loss for 4 years. For moderate deficit diets (1200 calories per day for women and 1400 for men), there is less long-term data, but they note that on average patients maintain 65 to 70 percent of their weight loss in the first year after treatment. For very low-calorie diets (<800 calories per day), they state that "the majority of patients regain all weight loss over the next five years." For pharmacotherapy, the long-term outcome is positive for patients who remain on the weight-loss drugs (currently sibutramine or phenterimine), but that "after the cessation of medication, the majority of patients regain weight." Surgical treatment, which is considered as an option only for those who have failed to lose weight by other means, has the one of the best long-term success records, but still leaves patients regaining 55% of their preoperative excess weight at 10 years postoperation.

The *Shape Up America!* guidelines state clearly that "higher percentages [of weight loss] are invariably associated with intensive post-treatment support." The NHLBI *Guide* says that "patients who continue to use weight maintenance programs have a greater chance of keeping weight off." However, the physicians and dietitians that we have talked to have made it very clear that the large majority of patients do not remain engaged with their treatment for the long term.

5.4 Recent research directions

In recent years there has been more research in understanding whether, how, and when existing weight loss treatments or combinations of treatments might be effective and why. The best current practice is a combination of several of behavioral therapy, lifestyle modification, pharmacotherapy, and surgical interventions. According to Wadden, et al., "participants who participate in a formal weight-loss maintenance program, exercise regularly, or both are likely to achieve the best long-term results" [116]. Ness-Abramof, et al. report that a combination of pharmacotherapy with long-term treatment to effect behavioral change may be effective to reduce the extremely high rates of recidivistic behaviors following weight loss [85]. The PREMIER study also showed that using behavioral interventions together with self-help treatment was successful at getting individuals to modify their lifestyle in order to reduce hypertension, resulting in some of the same behavior modifications necessary to achieve successful weight loss and maintenance [35].

Research in Internet-based methods of ongoing support have shown promise at delivering weight loss counseling. One study showed the effectiveness at using Internet-based methods to deliver weight loss counseling focusing on behavior change [108] and another showed that a combination of e-mail counseling with an Internet-based weight-loss program was effective at helping individuals lose weight [107]. The challenge in interpreting these studies is that "Internet-based" is potentially an extremely wide definition of treatments. It is possible to deliver anything from a web site that explains a diet to a support group where an individual can talk with others up to a video chat with a physician over the Internet. While these earlier studies showed the potential uses of the medium, clearly more work is needed to determine what therapies, interventions, and support methods are useful to those trying to lose weight or maintain their weight loss.

In addition to clinical research, there has been an increase in methods focused on this long-term behavioral change available to consumers. Two notable examples are the myFoodPhone and eDiets.com, both Internet-based services aimed at keeping people on their diets. MyFoodPhone is a service that allows individuals to use a camera phone to upload pictures of anything they eat to a web site where they can get feedback from the community of others trying to lose weight, as well as from a nutrition advisor [3]. eDiets.com is a web site that allows users to choose from among twenty-two diets and then helps them track progress [2]. As noted above in Section 5.2, there is little evidence as of yet to support any of these programs, although some of them have caught on with consumers. Womble, et al. studied eDiets.com in particular in a comparison with a self-treatment manual and found that women lost significantly more weight when given the LEARN manual for weight loss [23] than when assigned to use eDiets.com [129].

Chapter 6

Design Requirements for a Weight Loss Coach

In this chapter, we present a concrete example of a sociable robot system that applies the principles presented in the previous chapter. We describe the development and evaluation of a sociable robot system to assist people who are trying to lose weight. The system was designed to help people more easily do what clinicians currently ask them to do in weight loss programs, namely keep track of their daily caloric intake and their daily time spent exercising. A description of the application is provided, along with sections that parallel the design principles chapter and explaining the decisions that were made for implementation.

In designing and constructing the weight loss coach, we addressed the four main areas for creating a sociable robot system:

- We created the *sociable robot system* by constructing our own robot with customized software and minimal need for integration with other components to allow for more rapid deployment.
- The *interactions* with the user were carefully considered to support the next two design areas. Successive iterations of interactions were created to allow for testing and feedback and to integrate with the robot hardware and other software components as they were developed.
- The model that was created to develop, manage, and track the *relationship* between the user and the system is one of the most important parts of the system. A clear understanding of what the trajectory of the relationship should be, as well as how to respond depending on the state of the relationship, is very important for a successful implementation of this sociable robot system.
- Understanding the needs of *target audience* is another key aspect of developing a successful sociable robot system. For this application, we assumed that our

potential users were not necessarily computer literate and did not have much experience with technology. These assumptions were borne out in our study for some of our users and the resulting design decisions proved to be useful for all users.

We have created this sociable robot system to address the biggest known shortfall in current weight loss programs, getting people to remain engaged in their own treatment for longer periods of time. Each time a user interacts with the system, it greets them, makes small talk, asks for recent data about eating and exercise, offers feedback and suggestions, asks questions about the interactions, and encourages them to come back again. Overall, these types of interaction encourage the user to form a relationship with the robot that keeps them coming back and using it on a regular basis. (A more complete description of the interaction is in the 8.1 section of Chapter 8.)

6.1 Sociable Robot System Requirements

The overall system was made up of two technological components: the robot and a pedometer. For many participants in the study, a health care provider (physician, dietitian, nutritionist, etc.) was also involved peripherally. The user is at the center of the system, connecting everything together. A diagram of the system is shown in Figure 6-1.

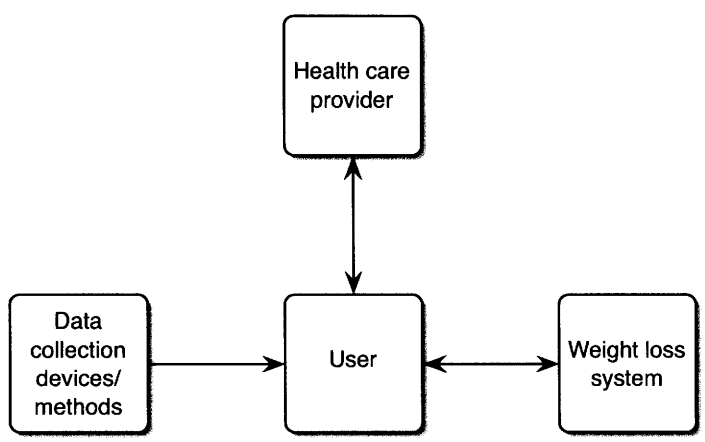

Figure 6-1: Block diagram showing the four main components of the system.

Robot

The robot is clearly the portion of the overall system that the user focuses on. It is also the most complex to create, particularly when building a set of robots in the laboratory that are intended to be placed in experiment participants' homes for periods of weeks at a time. Much of the time in preparing for the study was spent in designing, building, testing, and refining the sociable robot hardware and software. The four factors from the previous chapter are again addressed in the context of their application to creating this system.

The robot has a limited ability to *express state to the user* using physical capabilities (e.g. eyes, mouth, arms, hands), so we rely more on what it can say as well as display on its screen. The physical design of the robot, as will be discussed in Chapter 7, has four degrees of freedom in the neck and eyes. This, along with a camera and face tracking software, allows the robot to make eye contact during interaction, which we know to be very expressive and engaging. The contingent movement of the robot head and eyes to the user's face draws the user into interacting with the robot.

Because the entire robot, hardware and software, was designed in the laboratory, we could completely control its *ability to be integrated as part of the larger system.* The hardware and software were designed with this integration in mind, which greatly reduced the challenges that would have been faced had a commercially available robot been used as the interface to the weight loss system.

Likewise, the *programmability of the robot* was completely under our control. All of the software, with the exception of a few open source components used to provide peripheral features, were written expressly for this system. A complete description of the software that has been developed is in Chapter 8.

The *availability of the robot* was a factor of our ability to produce them in the laboratory. This was much more complicated and time-consuming than purchasing an off-the-shelf robot, but there was no existing robot that was available that would have been capable of meeting all of the other requirements necessary for creating this system. We built seventeen robots that could be deployed in our long-term study.

Technological artifacts

The design of this system required a minimum number of components outside of the robot. The touch screen display on the front of the robot is in some senses a component outside of the robot, but it was very tightly integrated into the robot itself. This display allowed the user to read information that the robot was speaking aloud (the computer generated speech was not always perfectly understandable to some users) and to respond to the robot's questions about calorie consumption and exercise behavior.

Participants in the study were also given a pedometer to help them keep track of their exercise by counting the number of steps that they took throughout the day. The integration of this component did not include a direct technological link, rather the robot's interaction with the user asked them to read off the information from the pedometer at an appropriate time. The experimenter also explained the use of this pedometer to study participants to give them motivation for using it by explaining how it was an important part of using the weight loss system. Together, these made the pedometer an integral part of the weight loss system for many participants in the study.

Means of interaction

The methods that were used for interacting with the user are created through the robot and the user interface on the display. All of the interactions are driven by the user and the combination of the robot's physical and vocal actions along with the text and graphics on the screen guide the user through using the system. The aforementioned consideration for non-technically trained users ensured that the system would be simple to use for anyone.

The robot had a small set of behaviors that it could draw from during interactions. The most commonly used was the look-at behavior. While in this mode, the face tracker application passed the location of the user's face relative to the robot to the motor system, which kept the eyes of the robot looking at the user and appearing to make eye contact. This might be interrupted for two reasons: when the system wanted to draw the user's attention to the screen, the robot would initiate a behavior of look-at-screen; and when the interaction had finished, the robot would use a look-down behavior in a slight imitation of sleepiness. Both of these seemed to be effective at being interpreted as the designers had desired during early testing and were used in the final implementation. More detail on the hardware and software support of these behaviors can be found in the following two chapters.

The user interface had three basic types of screens: showing spoken output from the robot, gathering feedback from the user, and showing collected data to the user. The first type of screen, displaying spoken text, was used for two reasons. The computer-generated speech could be difficult to understand for some users in early testing, but we found that it could be easily disambiguated by showing the text on the display at the same time. We concurrently used the same screen layout design to allow the user to continue the interaction by responding to the robot. These responses were in the form of buttons across the bottom of the display and the user could choose what they perceived as an appropriate response at that time. The second type of screen were those that got information from the user. This information was either numerical (number of calories, amount of exercise) or on a slider (relationship-based questions). Both of these were introduced to the user in ways that would be familiar: the numerical inputs were described as akin to a calculator or an ATM display and the slider was compared to Likert scales on a questionnaire that the users had just completed during the intake process at the point when they were shown the interface on the screen. The final type of screen used a graph-based display to show the user information that they had entered into the system in recent days. (All of these screens are illustrated in Chapter 8.)

Based on early feedback, we created the system in such a way as to guide the user through the entire process of keeping track of their data. Once they touched the *Start Interaction* button, the system explained each step of the process. The explanation varied over time and depending on relationship state. During the first interactions, the system offered more explanation as to how to complete each step of the process and why it was being done. Over time, these explanations were shortened to make the interactions faster and so as not to annoy the user with repetitive, extraneous information. If the state of the relationship were judged to need repair, the robot would return to meta-relational behaviors that included more discussion on the importance of some of the steps in the interaction.

Network of people

When researching the needs for a system such as our weight loss coach, another important factor for people who are more successful at losing and keeping off weight is the support of others around them. There are generally two categories of people who provide support: friends and family who are around the person on a regular basis and professional caregivers (physicians and other clinical staff as well as personal trainers or coaches) who provide support and advice on a less-frequent basis. The motivations for interacting with each of these two groups is different and the system must be designed to support them in different ways.

The most common form of support from family and friends is what we commonly refer to as moral support – congratulating the person when they are successful and providing goodwill and encouraging words when needed. The level on which sharing with this group happens is abstract and not data-driven. We offer two ways in the system to support this. The first is a demonstration mode on the robot. This allows the user to show off the system and its capabilities without sharing their personal data about calories and exercise. It lets them engage another person by showing off the capabilities of the system and sharing what it is that they are doing on a daily basis without requiring that the other person sit through a full four or five minute interaction. There is also a shortcut to showing the most recent week's graphs of calorie consumption and exercise directly from the home screen when the robot is started. We have found that many individuals wanted to be able to share this high-level sign of progress or accomplishment with their friends on family when they had someone close who provided support.

Many participants in the study were also seeing a doctor, dietitian, nutritionist, trainer, or weight loss coach on a regular basis. These visits ranged from somewhat frequent (once every two weeks) to fairly infrequent (once every two to three months). As with many weight loss programs, many of these had asked our study participants to track the very things we were asking them to. Almost none of the participants starting the study had been tracking this data at the point when they started the study, however. For those using the robotic system, they wanted to be able to share this detailed data with their professional weight loss helper. Because the duration of the study was relatively short, we did not build a way into the system for them to print their data directly, but we did provide them with a printout or copy of their data at the conclusion of the study. Had the period during which they were using the system been longer, it would have been important to directly give to them the capability of printing or otherwise sharing this information on a regular basis.

In terms of the three types of interactions discussed in the previous chapter, the demo mode can be either the first type (system to another person) or second type (robot to group of people including main user) depending on the user's preferences. The data for other weight loss providers is the third type of interaction (person to person).

A notable difference between the proposed work and previous work on behavior change systems (discussed previously in section 3.6) is the way this system is designed to fit into an existing treatment and support network. While the work of Bickmore [13], for example, is directed at building an entire social support structure using a technological system in the form of a relational agent in the rôle of an exercise advisor, a design goal of this project is to have the system fit into an existing, functioning social support network.

Figure 6-2 conceptualizes the idea of social support networks as described in section 3.5. In this model of a patient's social support network, the patient interacts with family, friends, health care workers, and the weight loss system. The person who is trying to lose weight is shown at the center of the diagram. Around him are the potential components of his social support network. From the top right moving counter clockwise these are a physician, friends and family, other health care providers, two input components of the system described here, and the robot. This shows the intended design of the system, having it fit into an existing social support network rather than replacing it.

There are three kinds of patient-specific information in the system, goals set with their healthcare provider, data about their daily activities, and responses to inquiries from the system. Table 6.1 summarizes the data that is kept, who has access, and how that access occurs.

Goals are agreed upon between the user and their health care provider at regular meetings or determined solely by the user. The goals are then input into the system by the user. Information on daily activity is collected by the user on a regular basis and is accessible to the user at any time. If the user decides to share the information

Figure 6-2: Social support network model.

with their health care provider that may be done, but to protect the user's privacy there is no mechanism for automatically transmitting that data. Finally, the system requests user feedback through the robot and the on-screen interface and will collect statistics on usage of the system. This information is available only to the experimenter for purposes of evaluation of the system and users were fully informed as to what information is collected, how it is used, and who has access.

Data type	Accessible by	Access how
Goals	User	Direct access to system
	Healthcare provider	Shared by user
Daily activity	User	Direct access to system
	Healthcare provider	Shared by user
System responses	Experimenter	Direct access to system

Table 6.1: Data kept by system, who has access, and how access occurs.

6.2 Interaction Requirements

The interactions with the weight loss system were designed with the three requirements from the last chapter in mind: initial and ongoing strategies for *engagement* to get the user to interact with the system, the ability to *motivate* the user with respect to their goals on a continuous basis, and the formation of *trust* over time so that the user would be able to depend on the system. The techniques that were employed for each of these three aspects of successful interaction are discussed here. The components of the system that the user interacts with are illustrated in Figure 6-3. The person interacts with the robot and the touch screen display. Also shown is the pedometer, used for tracking exercise.

Figure 6-3: Main components of the system.

Engagement

Initial and immediate engagement with the system is relatively easy for two reasons. The first has to do with our user population: they are looking for something to help them to lose weight and keep it off, so the promise of the system draws them in. The second has to do with the nature of human psychological response to a robot that looks at them. We created a robot that would attempt to make eye contact immediately, which we know draws a person into the interaction very quickly.

Once the person starts to interact with the system, the robot uses small talk and humor to continue the engagement. These methods (discussed previously in Section 3.4) are known to be effective in human interpersonal communication and have also been effectively deployed in previous interactions between humans and technology. These conversational behaviors, alongside the physical behaviors, are beneficial to keeping up engagement over time. We have seen that people respond positively to these behaviors when they are performed by the robot and cite them as one of the main reasons for continuing to use the system over time.

Motivation

The robot provides motivation through its regular feedback to the user about their behavior and progress toward their goals. Regular feedback is a useful tool for keeping a person motivated when performing a behavior over time. The system gives both short-term and long-term feedback which helps to encourage users about behavior that has recently been performed as well as about their actions over time. The short-term feedback is a verbal statement (as well as being printed on the screen as with all spoken language) about the behavior that has just been reported for the current day. For example, if the user has come in under their calorie goal, the robot might say something like "Good job coming in under your calorie goal so far today. I hope you can keep it up!" and if their exercise has fallen short of the goal they have set, the feedback could be "I see you haven't met your exercise goal so far today. Do you think we could work on that?" Many participants report that this feedback keeps them motivated to work toward their goals within a given day.

The longer-term feedback is a graph of recent calorie consumption or exercise amount. This is a bar graph (that can be seen in Chapter 8) that shows seven days of data along with a line showing the goal. Users report finding this graph to be very useful at seeing the longer-term trends in their behavior and letting them know how their activities have changed over a week. This has been seen to provide motivation to keep up with positive behavior (not wanting to upset a trend of successful days) or encourage turning around bad behavior (seeing several bad days and wanting to make up for it).

Trust

The ability to create and build up trust over time is important to keeping the user happy with the system and believing that it might do something worthwhile for them. Trust is set up by initially making promises about what the system can do. These are made in two ways. The first is that the experimenter describes to potential participants and then participants who begin the study what the system is designed to do for them. These comprise some of the explicit promises that are made about the capabilities and benefits of the system. Once the user begins to use the robot (the experimenter is no longer involved after the initial visit until the study period has ended), the robot begins to make claims about what it can explicitly do (help the user keep track of their progress) and implicitly provide (getting them to their weight loss goals).

Once these expectations have been set, the system must live up to them by working reliably and correctly over time. Reliability has to do with the hardware and software functioning as expected when needed. This mostly requires testing of the physical components and the various states of the software. This can be accomplished by following traditional mechanical, electrical, and software engineering methodologies.

The perception of working correctly has to do with the system providing the appropriate feedback and suggestions to the user at the right time. There is no one way to do this that will work for all users, so the system must learn and adapt over time to be able to make suggestions that a user finds useful. In the case of the weight loss system, the robot provided mostly helpful, supportive suggestions that were tailored to recent trends in activity on the part of the user. In the study, most users perceived that the graphing and feedback mechanisms were working well and living up to their expectations. Those who were disappointed wanted a larger variety of suggestions if they found that they were already acquainted with many of the types of suggestions offered to them by the robot.

6.3 Relationship Requirements

Relationship model

As described in Section 4.3, developing a model for creating a relationship between a user and the sociable robot system is one of the most challenging aspects of this work. This section builds on that theoretical description to describe what we have built for the weight loss system implementation.

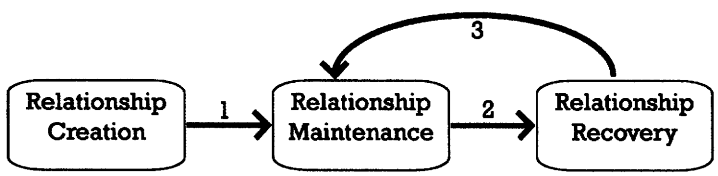

Figure 6-4: Three states of human-robot relationships

There are numerous kinds of relationships that could be used as the model for the system. The choice of these models impacts the design of the three phases laid forth in the previous chapter. We use the model discussed there in order to describe the overall trajectory of the relationship and it is shown in Figure 6-4.

The interaction model then defines the personality type that the robot attempts to project to the user. The sociable robot system could act as a fitness coach, advising the user on their exercise habits and encouraging ones that would contribute to their weight loss or maintenance goals. It could model a weight loss patient's relationship with their doctor, offering advice on their general health and health factors related to overweight and obesity such as obesity or cardiac disease, as well as making suggestions for treatment and lifestyle changes. The relationship could be that of a nutritionist or dietitian, with the system asking for information about the user's eating habits and constructing advice around proper diet and changes that should be made to the user's diet. Another model is that of a friend who is going through similar challenges in weight loss, which is known to be effective. The system and user could discuss and commiserate over the difficulties of exercising regularly and eating correctly.

Each of these models has its attendant challenges. A fitness coach is thought by many people to be limited to talking about exercise-related topics. A doctor has a much larger set of knowledge and expertise than we can reasonably anticipate putting in a sociable robot system. As with a coach, the nutritionist/dietitian is also thought to be limited to discussing one factor related to weight, in this case the user's diet. The model of robot as friend is one that we believe to be disingenuous and would be seen as such by a user, as the range of topics it is capable of discussing and the emotions it can understand and convey are both limited. It is obvious that the robot and the system are not truly going through the same problems that the user is, so it would likely be seen as fakery and not adhered to.

This leads to the model that has been chosen, that of the system as a helpful companion that keeps track of progress and offers suggestions. The system situates itself as having access to some useful information as opposed to being an "all-knowing" entity. This model draws on some aspects of the other models that are described, such as the advice that might be given by a coach, dietitian, or nutritionist or even simple advice that may be offered by a physician. Important aspects of creating this include communicating to the user the capabilities, as well as the limits of the capabilities, of the system. Building on the relationship model that we have developed for sociable robot systems in general, this implementation will add components for weight loss and the nature of the relationship in order to create the correct interactions and long-term behavior of the system with the user. In particular, based on our clinical observation phase of research, the system should always remain upbeat, friendly, and helpful regardless of the user's recent performance towards their goals.

Relationship creation

The first part of the relationship model is the creation of the relationship between the user and the system. Initially the experimenter describes the capabilities of the robot to the user, which sets up certain expectations before the user has their first interaction with the robot. We keep this discussion to a minimum, mostly describing how the robot works and what the user can do with it. During early interactions with the system, the robot offers explanations of its capabilities, of what it is trying to accomplish with the user (i.e. helping them to stick to their diet), and how the user can interact with it (e.g. "Use the buttons on the next few screens to tell me about what you have eaten so far today.").

These interactions at the beginning of the relationship between the user and the system set up the ability to build trust over time. The robot tries to clarify what capabilities it is capable of providing for the user (namely, working toward their goals by keeping track of data) and supporting these assertions by giving regular feedback and suggestions that correlate with the user's activities. The successive interactions should be able to build on this early set of interactions to create a sustainable relationship over time.

Long-term relationship maintenance

As the user continues to interact with the robot, the system assumes that they are learning about its capabilities and how the interactions work. Much like a human in a teaching/learning scenario, over time it reduces the amount of discussion about its capabilities and about how to interact with it, letting the user recall details from previous interactions. This allows the user to develop a sense of mastery in using the system, as their interactions speed up over time.

When the system detects that the relationship is not going well based on responses to its queries to the user about the interactions, it enters into a recovery phase. Much like the initial relationship-building period, in the recovery phase the system returns to meta-relational discussions regarding the interactions. The purpose of these recovery period interactions is to increase the user's belief in common goals and tactics for reaching those goals. Once the relationship state seems to have recovered, again based on user input to questions about the relationship, the system returns to the normal mode of interaction.

6.4 Target Audience Requirements

Chapter 5 gave an introduction to current clinical findings and ongoing research in weight loss and weight maintenance. In this section, we briefly discuss the applicability of these systems to our work.

There are two types of needs that we are considering for our target audience: those having to do with weight loss and needs relating to technology.

To better understand the needs of potential users, we spent time beginning early in the project conducting ethnographic research on current methods for treating obesity and the weight loss process. Working with a physician, nutritionists, and their support staff, all at the Center for Nutrition and Weight Management at the Boston Medical Center, allowed insight into current techniques and methodologies for treating patients who desire to lose weight. This also gave us a view into the practices of the individuals attempting weight loss or maintenance to better understand what their needs are. In order to build a successful system, spending time with physicians in the clinic, in clinic-based group settings where people discuss their progress in managing their own weight, and in non-clinical settings such as people talking about their experience in Weight Watchers™groups was very informative and useful.

When engaging in any type of weight loss or management program with a health practitioner, patients are asked to keep written records of calories eaten and the amount of exercise done, or food and exercise logs. The goal of these logs is to make patients more aware of their daily activities that affect their weight. During visits to the doctor or dietitian, their daily calorie limit and target exercise time is set. The logs also help the patient to engage in a more meaningful dialog with their doctor when they bring them in. While doctors and dietitians have remarked that the patients who do come back with their logs are the ones that are more successful at losing and keeping off weight, they have told us that very few patients come in with their logs. In the 14 doctor-patient sessions observed during the first period of clinical observation with returning patients, one brought completed food and exercise logs in with them.

The work of Wing and Hill highlights strategies of people who successfully maintain their weight after weight loss [127]. They define long term weight loss as "achieving an intentional weight loss of at least 10% of initial body weight and maintaining this weight loss for at least one year." They cite keeping careful record of dietary consumption and frequent weighing as two components of what they refer to as a "general construct of cognitive restraint (i.e. the degree of control one exerts over eating behaviors)." It is this cognitive restraint that they suggest is what sets apart people who are successful at long-term weight maintenance from those who are not as successful.

What the various more successful methods of long-term weight loss have in common is low long-term adherence to the program. This is exactly the behavioral issue that we address in the design and construction of our system.

Weight loss lessons

What we can see from the related work is that making the lifestyle changes that lead to weight loss permanent is an enormous challenge. Changing perceptions of weight loss from a one-time diet to an overall modification of behavior is the focus of some of the current research in weight loss. Our system is designed to fit in with current best practices as either a standalone assistant for encouraging behavior change or as an adjunct to existing weight loss programs, pharmacotherapy, or surgical procedures. The goal of the sociable robot weight loss coach is to help individuals who are trying to lose weight and maintain their weight loss to remain engaged in keeping up their healthy behaviors over long periods of time. The relationship that can be created between a person and the robot could be a large improvement in maintaining adherence to changes that have been made and therefore in reducing weight gain over time.

Robot requirements

The criteria that we placed on the initial robot designs were mostly related to appearance. We wanted to robot to be viewed in a particular way in users' homes and as part of their everyday lives. The robot should appear friendly and warm, not like something imagined out of a science-fiction film. We also desired to have a slightly feminine appearance. Nearly all users will attribute gender to the robot (for some reasoning, see older work by Nass, et al. [82]), so we wanted to suggest a particular gender to them and a female personality will typically be seen as more warm and friendly – cultural stereotypes of females – as well as more likely to be listened to by women, who made up the majority of our study participants. (Background on gender in computer-generated voices such as the type we employed can be found in several papers by Nass, et al. [83, 80, 73].)

The robot was also created with big brown eyes that appear friendly. The movement of the eyes and the neck are slower and more exaggerated than a human or many animals. In early tests, this movement gave the appearance of a better match with the look of the robot to observers. It was also easier to interpret the movement than when the robot moved too quickly. Refining the speed and trajectories of the movement was an ongoing process starting with initial construction and finishing only when the robots were deployed for the study.

Integration of components

The software architecture that we designed allowed for complete control in changing the on-screen interface, face tracking, head and eye movement, and vocal output independently of one another. During our iterative system prototyping, this allowed for continual changes to subsystems to improve their working with the overall system. All of these components were modified after they were initially created while we iterated the design and interactions between users and the robot.

Users found the final version of the system to be very easy to use. Individual users had only to set their goals in the beginning (they could be updated later) and enter data on a regular basis. The data entry screens shared formats with one another and used layouts that should have been familiar to most users, that of a calculator or ATM interface. In practice, we found that this interface was indeed very easy for everyone to learn and use regularly.

Usability requirements

The entire system must be easy to use for any potential user. As previous sections have discussed, we designed this system, in particular the robot and its on-screen interface, to be simple to learn and to use for any user, whether or not they are experienced and comfortable with technology. There were several things that were important considerations throughout the design process: the system had to guide the user through each step of use; the display had to be easy to read, even for people with limited vision; the buttons on the touch screen had to be large and well-spaced, particularly for our older users with reduced manual dexterity; and the robot had to be explicit in its movements so that they would be readily understood.

Portions of this can be accomplished through proper accessibility design in the UI, namely the ability to read and respond to items on the screen. The text size; text and background colors; and button shape, size, and spacing were all developed to achieve these goals. Once there was a working set of UI parameters, these were coded in the UI manager, which made it simple for the remainder of the system to utilize the correct display options. Based on previous robotic work and early prototypes, we developed an understanding of the appropriate factors that affected user interpretation of the robot's movements. The range of motion, speed of movement of each degree of freedom, the timing of motions with one another and with what was happening in the interaction, and the actual positions of the head and eyes were all components of creating useful and believable motion. For example, the robot would look down at the screen when trying to draw the user's attention there or put its head and eyes down in an imitation of sleep when a particular interaction had ended. These behaviors were informally tested on naïve users until they were read in the way that we had intended.

The overall ease-of-use of the integrated system was the biggest challenge. We wanted the system to be able to guide any user through its use, particularly novice technology users. At the same time, it shouldn't be frustrating to experienced computer users by seeming too oriented toward beginners. Much of the effort in our iterative prototyping was focused around this issue. This problem was approached in two ways. The first was by observing novice users attempt to interact with early versions of the system and understand what questions arose for them during their use of the system. As a result of these observations the system was either changed to remove the actions or steps that were not understood or the text or behavior of the robot were added to in a way that helped to explain to the user what should be done at the point of possible confusion. The second aspect of this explanatory behavior was the ability to scale it back over time as the user learned how to use the system. The system knew how many times and how frequently the user had interacted with it. Based on these variables, the amount of explanation given at any particular time could be modified based on the user's history or preferences. In combination, these techniques worked very well in addressing a variety of user backgrounds and capabilities.

Chapter 7

Hardware Design

7.1 Overall design

The overall design of the robot was created with several factors in mind:

- We wanted to utilize off-the-shelf computer components and hobby servos to make the construction process faster, so the size and shape of each of these existing components had to be taken into account.
- We wanted to minimize the number of degrees of freedom in order to make construction simpler and improve the lifetime reliability of the robot to prevent (or minimize) repairs while robots were in homes.
- A figure suggestive of a human was desired. We also wanted to give the robot a slightly feminine appearance.
- A touch screen was needed as input so that we did not have to rely on speech recognition.
- Moving eyes were a key feature for initially engaging a user in the interaction.

The design process began with the selection of the off-the-shelf components that would be used, as the rest of form would be built around that. Once those components were decided on, we began a process of exploring different forms and configurations based around these items. An early cardboard mockup can be seen in Figure 7-1.

From here, we worked with a succession of outside designers to create form sketches, which can be seen in Figures 7-2, 7-3, and 7-4. The final model was then 3-D printed as a prototype and used as a basis for the construction process described below.

Figure 7-1: Early cardboard mockup of robot form.

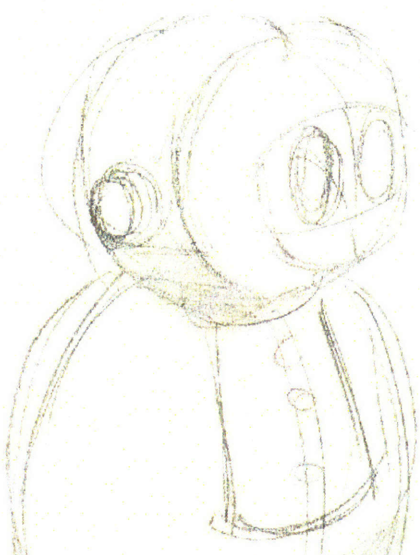

Figure 7-2: First iteration of design.

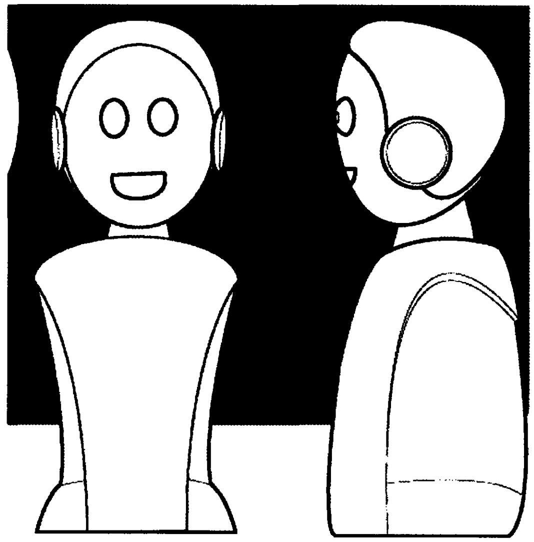

Figure 7-3: Second iteration of sketching.

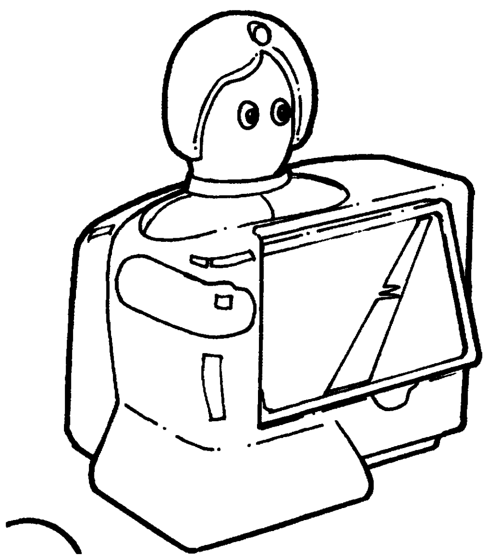

Figure 7-4: Final design before solid modeling.

7.2 Moving components

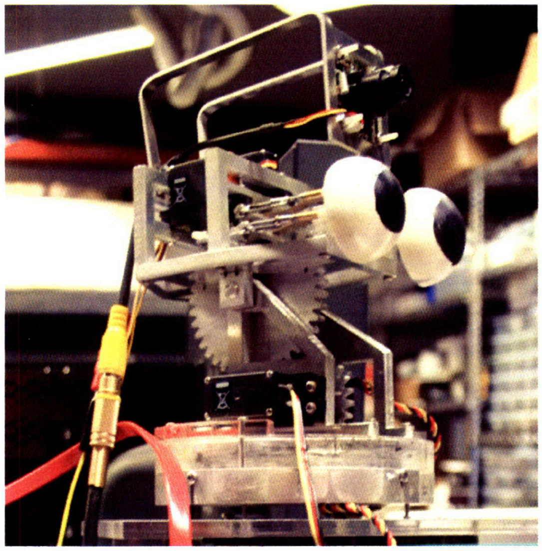

Figure 7-5: Original head design prototype.

The robot has four degrees of freedom: neck up/down, neck left/right, eye up/down, and eye left/right. The eyes are coupled together so that their motion is always paired; the lack of vergence is not noticed with this robot design. This is a simple way to give a full circular range of motion for both neck and eyes, giving the robot the ability to follow a person within a reasonably large area in front of it. Based on these principles, early sketches were drawn up and turned into a solid model that could be checked for fit and dimension. From this a first prototype of the head components were created and the structure was assembled, as shown in Figure 7-5. After testing this assembled head, the design was slightly revised for both the eyes and the neck to allow for better range of motion with the head shells on and a final design was created. The set of heads that were assembled based on this final design can be seen in Figure 7-6.

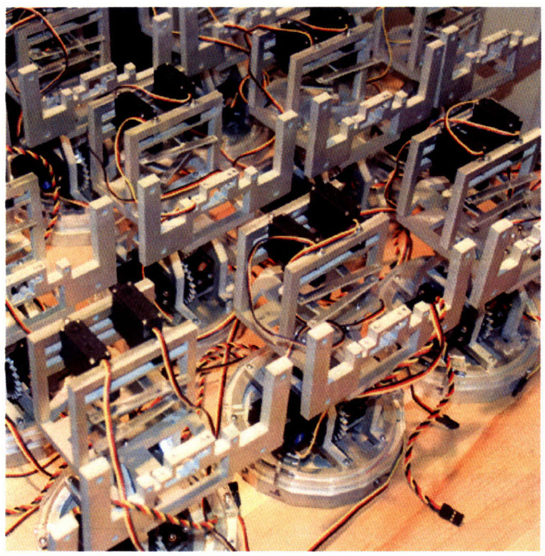

Figure 7-6: Final head design assembled.

7.3 Electronics

Most of the electronic components for the robot were purchased from PC and RC hobby companies. The computer components of a robot consist of an ATX motherboard, a 3GHz Pentium processor, 1GB of RAM, a 320 GB SATA hard drive, and an ATX regulated power supply. There is a Mini SSC II 8-channel servo controller from Scott Edwards Electronics that connects to the computer via serial interface and directly to each servo and the power supply. There is a small CCD camera from Supercircuits mounted in the head that is connected to a KWorld video converter to digitize its output. This is in turn connected to a USB port on the motherboard. There is a small speaker for audio output connected to an audio amplifier board. A PCI slot fan is used on the side of the robot to prevent overheating of the main area that contains the processor. Finally, the touch screen is a 7" VGA touch screen from Lilliput Electronics (China). The display takes input from the VGA output of the motherboard and sends touch position output via USB.

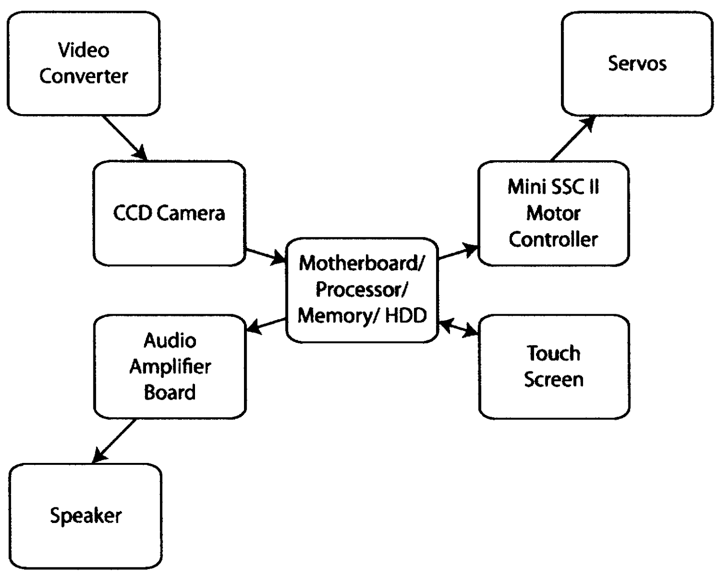

Figure 7-7: Diagram of electronics components in robot.

A diagram of the electronics hardware is shown in Figure 7-7.

The only custom electronics component is an audio amplifier board. This was designed to take the output from the audio line out of the motherboard and amplify it to appropriate levels for the speaker. The board was sent out to be fabricated and is shown in Figure 7-8.

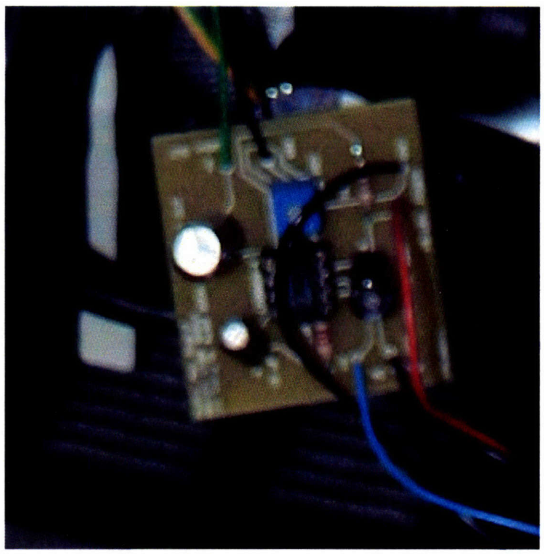

Figure 7-8: Audio board for driving speaker output.

7.4 Structural components and shells

The main internal structure of the robot is built from polycarbonate for strength and durability. All of the other components of the robot are mounted off of this frame, which is seen in Figure 7-9.

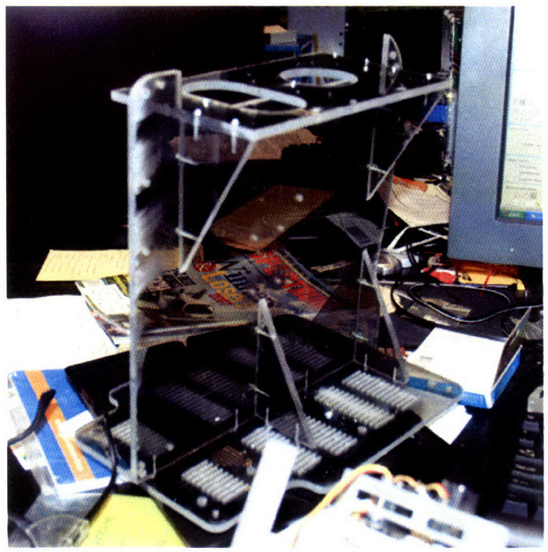

Figure 7-9: The bare assembled frame.

This structure consists of a base, an upright component, and a top, along with six supports for assembly. There are six shell pieces that are attached to the structure and cover most of the internal components: two head shells, two neck shells, and two body shells. These can be seen in Figure 7-10. The construction of each of these is described in the next section.

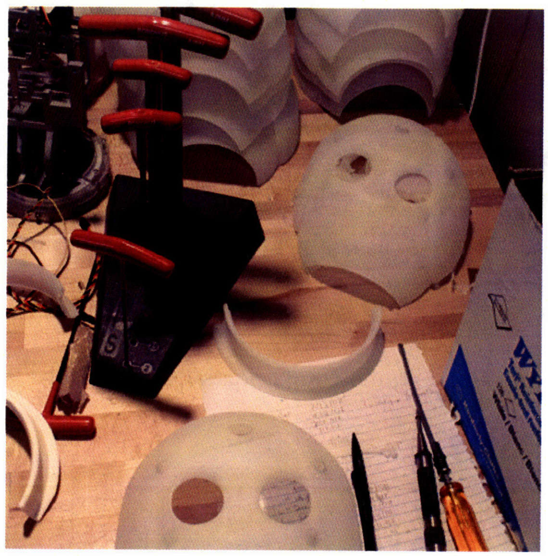

Figure 7-10: Stack of shells waiting to be painted

7.5 Construction process

The construction of the physical robot was the most time-consuming part of the work. This section describes and illustrates the construction process for each of the components of the robot.

Figure 7-11: Frame components cut and laid out.

Frame

The internal frame consists of nine components and is cut on the water jet from polycarbonate based on drawings from a SolidWorks model. The pieces can be seen in Figure 7-11. It is assembled into the structure seen in Figure 7-9 using 30 screws. This frame is structurally very sturdy and all other components of the robot are attached to it. It rests on four rubber feet that elevate it slightly to allow for airflow through vents on the bottom and to protect any surface from being scratched by the screws used for assembly.

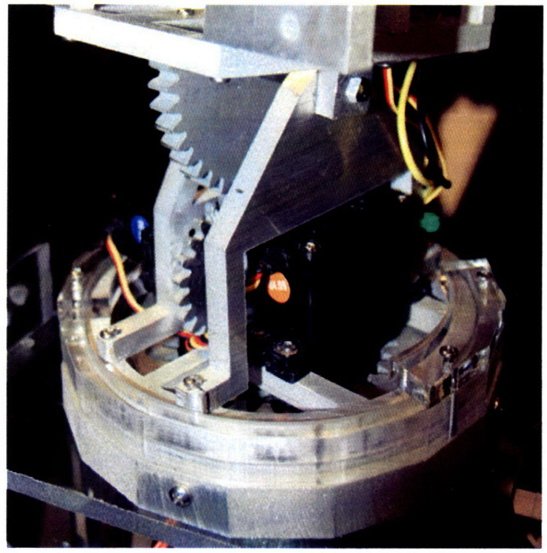

Figure 7-12: Neck servos connected to gears.

Head

The head and neck assembly is the most mechanically complicated portion of the robot. The two degrees of freedom (DOF) in the neck are driven by CS-70MG (metal gear) and CS-30MG hobby servos, which are reasonably powerful, compact servos. The metal gears (as opposed to plastic) make the servo more durable. These two DOFs are direct-drive gears, as seen in Figure 7-12. The left/right servo is mounted to the main portion of the head, which rests on small rollers above the neck. The shaft of this servo has an aluminum gear attached to it and this gear is mated to a larger gear that is mounted in the base of the neck, which in turn is attached directly to the frame of the robot with four screws. Turning this servo turns the head in the opposite direction. The up/down servo is mounted to this main portion of the head next to the left/right servo. It has an aluminum gear attached to it which mates with a half-round gear that is attached to the upper portion of the head. Turning this servo directly moves the head up or down.

The upper portion of the head has two CS-12MG servos mounted in a frame as seen in Figure 7-13. These are connected to the eyes through T-shaped aluminum pieces. The base of the T is connected to a servo and then connected to the eye mechanism in a position that is offset from center. The up/down servo is connected above the center and the left/right servo is connected to the side of center. Each of these is offset from the center axis of the eye by approximately half an inch, allowing for direct control of each axis by pushing or pulling on the rod connecting the servo

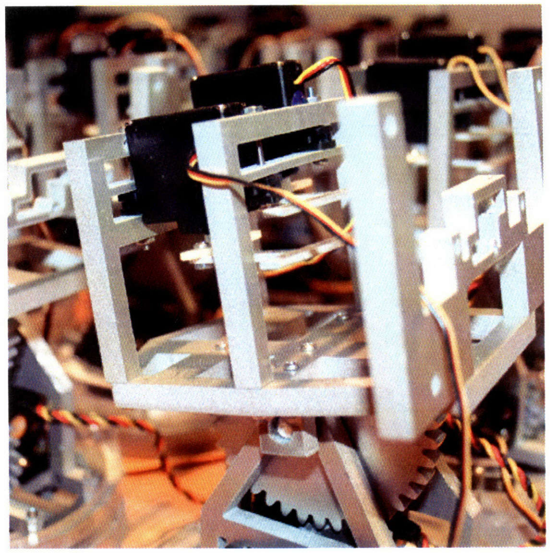

Figure 7-13: Eye servos attached to frame.

to the eye assembly. This mechanism without the eyeball attached can be seen in Figure 7-14.

All components of the head were constructed based on the solid model depicted in Figure 7-15. Most components are made of aluminum and were cut on a water jet. Parts of the base that hold the upper portion of the head in place and the cross mechanism to which the eyeballs are attached were made of clear acrylic and were cut on a laser cutter. All pieces were finished (sanding and filing) by hand and assembled by hand. Each head has approximately 140 components. A fully assembled head without eyes or shells attached is shown in Figure 7-16.

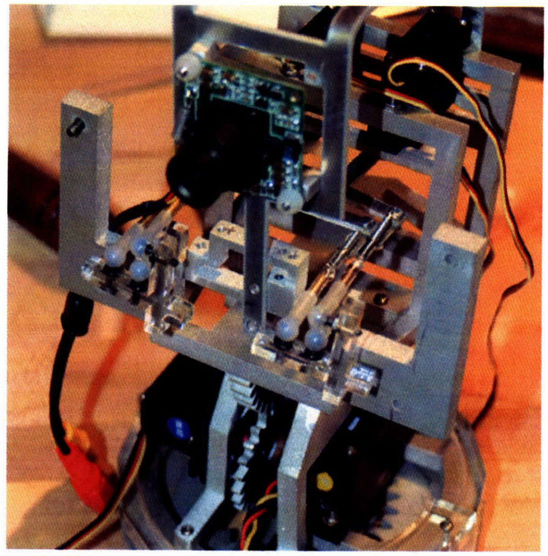

Figure 7-14: Eye attachment mechanism.

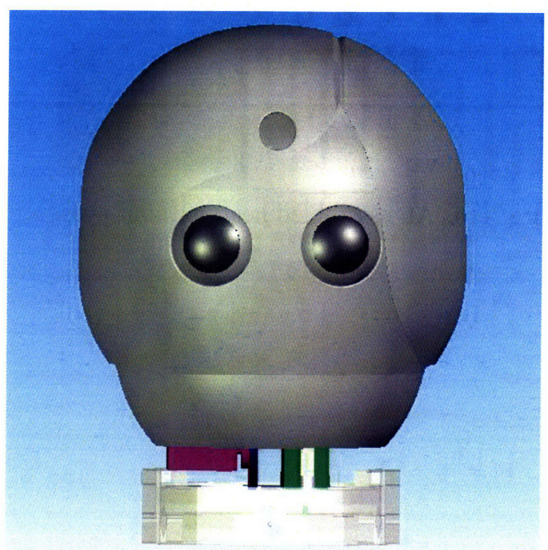

Figure 7-15: Software solid model of the head.

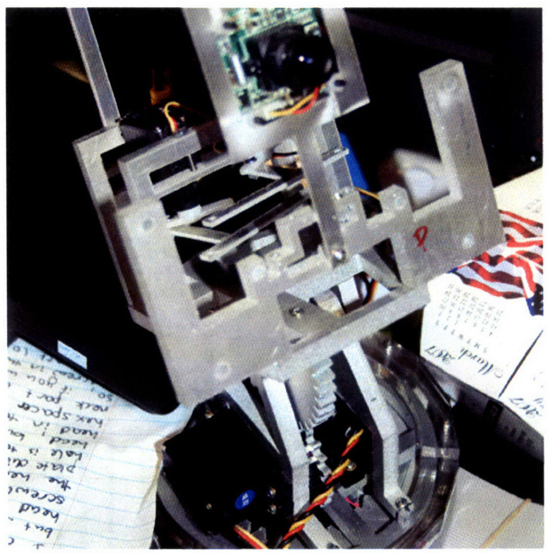

Figure 7-16: An assembled head without eyes.

Body shells

Figure 7-17: Software solid model of the body.

The shape of the shells was initially modeled in SolidWorks as depicted in Figure 7-17. The models were then cut at 1.5" intervals vertically and the cross-section for each of these pieces was printed and cut from dense foam. The pieces were then glued together and alternately coated in plastic and sanded and then coated in silicone. The resulting mold is shown in Figure 7-18.

This mold was then used to thermoform pieces of PETG plastic. The plastic piece for the front can be seen in Figure 7-19 The resulting plastic shells were then cut out from the full sheet of plastic, all cutouts and holes were created, and the piece was painted. The final shells after being painted and before being attached to the robot are shown in Figure 7-20.

After completion, the shells were then attached to the robot, as seen in Figure 7-21.

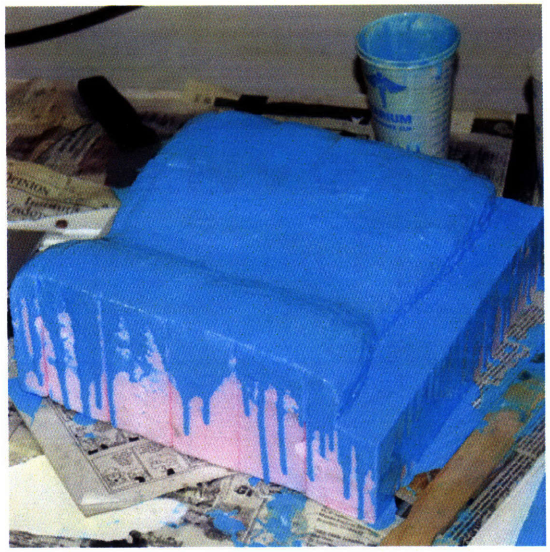

Figure 7-18: Body mold ready for thermoforming.

Figure 7-19: Thermoformed body shell before painting.

Figure 7-20: A row of completed and painted shells.

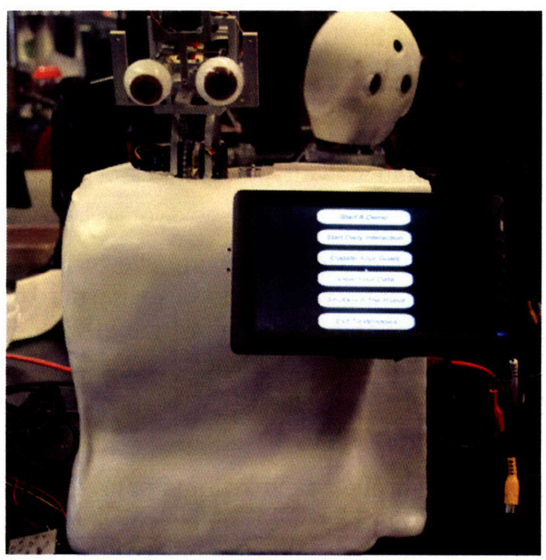

Figure 7-21: Robot with body shells attached.

Head and neck shells

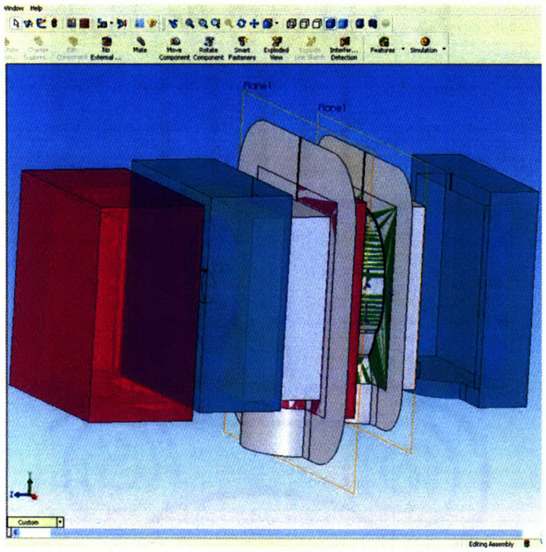

Figure 7-22: Four-part face molds modeled in software before printing.

Creating the shells for the head and neck was a lengthy multi-step process. Two-piece molds for each of the four pieces (head front, head back, neck front, neck back) were created in software, resulting in eight pieces. Then one-piece molds for each of these pieces were created. The resulting set of software molds is shown in Figure 7-22. Each of these molds were then printed on a ZCorp Z510 3D printer. The four larger molds had to be broken into four pieces each because of limitations in reliability of the printer that would not allow for pieces of the desired size to be printed.

The molds that came directly out of the printer are shown in Figure 7-23. The pieces coming straight out of the printer were not strong enough to be used for mold-making, so each of the twenty pieces had to be impregnated with cyanoacrylate by hand (see Figure 7-24) and then sanded until smooth (see Figure 7-25). The molds that were printed in pieces were then glued back together, resulting in full-size molds that looked like the one in Figure 7-26.

After the molds were prepared, silicone was mixed and poured or injected into each of the eight full molds (Figure 7-27). The pieces pulled out of these molds were then a set of four pairs of silicone molds that could then be used to make each of the four plastic parts needed as shells for the robot, an example of which is shown in Figure 7-28.

These molds were cleaned up and acrylic boxes were created to hold the neck molds so that they would not deform while being used. Batches of plastic were mixed one

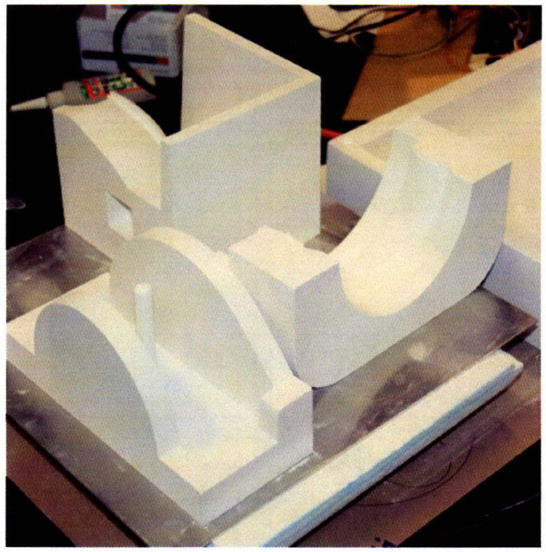

Figure 7-23: Printed molds directly from 3D printer.

at a time and poured into a pair of molds (as in Figure 7-29). The poured plastic pieces were removed from the molds after setting for four to six hours, cleaned, sanded, and painted. The final pieces are seen in Figure 7-30.

After preparing all of the plastic pieces, they were attached to the frame of the head and body of the robot, as shown in Figure 7-31.

Figure 7-24: Applying cyanoacrylate to harden molds.

Figure 7-25: Sanding molds before using to make plastic parts

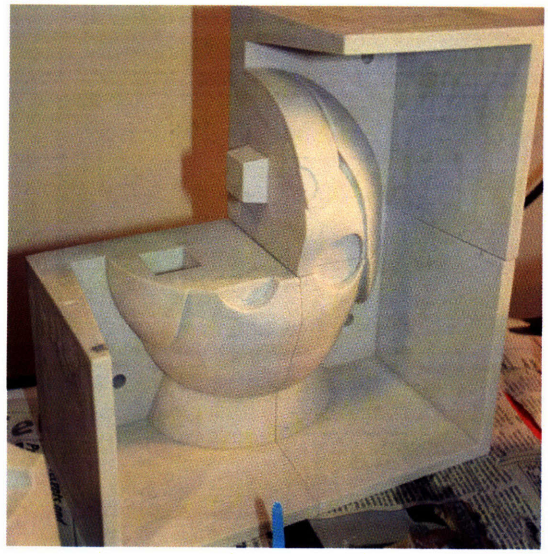

Figure 7-26: Three-fourths of a four-part mold

Figure 7-27: Injecting silicone into one mold set.

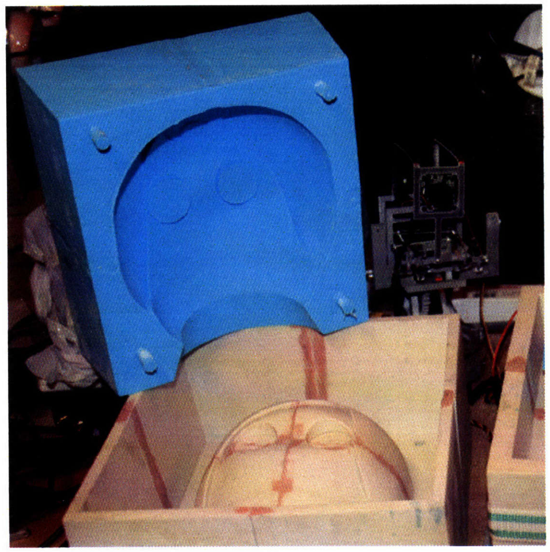

Figure 7-28: A silicone mold removed from the 3D printed mold.

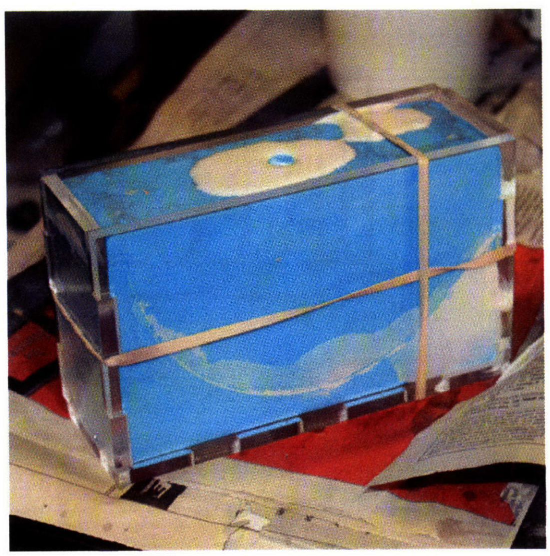

Figure 7-29: Plastic poured into two-part silicone mold.

Figure 7-30: A poured plastic part that has been finished.

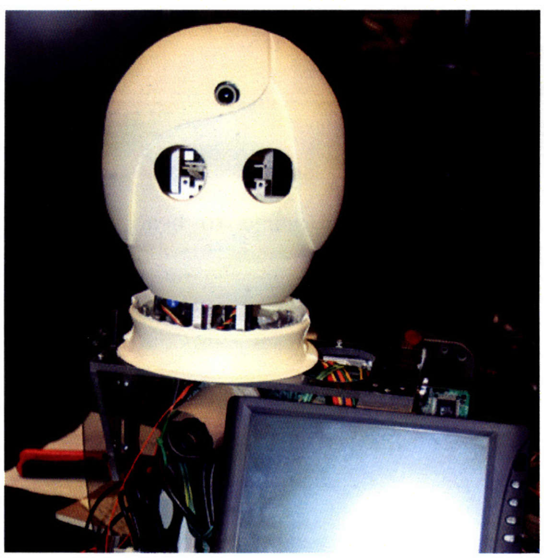

Figure 7-31: Head and neck shells attached to frame without body shells.

Eyes

The final part of the robot that was created were the eyes. Each eye actually consisted of 8 parts: the eyeball, an acrylic cross-piece mounted inside the eye, and a combination metal and plastic ball-and-socket joint that was screwed into the cross-piece and the arms attached to the T-mounts as described above. The eyeballs are made from half-sphere acrylic domes. They were painted in three coats (white, brown, and black) and then covered with a clear spray-on acrylic coat for protection. Each eye has a cross-bar mount attached on the inside. This mount has three screw-on mount points, one at the center axis for attachment to the frame, one offset to the top for the up/down servo attachment, and one offset to the side for the left/right servo attachment. The attached eyes can be seen in Figure 7-32.

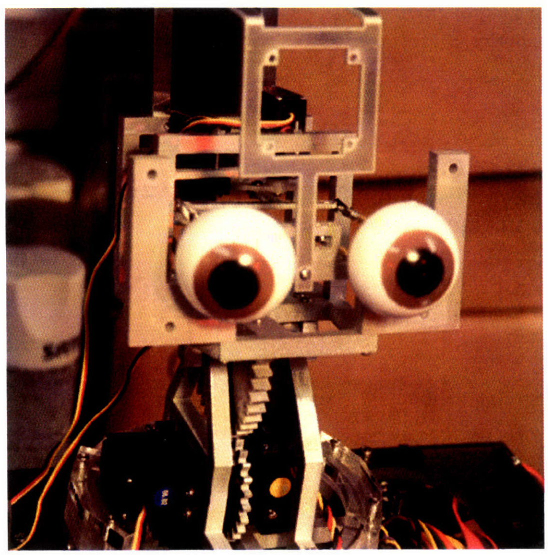

Figure 7-32: Eyes attached to head frame without shell.

Full assembly

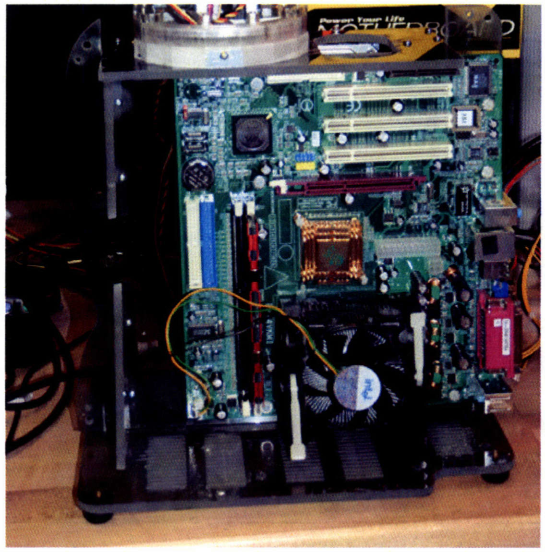

Figure 7-33: Electronic components attached to body.

All of the components of the robot described above were assembled to create the complete system. Each robot has approximately 270 parts. Once the frame is together, all of the electronic components are attached (Figure 7-33). The head and eyes are then attached (Figure 7-34).

Finally the painted shells are attached and all motors are calibrated (a single complete robot is shown in Figure 7-35). A small set of the assembled robots is shown in Figure 7-36.

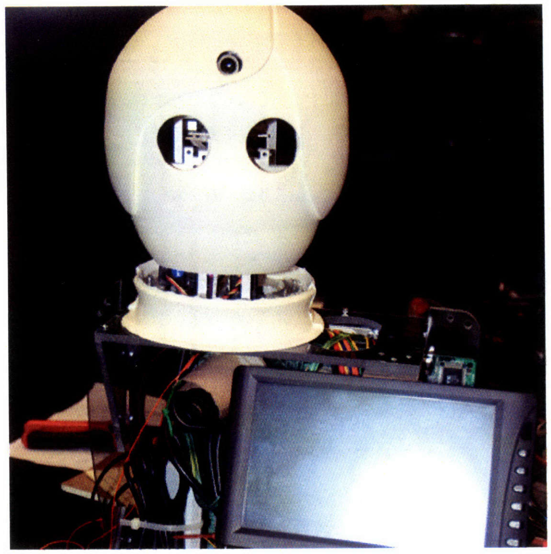

Figure 7-34: Frame with head and head shells attached.

Figure 7-35: Fully assembled robot.

Figure 7-36: A line of fully-assembled robots.

Chapter 8

Software Design

There are five main pieces of software that create the interactions between the weight loss coach system and the user. The main piece of software coordinates all input and output, maintains the overall state of the interaction and relationship with the user, and handles the flow of interaction based on input from the user. There are four peripheral pieces of software as well: the motor control system, the vision system, the speech output server, and the user interface controller. Each of these five software components is discussed in this chapter.

8.1 Control system architecture

The main software system handles the control flow of an interaction and the communication between all subsystems. The overall architecture is depicted in Figure 8-1. This central piece of software is written in Java and either instantiates subsystems as other Java classes (as with the motor control and user interface) or uses sockets to communicate with them (the face tracker and speech output).

The basic control flow driven by the user. The user can select an option from the initial menu (shown in Figure 8-2), which then chooses the appropriate script to be run. There are five options on the main screen: start the daily interaction, update goals, view data, show a demo, and shutdown the robot. The first, *Start Daily Interaction*, is what the user does most frequently. This interaction and how it is performed is described in detail below. *Update Goals* allows the user to enter or modify their daily exercise and calorie goals. Based on what is known about weight loss and maintenance, the user should have some goal towards which they are working, which is what this system is designed to support. The *View Data* option lets the user go directly to graphs of their exercise or calorie entries for the previous seven days. More information on what is shown for these graphs is below in the description of the full interaction. *Start Demo* lets a person show off the capabilities

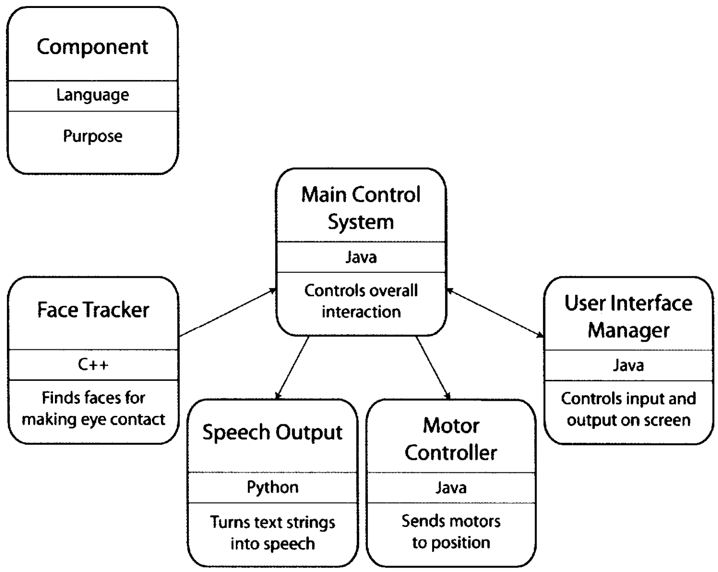

Figure 8-1: High-level software architecture.

of the system without revealing their data on exercise or calorie consumption. This is implemented to allow study participants to show family members and friends who may be curious about the robot how it works without having to display their personal data. Finally, *Shutdown the Robot* is a button which exits the software and powers down the entire hardware and software system.

The following two subsections give an example of an interaction followed by details of how this interaction is implemented in software.

Daily Interaction – example

When the user starts the robot, they get the main menu shown in Figure 8-2. When they select *Start Daily Interaction*, the system greets them by speaking aloud and displaying any text that is spoken aloud on the screen as shown in Figure 8-3. At the bottom of any screen of text, there are one or more responses that the user can select in order to continue the interaction. When there are three options (the most common situation), one is usually neutral in affect (e.g. "OK"), one is positive (e.g. "Thanks!" or "That was helpful!"), and one is negative (e.g. "I didn't want to hear that." or "Let's just move on."). The options given are based on the text spoken and displayed on the screen. The robot then makes a little small talk based on the time of day and how long it has been since the last interaction. It then introduces the data gathering portion of the interaction by saying something like "I would like you to tell me about your eating and exercise so far today," followed by asking the

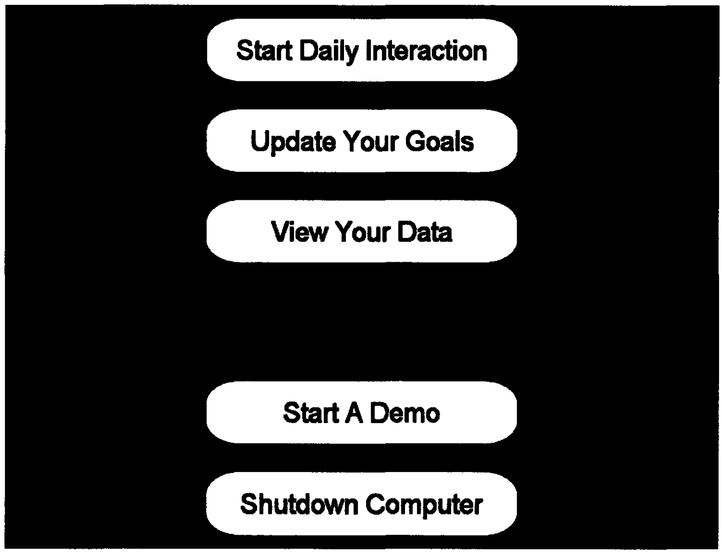

Figure 8-2: Main screen menu seen when user starts robot or completes any full interaction.

user about their calorie consumption. It then gives a screen like the one in Figure 8-4, at which point the user can enter any calories consumed during the day.

After the user presses the "Done" button on the enter calories screen, the robot offers to let them enter information from a previous day. For users with the system in their homes who have missed a day or remember something from a past day that they haven't put in, this gives them the option of entering data for up to three previous days. After finishing the calorie entry, the same kind of interaction and a similar set of screens are used to gather information about exercise. A user can enter exercise either in number of minutes spent exercising or number of steps taken if they are using the pedometer that was given to them as part of the study. After completing the exercise entry for the current day and any previous days, the robot thanks the user by saying something meant to be encouraging like "Thanks for the information. That will help us in reaching your goals."

Next the system offers to show the user graphs of their recent activity. If the user chooses to view these graphs, they get the option of seeing a graph of calorie consumption or of exercise. After choosing a graph, the system first gives feedback based on the day's activities (e.g. "Good job meeting your calorie goal today! You're doing even better than the goal you set for yourself." or "You haven't quite met your exercise goal yet today. Do you think you could keep working on that?") and then shows the graph. The graph is a simple bar graph like the one shown in Figure 8-5 and contains seven days of information chronologically with the current day at the right. There is also a line across the graph showing the current goal that the user has set. After pressing the "Done" button, the robot returns to the screen giving

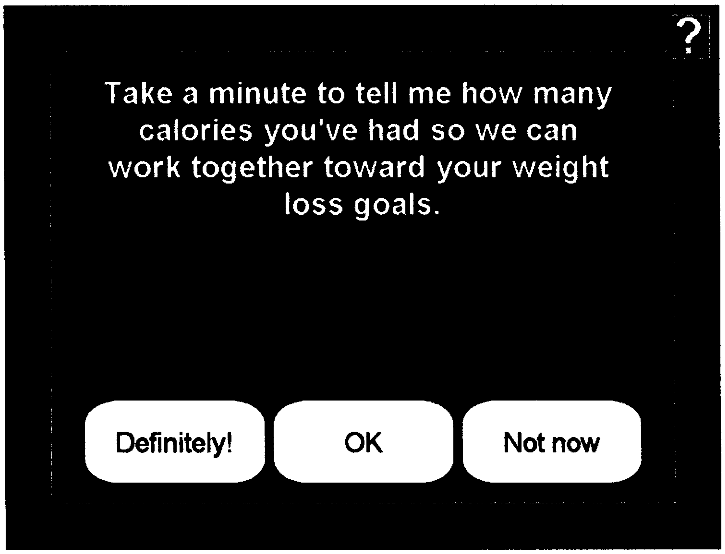

Figure 8-3: A screen showing spoken text printed to screen.

the graph options, allowing the user to choose to see another graph or to continue the interaction.

Once the user finishes viewing the graphs, the system next offers a suggestion about diet, exercise, or nutrition. These suggestions are based on recent data that the person has entered, with the system attempting to choose a piece of advice that might be most helpful to the user at the time. Next the system tells the user that it wants to ask them a couple of questions. These questions are from a short version of the working alliance inventory (short form) scale. The question is displayed on the screen and spoken aloud. The screen also shows a sliding scale (shown in Figure 8-6 on which the user can indicate how much they agree or disagree with the statement. After answering the first question, the robot says something like "Thanks for the answer. Just one more question today," and offers the second question. The robot then thanks the user for answering the questions.

Finally, the robot makes a little more small talk to encourage the user to continue using the system. This frequently takes the form of asking for commitment to return the following day with a statement like "I hope to see you again tomorrow. Will you be able to come back?" and offers response options such as "Certainly," "I'll try," or "Maybe." After the users chooses a response the robot says goodbye and thanks them for talking with it. After a few seconds it returns to the main screen and lowers its head and eyes in a subtle imitation of sleep as an indication of finishing the interaction.

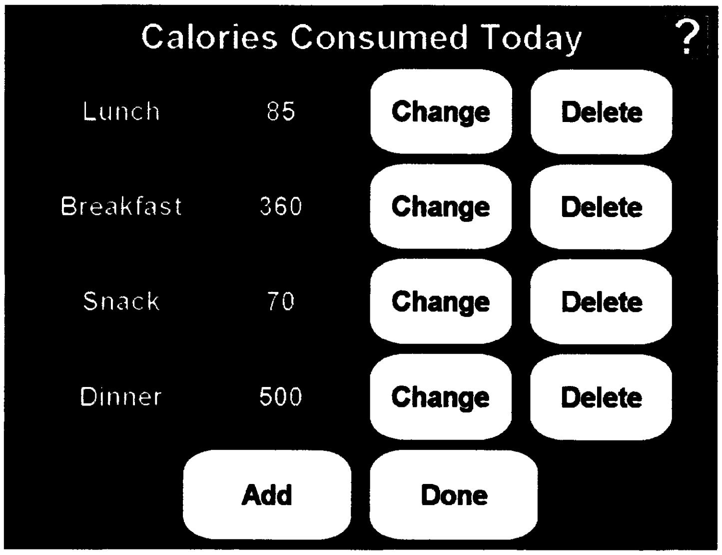

Figure 8-4: A screen showing calories entered today with options to add something else or move on to the next part of the interaction.

Daily Interaction – implementation

The control flow of the interaction is the most complicated part of the software system created for the robot. The basic flow is written to be easily modifiable, which allowed for rapid changes based on early and ongoing feedback that was solicited on the interactions with the system. There are a number of factors that can change what the robot says or does at a given instant.

All interactions are driven based on scripts and data in several databases that were loaded prior to the user beginning to use the robot and created as a result of the interactions. When a user selects an action from the main menu, the system chooses a script appropriate to that particular interaction. Scripts are made up of a set of tags that recursively generate the full, detailed interaction script using a Backus-Naur Form grammar. An example script used to create a daily interaction is shown in Figure 8-7. In this figure, each terminal tag (a tag without another tag to the right of it) is executed by the robot. Each tag can be one of three types: a recursive tag, a terminal tag, or a generated terminal tag. The first, the *recursive tag*, simply generates a new set of tags that are then sequentially processed by the system. An example shown in the daily interaction is ⟨*daily_scenario*⟩, which generates a set of tags ⟨*intro*⟩, ⟨*body*⟩, and ⟨*closing*⟩. A *terminal tag* is one that calls a piece of code to perform some action, such as the [*get_calorie*], which uses the same set of screens each time to gather data. The final type, a *generated terminal tag*, generates the text and/or action to be performed in real-time based on the sequence of events leading

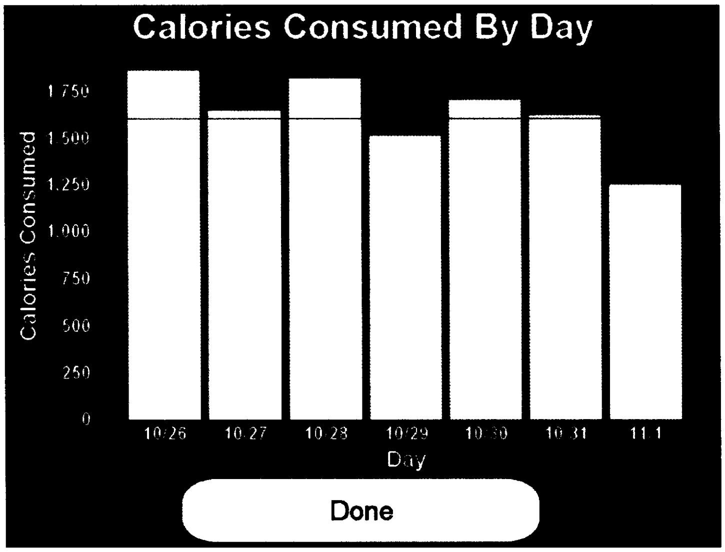

Figure 8-5: Screen that displays a week's data on calories consumed.

up to the call in the current interaction as well as data stored in the database. An example of this tag is the [*intro_data_gathering*] tag, which generates an appropriate phrase based on time of day and relationship state.

The decision of what a particular *generated terminal tag* will create is based on several factors. Simple ones are time of day (e.g. "Good morning" versus "Good evening") and time since last interaction (e.g. "Good to see you back again. I'm glad we're getting a chance to talk" versus "Thanks for coming to talk to me today.") Somewhat more complex is the state of the relationship, which is calculated to be in one of three states based on the WAI-SF responses. This state can be either initial, normal, or repair, and the calculation of the state is described below. It the state is initial, the system uses language that is more explanatory in nature. For example, instead of simply saying "Can you tell me how much you have eaten and exercised today." the robot might add something like "It will help us to reach your goals if we keep track of what you do each day." In the normal state, the system uses relatively short forms of dialogue as in the example interaction given above. In the repair state, it will uses meta-relational dialogue with the user. To introduce the questions about gathering data, it would say something like "Let's work together to keep track of your progress toward your goals" or "Thanks for the information. It helps us to work together to meet your goals" after getting information from the user.

Figure 8-6: Question asked to user about interaction with sliding scale to respond.

Calculating relationship state

The relationship state can be either *initial*, *normal*, or *repair*. *Initial* is used for the first few days of interaction, so there is no calculation to be made. The Working Alliance Inventory – Short Form (WAI-SF) consists of eight questions and the robot rotates through the questions, asking two each day, thus repeating every four days during daily use. Currently the *initial* state is used for four days. The *normal* state is then used for four days. Starting at the ninth day (or ninth interaction), the system calculates a score based on the following formula:

$$WAI_{state} = \frac{\sum_{day=-3}^{0}(WAI_{day})}{8} - \frac{\sum_{day=-7}^{-4}(WAI_{day})}{8}.$$

The result is an average difference in responses on a scale of 0 to 600 (the range for any one question). If the WAI_{state} is greater than -25 (allowing for minor variation in responses or UI input error), the relationship state is deemed *normal.* If the result is less than -25 (i.e. the responses to questions are in general lower over a period of time), the relationship state is set to *repair.*

Aspects of the interactions

As a result of these calculations and generation of interactions, the dialogue that is generated between the robot and the user is extremely unlikely to be the same

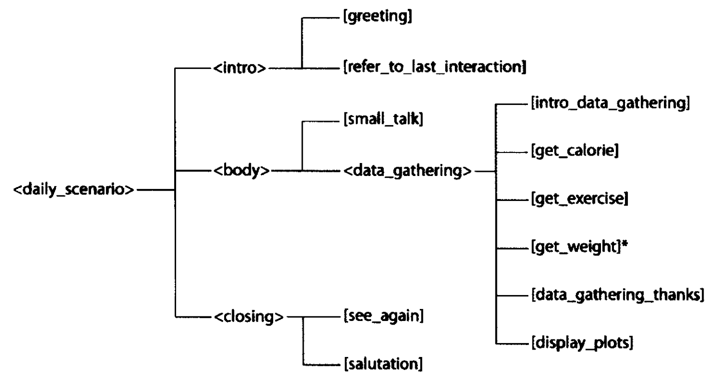

Figure 8-7: A typical generative script for a daily interaction.

for any two interactions during the six-week study. This variety makes the system seem more capable of interacting with the user and much less likely to bore the user during the weeks of continuing interaction.

The robot also performs small gestures throughout the interaction in addition to looking at the user. When introducing a part of the interaction where a response on the screen is expected, the robot will look away from the user and glance down at the screen as a subtle indication to the user that their attention is expected there at that particular time.

Every response from the user – data on calories and exercise that is entered, WAI-SF questions answered, and responses to each piece of dialogue – are recorded in an interactions database. Some of this is used later, such as in calculating the relationship state. All of it is available post-experiment for analysis of the interactions and correlation with other information collected in questionnaires before and after the study.

8.2 Motor control system

The motor control software subsystem for this robot is relatively simple and is split into two Java classes. The hardware controller is a Mini SSC II from Scott Edwards Electronics that connects to the robot via a serial interface. We created a small Java class that abstracts the operation of the hardware and has an interface that takes as input two integers: a motor number and a position. When instantiated, it opens a connection to the serial port on the robot and maintains that connection for as long as the robot is running. Upon receiving a command, it sends the updated position(s) directly to the hardware motor controller.

The second class has a basic model of the robot's four degrees of freedom and movement in order to properly handle movement with the robot's capabilities. This class allows software limits for each degree of freedom in the robot to be designated in order to provide protection against trying to push part of the robot beyond its physical limits. (For example, the neck left/right motion might have a minimum extent of 47 and a maximum of 212 within the motor's unrestrained physical range of 0 to 255.) This interface also allows a maximum speed for each degree of freedom to be set. This is accomplished by assuring that a movement update will not be sent per instruction cycle time greater than the maximum allowed range for one period of time. The frequency of updates to the hardware can also be controlled from this class. (For example, if the updates to the physical robot are being sent at 10 updates per second and the maximum movement per second for a degree of freedom is 20, no update should be more than +/- 2 from the current position.)

8.3 Computer vision

The vision system on our robot is running the face tracking portion of the open source OpenCV engine [102]. The face tracker is implemented in C++ as a standalone piece of software that is automatically run when the robot boots up. This software allows multiple faces to be detected and sends out an (X, Y) coordinate set for each face found in a video frame over a socket. The main control system has code that is constantly listening for any output from the vision system and handles the input when necessary.

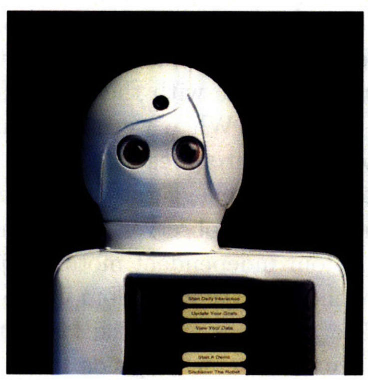

Figure 8-8: Close up of robot's head with camera seen above eyes.

The action that the face tracker takes depends on the current mode of the robot. In most situations, the robot is attempting to maintain eye contact with the user. This is done using the fact that the camera position on the robot is in the center of the forehead between the eyes (see Figure 8-8) and when the eyes are looking straight ahead and a face from the face tracker is found to be in the center of the image, it appears to a user as though the robot is looking at them. (There is a slight offset used to account for the camera being above the line of the eyes, but this is accounted for in the motor controller code.) Thus the tracker simply has to center the face in its vision system to give the appearance of matching the gaze of a user. An example of what the face tracker sees is in Figure 8-9. The red square indicates a face that is detected (more than one of these may be seen on a screen). The green circle shows where the robot is currently looking and may or may not correspond with a face on any given frame of video, depending on current tracking behavior and physical movement progress across frames.

Figure 8-9: View from camera on robot's head.

The actual tracking algorithm is more complicated than simply sending the appropriate command to the neck left/right and up/down motors that would center the face. If this were the action performed, the robot would appear to be very "jerky" and not at all human-like. We know that humans looking at a person in a similar situation would quickly perform a saccade with their eyes, followed nearly instantaneously with movement of the head. When we mimic this exactly on a robot, we still get an effect where the movement appears to be too rapid. When the eyes follow the person quickly, followed by an exaggeratedly slow movement of the neck, this appears to be more appropriate to an observer. Thus when a new face position is detected, the robot calculates four independent motor trajectories to accomplish this movement, two for each of the degrees of freedom in the eyes and two for each in the neck. The speeds used for the eyes are much faster than that of the neck, resulting in the desired difference in movement speeds.

Once these movement trajectories are calculated, the high-level motor control begins sending outputs to the low-level motor controller. This process of calculating trajectories is then immediately repeated a few milliseconds later with the newest position from the face tracker. This allows for correct updates if the person is moving while the robot is in the process of looking to a new face position of the user quickly enough for it not to be noticed by the person.

There are two challenges in using the OpenCV face tracking system. In any environment with visual clutter, it frequently picks up fleeting false positive faces that may appear for a frame or two (50 to 500 milliseconds depending on the current processor load and over how many frames the false positive lasts). There is also no identification or ordering of faces, which means that when more than one face is detected, there is no output that labels faces consistently from one frame to the next (e.g. if two faces are detected, it might send the coordinates of person A followed by person B in one frame and in the reverse order in the very next frame). Both of these potential problems are handled by implementing a maximum movement distance between frames. From simple calculations based on measurements of actual human movement in front of the robot, we calculated a maximum likely movement between frames of vision output. This is taken into account in the vision system by ignoring any face detected outside of a window defined with a center of the last face position detected and the bounds of maximum likely movement in any direction. If no face is detected within that window for a given period of time, the entire camera frame may be used again for finding new faces.

8.4 Speech output

The speech capabilities of the system were created using an off-the-shelf text-to-speech (TTS) software package. Microsoft's TTS engine, SAPI5, and the Mary voice were chosen for their ease of use and the fact that it is freely available on the Windows platform that we were using. This was combined with the pyTTS module for python which provides a wrapper around the SAPI interface.

The resulting system written in Python was built as a standalone server that is started when the robot starts. It listens on a particular port for strings of text to be passed to it. Upon receiving a text string, it uses the SAPI interface to convert the text into speech and plays the result over the robot's speakers.

8.5 User interface

The user interface (UI) code is woven tightly into the main control code, but is a separate piece that manages all of the input and output to the touch screen on the front of the robot. The main function of this code is to take a message that should be displayed to the user on the screen (such as a piece of text, a question, or a menu), format the item for display. An example menu is shown in Figure 8-2 and an example statement requesting user input is shown in Figure 8-3. There are also a set of screens that allow the user to enter calorie and exercise information. An example screen showing data entered for a day with the option to enter more is shown in Figure 8-4 and the screen to enter new calorie data is seen in Figure 8-10. Similar screens exist for entering exercise information. The final type of screen is the graph showing activity over the past week, which is depicted in Figure 8-5.

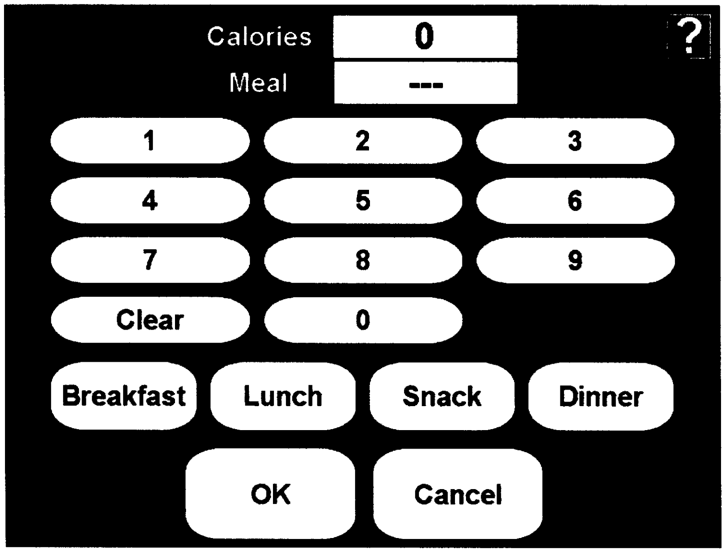

Figure 8-10: Screen for entering new information about calories consumed.

The UI is written in Java using the Swing toolkit. All of the code was developed for this particular robot and the type of output screens were created based on the needs of the interaction for weight loss and weight management. The actual content of most screens is parameterized so that the main control code can determine the text or data to be shown on a given screen at runtime.

Part III

System Evaluation

Chapter 9

Technical Evaluation

Before deploying the weight loss coach sociable robot system to users, we evaluated it along a number of criteria. The hardware, the software, and the combination of the two had to meet certain specifications before it would be expected to function in the homes of users for six weeks. This chapter describes those evaluation criteria and how the system performed against them at the time of deployment.

9.1 Hardware

There are four factors that were used to evaluate the physical robot before giving it out to users. The appearance of the robot had to be refined enough so that it would fit into participants homes. Getting the movement of the components smooth and reliable enough that any problems would not be consciously noticed by users was important. Ensuring that all of the physical components were durable and reliable enough to last for the six week study involved testing of individual parts and of the entire assembly. Finally, the ability to maintain the hardware in the field was a consideration in completing development of the system.

Appearance

The appearance of the physical robot was one of the concerns that we had when considering how the system would fit into the daily lives and the homes of our users. Ideally the robot would look like a refined, store-bought product with clean lines, nicely finished parts, and smooth movement. Unfortunately, some of the tradeoffs that were made while attempting to complete a set of seventeen robots and get them in the hands of users had to do with appearance. While the look of some parts, such as the eyes, was a priority, some of the other components were not as refined as had been initially desired.

Although the designers of the system were critical about the finish of the shells, the calibration of the eyes, and the lack of color on the finished robot (see Figure 7-35), we decided at a certain point to begin the study in order to get feedback on the overall system. A few study participants did indeed describe these aspects as issues with the system. This is indicative of a larger number of participants at least subconsciously noting the appearance of the robot as something that hindered their interaction with the system.

While creating a set of nicely finished robots will remain a challenge for human-robot interaction researchers for some time to come, it is clear that spending the time and effort on this aspect of the design and construction phase of a project is vital to the outcome.

Movement of components

At least as important as how the robot looks is how it moves. Achieving smooth, coördinated, and appropriate movement is a combination of both the hardware and software components of a robot. The hardware portion relies on the quality of the motors, the design of their connection to the rest of the hardware (gears and linkages), and the tolerances in fitting these pieces and their coverings. In our case, we opted for inexpensive motors and tried to minimize backlash using direct gearing and a minimal number of linkages as well as adapting the software to work well with the degrees of freedom we had designed.

The initial version of the head was constructed based on solid models that appeared to give the range of motion and smoothness that we desired. While this version was useful for getting the vision and tracking systems working, it was quickly found to be insufficient for providing the desired quality of movement. Based on engineering expertise from constructing other systems, the design was modified and a second version of the head was built. This version gave the smoothness in motion that was needed and was modified a second time so that the fit with the other internal components as well as the shells was satisfactory. The third and final head design was constructed and tested. As this was found to be satisfactory for meeting our criteria, the parts were duplicated and sixteen additional heads were created.

Durability and reliability

The ability for the robot to withstand regular movement as well as possible contact with people is important. Additionally, the robot must be transported to and from users' homes reliably at the beginning and end of the study. The durability and reliability of the robot were handled in two complementary ways. The first was attempting to ensure that the system would not break under the stresses present in normal use conditions. The second was creating extra components for everything on the robot and particularly for any that were shown to be more likely to break during use.

The materials used in construction were chosen in part for their durability and likeliness to last for at least the duration of the study. The frame of the robot was built with polycarbonate, a very durable plastic that could withstand forces placed on it by mounting all of the other components to it. Many of the moving parts were constructed from aluminum, which was quite sufficient for this application. One of our biggest challenges was keeping the hobby servos from burning out. While the servos had enough power to move the robot under normal conditions, it appeared that the gearing would at times put significant extra torque on the motors, causing them to burn out after a period of time. The gears were hand-finished to be as well-fitting as possible, but this problem was never entirely eliminated.

In addition to repairing problems during the construction process, the pieces that were deemed more likely to break were noted. Before deployment of the robots, time was spent preparing or purchasing extra sets of these components as backup so that robots could be quickly repaired as necessary. In the final design, these parts included the neck servos (which burned out), the fasteners for the head (screws stripped after repeated use), and the camera in the head (several mysteriously burned up, a problem that was never solved).

Maintenance of hardware

As indicated in the discussion of durability and reliability, ongoing maintenance of systems was a serious concern in the design process for the study. In addition to the above measures, the decision was made to create all of the robots to be identical and to construct additional robots other than those needed for the study. The reasoning was that if there was a problem with a robot while in a home, the experimenters could simply copy the data onto a new robot, swap the robots out, and return the original robot to the lab to make repairs. Fortunately there was only one problem with a robot during the experiment (a burned out servomotor) that required this to be done.

One difficulty that was not corrected had to do with the challenges presented by the complex eye and head assemblies. The entire eye assembly was made up of approximately forty components and was extremely tedious to assemble and calibrate correctly. What was discovered is that over time the calibration of the eyes with one another would drift and the robot would appear cross-eyed or to have a lazy eye. Because this was not a serious enough problem that experiment participants would call us to repair it, we did not find this problem until the end of the study.

While creating the overall assembly, care was taken to make it relatively easy to open up and access all of the components of the robot. While some pieces like the servos were challenging to remove and replace, all components could be seen and accessed by simply removing the outer shells. This made diagnosing, if not repairing, problems straightforward when something happened with a robot. The next step would be to create replaceable subassemblies (such as the entire eye mechanism or the neck section), which would make repairs very quick, but this was not done with the robots that were deployed.

9.2 Software

Evaluating and testing the software before deployment is also very important for ensuring a successful experiment. Testing the software for completeness and robustness across the variety of conditions that it would be expected to encounter with users meant creating test applications as well as carefully studying all possible conditions that the code might reach. The testing was done iteratively as subsystems were developed and integrated as well as on the complete system.

Functionality and integration

The simplest test is making sure that all of the desired functionality was created, functioning, and integrated into the main system. The architecture that was used allowed for components to be plugged into or accessed by the main control system. This adaptability made changes easier to integrate into the overall system, but is also challenging to thoroughly test. The input and output of each subsystem was tested in different ways. The speech system was simplest; as long as it would reliably run and provide speech output, it was functioning well. The face tracking vision system was more challenging. A variety of situations involving zero, one, and multiple people in front of the camera had to be tested to determine the output. This was a process difficult to automate, as the system acted on a live video feed that could change depending on background, lighting conditions, and people in front of the camera.

Testing the motor control system was relatively straightforward. Test cases for the complete range of motion and speed could be written. These would check not only the ability of the motors to correspond with the software commands but also the ability of the software to limit the motors to safe ranges that had been set. The UI output was tested by checking each screen's output, paying particular attention to extremes such as a user entering a large number of calorie or exercise entries in a given day or passing particularly long text strings to the handler for creating buttons or spoken text displays. Some minor modifications were made to the code as a result of many of these tests.

The final part of the integration was to check that data passed between systems was sent and received correctly. As there were a fixed number of subsystems and types of data passed among them, it was straightforward to create a fixed number of test cases to see that data was being correctly passed.

Relationship state calculation

Once the systems were individually tested and integrated, we also wrote test code that would allow the creation and insertion of data sets into the database that would mimic a variety of states that would possibly be encountered during the actual experiment. These were used to test all parts of the system, but most important was the ability to test the relationship state calculation and its effect on the rest of the interaction. The calculation of the relationship state itself is a simple formula, but the way that the result of this calculation cascades through the system can be challenging to test without repeatedly going through the interactions. When problems were found, we could trace through the code to understand where the bug was and correct a class of potential problems. With a finite set of tests, we could be reasonably assured that this portion of the code would work correctly during the study.

Fortunately the variety of statements made by the robot made the testing fun as well – we never knew exactly which joke it would come up with next and be caught off guard even though we had written every line of dialogue.

Accuracy of data recording and presentation

Ensuring the completeness and correctness of the database that stored user information was critical for correct operation of the system during the study and for evaluation of the data at the conclusion of the study. This consisted of two parts: making sure all data was written to the database and done so correctly and ensuring that data was properly read from the database when needed. To check the writing of data, we checked the code to make sure that all writes were being performed and then recorded entire interactions and checked our observations of what happened with the database. When both of these were found to be correct, we were comfortable with everything being written to the database during actual use.

Reading data from the database and operating on it was slightly more challenging because of the large variety of data that could be written to the database and the resulting states that this could put the system in. This was accomplished by creating test data where we knew what the appropriate set of outcomes should be and then checking against the actual performance of the system.

Reliability

Ensuring that the software would always run on startup of the robot and always function as the users expected was necessary before giving the robots out to users. The main point of all of the testing was to make sure that from the users perspective the robot would be seen as reliable. In the end, the software had to perform in such a way that the user perceived that it was functioning correctly and to their expectations. In addition to the test cases, we repeatedly used the system and had early test users go through interactions with it to try to make sure that everything functioned as we hoped.

The final set of software that went out to users passed all of the above tests and functioned very well during the six week interaction. Only two problems were found: the system did not regularly ask for the persons weight and a number of the computers had their Windows clock set to the wrong time for a period of about a week during the middle of the study. (The exact number is not known. One person in the study reported explicitly that this had happened and we found the same issue with one machine that was back in the lab. Two other individuals reported that their computer sometimes seemed to be "confused" about the time of day because it misspoke when greeting them. All computers with the error fixed themselves within a week, so we could not determine which had the problem when they came back.) Fortunately neither of these problems had a significant impact on the outcome of the study.

9.3 Hardware and software integration

The final step in verifying the system before giving it to users was testing the fully integrated hardware/software system, or the complete robot. Most of the testing was done as described above, but there were two main areas that had to be checked on the full-assembled and integrated system. These were testing the movement behaviors along with the software and understanding any performance issues with the robot.

Look-at behaviors

Much of the functionality of the motors could be tested through simple software interfaces that were built to check the motors individually or in combination. The final calibration and testing of the look-at-person and look-at-object behavior could only be tested on each fully-assembled robot by running the face tracking and motor control systems. The appearance of looking at the appropriate location, be it face or screen, or the sleeping behavior of the robot had to be checked by running those functions on each robot. Based on the way that the individual robot functioned, final calibrations to its motor positions could be input into the system. In some cases, minor hardware modifications (tightening or loosening screws or lubricating joints) were made to make the robot perform as was desired.

Performance of integrated system

The other aspect of the robot that had to be tested on a fully-integrated system was the overall performance of the hardware and software together. This included things like starting up and shutting down of the system; volume of speech and placement of the speaker; proper assembly of the shells; pauses and intonation in speech; and timing of the speech, motor actions, and on-screen displays with one another. This was a process of continuously interacting with the system and making small adjustments to the hardware and software. This was performed in part by getting feedback from a variety of people who had not used the robot before.

Maintenance of overall system

An important aspect of successfully running a study with this system was any ongoing maintenance that would be necessary. We were able to engineer the system in such a way that it did not require much hands-on maintenance during the six weeks that the systems were in users homes. One decision that was made was to not connect the robots to the Internet. The reason for this was to not have to be concerned with possible viruses or outside access to the user's data as well as avoiding technical issues with setting up a network connection for systems while in homes. The downside is that the experimenters did not have remote access to the systems and could not check on their status or make any corrections.

During the experiment, problems were experienced with Windows (the previously mentioned problems of system clocks being temporarily off by several hours, thus affecting the systems ability to make small talk correctly based on time of day), the touch screen (the input drivers would sometimes quit working for a period of time or permanently), and a motor (one motor in the head burned out during the study). Fortunately no other problems were experienced with the hardware or software that we constructed.

Chapter 10

Experimental Evaluation

10.1 Study purpose

There were two major goals in designing and running the study with the robotic weight loss coach. The first is to better understand how to run a long-term human-robot interaction study, what data to collect, and how to analyze it. The results of this are reported in Part IV. The second is to understand whether such a sociable robot system might be useful to people who are trying to lose and keep off weight. These results are presented in the next chapter. The overall design of the study is explained in this chapter.

Hypotheses

In the weight loss application experiment, there are four sets of hypotheses. These are:

- Participants using the robot will stick with it longer than those using the computer or paper systems. This measure can be determined through analysis of interactions.

- Participants using the robot will like using their system more and feel a closer relationship with it. This will be measured using mainly the working alliance inventory, but also measures of trust in the system, perceived reliability, and perceived information quality of the system.

- Participants using the robot will relate to their system more and develop a stronger affinity to it. This will be analyzed mostly through post-experiment interviews with participants.

- Participants in all three conditions will lose weight and the difference between systems will not be statistically significant. This is because we can expect anyone participating in such a study to lose weight and that the effects of using the system for longer periods of time only become important and differentiable in terms of weight loss after a much longer period.

The detailed hypotheses are presented in the following chapter along with the analysis and results of each.

10.2 Study design

The evaluation of the sociable robot weight loss system was carried out using a between-subjects, longitudinal study where people who were attempting to lose weight used the system for four to six weeks. One-third of the participants received the sociable robot system described in earlier chapters. An equal number in a second group received a computer running identical software with the same touch screen that is on the front of the robot. This system was not capable of looking at the participants, as it had no camera or eyes. This system also did not speak text aloud; all text appeared only on the screen. A third group, with an equal number of participants to each of the first groups, received a paper log that was based on the log currently used in the Nutrition and Weight Management Center at Boston Medical Center.

There are four phases for each participant in the study. These are recruitment, initial visit and setup, study period, and final interview. During the recruitment phase, potential participants are told about the study and the requirements and potential benefits entailed by taking part. They are also qualified using the criteria discussed below in Section 10.2. The initial visit consists of the participant completing questionnaires and the researcher explaining the use of the system. The participant then uses the system for four to six weeks and a final visit is conducted, which includes questionnaires, an interview, and collecting the system. The study protocol is explained in greater detail in Section 10.2.

Measures

This study utilizes three types of measures to better understand the interactions between participants and the sociable robot system. Participants are asked to complete questionnaires before and after the study period, which allows for standard, proven scales to be used. During the study period, details about each interaction are recorded to the database for later analysis. After the study period concludes, the experimenter interviews each participant using a loosely-structured interview to gather their thoughts regarding their interactions with the system.

The questionnaires that are used comprise a number of different scales. A summary is provided in Table 10.1 and a listing of the questionnaires is shown in Appendix B.

Measure	Reference
Satisfaction with system	[59]
Working Alliance Inventory	[36, 47, 43]
General health	[44]
Big-Five	[50]
Specific trust of system	[25, 26]
General social trust	[104]
Feelings about use of system	[105, 112]
Weight-related measures	

Table 10.1: Questionnaire-based measures used in the study.

During the study, the system recorded numerous pieces of information that allows us to retrieve data about what happened while a person was interacting with the system each time. Questions were explicitly and implicitly asked of the user and the system also records those responses. A list of all of the information recorded is shown in Table 10.2.

Measure	Example or how recorded
Timestamp for each interaction	19:13:52
Duration of each interaction	04:23
Selection at each multiple-choice response	-1 = negative, 0 = neutral, 1 = positive
Calorie consumption entries	breakfast = 220 calories, lunch = 430 calories
Exercise amount entries	walking = 25 minutes, jogging = 15 minutes
Responses to WAI-SF questions	Q1 = 143, Q2 = 98
Path through interaction	timestamped list of all actions by person and system

Table 10.2: System-recorded measures during the study.

The interview was based around a set of questions (shown in Appendix C), but was deliberately left open-ended to allow the experimenter to discuss each participant's experiences with interacting with the system.

Research model

The longitudinal design of the study allows for the measure of factors over time. One type of analysis that can be done with this study design that was not possible in the previous studies that were discussed in Section 2.2 is tracking things like satisfaction or perceived alliance with the system over time. A criticism of short-term laboratory-based work is that novelty effects may have an impact on the result. We can analyze changes over time across a group of users in an attempt to better understand the rôle of novelty effects in human-robot interaction research.

Carrying this out as a between-subjects study is necessary for two reasons. There would be strong ordering effects if participants were to use one and then the other system. The second (or third) system that any participant would use would then be received at a different phase of a diet program, likely at a maintenance phase instead of a weight loss phase. This would have a significant impact on how the system was perceived as well as how it would be used. The other reason is practical: running a long-term within-subjects study could take years given the amount of time it takes to coördinate participants' involvement in the study. (The study described herein included 45 participants for up to six weeks each and was conducted on more than a full-time schedule by one researcher for four months.)

Participants

The study consisted of forty-five participants, fifteen in each of the three study groups. Participants were recruited using flyers in local athletic clubs and restaurants as well as by the researcher talking to new patients in the Nutrition and Weight Management Center clinic at Boston Medical Center. After a participant was accepted into the study, they were randomly assigned to one of the three study groups.

Qualification for the study was based on weight and health-related criteria. We wanted to find participants who were in need of losing weight and ready to do so, but exclude those for whom there may be a significant health risk. To bound the weight-related criteria, we used patients who were considered overweight or class I or II obese at the time of the intake interview (BMI range of 25 up to 42). (This excluded class III obesity, for which there is a higher risk of concomitant comorbid factors.) Participants were also asked to complete the Physical Activity Readiness Questionnaire (PAR-Q), which is designed to screen out individuals for whom physical activity may pose a problem or hazard [109]. Participants had to be fluent in both spoken and written English, as this is the only language that study materials had been prepared in.

Participants were not screened for any criteria relating to familiarity with technology or access to a computer on a regular basis. Potential participants were told only that the study involved tracking calories and exercise for a four-week period. Participants only knew about the existence of the robot coach at the beginning of the study if they were randomly selected into the robot group or after the conclusion of the final questionnaires and interviews otherwise.

The group that entered the study ranged in age from 18 to 72 (Average age was 50.1 years, $\sigma = 10.6$; no significant different between groups.). 80% of participants were female and 20% male.

Protocol scripts for the initial visit and followup contacts are shown in Appendix E.

Protocol

The four components of the study were recruitment and qualification, initial visit and setup, study period, and final interview. Each of these is described here.

Recruitment and qualification

Participants were recruited as described in the previous section. If a potential participant was interested in the study, they could talk to the researcher about the study in the clinic or contact the researcher via an intake web page or telephone number. The URL and telephone number were provided on all recruitment flyers and e-mails that were distributed during the recruitment phase of the study. During recruitment, the researcher explained that the study was designed to help find ways to help people better keep track of their calorie consumption and exercise amount. Previous research findings showing the benefits of doing so were briefly summarized. Potential participants were told that if they were to participate in the study, they would be asked to use a system that they would be given once a day to record their calorie consumption and exercise amount.

The researcher explained that there was no cost to participants who chose to become part of the study and that there was no pay, but that participants would be allowed to keep the pedometer that they would be given to use during the study (an Omron HJ-112, approximately $20 value). The protocol for the experiment was also explained.

After a potential participant expressed interest, they would then complete the intake screening questionnaire on the web, verbally over the phone, or verbally in person. For participants who passed the screening, the experimenter would set a time for the initial in-home visit and setup of the system.

Initial visit and setup

The initial visit to a study participant's home lasted approximately forty-five minutes. During this visit, the experimenter would again explain the protocol of the study and ask participants to complete a consent form. After any questions were answered and the form was signed, initial questionnaires were then administered.

These were a repeat of the intake questionnaire (data could be kept now that informed consent had been obtained) and the questionnaires described above in the Measures section.

The participant was then given the pedometer that they would use during the study. The experimenter set up the pedometer for each participant (setting time, participant weight, and participant stride length) and explained how to use the pedometer as well as how to attach it to clothing if desired. Any questions about the use of the pedometer were then answered.

The experimenter then explained the need to set daily calorie and exercise goals and asked the participant if they had goals in mind. If they did not, the experimenter suggested general guidelines and asked the participant to choose an initial goal and explained that the goal could be changed at any time and as frequently as desired during the course of the study.

Finally the experimenter introduced one of the three record-keeping systems to the participant and explained how to use it.

For the robot or computer system, the participant was asked where they would like to place the system in their home. The experimenter then plugged in the system to power and had the participant turn it on. After booting up (approximately 45 seconds), each button on the main screen was explained to participants. Participants were then asked to press the "Update Goals" button and set their initial calorie and exercise goals. The calorie goal was a maximum number of calories per day and exercise was either number of minutes per day or number of steps per day that the participant would try to attain. After finishing the goal setting and returning to the main screen, participants were asked to press the "Start Daily Interaction" and go through the interaction once so that the experimenter could explain a few points and answer any questions. During this interaction, the experimenter would explain that the system would show everything spoken aloud in the screen (in the robot case) or simply display dialogue on the screen (in the computer case) and that the user could select any option on the screen to continue the interaction. The calorie entry system was also explained, as well as using the scales at the conclusion of the interaction to respond to the questions asked by the system. After returning to the main screen, participants were asked to press the "Shutdown" button to turn off the system.

For the paper system, participants were shown the layout of the paper log and shown where to input their goals, their calorie consumption, and exercise amounts. Participants were asked to write their initial goals across the top of the first page and to write any changes in goals across the top of the page that corresponded to the day on which they made the change.

Participants were again reminded to use the system that they had been given at least once a day and left with contact information for the experimenter in the event that they encountered any problems while using the system.

Study period

During the initial four-week period of the study, the experimenter initiated no contact with participants. The experimenter was contacted by two participants in the robot group, one in the computer group, and two in the paper group. One of the robots had burned out a motor and had to be replaced. The touch screen on one computer stopped responding and the experimenter had to plug it back in. Two participants in the paper group lost their pedometers and had new ones sent to them. No problem was ever identified for the other participants in the robot group; one person called twice to discuss the system, but with no discernible problem.

At approximately five days before the end of the four-week period, participants were contacted and told that all participants in the study were being given the opportunity to continue the study for an additional two weeks. If participants chose to continue, they were advised to continue using their system in the same way they had been. For participants in the paper group, an additional two weeks of paper logs were mailed so that they would have them before the end of the initial period. Participants who chose not to continue were asked to schedule a follow up visit for as soon as possible after the conclusion of their four weeks. Participants who continued for a full six weeks were contacted again a few days before the end of the six week period and asked to schedule a follow up visit for as soon as possible after the conclusion of the study.

Final interview

The final visit to participants' homes was shorter in duration than the initial visit. This visit consisted of questionnaires, an interview, and debriefing the participant on the purposes and design of the study.

The questionnaires administered during this visit were described above in the Measures section. After participants completed the questionnaires, an interview was conducted. The questions and nature of this interview was also described above. Finally, participants were informed about the study design, the other two groups that they were not part of, and the plans for data analysis and presentation. Any questions were answered by the experimenter and the participant's system was collected to take back to the laboratory for analysis.

10.3 Shortcomings

There are several potential problems with the design and implementation of the study. The most significant problem is that the study was not double blind nor completely blind to participants in that some knew that that there was a robot involved even when they were randomly assigned to one of the control conditions. Given that the study was run by a single researcher and the fact that this researcher had to deliver the hardware or paper log, a double blind study would have been very challenging to create. During recruitment, some participants were also informed about the study as a "robot study" before they were randomly assigned into a study condition.

Several steps were taken to ameliorate these problems. The recruitment for study participants was as similar as possible and the study materials were discussed as "a system to help you keep track of how much you are eating and exercising." All participants were randomly assigned to one of the three study groups at the time when they actually started the study, which was at a later date from recruitment. During the intake session at their home, a script was used to help keep all interactions as similar as possible. Scripts were also used for follow up contact at four and six weeks as well as for the final visit and interview. These scripts can be seen in Appendix E.

As an improvement over this protocol, a follow-up study should be blind in order to minimize any expectation effects on participants. This could be achieved using multiple researchers to conduct the experiment. Maintaining a double-blind study would still be challenging, as participants who are discussing their participation in the study talk about the robot, computer, or paper log that they are using. Different researchers conducting different phases of the study (recruiting, admission, and followup) would be a way to help to minimize these effects in the future.

The short form of the Working Alliance Inventory used at the end of each interaction was beneficial for estimating relationship state, but answering the questions rapidly became repetitive to participants. Significant effort was made to assure that all other aspects of the interaction would vary with each interaction, so these questions were a noticeable exception. Many participants in both the robot and the computer conditions of the study remarked that they did not like having to regularly answer these questions during the final interview.

Chapter 11

Experimental Results

We used three types of data collection in the experiment to approach the four hypothesis. The data collection methods were questionnaires, interviews, and interaction data recording. The sets of hypotheses from Chapter 10 were:

1. Participants using the robot will stick with it longer than those using the computer or paper systems. This measure can be determined through analysis of interactions.
2. Participants using the robot will like using their system more and feel a closer relationship with it. This will be measured using mainly the working alliance inventory, but also measures trust in the system, perceived reliability, and perceived information quality of the system.
3. Participants using the robot will relate to their system more and develop a stronger affinity to it. This will be analyzed mostly through post-experiment interviews with participants.
4. Participants in all three conditions will lose weight and the difference between systems will not be statistically significant. This is because we can expect anyone participating in such a study to lose weight and that the effects of using the system for longer periods of time only become important and differentiable in terms of weight loss after a much longer period.

Hypothesis 1 is measured using the data recorded by the systems in the computer and robot conditions. For the paper system users, we can see the paper logs if they completed the experiment. With all groups, we asked about their usage habits during the final interview as well. We can also determine the dropout rate for the experiment for each group to see if there is a difference. The analysis of hypothesis 2 is done using all three types of data: responses to specific questionnaires, discussions during the interviews, and data from the interaction in the robot and computer conditions. The interview and the questionnaire responses will be used to understand hypothesis 3. Hypothesis 4 is the simplest – it can be analyzed using before and after weight as reported by participants.

All analyses in this chapter except for calculation of the dropout rate are carried out using data from the thirty-three participants who completed the full study, including questionnaires at the conclusion of the study. Details are presented in the dropout rate section. Further details on statistical analyses are shown in Appendix D.

11.1 Dropout rate

Before analyzing the data with respect to our hypotheses, we must determine the participants for whom we will use their data. As with any weight loss study, we may have a high number of participants who start the study discontinue their participation before the conclusion of the study period.

In this study, we did a followup interview with 39 of the 45 participants who began the study. This included 14 of 15 with a robot, 14 of 15 with a computer, and 11 of 15 with a paper log. Of these, the number who had actually used the system for at least one week (the minimum threshold set for considering a person to have tried the system) was 10 of 14 with a robot, 12 of 14 with a computer, and 8 of 11 with a paper log.

Condition	Started	Final Interview	Used 1 week+
Robot	15	14	10
Computer	15	14	12
Paper log	15	11	8

Table 11.1: Experiment completion and system use.

Through the interviews, we discovered that reasons for dropping out in the computer and robot case rarely had to do with not liking the system. (Only one person cited this as the reason for discontinuing the use of the robot; more discussion is found in Section 14.3.) Nearly all participants who dropped out in the robot and computer cases and a few in the paper log case cited other interfering issues: illness or hospitalization (2 participants), caring for an ill family member (1 participants), or unexpected extended travel (1 participant). Table 11.1 summarizes the numbers of participants at each stage.

Most participants completed the final interview in all three cases, but analysis of the data showed that several had not actually used the system. This is reflected in the third column of the table. The participants who completed the interview and used the system are used in the remainder of the analyses.

11.2 System usage

A central goal in creating this weight loss system is to have users of the robot continue with it for longer than with other methods. Our first hypothesis states that:

> **H1**: Participants interacting with the robot will use the system for an overall longer period of time than participants who have a computer or a paper log.

This duration is the time from first use to last use during the study period over which people use their system.

The analysis of the data shows that this hypothesis is supported. Participants with a robot used their system on average 50.6 days, while participants with a computer used their system for 36.2 days on average, and participants with a paper log reached an average of 26.7 days. A one-way ANOVA shows a significant difference among groups: $F(2, 30) = 11.51, p < 0.001$. The post-hoc Tukey HSD shows a significant difference between the robot group and the computer group ($p < 0.05$) and a highly significant difference between the robot group and the paper log group ($p < 0.01$).

The astute reader will note that the 50.6 days is equivalent to over seven weeks, which is longer than the purported six weeks of the study, while the computer group comes in at just over five weeks. This is a result of many participants in the robot group delaying the end of the study so that they would not have to give up their system. This is discussed further in Chapter 14.

11.3 Feelings toward system

How well a person thinks that they can work with the system is an important factor in predicting longer-term success. As was discussed in Chapter 4, the Working Alliance Inventory is a known correlate to outcome measures in caregiver/patient relationships. We use two forms of the WAI in this study to give the system an immediate measure of relationship state as well as a full form at the conclusion at the study to judge the overall relationship as viewed by participants.

We anticipate that participants will enjoy working with the robot more so than with the other two systems and judge it more highly across several measures. In addition to the WAI, we use a variety of measures that have been utilized in previous work to survey perceptions of the system. Each of the seven hypotheses in this section look at one aspect of interaction.

The first two hypotheses use the Working Alliance Inventory that was introduced in Section 4.3. The first uses the short form of this, two questions of which were asked of the user at the end of each interaction. This allowed the system to estimate the current state of the relationship on an ongoing basis. The first hypothesis is:

> **H2**: Participants interacting with the robot will rate the system higher on regular responses to the short version of the working alliance inventory (WAI-SF) than participants who have a computer.

This hypothesis was clearly shown to be true. Questions were presented to uses as a continuous scale anchored at three points ("Strongly Agree," "Neutral," and "Strongly Disagree"). The scale was discretized on a scale of 0 to 600 for coding responses, with 0 correlating with "Strongly Agree." The average response for participants in the robot group was 68.2, while the average score in the computer group was 234.1. A double-sided t test shows $t(17) = -5.1$ with $p < 0.001$.

The next hypotheses concerns the use of the full Working Alliance Inventory administered using a paper questionnaire with 7-point Likert scale administered at the conclusion of the study as part of the final home visit. This was one of the scales administered to all participants, so we can measure across all three groups, robot, computer, and paper. This hypothesis states:

> **H3**: Participants interacting with the robot will rate the system higher on responses to the full version of the working alliance inventory (WAI) administered at the end of the experiment than participants who have a computer or participants using paper logs.

Analysis showed that this was the case. A one-way ANOVA for independent samples shows a significant difference among cases ($F(2, 30) = 5.54, p < 0.01$). Tukey HSD tests report no significant difference between the computer and paper cases, but a significant difference between the robot and computer cases ($p < 0.05$) and the robot and paper cases ($p < 0.01$).

The third hypothesis regarding wanting to work with the system looks at the perception of users of the quality of the information they are receiving from the system. This uses the perceived information quality scale of Nass, et al. [81] with a reported Cronbach's alpha of 0.92.

> **H4**: Participants interacting with the robot will rate the system higher on responses to a scale of perceived information quality administered at the end of the experiment than participants who have a computer.

A t-test shows no significant difference ($t(17) = 2.0, p = 0.059$) with an average score on a 7-point Likert scale of 6.3 for the robot condition and 5.36 for the computer condition.

Another measure of participants' relationship with the system is a measure of specific trust.

> **H5**: Participants interacting with the robot will rate the system higher on responses to a scale of specific trust administered at the end of the experiment than participants who have a computer or participants using paper logs.

A one-way ANOVA yields a significant difference: $F(2,30) = 4.98, p < 0.05$. The post-hoc Tukey HSD gives only a significant difference between the paper and robot conditions ($p < 0.01$).

Altruism is a measure that we have used in the past to understand how participants feel about a system having their best interests in mind. Our hypothesis in this case is:

> **H6**: Participants interacting with the robot will rate the system higher on responses to a scale of altruism administered at the end of the experiment than participants who have a computer or participants using paper logs.

A one-way ANOVA shows no significant difference ($F(2,30) = 2.78$).

The reported level of engagement is a useful measure of how much participants felt that interacting with the system drew them in. We hypothesize that:

> **H7**: Participants interacting with the robot will rate the system higher on responses to a scale of engagement administered at the end of the experiment than participants who have a computer or participants using paper logs.

A one-way ANOVA yields a significant difference: $F(2, 30) = 3.99, p < 0.05$. The post-hoc Tukey HSD gives only a significant difference between the paper and robot conditions ($p < 0.05$).

The last self-report measure regarding feelings toward the system is about the reliability of the system:

> **H8**: Participants interacting with the robot will rate the system higher on responses to a scale of reliability administered at the end of the experiment than participants who have a computer or participants using paper logs.

A one-way ANOVA yields a significant difference: $F(2, 30) = 7.80, p < 0.01$. The post-hoc Tukey HSD shows a significant difference between the paper and robot conditions ($p < 0.01$).

11.4 Relationship to system

We expect that participants who are interacting with the robot will develop a different relationship and closer ties with their system than those who have either a computer or a paper log. Our hypothesis is that:

> **H9**: Participants interacting with the robot will develop a closer relationship by the end of the experiment than participants who have a computer or participants using paper logs.

A particular scale to measure this was not used. Rather we rely on data such as noting that a majority of participants named their robot (9 of 14 who finished the study and 9 of 12 who used the system for at least a week), the fact that at least three people dressed their robots, and that we had a challenge scheduling some of the followup visits with people who had robots because they did not want to give them back. None of these happened with participants who had a computer or with those using the paper log. More discussion of the interaction can be found in Chapter 14.

11.5 Weight loss

The last type of measure that we looked at was percentage of body weight lost during the study. Given the duration of this study, we expect that the weight lost will be small. We would also expect that the duration is not long enough for there to be a notable difference between groups. Previous research has shown the likelihood of many weight loss methods producing short term weight loss. As we have stated before, the bigger challenge is in maintenance. Therefore we hypothesize that:

> **H10**: There will be no difference in the amount of weight lost across all three groups at the end of the six week study period.

The results indeed bear out this hypothesis. (One-way ANOVA: $F(2,29) = 0$). The mean percentage of starting body weight lost per group was: robot = 2.2%, computer = 2.0%, paper = 2.4%. (If we exclude one extreme outlier in the study who happened to be in the robot group who gained 10 pounds during the study, the robot group is 3.2%, still resulting in no significant difference: $F(2,28) = 0.44$.)

11.6 Physician use of system

In followup discussions with a physician treating patients for overweight and obesity, some of whom were participants in our study, we discussed the usefulness of this system in their clinical practice. In general, the system was viewed as a potentially useful addition to existing methods of treatment. Something that helps patients to keep with their diet between visits would be seen as a valuable addition to existing clinical practice.

The level of detail in the data that is collected is not something that would be useful to a professional caregiver if all of it were to be presented. The output must be easy to interpret quickly, similar to the graphs that are shown at the end of each interaction. A likely use would be to have a staff member in a weight loss clinic regularly review patients' data (i.e. once every week or two) and follow up with any patients who might need intervention more immediately than their next scheduled visit.

11.7 Summary

We developed and tested eleven hypotheses using the robot, the computer, and the paper logs. The central hypotheses concerned the length of time participants would use the system and their relationship with the system as measured through the WAI and through observation of their behavior. Table 11.2 summarizes the overall results of the experiment. The analysis of hypothesis 2 shows that participants with a robot kept up with tracking their diet and exercise for longer than did participants using the computer or the paper log. Hypotheses 3, 4, and 10 deal with the relationship question and the analysis of these three show a clear difference in the relationship that is developed with the robot when compared to the computer or the paper log.

Hypothesis	Confirmed	Synopsis
1	Yes	Participants with a robot used the system for significantly longer.
2	Yes	Participants had a closer alliance with the robot (compared to computer) as shown with the short form WAI.
3	Yes	Participants had a closer alliance with the robot (compared to computer and paper) as shown with the full WAI.
4	No	Participants using the robot and computer had similar responses to information quality.
5	Yes	Participants with the robot trust it more than those with paper logs.
6	No	There was no difference in perceived altruism of the systems.
7	Yes	The robot was seen as more engaging to participants than the paper log.
8	Yes	The robot was seen as more reliable in function to participants than the paper log.
9	Yes	Anecdotal evidence shows a clear difference in relationships between participants and systems.
10	Yes	As expected, the difference in percent of body weight lost was minimal.

Table 11.2: Summary of experimental findings.

Part IV

Lessons for Sociable Robot Systems

Chapter 12

Design Rules

This is the first of two chapters that summarize what has been learned in the process of designing a sociable robot system for long-term interaction and carrying out an experiment and its analysis. This chapter will mirror chapter 4, highlighting what we believe are the key points after completing the work.

12.1 Sociable Robot System Requirements

Developing an in-depth understanding of the application domain was an important factor in creating a successful system. Before beginning the process of creating hardware and software, spending time with potential users and others who know the domain is extremely valuable. In the case of the weight loss system, the interactions, observation, and discussion with individuals trying to lose weight and those providing care, advice, and assistance to these individuals heavily influenced the design of the system that was built.

In terms of practical system construction, the fact that we ended up building our own robot, as opposed to using something that was available and already built, gave us control to fully integrate all of the components of the system. It is possible that this could have been done with another system, but creating our own allowed for this integration to begin with the design phase, which inevitably made it easier than it would have been otherwise.

Our experience in creating and using many different types of interactions across a variety of robot platforms conferred a significant advantage in designing and realizing the interactions between the weight loss coach robot and the user. Across a series of studies, we have studied in detail approximately 300 individuals interacting with robots and have seen an additional several thousand people interact with our robots on an informal basis. This experience has allowed for the creation of the successful interaction techniques that are described in this work.

12.2 Interaction Requirements

There are several aspects of the interaction that have made important contributions to creating a successful system. One that was mentioned in the criteria for designing this robot system was the moving eyes and the appearance of eye contact with the user. This did turn out to be extremely important, as anticipated. Numerous participants who had the robot (and countless others who have seen or interacted with it for short durations) noted during the final interview that the eyes of the robot and the fact that it looked at them drew them into interactions with the system and made it feel more lifelike. Users were clearly more engaged with a system that looked at them than with the computer running the same software. Indeed, several participants who claimed that the eyes on their robots were not working well (a fact noted in Chapter 7 was the difficulty in getting the eyes to work consistently across all robots) used the robot for a much shorter period of time than others. There were not enough participants nor a controlled way to measure eye gaze performance to analyze this in detail.

Another part of the interaction that was important was the overall software architecture of the system. This architecture allowed us to be very flexible with the design of interactions and the components that were used throughout the development cycle. The ability to plug in modules such as the text-to-speech system or the motor controller allowed for changes to subsystems to be made independently of the core interaction code. This flexibility saved time during the development process and allowed improvements to be made easily in any of these subsystems. The database and script-driven nature of the interaction was also a key element in creating a wide variety of interactions. This allowed us to quickly add on additional pieces of conversation and interaction as they were developed and to increase the variety in the interaction on an ongoing basis.

12.3 Relationship Requirements

Having a clearly defined model of the relationship made the development of a cohesive system possible. There are two aspects of this model that were necessary to understand. The first is the trajectory of the relationship. As described in Section 6.3, we had developed a model based on human psychology that was used. This model is relatively simple, but an understanding of what the differences are in how the system relates to the user at each stage can be somewhat nuanced. Having drawn on social psychological models of relationships, we can look to examples of how people would behave in such a situation and model the robots behavior off of that.

The other important part of the relationship model is the type of relationship that we were trying to create. Using the interactions between medical caregivers and weight loss patients, as discussed in Section 6.3, gave a clear focus to all aspects of the interaction. In this case, this is a relationship where the caregiver is always supportive, positive, and helpful. Thus everything that the robot says in interactions with the user was written with this in mind. Based on participant feedback, it is clear that this model worked well for the relationship that we were building. Many users found the suggestions and the overall tone of the system to be helpful to them and told us so.

12.4 Target Audience Requirements

Designing with end users in mind was easier after spending time with the target population before beginning to create the system. Even with that, however, it is difficult to anticipate how individuals will respond to a system. Each person has widely divergent ideas about what is good or bad and useful or intrusive in such a system. We did some user testing along the way, but to create a more useful system, a more intensive iterative testing approach would be highly recommended. Our testing was short term – having people use particular aspects of the system once or twice – rather than giving people systems to use for a week or two as a test and then making changes and improvements before repeating that process. While this clearly presents challenges in doing this on a large scale (either number of robots or time), it would undoubtedly make for a more useful system in the end.

Continuous testing of a system like this is also necessary. Many of the fixes to the system that we made during testing are not "bugs" in the traditional sense. There is no easy way to determine that the timing of a look-at behavior is not quite right or that the phrasing of some of the robot's conversation does not quite fit its personality using traditional software or hardware testing and debugging techniques. At this stage, only consistent use of and familiarity with a system can uncover these issues. It can be difficult to do this: interacting with the same system day after day for the people designing it becomes a challenge. It is, however, the best way to create a system that others will want to interact with in their daily lives.

Finally, the design challenge of making this robot system as simple and intuitive as possible was clearly worthwhile. Taking advantage of the robot's ability to guide people through the interaction, along with creating software that supported this notion, made the system easy to use for even novice computer users. We managed to strike the right balance between explanation and terseness that allowed individuals at all levels of competence use the system. This relates to the relationship stages as well and the ability of the robot to estimate the user's need for more or less explanation at appropriate times worked well.

Chapter 13

Evaluation Methods

In order to continue creating more useful systems, conducting effective and efficient research is critical. This chapter presents the lessons learned through conducting a study of the weight loss coach sociable robot system.

As with any research, a clearly defined hypothesis and evaluation metrics at the outset makes the study design easier. The study that was reported here had this in part, but a portion of it was exploratory in nature. The open-ended interviews with participants at the conclusion of the study were very useful for developing a broader understanding of the interactions, but are difficult to evaluate in terms of controlled data gathering and statistical analysis. At this stage in the development of sociable robot systems for long-term interaction, we believe that both controlled and exploratory experimentation are important to both understand what the important questions are and to answer specific questions. We certainly do not yet know enough about every facet of long-term interaction to ignore the open-ended, exploratory format of study.

Finding appropriate measure to the type of interaction that is being created is important for developing useful studies. For the weight loss coach, our measures of participants feelings about working with the system (the Working Alliance Inventory) as well as tracking the desired behavior in using the system (duration spent with it), were the ideal measures. These were taken directly from the applicable measures of human-human interaction, for which many human-robot relationships will have a correlate. Understanding and mining the relevant fields of human interactions is a useful source of reliable and valid measures in human-robot experimentation.

One new challenge in long-term HRI experiments that we don't have in the laboratory is the significant dropout rate. As we reported, only 87% of our participants even completed a final interview and only 67% of those who started the study actually completed a significant period of interactions. While many of these dropouts make sense in terms of conducting a weight loss study, they are not problems that are typically encountered in a laboratory-based HRI study. While working in the laboratory to conduct short-term experiments, we can assume that the external world will not unduly intrude on those who participate in a study. In a real-world, long-term study, however, there are significant other factors that are involved. Participants become sick or are hospitalized. Family members need care. Jobs send them away. People lose interest. All of these are challenges in carrying out such a study and must be considered when designing a long-term HRI study. The number of participants needed is higher, the logistics of contacting them are challenging, and simply keeping track of robots and other equipment is difficult. While we have found that a no-show rate of approximately 15% is common in a lab-based experiment, it is difficult to determine a number yet for in-home experiments. Our experience has been that approximately 60% of those who showed interest in this study initially ended up participating. Thus from initial interest to those who completed the study we retained roughly 40%.

The weight loss coach study only selected participants based on body mass index and general health (screening out those who should be under medical supervision while engaged in a diet and exercise program when we were not recruiting them in a medical clinic with a recommendation from their physician). There were no selection criteria for gender, age (other than ruling out minors because of institutional review board criteria), familiarity with technology, or other factors that may influence participation in or success with the study. This means that we had a wide range of participants in age (18 to 72), mixed gender (80% female and 20% male), and a variety of background with technology (ranging from people who carried a laptop and PDA everywhere to never having owned a computer before). We found this useful in this study to have such a mix of people to be able to observe the different reactions to the robot. If we were designing a study to better understand how a particular subset of people (for example, those familiar with computers or those in a particular age group) would interact with a sociable robot system, then narrowing by those criteria would be necessary. As long-term HRI work progresses as a field to develop specific systems for people to use, these are the types of studies that we will undertake. For now, however, we need a good, broad understanding of the creation of robots for long-term interaction that a broad base of participants allows us to develop.

Our experimental protocol allowed for little interaction between participants and the experimenter during the study. We believe that this was appropriate in that it mimics likely real-world condition under which people might acquire robots in their everyday lives. The initial visit, which was approximately 40 to 45 minutes, consisted mainly of participants completing questionnaires on health, weight loss history, and personality. The experimenter then explained once how to use the system while watching the participant try it. It was incumbent on the system to explain to the participant how to use it, which is the likely case if we are creating systems that would go out to large numbers of people.

Overall, the biggest desirable change in the experiment that we conducted would be to increase the number of participants so that the number of those successfully completing the study would be significantly higher. This would be extremely challenging for a single experimenter to conduct an experiment of such magnitude, however. We estimate the total incremental time per participant for this type of study design to be at least ten hours over the experiment period. Scaling this to several score more participants in a study would simply require more experimenters to manage the process.

Part V

Conclusions

Chapter 14

Experimental Lessons

This chapter contains lessons and stories from running a large-scale human-robot interaction experiment with users in their homes. It is a break from the rest of the thesis – these are meant to be stories from which insights might be gleaned. There are no statistical analysis or hypotheses. All names used in this chapter are pseudonyms for experimental participants.

14.1 First names

Rose was one of the first participants to start the study. She has been dieting for a number of years and has successfully lost a significant amount of weight before. She hasn't been able to keep it off, however, and has found her weight fluctuating in the last few years. Rose and her husband live in a close-in suburb of Boston and when I delivered the robot, she and her husband had a hat on it and were discussing names before I was out of their home.

For her, this turned out to be just the beginning of her relationship with the robot. I heard from her during the study that they had decided to name her (the robot) Maya. She told me that Maya had become a part of the family and that she really enjoyed talking to her every day. For the purposes of the study, Maya was doing for her exactly what I had hoped – engaging her in regular interaction that kept her on her diet, thinking about her daily eating and exercise decisions, and trying to make a conscious change in her lifestyle. It seemed clear to me that when this kind of relationship could be engendered, this system might really have a chance of success.

Following along with the study design, I contacted Rose just before the end of the initial four week period of the study to offer her the option o continue for an additional two weeks. She readily accepted and I told her that I would follow up in an additional two weeks to schedule the final followup visit. When I got in touch with her near the six week mark, she held off on responding to my e-mails and phone calls and when she did respond, she avoided the question of scheduling the followup visit even though this was the purpose of the communication.

By the time I managed to schedule a visit, Rose had kept the robot for a full eight weeks. Although she knew the study was over after six weeks, this wasn't like other participants who were too busy to schedule a visit and stopped participating in the study after 42 days exactly – she used it up until the day that I arrived to collect Maya and talk with Rosie about the study.

During the followup visit, she didn't hesitate to talk about the robot by name – the name she had given it – and tell me stories about their conversations. Indeed, she asked to use the robot one more time before she was taken away, which I gladly indulged. Before I made it out the front door, we had taken pictures and said several goodbyes, before she finally came to the car to see maya strapped in and wave her final goodbye.

This was one of the strongest relationships that was acknowledged during the study of the fifteen people who were given a robot to interact with. Rosie was one of the people who quickly named their system. No one was prompted to name it, but the robot brought out an instinct in most people who had one in heir home to give it a name and begin to interpret its personality.

14.2 Private conversation

Professor Gordon was a fairly quiet and reserved participant in the study. He told me that he had tried several diets and ways to lose weight, but just wasn't having any success in keeping it off. While he seemed hesitant to think that a robotic coach might worked, he agreed to give it a try. This was possibly more out of curiosity for what the thing would do rather than any belief that it might work for him.

The initial home visit was rather uneventful. He quietly completed the questionnaires, arguing about some of the question wording as he went through them. When it came time to set up the robot, he decided that we would place it on a table just behind the living room sofa, wedging it between the sofa and the wall. This would required him to sit backwards or kneel on the sofa tin order to interact with the system. It didn't seem the most logical place to me, but I left the placement of the system entirely up to the user, telling them only that it needed access to a power outlet. We set up the robot, plugged it in, and he went through the interaction once. The professor quickly showed me to the door, saying that he would try to use the system in the upcoming month.

At the four week mark, Professor Gordon agreed via e-mail to continue the study. No emotion, no comment, just that he would continue for an additional two weeks.

When I arrived for the followup visit, we again sat in the living room for him to complete the questionnaires and conduct the interview. I immediately noticed that there was no robot behind the sofa, but there was no comment nor mention of it by the professor. I gave him the questionnaires to fill out and he started with the one that was intended to garner information about how human-like people found the interactions to be. All participants in the study are given the exact same questionnaires, so I sometimes got comments from people with the paper log when they encountered statements like "the system was sincere in trying to help me" or "the system was interested in interacting with me." Those in the computer group would also inquire about these on occasion, but thus far no one else who had a robot had asked about the questionnaire. This participant was insistent that most of the questions were faulty. "You shouldn't ask questions like this about a machine," he told me several times. "These questions don't make sense. You talk about this thing like it has feelings." It was clear that he wasn't happy with the direction of the inquiry, so I was expecting this to turn more negative as we started the interview.

Indeed during my first few questions about what he thought of using the system, whether it was useful for getting him to his weight loss goals, or how frequently he used it, he managed to turn several of the answers into a discussion about my choice of questionnaires and why talking about the robot in this way did not make sense. He noted that "there were terms like "relationship," "trust," and a couple of others, I didn't really... I wasn't comfortable saying I trusted it, or that I had a relationship with it."

Later in the interview I ask people about whether they named their robot and to tell me about its personality. With some participants these are easy questions. Several have told me the name as soon as we started talking. For others though, this can be a more delicate process. I have found it useful to start out saying something like "If you were talking to someone else about your robot, how would you refer to it?" In this case, that was clearly the tact to take – something more oblique. His answer to this question was evasive, so I tried being a little more direct about whether the robot had acquired a name under his care. He quickly got a sheepish grin across his face – the first smile I had seen in two visits – and told me "Ingrid was the name." From then on in our discussion, he referred to the robot as "Ingrid" or "her" and was much more open about his interactions.

I finally asked about where the robot was now. Apparently she had been moved shortly after the first visit because "a couple of the people would find some humor in this whole process. They were certainly not trusting, and they didn't think it was useful." As a result, he had moved her downstairs to his bedroom so that they could have private conversations.

14.3 Challenges of a robot

One of the longest deliveries was to a house in a nearby western Boston home. James told me on the telephone that he was interested in participating in a weight loss study. He understood that he would be asked to keep track of his eating and exercise for four weeks and thought that it might be useful since he needed to lose weight after a recent lengthy illness.

When I arrived at his home it took him at least five minutes to answer the door. I was patient, as I could see him through the front window talking on the phone and blithely ignoring the doorbell, which I could hear coming through the open front window each time I pressed the button. Once I was invited in, I went through the usual routine of again explaining everything that I had told potential participants on the phone. Now James wasn't sure about keeping track of diet and exercise and said that he did not know why I had wanted him to do so. I gave him the opportunity to decline participation in the study, but he decided that he would like to go ahead.

Completing the questionnaires went well. Not quickly, but not too slowly. At this point, I usually return to my vehicle to pick up the robot or computer and in James' case, he had been randomly selected into the robot group. As I returned to his living room, James was trying to decide where to place the robot. After an extended discussion about the pros and cons of several locations (again, I provided little direction and left if up to participants to determine where they wanted to place it), he decided it was best to set it up on the living room coffee table and he would move it later after he was able to think about it further.

Just as I was asking him to turn on the robot so that he could try out one interaction to see how it worked, his pest control service came to the door. He had apparently scheduled both of us for the same time and became quickly annoyed that I would not simply leave and let him figure out the operation of the robot on his own. Having not even shown him the power button and not wanting to use a different protocol for this one participant, I told him that we would need another five minutes to finish the visit. He told me to wait for "just a minute" and then proceeded to spend about 25 minutes showing the pest control man every part of the house where he had seen a bug or evidence of one. After finally rejoining me in the living room, he hurriedly and distractedly went through the single interaction with the robot and asked me to leave.

The following day I received a voice mail from James stating that the robot wasn't working. I was able to get him on the phone later in the day planning to schedule a visit to repair or replace the malfunctioning robot. He was clearly agitated on the telephone telling me that the robot wasn't going to work for him, that it was too difficult to use, and that it wouldn't turn on. I asked if he would like me to return to show him again how to use it and he told me that I could not do that, instead I had to come pick it up right away. "Actually," he said, "it's coming on at night when I'm sleeping and doing stuff." This was difficult to argue with, as I knew that the only way the system could come on was by him plugging it in and turning it on.

After another week of attempting to find a time when I could come by to retrieve the evil robot, he finally agreed to a time when I would be intruding on his schedule less. (James did not hold a job and his schedule consisted of doctors appointments once or twice a week for a serious medical condition.) When I arrived at his house, the robot had been placed outside on the front step with the power cord wrapped several times around its neck. I rang the bell to let him know that I was taking the robot and he talked to me through the locked porch door.

When I returned to the lab and looked at the data on the robot, I realized he had never used it after I left the first day. He had not even gone so far as turning it on again. Clearly not everyone is willing to give the system a try, so I had the one dropout in the robot condition of the study.

Chapter 15

Future Work

In this work, we have created a feasible sociable robot system for everyday use. This system is a proof-of-concept for further work in creating robots that will continue to become increasingly useful in the everyday lives of many people. There are two major directions in which work will continue from this point: both continuing research and the application of this technology to real-world problems.

15.1 Research steps

Having fifteen robots in homes for up to six weeks has shown that it is possible to do this kind of long-term research with a robust, functioning system that is designed and constructed in the laboratory. While it still takes a significant amount of work to create this type of system, we anticipate that this process will only become easier over time as both the hardware and software necessary continue to mature.

Human-robot interaction

As more robots are created as parts of long-term systems, there are several ways in which the research will develop in terms of human-robot interaction. A first is the ability to look at the applicability of such robots in other domains. We chose to work in the area of weight loss, but believe that the success of this undertaking shows the ability for sociable robot systems to succeed in a variety of long-term behavior change applications such as the treatment of chronic disease, monitoring medication compliance, or even quitting smoking. There is a plethora of other applications beyond these health care examples: educational or motivational systems, in-home helpers, or office-based assistants are ones that may come immediately to mind of anyone working in human-robot interaction, but this is just to name a few. As research continues, we will undoubtedly create many more applications of interest.

A second front in research will be in conducting longer studies. We have made a tremendous leap in moving from half hour in-laboratory studies to six week in-home studies. We have gleaned an enormous amount of data as well as very interesting and useful results from a month and a half of use. However, it is of great interest to understand what would develop over even longer periods of time. Can we model a richer trajectory of a relationship over six months or a year? Does the way a person thinks about the relationship change over this longer period of time? As systems become more robust, it will be possible to consider experiments over these extended time periods, which will continue to yield new and interesting results that will help to direct the future of long-term human-robot interaction.

The final direction that we see research moving in is to incorporate more people into these studies. The number of participants in our study was sufficient to give interesting results. However, given both the variability in the participant group as well as the dropout rate for a long-term study, it would be highly desirable to have a larger number of participants. It will likely take two things for this to happen: making sociable robot systems easier to build and increasing the study personnel. Both the creation of the systems and the running of the study are very person-hour intense undertakings. Since we have shown the feasibility and promise of such a study, we hope that such work will continue in the near future.

Weight loss

The other significant research step that this work leads us in is in the treatment of overweight and obesity. When we compare the duration over which participants in this study continued to use the robot to keep up with their diet and exercise program, we see clear possibilities for new clinical options in addressing this great health care challenge that we are presented with today. While the study described here is too short to be the basis for acceptance of this technology within the medical community, we can use the results as a promising beginning of new options, not only in weight loss and management, but potentially for many other long-term behavior change needs. It is clear that continued research with these systems should be conducted to determine their long-term efficacy.

In practice, the current system was not used by medical caregivers during the study. Completing that portion of the integration of this sociable robot system is an important future step towards creating a more useful platform. This would also allow for a greater degree of informed feedback on the applicability in the problem domain.

15.2 Real-world application

In addition to the research directions, we strongly believe that the promise shown in this study merits creating sociable robot systems for real-world applications. The weight loss coach provided a clear advantage over existing systems and many study participants, whether or not they were in the robot condition, wanted a robot to keep. This desire, combined with our results, shows a clear need for such a system to leave the lab and enter everyday lives. A plethora if ideas were given above and we hope to see sociable robot systems that address many of them in the near future.

Chapter 16

Conclusions

16.1 Summary of contributions

This thesis has presented a set of design principles for creating sociable robot systems that are intended for long-term interaction. We have also laid forth evaluation methods and criteria that can be used for understanding the effectiveness of these systems. A particular example was presented through the design, construction, and study of our robotic weight loss coach.

The design principles discussed in this thesis will guide the creation of future sociable robot systems. We have presented both the theoretical principles in Chapter 4 and a concrete example of how they have been applied in Chapter 6. These principles draw on numerous fields related to human-robot interaction, including psychology, human-computer interaction, affective computing, They also show how to incorporate domain-specific fields, in the case of the system we built, this brings in expertise from medical weight loss.

Criteria and suggestions for evaluating a constructed sociable robot system conducting long-term studies outside of the laboratory environment are discussed in Chapters 9 and 10 in the context of the weight loss coach. The experiment design and analysis are presented in Chapter 11.

The weight loss coach was deployed into homes where study participants interacted with it on a daily basis for up to two months. We showed that such a system could be successfully constructed and put into use and that it compares favorably to existing methods of compliance in weight loss studies.

16.2 Conclusion

The effectiveness of our weight loss coach sociable robot system gives an early glimpse at the possibilities for sociable robot systems. Participants in our study enjoyed working with this robot and many did not want to give it up at the end.

We hope that the creation, deployment, and study of this robot is a precursor to many other sociable robot systems that will soon enter our everyday lives. The possibilities for creating these type of robots that we will interact with on such a regular basis that they become part of our lives has entered the popular culture long before now. We are finally capable of beginning to create robots that will live up to these ideas. Previous robots have shown the promise of human-robot interaction, now we have begun to take these capabilities out of the microcosm of the laboratory and bring them into our lives.

The relationship that was formed between people and their robots – I call her Autom, but they used Maya, Wendy, Casper, or Ingrid – is clearly a significant step towards developing an understanding of the relationships that are possible between us and our robotic creations. Kismet took the first step along this path, showing us how quickly and completely engaged some people might become when interacting something that looks, talks, and otherwise uses social cues. Autom adds another layer to this and lets us see that people will continue these relationships over time. It's not just an "I saw a robot!" in the lab experience, rather it's "I have a robot" (or coach or pal) at home and I'll use it every day.

We also see here that there is clear applicability to one of the big challenges that is presented to us in the health of much of our population. One of the biggest difficulties for the many tens of millions of people who are struggling to lose weight is keeping with their diet and exercise program and keeping that weight off over time. The robot that we deployed clearly has promise in helping people to do just that. Sociable robots are now a reality; it's time for us to put these engaging technologies to work in ways that we find helpful and productive.

Part VI

Appendices

Appendix A

Intake Questionnaires

These questionnaires were given to participants at the commencement of the study during the first in-home visit. The consent form was completed first, followed by the questionnaires.

CONSENT TO PARTICIPATE IN
NON-BIOMEDICAL RESEARCH

Sociable Robots for Motivating Adherence to Weight Management
MIT Committee on the Use of Humans as Experimental Subjects Approval #0608001872
Robotic Interface Group

You are asked to participate in a research study conducted by Cynthia Breazeal, Ph.D. and Cory D. Kidd, MS, from the Media Lab at the Massachusetts Institute of Technology (M.I.T.). The results of this study will be used in the Ph.D. dissertation of Cory D. Kidd. You were selected as a possible participant in this study because you have indicated that you are ready to begin or have just begun a diet or weight loss program. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

- **PURPOSE OF THE STUDY**

The purpose of this study is to understand whether interactive systems for keeping track of information related to weight loss or weight management are more effective at long-term adherence to a weight loss program than traditional paper-based methods.

- **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do the following things:

Beginning of Study
First we will ask some questions about each of the following areas:
- your dieting and weight loss history,
- basic information about your current health, and
- what kind of diet or weight loss program you plan to start.

You have been randomly assigned to a group that will receive a robotic interface to help you keep track of information related to your diet or weight loss program. A researcher will deliver the system to your home, set it up for you, and explain how it works.

Figure A-1: Informed Consent

During the Study
The study will last for 4 weeks. During these 4 weeks, you will be asked to interact with the system at least once a day to input your calorie consumption and exercise amounts. The system will also ask you questions once in a while about your interactions with it. These daily interactions should take about 5 minutes each day.

After the 4-week study, you may be able to keep the system for an additional period of time if you would like to continue using it.

Throughout this entire period, you will be able to contact the researchers if you have any questions about the system or problems using it.

Conclusion of Study
After the 4-week study, the researchers will ask you to complete a questionnaire about your use of the system. This questionnaire will be online and you can complete it from any web browser. (Alternately, you can have the researchers mail a paper copy of the questionnaire to you.) The researchers will also conduct a short telephone interview with you at that time.

If you choose to keep the system for an additional period, the researchers will also ask you to complete a questionnaire at the end of that period. This questionnaire can also be completed online or on paper. At the conclusion of this period, the researchers will also request you to allow them to ask you several questions in person about your use of the system. If you do not keep the system for the additional period, this interview will happen after the 4-week study is completed.

- **POTENTIAL RISKS AND DISCOMFORTS**

We do not expect you to face any additional risks by participating in this study that you would not face by starting a diet or weight loss program without using this system.

- **POTENTIAL BENEFITS**

Participants in this study have the opportunity to use new technology that may help to motivate them to stay with a diet or weight loss program for longer than traditional paper-based methods. Individuals may benefit by gaining information regarding strategies for successful weight loss, including diet and exercise guidelines, healthy dieting suggestions, and information and education regarding health conditions including obesity, heart disease, other cardiovascular conditions, and diabetes mellitus. In addition, participants may gain useful knowledge into the prevention and treatment of such health conditions.

Participants may also gain the opportunity to use a system to help with keeping records of their daily weight-loss related behaviors including calorie consumption and exercise amount. Some participants may also gain the opportunity to get feedback on their daily activities from an interactive component of the system.

All participants in this program will have a chance to make weight management related behavior changes and achieve weight loss. Participants may also benefit by seeing a reduction in weight, BMI, BP, and waist circumference.

This research aims to understand the potential benefits of an interactive system for weight loss and other health-related conditions that can benefit from consistent attention or monitoring. This will be the first study to examine the use of such systems for weight loss support. The research will lead to a greater understanding of the role of such a system as an aid to weight loss and will lead to future versions of an interactive coach/companion system tailored more specifically to the needs of patients who are attempting to lose or maintain their weight.

- **PAYMENT FOR PARTICIPATION**

All participants in the study will be allowed to keep the pedometer that they use for keeping track of their exercise during the study, including those who leave the study before the 4-week period has ended.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

All information that is collected will be associated only with an identification number that has been assigned to you. Your name or other identifying information will not be used along with any data that is collected. You will be offered a copy of all data that is collected during the experiment once the experiment has concluded.

Data will be reported along with that of other participants of the study. Most data will be reported as averages over the entire group. Some individual data will be used to illustrate use of the system in publications or talks about this work, but that data will not use your name or any other identifying feature.

The system will not record any audio or video while you are using it. At the end of the experiment, the researcher will ask to audiotape a final interview in order to later transcribe the interview. You may review the tape if you would like and ask that any part or all of the tape be erased. Only the main researcher will have access to the original audiotape.

If the researchers would later like to use the audiotapes or other information, you will be contacted via telephone or letter and asked for your permission. If you do not give permission, the tapes or individual information will not be used.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact:

Cory D. Kidd, investigator
77 Massachusetts Ave., E15-485
Cambridge, MA 02139
coryk@media.mit.edu
617 452-5612 (office)
857 205-3133 (cell)

Cynthia Breazeal, principal investigator
77 Massachusetts Ave., E15-449
Cambridge, MA 02139
cynthiab@media.mit.edu
617 452-5601 (office)

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the MIT Insurance and Legal Affairs Office at 1-617-253 2822.

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

______________________________ ____________
Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

______________________________ ____________
Signature of Investigator Date

Participant #:___

Study Qualification

Are you planning to start a diet or weight loss program now or in the next three weeks or have you started a diet or weight loss program in the previous three weeks?

Yes No

Are you willing to keep track of the calories you consume on a daily basis for 4 weeks?

Yes No

Are you willing to keep track of amount of exercise you get on a daily basis for 4 weeks?

Yes No

Are you willing to be interviewed by a member of the study team at the end of the study?

Yes No

Are you willing to answer short questionnaires during the study?

Yes No

Health Information

Height: ___ feet and ___ inches

Weight: _____ pounds

Have you lost 10 pounds (4.5 kilograms) or more within the last 2 years?

Yes No

How many diets or weight loss programs have you tried in the last 12 months? These can be on your own, under the supervision of a clinician, or as part of a commercial weight loss program. (circle one)

0 1 2 3 or more

Intake Form Page 1 of 2

Figure A-2: Intake Qualification

Participant #:___

Has your doctor ever said that you have a heart condition and recommended only medically approved physical activity?

Yes No

Do you have chest pain brought on by physical activity?

Yes No

Have you developed chest pain at rest in the past month?

Yes No

Do you lose consciousness or lose your balance as a result of dizziness?

Yes No

Do you have a bone or joint problem that could be aggravated by the proposed physical activity? (regular exercise)

Yes No

Is your doctor currently prescribing medication for your blood pressure or heart condition? (e.g. diuretics or water pills)

Yes No

Are you aware, through your own experience or a doctor's advice, of any other reason against your exercising without medical approval?

Yes No

Intake Form Page 2 of 2

Participant #: ___

Date of Birth: __________

What has been your highest adult weight? (best estimate) _______ lbs.

What was your weight at age 18? (best estimate) _______ lbs.

What has been your lowest adult weight (not due to illness) that you maintained for at least 1 year? _______ lbs. Maintained for ___ years

Was this weight achieved with weight loss effort? Y N

What was your weight: 6 months ago? _______ lbs.
1 year ago? _______ lbs.
2 years ago? _______ lbs.

Were you overweight as a child? Y N

Your goal weight: _______ lbs.

Was there a time in your life when you experienced a noticeable weight gain or loss? Y N
If so, please record your age, weight at start, pounds changed, and reason or method.

Age at time	Weight at start	Pounds lost/gained	Reason/method
________	___________	______________	____________________
________	___________	______________	____________________
________	___________	______________	____________________
________	___________	______________	____________________

In the past year, how many times have you started a weight loss program on your own that lasted: More than 3 days:_____ Less than 3 days:_____

Marital status: (circle one)

Single
Separated
Married
Widowed
Divorced

Living situation: (circle all that apply)

Living alone
Living with parents/stepparents
Living with spouse/partner
Living with other relatives
Living with significant other
Living with roommates
Living with children

3. If you live with another person, do they support your efforts to lose weight? Y N

4. Do you have a person(s) who will support you in your weight loss efforts? Y N

General Questionnaire Page 1 of 1

Figure A-3: Weight History

Participant #:___

1. In general, would you say your health is:

- ☐ Excellent
- ☐ Very good
- ☐ Good
- ☐ Fair
- ☐ Poor

2. Compared to one year ago, how would your rate your health in general now?

- ☐ Much better now than one year ago
- ☐ Somewhat better now than one year ago
- ☐ About the same
- ☐ Somewhat worse now than one year ago
- ☐ Much worse now than one year ago

The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

3. Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports

- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

4. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf

- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

5. Lifting or carrying groceries

- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

6. Climbing several flights of stairs

- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

General Health Questionnaire Page 1 of 7

Figure A-4: General Health Questionnaire

Participant #:___

7. Climbing one flight of stairs
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

8. Bending, kneeling, or stooping
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

9. Walking more than a mile
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

10. Walking several blocks
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

11. Walking one block
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

12. Bathing or dressing yourself
- ☐ Yes, Limited a Lot
- ☐ Yes, Limited a Little
- ☐ No, Not limited at All

Participant #:___

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

13. Cut down the amount of time you spent on work or other activities

- ☐ Yes
- ☐ No

14. Accomplished less than you would like

- ☐ Yes
- ☐ No

15. Were limited in the kind of work or other activities

- ☐ Yes
- ☐ No

16. Had difficulty performing the work or other activities (for example, it took extra effort)

- ☐ Yes
- ☐ No

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

17. Cut down the amount of time you spent on work or other activities

- ☐ Yes
- ☐ No

18. Accomplished less than you would like

- ☐ Yes
- ☐ No

19. Didn't do work or other activities as carefully as usual

- ☐ Yes
- ☐ No

20. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

21. How much bodily pain have you had during the past 4 weeks?

- ☐ None
- ☐ Very mild
- ☐ Mild
- ☐ Moderate
- ☐ Severe
- ☐ Very severe

22. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

- ☐ Not at all
- ☐ A little bit
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks . . .

23. Did you feel full of pep?

- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

24. Have you been a very nervous person?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

25. Have you felt so down in the dumps that nothing could cheer you up?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

26. Have you felt calm and peaceful?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

27. Did you have a lot of energy?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

Participant #:___

28. Have you felt downhearted and blue?
- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

29. Did you feel worn out?
- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

30. Have you been a happy person?
- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

31. Did you feel tired?
- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

32. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?
- ☐ All of the time
- ☐ Most of the time
- ☐ Some of the time
- ☐ A little of the time
- ☐ None of the time

Participant #:___

How TRUE or FALSE is each of the following statements for you.

33. I seem to get sick a little easier than other people
- ❑ Definitely True
- ❑ Mostly True
- ❑ Don't Know
- ❑ Mostly False
- ❑ Definitely False

34. I am as healthy as anybody I know
- ❑ Definitely True
- ❑ Mostly True
- ❑ Don't Know
- ❑ Mostly False
- ❑ Definitely False

35. I expect my health to get worse
- ❑ Definitely True
- ❑ Mostly True
- ❑ Don't Know
- ❑ Mostly False
- ❑ Definitely False

36. My health is excellent
- ❑ Definitely True
- ❑ Mostly True
- ❑ Don't Know
- ❑ Mostly False
- ❑ Definitely False

Participant #:___

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Disagree Strongly	Disagree a little	Neither agree nor disagree	Agree a little	Agree strongly
1	2	3	4	5

I see Myself as Someone Who...

___1. Is talkative

___2. Tends to find fault with others

___3. Does a thorough job

___4. Is depressed, blue

___5. Is original, comes up with new ideas

___6. Is reserved

___7. Is helpful and unselfish with others

___8. Can be somewhat careless

___9. Is relaxed, handles stress well

___10. Is curious about many different things

___11. Is full of energy

___12. Starts quarrels with others

___13. Is a reliable worker

___14. Can be tense

___15. Is ingenious, a deep thinker

___16. Generates a lot of enthusiasm

___17. Has a forgiving nature

___18. Tends to be disorganized

___19. Worries a lot

___20. Has an active imagination

___21. Tends to be quiet

___22. Is generally trusting

___23. Tends to be lazy

___24. Is emotionally stable, not easily upset

___25. Is inventive

___26. Has an assertive personality

___27. Can be cold and aloof

___28. Perseveres until the task is finished

___29. Can be moody

___30. Values artistic, aesthetic experiences

___31. Is sometimes shy, inhibited

___32. Is considerate and kind to almost everyone

___33. Does things efficiently

___34. Remains calm in tense situations

___35. Prefers work that is routine

___36. Is outgoing, sociable

___37. Is sometimes rude to others

___38. Makes plans and follows through with them

___39. Gets nervous easily

___40. Likes to reflect, play with ideas

___41. Has few artistic interests

___42. Likes to cooperate with others

___43. Is easily distracted

___44. Is sophisticated in art, music, or literature

Please check: Did you write a number in front of each statement?

Personal Preferences Questionnaire Page 1 of 1

Figure A-5: Big Five Scale

Appendix B

Final Questionnaires

This appendix shows the questionnaires that were administered to participants during the followup visit at the conclusion of the study.

Participant #:___

1. In general, would you say your health is:

- ❑ Excellent
- ❑ Very good
- ❑ Good
- ❑ Fair
- ❑ Poor

2. Compared to one year ago, how would your rate your health in general now?

- ❑ Much better now than one year ago
- ❑ Somewhat better now than one year ago
- ❑ About the same
- ❑ Somewhat worse now than one year ago
- ❑ Much worse now than one year ago

The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

3. Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports

- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

4. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf

- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

5. Lifting or carrying groceries

- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

6. Climbing several flights of stairs

- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

General Health Questionnaire Page 1 of 7

Figure B-1: General Health Questionnaire

7. Climbing one flight of stairs
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

8. Bending, kneeling, or stooping
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

9. Walking more than a mile
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

10. Walking several blocks
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

11. Walking one block
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

12. Bathing or dressing yourself
- ❑ Yes, Limited a Lot
- ❑ Yes, Limited a Little
- ❑ No, Not limited at All

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

13. Cut down the amount of time you spent on work or other activities
- ☐ Yes
- ☐ No

14. Accomplished less than you would like
- ☐ Yes
- ☐ No

15. Were limited in the kind of work or other activities
- ☐ Yes
- ☐ No

16. Had difficulty performing the work or other activities (for example, it took extra effort)
- ☐ Yes
- ☐ No

During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

17. Cut down the amount of time you spent on work or other activities
- ☐ Yes
- ☐ No

18. Accomplished less than you would like
- ☐ Yes
- ☐ No

19. Didn't do work or other activities as carefully as usual
- ☐ Yes
- ☐ No

20. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

21. How much bodily pain have you had during the past 4 weeks?

- ☐ None
- ☐ Very mild
- ☐ Mild
- ☐ Moderate
- ☐ Severe
- ☐ Very severe

22. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

- ☐ Not at all
- ☐ A little bit
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks . . .

23. Did you feel full of pep?

- ☐ All of the Time
- ☐ Most of the Time
- ☐ A Good Bit of the Time
- ☐ Some of the Time
- ☐ A Little of the Time
- ☐ None of the Time

24. Have you been a very nervous person?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

25. Have you felt so down in the dumps that nothing could cheer you up?
- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

26. Have you felt calm and peaceful?
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- ❑ None of the Time

27. Did you have a lot of energy?
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- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

Participant #:___

28. Have you felt downhearted and blue?

- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

29. Did you feel worn out?

- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

30. Have you been a happy person?

- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

31. Did you feel tired?

- ❑ All of the Time
- ❑ Most of the Time
- ❑ A Good Bit of the Time
- ❑ Some of the Time
- ❑ A Little of the Time
- ❑ None of the Time

32. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?

- ❑ All of the time
- ❑ Most of the time
- ❑ Some of the time
- ❑ A little of the time
- ❑ None of the time

Participant #:___

How TRUE or FALSE is each of the following statements for you.

33. I seem to get sick a little easier than other people
- ☐ Definitely True
- ☐ Mostly True
- ☐ Don't Know
- ☐ Mostly False
- ☐ Definitely False

34. I am as healthy as anybody I know
- ☐ Definitely True
- ☐ Mostly True
- ☐ Don't Know
- ☐ Mostly False
- ☐ Definitely False

35. I expect my health to get worse
- ☐ Definitely True
- ☐ Mostly True
- ☐ Don't Know
- ☐ Mostly False
- ☐ Definitely False

36. My health is excellent
- ☐ Definitely True
- ☐ Mostly True
- ☐ Don't Know
- ☐ Mostly False
- ☐ Definitely False

My current weight is _____ pounds.

Participant # ___

Instructions: Please circle the number that best represents your opinion to the following twenty-one questions.

Example: 1 2 3 4 5 6 7

How relevant were the system's suggestions?

NOT AT ALL RELEVANT	1	2	3	4	5	6	7	EXTREMELY RELEVANT

I could trust this system to work whenever I might need it.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

How engaging were the interactions?

NOT AT ALL ENGAGING	1	2	3	4	5	6	7	EXTREMELY ENGAGING

The system was sincere in trying to help me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

I could depend on this system to work correctly every time.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The system has my best interests in mind.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

How relaxing or exciting were your experiences with the system?

VERY RELAXING	1	2	3	4	5	6	7	VERY EXCITING

If I did the same task with the system again, it would be equally as helpful.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

How completely were your senses engaged during interactions with the system?

NOT AT ALL ENGAGED	1	2	3	4	5	6	7	COMPLETELY ENGAGED

The system was open to my ideas.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

Multiple scale questionnaire

Page 1 of 2

Figure B-2: Multiple Scales in Single Questionnaire

Participant # ___

The system was honest in communicating with me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

How insightful were the system's suggestions?

NOT AT ALL INSIGHTFUL	1	2	3	4	5	6	7	EXTREMELY INSIGHTFUL

The system was interested in interacting with me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The system has a main goal that has nothing to do with helping me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The experiences caused real feelings and emotions for me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

How helpful were the system's suggestions?

NOT AT ALL HELPFUL	1	2	3	4	5	6	7	EXTREMELY HELPFUL

The system was willing to listen to me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The system acts the way it does because it wants to help me.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The system wanted me to trust it.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

I was so involved in the interactions that I sometimes lost track of time.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

The system seems reliable.

STRONGLY DISAGREE	1	2	3	4	5	6	7	STRONGLY AGREE

Participant #:___

I feel uncomfortable with the weight loss system.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I agree about the things I will need to do to help improve my situation.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I worried about the outcome of the daily sessions.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

What I have done with the weight loss system gives me new ways of looking at my problem.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I understand each other.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system perceives accurately what my goals are.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I find what I am doing in the daily sessions confusing.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I believe the weight loss system likes me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I wish the weight loss system and I could clarify the purpose of our sessions.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I disagree with the weight loss system about what I ought to get out of the sessions.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

WAI-LF Page 1 of 4

Figure B-3: Working Alliance Inventory – Full Scale

Participant #:___

I believe the time the weight loss system and I are spending together is not spent efficiently.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I am clear on what my responsibilities are in this program.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The goals of these sessions are important to me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system does not understand what I am trying to accomplish in these sessions.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I find what the weight loss system and I are doing together are unrelated to my concerns.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I feel that the things I do in this program will help me to accomplish the changes that I want.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I believe the weight loss system is genuinely concerned for my welfare as best as it can be.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I am clear as to what the weight loss system wants me to do in these sessions.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I respect each other.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I feel that the weight loss system is not totally as honest as it can be about its feelings toward me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

Participant #:___

I am confident in the weight loss system's ability to help me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I are working towards mutually agreed upon goals.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I feel that the weight loss system appreciates me as best as it can.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

We agree on what is important for me to work on.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

As a result of these sessions I am clearer as to how I might be able to change.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I trust one another.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I have different ideas on what my problems are.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

My relationship with the weight loss system is very important to me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I have the feeling if I say or do the wrong thing, the weight loss system will stop working with me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The weight loss system and I collaborate on setting goals for my progress.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

WAI-LF

Page 3 of 4

Participant #:___

I am frustrated by the things I am doing towards my goals.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

We have established a good understanding of the kind of changes that would be good for me.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

The things that the weight loss system is asking me to do don't make sense.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I don't know what to expect as the result of my interactions with the system.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I believe the way we are working with my problem is correct.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

I feel the weight loss system cares about me even when I do things that it does not approve of.

Strongly Agree ***Agree*** ***Neutral*** ***Disagree*** ***Strongly Disagree***

Appendix C

Interview Questions

These interview questions were used to guide the final interview process. This list was not followed closely, but gives an idea of what topics were discussed.

Weight Loss Coach: Study Completion

Questions for interview

- Did you name the robot/computer? If so, what's the name you gave it?
- Can you describe its personality? Is there some story about where it came from?
- [P] How hard was it to understand what you were supposed to do?
- [P] What did you like about the system?
- [P] What would you change about the system?
- [P] How many times a week did you use the system?
- [P] Did you often go back and fill in days that you missed? How many days? How far back would you fill in?
- [P] Do you think that something like this is helpful for achieving your weight goals?
- [P] Would you want to continue using it if you could?
- [P] Would you recommend it to a friend?
- [P] Has your diet or exercise routine changed during this study? If so, do you expect those changes to last? Would that be different if you were to keep using the system?

Figure C-1: Interview Question Guide

Appendix D

Experiment Results Detail

H1: Participants interacting with the robot will use the system for an overall longer period of time than participants who have a computer or a paper log.

Condition	Mean	Std. Dev.
Robot	50.6 days	10.25
Computer	36.2	7.20
Paper log	26.7	15.53

Table D.1: Results for Hypothesis 1: Duration of Use.

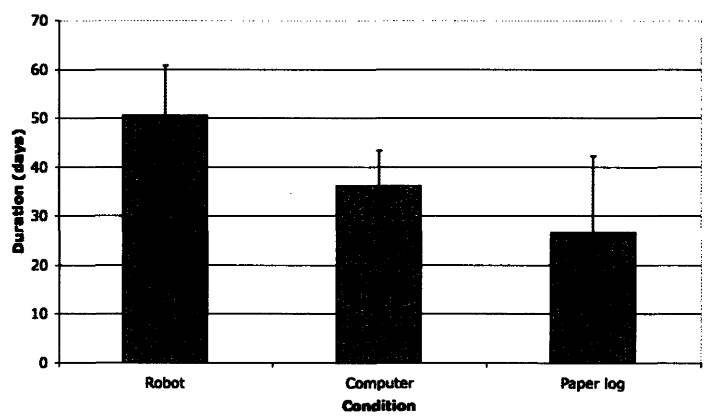

Figure D-1: Hypothesis 1: Duration of Use.

H2: Participants interacting with the robot will rate the system higher on regular responses to the short version of the working alliance inventory (WAI-SF) than participants who have a computer.

Condition	Mean	Std. Dev.
Robot	6.20	0.63
Computer	4.27	1.12

Table D.2: Results for Hypothesis 2: Alliance with System.

Scale is 0 (strongly disagree) to 7 (strongly agree).

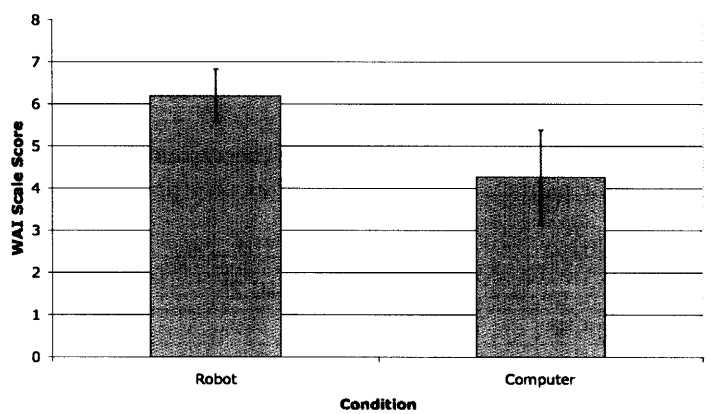

Figure D-2: Hypothesis 2: Alliance with System.

H3: Participants interacting with the robot will rate the system higher on responses to the full version of the working alliance inventory (WAI) administered at the end of the experiment than participants who have a computer or participants using paper logs.

Condition	Mean	Std. Dev.
Robot	4.19	0.45
Computer	3.64	0.59
Paper log	3.46	0.50

Table D.3: Results for Hypothesis 3: Alliance with System.

Scale is 0 (strongly disagree) to 7 (strongly agree).

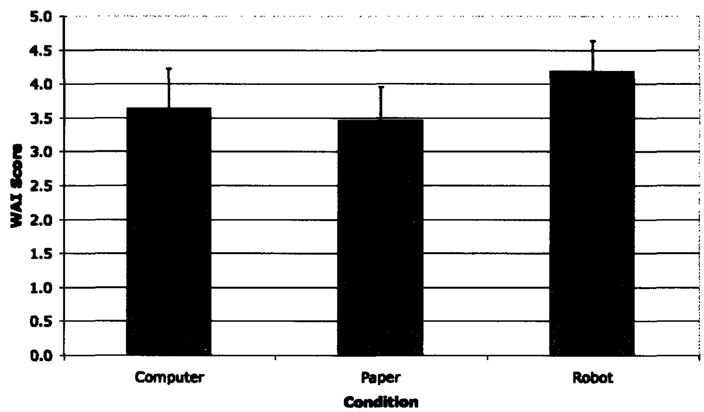

Figure D-3: Hypothesis 3: Alliance with System.

H4: Participants interacting with the robot will rate the system higher on responses to a scale of perceived information quality administered at the end of the experiment than participants who have a computer.

Condition	Mean	Std. Dev.
Robot	6.03	1.09
Computer	5.36	1.38
Paper log	3.45	1.86

Table D.4: Results for Hypothesis 4: Perceived Information Quality.

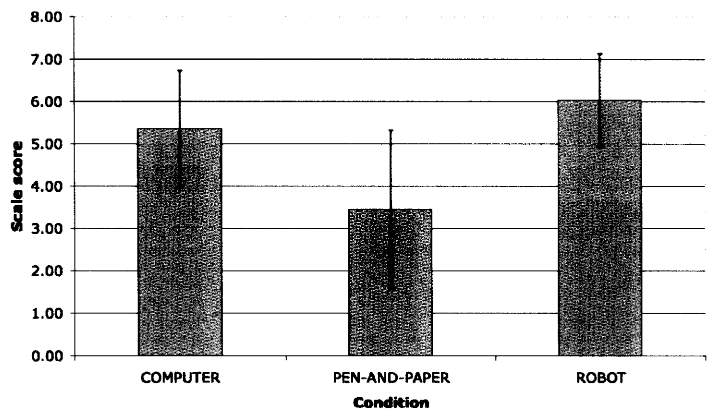

Figure D-4: Hypothesis 4: Perceived Information Quality.

H5: Participants interacting with the robot will rate the system higher on responses to a scale of specific trust administered at the end of the experiment than participants who have a computer or participants using paper logs.

Condition	Mean	Std. Dev.
Robot	5.58	1.81
Computer	4.75	1.37
Paper log	3.53	1.33

Table D.5: Results for Hypothesis 5: Specific Trust.

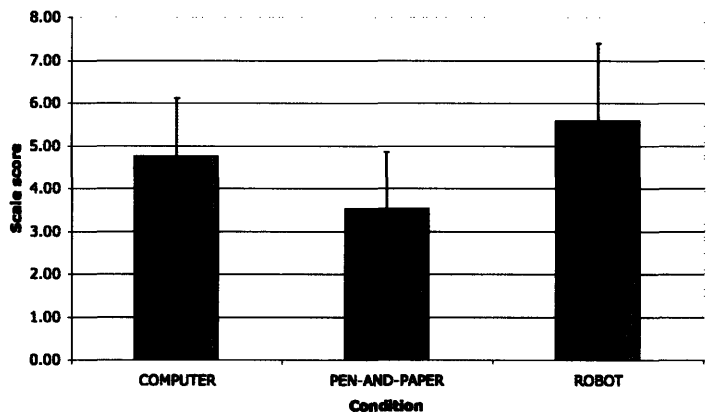

Figure D-5: Hypothesis 5: Specific Trust.

H6: Participants interacting with the robot will rate the system higher on responses to a scale of altruism administered at the end of the experiment than participants who have a computer or participants using paper logs.

Condition	Mean	Std. Dev.
Robot	5.87	1.85
Computer	5.50	1.60
Paper log	4.39	0.94

Table D.6: Results for Hypothesis 6: Altruism.

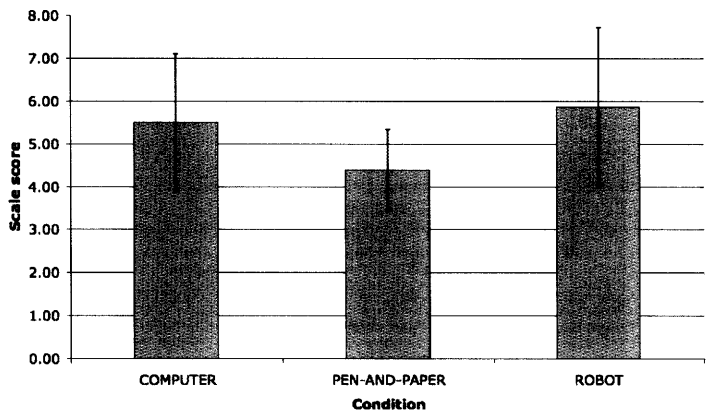

Figure D-6: Hypothesis 6: Altruism.

H7: Participants interacting with the robot will rate the system higher on responses to a scale of engagement administered at the end of the experiment than participants who have a computer or participants using paper logs.

Condition	Mean	Std. Dev.
Robot	5.10	1.76
Computer	4.00	1.56
Paper log	3.11	1.53

Table D.7: Results for Hypothesis 7: Engagement.

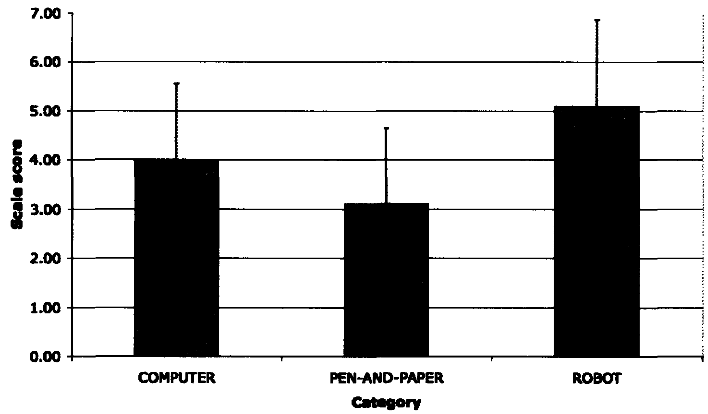

Figure D-7: Hypothesis 7: Engagement.

H8: Participants interacting with the robot will rate the system higher on responses to a scale of reliability administered at the end of the experiment than participants who have a computer or participants using paper logs.

Condition	Mean	Std. Dev.
Robot	6.48	1.01
Computer	5.35	1.22
Paper log	4.91	0.97

Table D.8: Results for Hypothesis 8: Reliability.

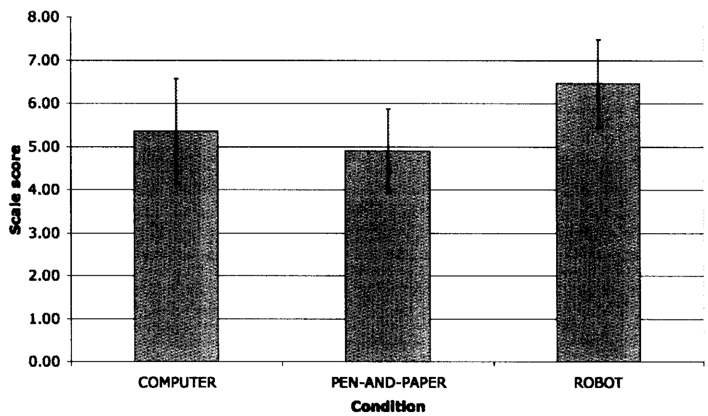

Figure D-8: Hypothesis 8: Reliability.

H9: Participants interacting with the robot will a closer relationship by the end of the experiment than participants who have a computer or participants using paper logs.

Results reported anecdotally.

H10: There will be no difference in the amount of weight lost across all three groups at the end of the six week study period.

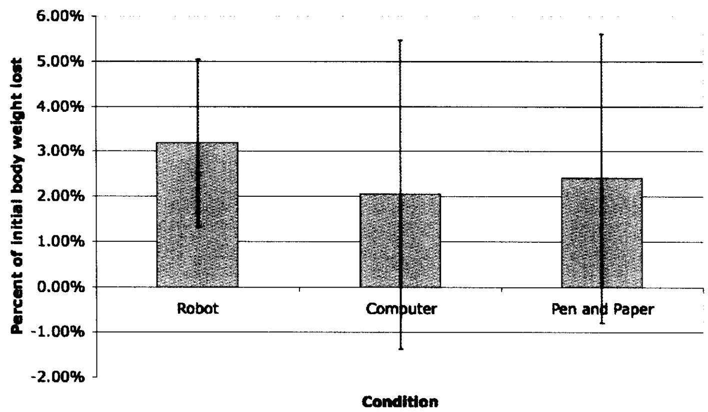

Figure D-9: Hypothesis 10: Weight loss.

Condition	Mean	Std. Dev.
Robot	3.2%	0.019
Computer	2.0%	0.034
Paper log	2.4%	0.032

Table D.9: Results for Hypothesis 10: Weight Loss.

Appendix E

Experimental Protocols

Protocol scripts used for intake:

Robot Group
Thank you for participating in our study. We are trying to find ways to help people who are dieting do a better job of sticking with their diet for a longer period of time than they otherwise might do. You have been randomly selected to work with a robot for the next four weeks. You will be asked to talk with it on a daily basis and it will help you keep track of how much you're eating and exercising every day.

In a few minutes, I will set up the robot for you and show you how to use it. After that, I'll be happy to answer any questions about how to use the system.

Before we do anything else, I would like for you to read and sign this form that talks about the study. If you have any questions about it, let me know. I also have a copy of this form that I will leave with you.

COUHES form

Thanks for completing the form. There are a series of questionnaires that I would like for you to fill out. This is the longest part of what we'll be doing today. While you complete the questionnaires, I am going to go our to my van to bring in the robot. It will take you twenty to twenty-five minutes to complete everything, so I'm going to get the robot set up while you do that.

Four intake questionnaires

Thank you for completing those. I have two things here that I am going to leave with you. This is a pedometer. If you're not familiar with something like this, it's just a small battery-powered device that you can carry in your pocket, clipped to your belt or clothing near your waist, or even carried in a bag. It will count how many steps you take and how far you walk. The other is the robot. First, let's set up the pedometer. We need an open space that you can take ten normal steps in for me to measure your step distance.

Measure stride, input stride, weight, and time. Show buttons on interface.

You can use this every day if you want. The battery should last for about a year and the pedometer will be yours to keep after the study, even if you do not complete the entire duration of the study. Do you have any questions about the pedometer?

Now I would like to set up the robot. It's very easy to do; I just need you to tell me where you want to put it. Ideally it will go somewhere like the living room or den where you will see it every day. Anywhere you have a counter top that's about waist level and access to a power outlet will work. I'll set it up for you and I hope that it can stay there for the entire period. If you do need to move it, just shut it down – I'll show you how to do that in a few minutes – and then unplug and carefully pick it up and move it. You can then plug it back in and it should work fine.

Set robot in place and plug in.

Now there are two buttons to turn on the robot. On the back here is the power switch. Press that first. As soon as you do that, you can press the power button here on the screen. It is necessary to press both of these in order to turn on the robot. I'll let you try it now.

Have them turn on robot.

As you can see, it takes about a minute to be ready to go, much like a computer. Once it's ready, you'll see this screen come up. Most of the time you'll want the "Daily Interaction" button here at the top. The entire screen is a touch-sensitive screen, so you can use your finger or this stylus at the back to press the buttons on any of the screens. Don't use a pen or a pencil or anything else that might scratch or write on the screen though. Pressing that will start your daily conversation with the robot. Before we do that for the first time, let me tell you about it.

The robot will speak out loud to you and display information on the screen at the same time. Each interaction will take about five minutes. The robot will ask you to enter two pieces of information about your weight loss plan: how many calories you have eaten today and how much exercise you have gotten.

To help you keep track of calories, I'll leave you with this guide that estimates calories for a number of common foods. As you probably know, a lot of food packaging has the calorie number on it and many restaurants and fast food places have signs or other information showing how many calories are in each item. You don't have to be exact, but try as best you can to keep track of how many calories you have at each meal and snack throughout the day.

For exercise, you can count in one of two ways. You can either use the pedometer to count the number of steps throughout the day or you can count the amount of time that you exercise each day. The robot will let you keep track of either one.

To use this system and participate in the study, you can use any diet that you want. If there is a system or plan that you want to take part in, you are welcome to do that. I will also give you this book about a diet called the DASH diet. It's from the National Institute of Health and was originally designed to help people lower their blood pressure. Doctors and dietitians have recognized that this is a good diet for anyone who wants to lose weight, so you can read through this and try some of the things that it suggests if you would like. The diet plan that you choose is up to you.

Regardless of which diet you choose, the robot will help you keep track of how many calories you're eating and how much you're exercising each day. We'll enter your initial goals into the robot now and you can change them any time you decide to.

Have them set initial goals.

You can change your goals any time you want by again choosing the "Change Goals" option from the main menu. It will look the same as what we just did.

Now let's try the daily interaction that you'll have with the robot. I'm going to let you go through it and I'll answer any questions that you might have. As you will do every day, press the "Start Daily Interaction" button on the screen.

Let them complete daily interaction.

That's what you should do once a day for the next four weeks. When you're done, you can press the "Shutdown the Robot" button and it will turn itself off. Next time you're ready to use it, you can start it up just like I showed you a few minutes ago. There is also a demo button at the top of the screen. If you want to see what the robot can do or want to show a friend without going through with the information that you have put in, you can press that button. The robot will move around and talk to you, but won't ask you about information or talk about how you've been doing. I already showed you the button for changing your goals. The last button here is to view the graphs of how you've done in the past week. If you just want to see that without going through the entire interaction, you can do that.

The last thing I'm going to leave with you is this sheet of ways to contact me if you need help with the system. If you have problems or questions, you can e-mail at this address or call at this phone number. I'll usually get back to you within a few hours. If there is an emergency with the robot and you need to contact me immediately, my cell phone number is at the bottom. If anything happens to the robot, you can use the emergency power switch here on the side to shut it down immediately and you can also unplug it from the wall. If you have to do either of these, please let me know.

Do you have any questions?

Computer Interface Group
Thank you for participating in our study. We are trying to find ways to help people who are dieting do a better job of sticking with their diet for a longer period of time than they otherwise might do. You have been randomly selected to work with a computer for the next four weeks. You will be asked to use it on a daily basis and it will help you keep track of how much you're eating and exercising every day.

In a few minutes, I will set up the computer for you and show you how to use it. After that, I'll be happy to answer any questions about how to use the system.

Before we do anything else, I would like for you to read and sign this form that talks about the study. If you have any questions about it, let me know. I also have a copy of this form that I will leave with you.

COUHES form

Thanks for completing the form. There are a series of questionnaires that I would like for you to fill out. This is the longest part of what we'll be doing today. While you complete the questionnaires, I am going to go our to my van to bring in the computer. It will take you twenty to twenty-five minutes to complete everything, so I'm going to get the computer set up while you do that.

Four intake questionnaires

Thank you for completing those. I have two things here that I am going to leave with you. This is a pedometer. If you're not familiar with something like this, it's just a small battery-powered device that you can carry in your pocket, clipped to your belt or clothing near your waist, or even carried in a bag. It will count how many steps you take and how far you walk. The other is the computer. First, let's set up the pedometer. We need an open space that you can take ten normal steps in for me to measure your step distance.

Measure stride, input stride, weight, and time. Show buttons on interface.

You can use this every day if you want. The battery should last for about a year and the pedometer will be yours to keep after the study, even if you do not complete the entire duration of the study. Do you have any questions about the pedometer?

Now I would like to set up the computer. It's very easy to do; I just need you to tell me where you want to put it. Ideally it will go somewhere like the living room or den where you will see it every day. Anywhere you have a counter top that's about waist level and access to a power outlet will work. I'll set it up for you and I hope that it can stay there for the entire period. If you do need to move it, just shut it down – I'll show you how to do that in a few minutes – and then unplug and carefully pick it up and move it. You can then plug it back in and it should work fine.

Set computer in place and plug in.

Now there are two buttons to turn on the computer. On the front here is the power switch. Press that first. As soon as you do that, you can press the power button here on the screen. It is necessary to press both of these in order to turn on the computer. I'll let you try it now.

Have them turn on computer.

As you can see, it takes about a minute to be ready to go, much like any other computer. Once it's ready, you'll see this screen come up. Most of the time you'll want the "Daily Interaction" button here at the top. The entire screen is a touch-sensitive screen, so you can use your finger or this stylus at the back to press the buttons on any of the screens. Don't use a pen or a pencil or anything else that might scratch or write on the screen though. Pressing that will start your daily interaction with the computer. Before we do that for the first time, let me tell you about it.

The computer will display information on the screen throughout the interaction. Each interaction will take about five minutes. The computer will ask you to enter two pieces of information about your weight loss plan: how many calories you have eaten today and how much exercise you have gotten.

To help you keep track of calories, I'll leave you with this guide that estimates calories for a number of common foods. As you probably know, a lot of food packaging has the calorie number on it and many restaurants and fast food places have signs or other information showing how many calories are in each item. You don't have to be exact, but try as best you can to keep track of how many calories you have at each meal and snack throughout the day.

For exercise, you can count in one of two ways. You can either use the pedometer to count the number of steps throughout the day or you can count the amount of time that you exercise each day. The computer will let you keep track of either one.

To use this system and participate in the study, you can use any diet that you want. If there is a system or plan that you want to take part in, you are welcome to do that. I will also give you this book about a diet called the DASH diet. It's from the National Institute of Health and was originally designed to help people lower their blood pressure. Doctors and dietitians have recognized that this is a good diet for anyone who wants to lose weight, so you can read through this and try some of the things that it suggests if you would like. The diet plan that you choose is up to you.

Regardless of which diet you choose, the computer will help you keep track of how many calories you're eating and how much you're exercising each day. We'll enter your initial goals into the computer now and you can change them any time you decide to.

Have them set initial goals.

You can change your goals any time you want by again choosing the "Change Goals" option from the main menu. It will look the same as what we just did.

Now let's try the daily interaction that you'll have with the computer. I'm going to let you go through it and I'll answer any questions that you might have. As you will do every day, press the "Start Daily Interaction" button on the screen.

Let them complete daily interaction.

That's what you should do once a day for the next four weeks. When you're done, you can press the "Shutdown the Computer" button and it will turn itself off. Next time you're ready to use it, you can start it up just like I showed you a few minutes ago. There is also a demo button at the top of the screen. If you want to see what the computer can do or want to show a friend without going through with the information that you have put in, you can press that button. The computer will show a demonstration of what it would do, but won't ask you about information or talk about how you've been doing. I already showed you the button for changing your goals. The last button here is to view the graphs of how you've done in the past week. If you just want to see that without going through the entire interaction, you can do that.

The last thing I'm going to leave with you is this sheet of ways to contact me if you need help with the system. If you have problems or questions, you can e-mail at this address or call at this phone number. I'll usually get back to you within a few hours. If there is an emergency with the computer and you need to contact me immediately, my cell phone number is at the bottom. If anything happens to the computer, you can unplug it from the wall. If you have to do this, please let me know.

Do you have any questions?

Paper Journal Group
Thank you for participating in our study. We are trying to find ways to help people who are dieting do a better job of sticking with their diet for a longer period of time than they otherwise might do. You have been randomly selected to work with a paper journal for the next four weeks. You will be asked to use it on a daily basis and it will help you keep track of how much you're eating and exercising every day.

In a few minutes, I will give you the journal and show you how to use it. After that, I'll be happy to answer any questions about how to use it.

Before we do anything else, I would like for you to read and sign this form that talks about the study. If you have any questions about it, let me know. I also have a copy of this form that I will leave with you.

COUHES form

Thanks for completing the form. There are a series of questionnaires that I would like for you to fill out. This is the longest part of what we'll be doing today. While you complete the questionnaires, I am going to organize the paperwork I have here. It will take you twenty to twenty-five minutes to complete everything.

Four intake questionnaires

Thank you for completing those. I have two things here that I am going to leave with you. This is a pedometer. If you're not familiar with something like this, it's just a small battery-powered device that you can carry in your pocket, clipped to your belt or clothing near your waist, or even carried in a bag. It will count how many steps you take and how far you walk. The other is the journal. First, let's set up the pedometer. We need an open space that you can take ten normal steps in for me to measure your step distance.

Measure stride, input stride, weight, and time. Show buttons on interface.

You can use this every day if you want. The battery should last for about a year and the pedometer will be yours to keep after the study, even if you do not complete the entire duration of the study. Do you have any questions about the pedometer?

Now I would like to show you the journal. It's very easy to use. Ideally it will go somewhere like the living room or den where you will see it every day.

Give them the journal.

The journal is used to enter two pieces of information about your weight loss plan: how many calories you have eaten today and how much exercise you have gotten.

To help you keep track of calories, I'll leave you with this guide that estimates calories for a number of common foods. As you probably know, a lot of food packaging has the calorie number on it and many restaurants and fast food places have signs or other information showing how many calories are in each item. You don't have to be exact, but try as best you can to keep track of how many calories you have at each meal and snack throughout the day.

For exercise, you can count in one of two ways. You can either use the pedometer to count the number of steps throughout the day or you can count the amount of time that you exercise each day. The journal will let you keep track of either one.

To use this system and participate in the study, you can use any diet that you want. If there is a system or plan that you want to take part in, you are welcome to do that. I will also give you this book about a diet called the DASH diet. It's from the National Institute of Health and was originally designed to help people lower their blood pressure. Doctors and dietitians have recognized that this is a good diet for anyone who wants to lose weight, so you can read through this and try some of the things that it suggests if you would like. The diet plan that you choose is up to you.

Regardless of which diet you choose, the journal will help you keep track of how many calories you're eating and how much you're exercising each day. We'll enter your initial goals onto the top of the first page now and you can change them any time you decide to.

Have them set initial goals.

Now I'd like you to make estimates for what you've done so far today. Just write the date at the top and write down everything you can remember eating and how much you've exercised so far today.

Let them complete daily interaction.

That's what you should do once a day for the next four weeks.

The last thing I'm going to leave with you is this sheet of ways to contact me if you have questions about the journal during the study. If you have problems or questions, you can e-mail at this address or call at this phone number. I'll usually get back to you within a few hours.

Do you have any questions?

Protocol scripts used for 4 and 6-week followup:

Phone/E-mail followup at 4 weeks

Hi <name>,

I hope that your participation in our study has been beneficial. The last day of the 4 week study for you is <date>.

We are giving you the option of continuing in the study for another 2 weeks if you would like. If you choose to continue for the additional period, we will conduct our final interview and questionnaires around the <date>. Otherwise, we will schedule this visit for around the <date>.

Please let me know as soon as possible whether you would like to complete the study after 4 weeks or after a total of six weeks. If you choose to continue, I will mail another 2 weeks of paper logs to you today.

OR

Please let me know as soon as possible whether you would like to complete the study after 4 weeks or after a total of 6 weeks. If you choose to continue, just keep using the system as you have been.

Sincerely,
Cory

Phone/E-mail followup at conclusion

Hi <name>,

As you know, the last day of your six week participation in our study is this coming <day>. I would like to schedule a followup visit to ask you to complete some final questionnaires, talk about your experience in the study in a short interview, and pick up the materials you have used in the study. This visit should take 20-30 minutes.

If you would like copies of the information that you have kept during the study, I can mail those to you the day after our final session.

I have the following times available in the coming week:
<date options>

Please let me know if there is a time in there that works well for you.

Thanks,
Cory

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