Doctoral Dissertation

Study on Active and Adaptive Behavior Change Support System

Zhihua Zhang

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Zhihua Zhang

Thesis Committee:

Professor Keiichi Yasumoto	(Supervisor)
Professor Satoshi Nakamura	(Co-supervisor)
Professor Yutaka Arakawa	(Kyushu University)
Associate Professor Manato Fujimoto	(Osaka City University)
Assistant Professor Yuki Matsuda	(Co-supervisor)
Professor Wolfgang Minker	(Ulm University)

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Abstract

Numerous technologies exist for promoting a healthier lifestyle. These technologies are collectively referred to as "Behavior Change Support System" (BCSS). To effectively induce a behavior change, it is essential to present information to users and let them comprehend it. However, the existing systems tend to adopt a passive approach that only reports the user's status upon opening the app. The existing systems also rely heavily on quantitative data representations, which has been shown that this approach might harm users' motivation and lead to a failure of promoting behavior change since it is hard to understand the meaning behind the data. Even though these systems provide explanations for the data, they would face another issue that different communication styles of explanations for the same data may lead to different outcomes. Therefore, an approach that is more active and more adaptive is needed. In this dissertation, we focus on two challenges to realize the active and adaptive behavior change support system: 1) the design of the active BCSS, and 2) the design of the active and adaptive BCSS that considers different communication styles. Before realizing the active and adaptive approach, it is necessary to investigate the impact and feasibility of active BCSS on inducing behavior change. Regarding the first challenge, we designed and developed an interactive signage system that actively talks to the passing user for promoting behavior change. Through the experiment, we confirmed that the proposed approach can effectively induce behavior change with low labor and lot time cost. For the second challenge, we extended the system to

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the smartphone platform so that the system can track users' status and interact with users in real-time. The extended system focuses on the improvement of physical activity as the common physical activity support systems are precisely the systems that rely heavily on quantitative data representations. The extended system promotes users to walk more by providing different levels of indirectness and elaborateness of explanations for the quantitative data. The result of the experiment indicated that our system had a positive effect on increasing the users' daily step count. The indirect and elaborate communication style led to the highest step increase rate (32.8%), while the direct and elaborate and direct and concise communication styles led to the lowest step increase rate (4.82%, 5.0% respectively).

Keywords:

Behavior Change Support System, Dialogue Systems, Communication Styles, Interactive Signage System

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1 Introduction

1.1 Background and Motivation

Nowadays, lifestyle diseases have become a global social problem [1–3]. As the term implies, lifestyles diseases are usually caused by individuals' poor daily habits (e.g, smoking, unhealthy diet, and physical inactivity, etc.), and may result in the development of chronic diseases such as heart disease, diabetes, obesity, etc. Meanwhile, chronic diseases have been the major public health problem worldwide. The World Health Organization (WHO) estimated that 60% of all deaths were attributable to chronic diseases in 2005 and it is expected to increase to 70% by 2030 [4]. Another fact is that 81% of adolescents globally aged 11-17 years were insufficient to perform physical activities and one in four adults do not meet the global recommended levels of physical activity [3], which is considered as a reason for the growth of obesity and overweight [2]. To prevent and treat lifestyle diseases, it is necessary to review individuals' daily life patterns and promote better lifestyles; this is referred to as "behavior change" in the medical field. The classical way of inducing behavior change is by holding consultations to inform people of future risks and ask them to do self-monitoring such as recording sugar intake, weight, and blood pressure manually. However, due to the huge burden of this approach on people, it is difficult to continue over the long term. Therefore, alternative approaches are needed.

With the rapid progress of technology in recent years, it has become convenient to achieve versatile functions by installing applications. The sensor-laden, broadly-adopted smartphones and increasingly penetrating wearable devices provide researchers and developers inexpensive and highly accessible means to collect users' data and sense the environmental context. By using these smart devices, numerous systems for promoting behavior change have been developed and positive results have been reported in some areas, such as in the management of smoking cessation, hazardous drinking, obesity, diabetes, asthma, tinnitus, stress, depression, and insomnia [5]. For instance, Saksono *et al.* [6] designed a mobile app for promoting family physical activity. Sankaranetal *et al.* [7] proposed a telerehabilitation application that can induce patients with coronary artery disease to comply with the treatment plan and prevent disease recurrence. Wang *et al.* [8] developed an app promoting stress self-regulation by visualizing users' degree of stress estimated based on heart rate.

These technologies for promoting better lifestyles are also collectively referred to as "behavior change support systems (BCSSs)", which are defined in the Behavior Change Support System Theory (BCSS Theory) as socio-technical information systems with psychological and behavioral outcomes designed to form, alter, or reinforce attitudes, behaviors, or acts of compliance without using coercion or deception [9]. According to the BCSS Theory, to effectively induce a behavior change, it is essential to present information to users and let them comprehend it. However, the existing BCSSs currently available on the market tend to adopt a passive approach that rarely interacts with users and only reports users' status upon opening the app, which may limit the effectiveness of the system in inducing behavior change. For example, the well-known fitness app Google Fit [10] sends notifications to users to inform them that they have achieved a certain exercise level. However, if the user constantly lacks exercise, Google Fit does not send any notifications to promote the user to exercise more, even though the user should care more about his/her health. Besides, the major of the existing BCSSs rely heavily on quantitative data representations, which has been shown that the quantitative approach might harm users' motivation and lead to a failure of promoting behavior change since it is hard to understand the meaning behind the data [11–13]. Even though these systems provide explanations for the quantitative data, they would face another issue that different communication styles of explanations for the same data may lead to different outcomes. According to Pragst *et al.* [14], the elaborateness and indirectness of content can influence users' perception of the information provided. Therefore, an approach that is more active and more adaptive is needed.

In this study, we aim to realize the active and adaptive behavior change support system. Before this BCSS can be realized, challenges must be addressed and solutions must be evaluated for their effectiveness.

1.2 Problem Statements

To implement the active and adaptive behavior change support systems, we must first describe the design of the architecture. Then the proposed approach must be evaluated to prove its effectiveness in inducing behavior change. We identify these challenges to be solved in this dissertation and we organize them as follows:

Challenge 1: How to design the active BCSS?

Before we realize the active and adaptive BCSS, it is necessary to investigate the impact and feasibility of the active BCSS on inducing behavior change. We tackle this challenge by reviewing the Persuasive System Design (PSD) Model and Behavior Change Support System (BCSS) Theory proposed by Oinas-Kukkonen *et al.* [9, 15]. We then design an active BCSS based on the PSD model and BCSS Theory, detailing each aspect of the system that should handle. Finally, we present an implementation based on this architecture and evaluate the effectiveness of the system in inducing behavior change.

Challenge 2: How to design the active and adaptive BCSS?

To present an adaptive interaction with a user, it is necessary to consider the communication styles of the contents. Therefore, we review the related work on the communication styles and upgrade our system based on the Dialogue System Theory. The upgraded system provides different levels of elaborateness and indirectness of representations for the quantitative data. We then extend the prior system to the smartphone platform so that the system can track users' status and interact with users in real-time. Finally, we conduct the field study to evaluate the effectiveness of the proposed approach.

1.3 Organization of Dissertation

This dissertation is organized as follows: we present a review of related literature in Chapter 2. In Chapter 3, we discuss more the foundation of the research, the

Persuasive System Design (PSD) Model and Behavior Change Support System (BCSS) Theory, and present an active BCSS to implementing these two theories. We then describe the evaluation experiment and the result to prove the effectiveness of the proposed approach. In Chapter 4, we extend the active BCSS to the smartphone platform and upgrade the system with the consideration of different communication styles. Then we describe the field study and its results to show the effectiveness of the active and adaptive BCSS (The work described in Chapter 4 is done by the collaboration between two research institutes, namely the Ubiquitous Computing Systems Lab at NAIST, Japan, and the Dialogue Systems Group at Ulm University, Germany). In Chapter 5, we present our conclusions.

2 Related Literature

In this chapter, we present a review of studies and discuss the concepts related to our study.

2.1 Persuasive System Design(PSD)

The information technology designed for changing users' attitudes or behavior is known as persuasive technology [16]. Fogg *et al.* has proposed a framework providing a useful method for understanding persuasive technology, which has been widely applied in many developments. However, Oinas-Kukkonen *et al.* argued that the framework was too limited to be applied directly to persuasive system development and/or evaluation [17]. To discuss the process of developing and evaluate persuasive systems as well as describe the content and software functionality in the final product, Oinas-Kukkonen *et al.*proposed the Persuasive System Design (PSD) Model [15], in which the persuasive system is defined as "computerized software or information systems designed to reinforce change or shape attitudes or behaviors or both without using coercion or deception" [15]. In the PSD model, there are three steps for developing a persuasive system: 1) understanding key issues behind persuasive systems, 2) analyzing the persuasion context, and 3) design of system qualities.

2.1.1 Understanding Key Issues Behind Persuasive Systems

In the first step, understanding key issues behind persuasive systems, Oinas-Kukkonen proposed seven postulates that need to be addressed when designing or evaluating persuasive systems:

1. Information technology is never neutral: It means that we are living in an environment full of information technology where we are always persuading or persuaded.

2. People like their views about the world to be organized and consistent: Users are more likely to be persuaded when the system provides the means of making commitments (e.g, share one's performance to his/her families).

3. Direct and indirect routes are key persuasion strategies: Persuading people by showing content and letting people process the information is called the "direct route", and persuasion through cues or stereotypes is the "indirect route". Different strategies may affect users' perceptions of the information provided and lead to different outcomes.

4. Persuasion is often incremental: Setting a goal far beyond one's abilities would lead to the failure of inducing behavior change. Therefore, it is necessary to divide the big task into smaller tasks and lead people to finish them incrementally.

5. Persuasion through persuasive systems should always be open: An ideal persuasive system promotes behavior change without using coercion or deception which means the system should not use untruthful or false information, otherwise it may reduce the persuasiveness of contents or end up misleading users.

6. Persuasive system should aim at unobtrusiveness: Persuasive systems should keep a positive impression in users' minds. Therefore the content provided and the timing of presenting the content should be careful. For example, it is improper to suggest doing exercise when the user is sick.

7. Persuasive systems should aim at being both useful and easy to use: Users may lose interest or even quit using the systems when the system is useless or useful but hard to use. Therefore, it is necessary to keep the easy usage and functionality of the system.

Through these postulates, we can understand there are three essential elements in designing a persuasive system: the goal of persuasion (the intent), the context of the problem (the event), and the way for presenting the information (the strategy). While addressing these elements, we should also keep the easy usage, functionality, and unobtrusiveness of the system to maintain users' motivation of using the system. The details of these elements have been described in the next step, analyzing the persuasion context.

2.1.2 Analyzing the Persuasion Context

There are three parts in the second step, analyzing the persuasion context: intent, event, and strategy.

The intent determines the change type, primarily whether the persuasion aims at the attitude and/or behavior change. It may be easy to promote one-time behavior change such as answering a question or turning off a switch, whereas permanent behavior change like quitting smoking or alcohol is much more difficult. An attitude change that directs behavior may be the most difficult to achieve [15]. Due to the differences of individuals (e.g., emotions, beliefs, experience), users' attitude can be varied in many ways which make it difficult for inducing an attitude change. Therefore, it is necessary to decide the target group and the goal of persuasion in the first stage.

The event determines the use context and user context of the system. The use context refers to the features of the problem domain. For instance, the users of persuasive systems promoting better lifestyles and well-being often have enough motivation and proper attitude to act but also difficulty taking action. In these cases, persuasive systems should focus on reinforcing users to maintain their motivation and making it easier to act. Meanwhile, individual differences may affect the processing of information. For example, people who have a high need for cognition tend to follow the direct route to persuasion [15]. Therefore, it is necessary to understand users' status such as needs, goals, current progress, past performance, and so on.

The strategy determines the message and route of sending triggers to users. The message not only refers to text contents such as slogans but also image contents such as charts, symbols, pictures, and so on. For instance, some governments require cigarette manufacturers to print unpleasant pictures such as diseased lungs on cigarette boxes to promote people to quit smoking. The design of the message usually depends on the route of presenting information to the user. The direct route shows content and lets people process the information while the indirect route promotes behavior change via cues. Due to individual differences, people have different tendencies of the message and route. Therefore, what kind of information (message) needs to be sent to the user and how to send the information (route) is an integral part of persuasion.

2.1.3 Design of System Features

To guide the design and evaluation of persuasive systems, Oinas-Kukkonen proposed four categories of the system features including Primary Task, Dialogue Support, System Credibility Support, and Social Support [15]. Each category has seven software features, and each feature has its effect. However, it is not necessary to apply all of these features to the design but only the necessary feature depending on their needs. The definition and description of these features are summarized in Tables 2.1-2.4.

Table 2.1: The List of Features of Primary Task Support

Feature	Content
Reduction	Divide a big task into smaller tasks to help users perform the target behavior
Tunneling	Guide users through a process or experience provide opportunities to persuade along the way
Tailoring	Tailor the information based on users' needs, interests, personality, usage context, or other user-related data
Personalization	Offer personalized content or service
Self-monitoring	Provide a way for users to keep track of their performance or status support in achieving goals
Simulation	Provide a method for observing the link between the cause and effect concerning users' behavior
Rehearsal	Provide a means to rehearse a behavior

Table 2.2: The List of Features of Dialogue Support

Feature	Content
Praise	Praise via words, images, symbols, or sounds as a way to provide users feedback information based on their behaviors
Rewards	Provide a reward to users based on their behaviors
Reminders	Remind users of the tasks they have to do
Suggestion	Suggest a behavior when the user is using the system
Similarity	Imitate users in some specific way
Liking	Design an interface that users appeal to
Social role	Adopt a social role

Table 2.3: The List of Features of System Credibility Support

Feature	Content
Trustworthiness	Provide truthful, fair and unbiased information
Expertise	Provide information showing knowledge, experience, and competence
Surface credibility	Have competent look and feel
Real-world Feel	Provide information of the organization and/or actual people behind its content and services
Authority	Refer to people in the role of authority
Third-party Endorsements	Provide endorsements from respected sources
Verifiability	Provide means to verify the accuracy of site content via outside sources

Table 2.4: The List of Features of Social Support

Feature	Content
Social learning	Provide means to observe other users who are performing their target behaviors and to see the outcomes of their behavior
Social comparison	Provide means for comparing performance with the performance of other users
Normative influence	Provide means for gathering together people who have the same goal and make them feel norms
Social facilitation	Provide means for discerning other users who are performing the behavior
Cooperation	Provide means for co-operation
Competition	Provide means for competing with other users
Recognition	Provide public recognition for users who perform their target behavior

2.2 Behavior Change Support Systems Theory(BCSS Theory)

Behavior Change Support System (BCSS) Theory [9] is an extended version of Persuasive Systems Design (PSD) Model [15]. The BCSS is defined as a sociotechnical information system with psychological and behavioral outcomes designed to form, alter or reinforce attitudes, behaviors, or an act of complying without using coercion or deception [9]. Compared with PSD Model, BCSS theory emphasizes more on the practical behavior change outcome. In this theory, Harri Oinas-Kukkonen proposed an Outcome/Change (O/C) matrix based on the intended outcomes and the types of change for helping design and research. The O/C matrix shows the three potential outcomes (formation, alteration, reinforcement) with three change types (attitude change, behavior change, complying). The contents of the O/C matrix have been summarized in Table 2.5.

Table 2.5: Outcome/Change Design Matrix

	C-Change	B-Change	A-Change
F-Outcome	Forming an act of complying (F/C)	Forming a behavior (F/B)	Forming an attitude (F/A)
A-Outcome	Altering an act of complying (A/C)	Altering a behavior (A/B)	Altering an attitude (A/A)
R-Outcome	Reinforcing an act of complying (R/C)	Reinforcing a behavior (R/B)	Reinforcing an attitude (R/A)

2.2.1 Outcomes

A forming outcome (F-Outcome) means the formulation of a new pattern that did not exist before, for example, starting jogging every day, quitting drinking. An altering outcome (A-Outcome) means an increase and decrease of the frequency, intensity, or duration of behavior such as increasing the amount of exercise, decreasing the number of cigarettes smoked per day. Meanwhile, stopping a behavior can also be taken as an F-Outcome since a new pattern has been formulated. A reinforcing outcome (R-Outcome) means the reinforcement of current attitudes or behaviors, making them more resistant to change [9].

2.2.2 Changes

With a compliance change (C-Change), the goal of the behavior change is making sure that the user complies with the request of the system, which is often seen in the health care applications such as guaranteeing patients take medicine every day. The goal of behavior change (B-Change) is to elicit a more enduring change than simple compliance once or a few times. For example, using a stair instead of the elevator, eating more vegetables, and so on. An attitude change (A-Change) means influencing one's attitude towards issues. For instance, changing a smoker's attitude to the cigarette. These changes are not exclusive to each other and a BCSS can aim multiple changes simultaneously. This is particularly important in areas such as providing support for overcoming addictive behaviors so that the users who are despite high motivation and proper attitudes may lack the skills can put their knowledge and attitudes into practice (a B-Change is needed), but at the same time, their self-efficacy may need further strengthening (an A-Change) [9].

2.3 Examples of Existed BCSS

With the rapid progress of technology in recent years, it has become convenient to achieve versatile functions by installing applications. The sensor-laden, broadly-adopted smartphones and increasingly penetrating wearable devices provide researchers and developers inexpensive and highly accessible means to collect users' data and sense the environmental context. By using these smart devices, numerous systems for promoting behavior change have been developed. Moreover, the approaches used for inducing behavior change are quite versatile.

One of the popular approaches is gamification since it can promote attitudes and behavior changes through its playfulness [18–21]. Through applying attractive elements, gamification may succeed to keep players' motivation in using the application. For instance, to increase users' activity, Consolvo *et al.* [22] proposed an application embedding gamification in which users can build a more beautiful virtual garden by increasing physical activity. Similarly, James *et al.* [23] created a social computer game called Fish'n'Steps which links a player's daily footstep count to the growth and activity of an animated fish in a fish tank. Murnane *et al.* designed a mobile application that contains a multi-chapter quest and ties the main character's progress to the user's physical activity [24]. The well-known augmented reality game Pokémon Go has also shown that it can increase players' physical activity [25].

Social support is another popular approach used in current BCSSs, which is not a single feature but containing seven software features listed in Table 2.4. With the influence of social relationships and peer pressure, even people with low self-efficacy and low motivation may also try to achieve the goal set by the system. As an example, Jaques *et al.* [26] developed a web-based pairing application in which the two paired participants need to help each other with achieving their goals like drinking more water. Luhanga *et al.* [27] conducted a social competition system to promote behavior change in losing weight and balanced diet.

Some studies try to enhance the effectiveness of systems by exploring the effects of different timings and frequencies of interactions on inducing behavior change [28, 29]. Also, inducing behavior change by extra wearable devices has been studied. For instance, there is a bracelet developed by Fortmann *et al.* [30] which promotes users to drink more water by showing the times of drinks and the time passed since the last time the user drank water with color-coded from green to red.

To induce behavior change effectively, it is necessary to present information to users and let them comprehend it [9]. Although the studies mentioned above helped to inform the design of BCSSs, the majority of existing systems still tend to apply quantitative approaches such as charts, graphs, and statistical reports as the way of presenting information, which has been suggested that can be hard for users to understand [11, 12]. A heavily quantitative approach may lower users' motivation and fail to improve health [13]. To tackle this issue, it is needed to provide explanations of the quantitative data as a supplement. Through the explanations provided, users can be aware of their situation more clearly so that the system can induce a behavior change more likely. Meanwhile, many reports are showing that different descriptions of the same data may lead to different outcomes. For instance, Pragst *et al.* [14] demonstrated that different levels of elaborateness and indirectness can influence users' perceptions of the information provided. Therefore, to enhance the effectiveness of a BCSS, it is necessary to consider the effects of different communication styles during the design process.

2.4 Adaptive Communication Styles

For Human-Human Interaction (HHI), it has been shown that people tend to adapt their interaction style (e.g., tone, amount of information, directness) to each other when they communicate [31–35]. Therefore, many researchers suggest adapting systems to users in a similar way in Human-Computer Interaction (HCI) [36–40]. By adapting the system's behavior to the user, the system may appear more familiar and trustworthy, and the interaction may be more effective, which is the reason why the research in the field of Spoken Dialogue Systems currently focuses on user-adaptive systems [41–45].

One adaptation approach is called "soft adaptation" which means keeping the propositional content of a system action the same and changing only the way it is presented [14], i.e., the communication style. Through a user study, Pragst *et al.* [14] proved that different levels of elaborateness and indirectness can influence users' perception of dialogue, which makes the level of elaborateness and indirectness valuable candidates for adaptive dialogue management. The level of elaborateness refers to the amount of additional information provided to the user. In response to a question concerning the current day's weather forecast, an answer with a low level of elaborateness might be providing only the requested information, whereas an answer with a high level of elaborateness provides additional information including the weather forecast for the next few days. The level of indirectness describes the concreteness of the information addressed by the system. For example, a direct answer to the question concerning the current weather would be an accurate description of the weather, such as "It is raining", whereas an indirect answer would be advised to take an umbrella or a raincoat. The meaning of an indirect answer can be inferred from the given information even it does not mention the weather directly. Through a user study, Miehle *et al.* [41,46] found that the level of elaborateness and indirectness of the system influences users' satisfaction and perception of the dialogue and they did not found a general preference for the communication style of the system.

Although these studies have shown that different communication styles affect users' perception of interaction in spoken dialogue systems, the impact of communication style on inducing behavior change remains unclear. Therefore, further investigation is needed to improve the effectiveness of behavior change.

In this dissertation, we focus on the design of Active and Adaptive BCSS, trying to investigate the answer of following questions:

1. How to design an Active BCSS?
2. Whether the Active BCSS can induce a behavior change?
3. How to design an Active and Adaptive BCSS?
4. Whether the Active and Adaptive BCSS can induce behavior change?

3 Active Behavior Change Support System

In this chapter, we lay the groundwork for our study. We describe the key issues behind the proposed active behavior change support system including the intent, event, and strategy for inducing behavior change. Then we design and discuss the architecture needed to create the active BCSS based on the key issues. Afterward, we develop a prototype of the proposed approach and evaluate its effectiveness.

3.1 Introduction

With the progress of technology in recent years, it has been common to use the Internet of Things (IoT) in our daily life. Meanwhile, due to the sophistication of Artificial Intelligence (AI) technology, it has been more accurate and natural when the system recognizes people's behavior and interacts with users. Through smart devices equipped with powerful sensors like heart rate monitors and accelerometers, we can achieve many functions by just installing applications. Based on this background, many technologies have been conducted to induce behavior change. Behavior change is also often called persuasion, meaning "reinforcing, forming or altering a user's attitude or behavior or an act of complying without coercion and deception" [9]. In the medical field, behavior change means reviewing patients' daily life patterns and leading them to a healthier lifestyle. Therefore, behavior change has been taken as a treatment of lifestyle diseases which are usually caused by peoples' poor daily habits. Conducting counseling and preaching the future is a classical way of inducing behavior change during which people might be asked to monitor themselves (e.g., sugar intake, weight, blood pressure). However, due to the huge burden of this approach on people, it is difficult to continue in a long term. To tackle this problem, many research and developments for promoting behavior change have shown up which are collectively referred to as “Behavior Change Support System”(BCSS).

3.2 Literature Review

Positive results have been obtained in the management of smoking cessation, hazardous drinking, obesity, diabetes, asthma, tinnitus, stress, depression, and insomnia with the assistance of BCSS [5]. For example, Want *et al.* [8] developed an application to promote stress self-regulation by visualizing users’ stress degree estimated by users’ heart rate. Sankaran *et al.* [7] developed a telerehabilitation application for promoting patients to comply with the treatment plan. These positive results make BCSS be considered as Digital Medicine and have been extensively studied in Europe and the U.S. [47].

There are also many examples that exist in other areas. For example, it has been shown that Pokémon Go (an augmented reality game) can serve as a behavior change support system in increasing players’ physical activity [25]. In the application developed by Consolvo *et al.* [22], users can build a more beautiful virtual garden by doing more physical activity. There are also some researchers trying to induce behavior change by using additional equipment and sensors rather than using smartphones only. For instance, Fortmann *et al.* developed a bracelet with embedded LEDs to improve users’ drinking behavior by showing the times of drinking during that day [30].

According to the Behavior Change Support System (BCSS) Theory, to effectively induce a behavior change, it is essential to present information to users and let users comprehend it [9]. However, the existing BCSSs tend to adopt a passive approach that rarely interacts with users and only report users’ status upon opening the app, which may limit the effectiveness of the system in inducing behavior change. For example, the well-known fitness app Google Fit* sends notifications to users to inform them that they have achieved a certain exercise level. However, if the user constantly lacks exercise, even though the user should care more about his/her health condition, Google Fit does not send any notifica-

*`https://www.google.com/intl/en_us/fit/`

tions to promote the user to exercise more. Therefore, a more active approach is needed. To tackle this issue, in this dissertation, we propose a design of an active behavior change support system.

3.3 Persuasion Context

In this section, we describe the three essential elements of the design of active behavior change support system: the intent (change type), event (use context and user context), and strategy (message and route).

3.3.1 The Intent

The intent determines the type of change, primarily whether the persuasion aims at the attitude and/or behavior change. It has been reported that most of the research on behavior change were focusing on the reinforcing outcome (R/B) and much less focused on forming (F/B) or altering a behavior (A/B) [48]. Due to individual differences, especially the differences in personal experiences, it is reasonable that altering or forming behavior is much harder than reinforcing an existing one. However, in our research, we aim to not only reinforce but also alter and form a behavior such as quitting smoking, using stairs instead of the elevator. Our design focuses on the common issues that people meet with during their daily lives including the improvement of health conditions (e.g., diet, sleep, exercise, stress, drink water) and the environment (e.g., save energy, keep the environment clean). Another common issue of BCSSs is the effectiveness of the system decreases as time pass in a long period. To tackle this issue, our design targets the enclosed environment (e.g., a company, a university, or an elder care center) where people nowadays usually spend a long time instead of random public spaces. As long as people are staying in the environment, our system is expected to be able to send stimulation to them and promote behavior change continuously, so that we can improve the efficiency of digital intervention and the quality of behavior change.

3.3.2 The Event

The event determines the use context (the features of the problem domain) and user context (users' status). There are many wasted pockets of time in people's daily lives which we believe could be used for behavior change such as promoting users to do a blood pressure checkup when they are waiting for the microwave to heat up their lunch, promoting users to use stairs when they are waiting for the elevator, and so on. To realize this, we collect users' needs, goals, past performance, and the current progress with the cooperation of smart devices such as smartwatches, interactive signages to better understand the user context.

3.3.3 The Strategy

For the convenience of development, in our design, we apply the direct route that presents the contents and let people process the information without cues and stereotypes. As for the content of the message, in this design, we send the message containing user-related information. The user-related information means personal data such as age, sex, and height. We expect that this information can attract the user more than non-related information. Also, to achieve voluntary participation, our system is deployed in the users' life action line (the moving route of users' daily life) and stimulates their senses continuously.

3.4 Architecture of Active Behavior Change Support System

In this section, we describe the form of our design based on the three essential elements mentioned above. This design is also inspired by the design of behavior change environment [49]. There are four stages in our design: recognizing, executing, reviewing, feedback, as shown in Figure 3.1.

In the recognizing stage, the system identifies and classifies users. To provide appropriate information to the user, we collect users' needs, goals, past performance, and current progress in this stage through the smart devices. After collecting these data, the system classifies users and divides them into different groups.

Figure 3.1: Form of Proposed Active Behavior Change Support System

The executing stage is the place where we try to induce a behavior change. In this stage, our system sends a message containing user-related information and social-related information to the target user actively after recognizing. The user-related information means the content containing the user's data like name, gender, age, or weight. The social-related information means the content containing other user's information (e.g., needs, goals, progress) and the information of the environment (e.g., the temperature of air condition, the amount of water left in the hot pot). The content presented to the user is adjusted depending on the group of the user. For example, the content focuses more on keeping the motivation of the user when he/she has high efficacy and focuses more on improving motivation when people are low-efficacy. To adjust the timing of presenting the information, we collect the user's physical data (e.g., number of steps, heart rate) and location information.

In the reviewing stage, we record the user's reaction toward the information presented by the system. We estimate users' reactions through users' data when the behavior is related to movement and location, whereas, in other behavioral patterns, we estimate reactions through users' answers to the inquiry and notifi-

Table 3.1: The Software Features Applied to the Design

Primary Task	Dialogue Support	Social Support
• Reduction • Self-monitoring	• Praise • Suggestion • Reminder	• Comparison • Facilitation • Competition

cations. Based on the result, the system reclassifies and regroups the user.

The feedback stage is for keeping and improving users' motivation. If the user responded to the message from the system, the system sends another message as feedback. Also, a ranking table and a chart of the progress of the whole group are a part of the feedback. A blog (or report) about the progress of an individual or a group is sent to social media periodically. The content of feedback depends on the group of the user.

3.5 Software Features Applied the Design

Table 3.1 lists the features we apply to our design among 28 features listed in the BCSS theory [9, 15].

Reduction means to reduce a complex behavior into simple tasks which help users perform the target behavior, and it may increase the benefit/cost ratio of a behavior [9, 15]. In our design, all the behavior patterns are broken into smaller tasks and guide users to achieve the small tasks step by step.

Self-monitoring is the most widely used in the current systems because it can show the progress of users and the distance to their goals [50]. In this design, we provide a way for the users to check their progress by themselves. Meanwhile, we also present their progress actively by the chatbot and signage so the low-motivation people can also be aware of their situation.

In this design, we apply both voice and text praise to our feedback part. The tone and the content of the voice message change based on the result of reviewing. The voice message is expected not only to arouse the user's curiosity but also to get trust from a user [51].

Reminders are quite useful for helping users to remember tasks they need to do based on the setting. However, it is also reported that the excessive use of reminders can harm users' memory of the tasks [52,53]. Therefore, in this design, the reminder is kept at a low level. Suggestions have a similar role as reminders, but it persuades people in softer ways. However, it is still unclear that how would the suggestion affect the user's cognition. Investigating the effect of suggestion is a part of this research.

System users have a greater motivation to perform the target behavior if they can compare their performance with the performance of other users, discern via the system that others are performing the behavior along with them, or be able to compete with other users [9, 15]. We consider the environment as a small society, and we apply comparison, facilitation, competition to our design. We present a ranking table listing the progress of the members who have the same need or goal to the user so that they can be aware of the situation of the others and compare the performance. Moreover, we also present other users' goals to the user who doesn't have the same goal. For example, " 20 members are trying to achieve walking 10000 steps a day!". To achieve the competition function, in our design, the chatbot writes a periodical blog/report about the user who does the best performance. For example, "Weekly star, the man who walked most" and "Monthly star, the man who saved the most energy" [49].

According to the theory of goal setting, people with high self-efficacy set higher goals and have higher performance than people with low self-efficacy [54]. Therefore, it is necessary to distinguish users' types and deal with them based on the type. In this design, we divide users into several groups based on their needs, goals, past performance, and current progress. Also, people who have high self-efficacy can set their own goals while the low self-efficacy people need to select the goals provided by the system [49].

Table 3.2: Software Features in Interactive Signage System

Feature	Way to Apply
Reduction	(1)Breaking a task into smaller tasks (2) Allowing users respond via button
Suggestion	Promoting users to complete a task via soft tone

3.6 The Prototype of Active Behavior Change Support System: Interactive Signage System

To evaluate the effectiveness of the proposed approach, we designed and developed a prototype based on the architecture mentioned above. In the prototype, we developed interactive signage for presenting the information to users and collecting users' reactions [55]. Along with the price reduction of large displays, digital signage is expanding as an information guidance system in public places. Meanwhile, digital signage equipped with sensors for interacting with viewers is spreading recently. For example, Intelli Signage can recognize viewers' age and gender by analyzing the photographs of viewers' faces taken by the camera attached to the digital signage and then shows relevant advertisements [56]. Compared with smartphones, interactive signage has three advantages: 1) it has a larger screen to display more content; 2) it is independent of users' setting (such as turning the smartphone to manner mode,) so that we can investigate users' reactions without bias; 3) it is able to interact with multiple people instead of only a specific one. Since this system does not exist in the previous study, we believe it is necessary to investigate users' reactions to the signage system before we apply all the points in our proposed design. Therefore, we developed the interactive signage system without the cooperation with other smart devices and only applied reduction and suggestion into the system as shown in Table 3.2.

Figure 3.2 shows the system configuration of the interactive signage system [55]. This system consists of a Bluetooth Low Energy (BLE) beacon worn by each user to identify themselves, a digital signage to receive beacon signals and present information to users, a server to store information of users, tasks, and records of

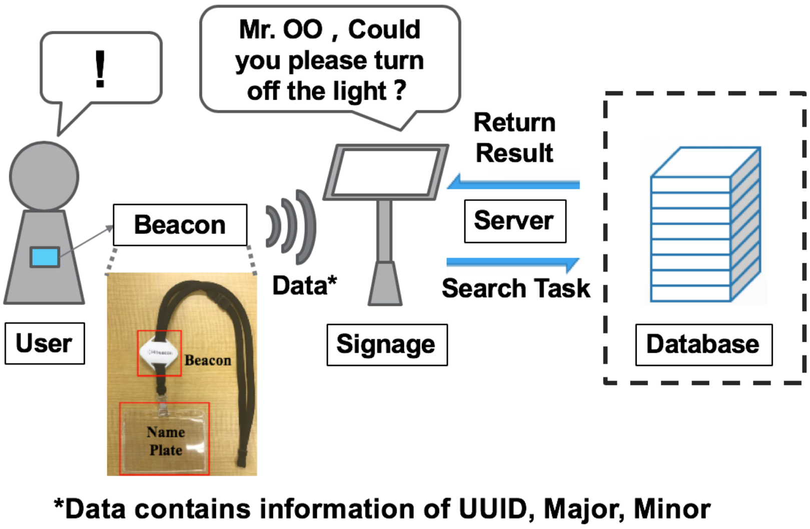


Figure 3.2: System Configuration of Proposed Interactive Signage System

users' reactions. The digital signage is equipped with a touch panel so users can respond with touch input. The digital signage continually monitors surrounding beacon signals. Every time a user approaches and the wireless signal sent from the beacon is detected, the system performs the following operations.

3.6.1 Recognizing

First, the digital signage obtains the received signal strength index (RSSI) from the beacon and compares it with a preset threshold. When the RSSI exceeds the preset threshold value, digital signage recognizes that a user is approaching. Then it requests the task appropriate for the user to the server. The request message contains the information of the received beacon signal (UUID, Major, Minor) and the ID of digital signage. Since RSSI varies depending on the structure of a building and the location of digital signage, the threshold value is adjusted empirically through the experiment. Compared to the existing signage systems that use a camera for user identification, the beacon-based identification system is robust against the angle and distance between a user and signage.

3.6.2 Executing

After identifying the user, the server searches for available and proper tasks for the user based on four factors:

- The time of day: In our system, available tasks change depending on the time of day. For example, the tasks for checking the quality of sleep and the state of breakfast are appropriate only in the morning, whereas the tasks for checking the state of dinner are available only after the evening.
- The attributes of a user: All the users have their user-related tasks. For example, if the user is Japanese, then the task is presented in Japanese. Otherwise, the task is presented in English.
- The status of the task: A user would not see the same task until the cooldown time of the task expires, trying to reducing the burden on users.
- Location: We deploy some digital signages at the corridor and public spaces and set fifteen minutes cooldown time to prevent the system from asking the user who stays in the same location for a long time questions too frequently. Each location also has its location-related tasks. For example, asking the amount of water left in the hot pot is only available for the coffee space.

After selecting available tasks based on the above four factors, the server sends the selected task back to the digital signage. Digital signage presents the task obtained from the server to the user via text and voice messages. The voice message is expected not only to arouse the user's curiosity but also to get trust from a user [51].

3.6.3 Reviewing

There are two ways for the user to respond to the task. The first way is pushing a button of choices shown on the screen of the digital signage, the simplest way, to prevent users from feeling bothersome. The second way is a text input which is suitable for collecting personal information such as age, height, weight, etc. at the initial stage. A reject button also appears on the screen for some personal tasks, providing a right to skip the inappropriate task explicitly. Based on the answer (including ignorance and rejection), the system regroups the user.

3.6.4 Feedback

After users respond to our system, digital signage shows a text message, "Thank you", as feedback and automatically goes back to the initial screen after getting a response from the user. Also, we set a timeout to handle the situation that a user cannot reply or does not notice the voice message. In such a case, the result is recorded as "ignored". If the user does not respond to the system, the digital signage goes back to the initial screen after a certain time period. Then the result (including ignoring and rejecting) is uploaded to the server and stored in the database.

3.7 Study 1: User's Reaction to The Interactive Signage System

In this study, we evaluate the performance of our interactive signage system and investigate the effects of the active behavior change support system. There are the following three points which we need to confirm.

1. First, to present the user-related information, it is necessary to collect personal information (e.g., weight, location, etc.). Therefore, it is important to check users' acceptance degree to the personal data collection of the system.
2. Second, the stimulation in our system is sending utterances to passing users to induce behavior change. Therefore, it is necessary to check whether users respond to the utterance from the interactive signage, which is also a behavior change since there is no such system in users' daily routines before.
3. Third, as our system promotes users to complete tasks by sending the utterance, it is necessary to check whether the stimulation can promote behavior change successfully or not.

To investigate the effects of active behavior change support systems, we designed a survey experiment and recruited participants from our laboratory. The experiment was planned to be held for two weeks (one week with the controlled condition, one week without the controlled condition). However, the actual experimentation period was extended to 3 weeks since there was a long holiday period in between (April 29th   30th, May 3rd   May 5th). The first week started on April 24th and end on April 29th, 6 days in total. The next two weeks started on April 30th and end on May 11th, 12 days in total. During the first week, participants are asked to respond to the utterance from interactive signage every time when they noticed the voice message, including pushing a reject button. During the next two weeks, participants were not asked to respond to the task definitely to eliminate the bias. The reason for this experiment scenario is to compare the difference of participants' reactions in an ideal condition (forced to respond) and a real condition (free to respond). To investigate the difference in response situation between the first week and the next two weeks, we kept the records of the Personal Task but deleted the personal information collected at the end of the first week.

3.7.1 Environmental Setup

We deployed four interactive signages at four places in our laboratory where lab members usually pass in their daily life as shown in Figure 3.3 [55]. The first location was a rest space in the student room (A406) where drinks and snacks are available, along with two beds and a shelf of comics. A member who wants to take a break or pick some drinks and snacks often comes there. To collect the data of the user's daily life pattern, we decided to set interactive signage here. In addition, a weight scale was also put there for promoting members to measure their weight. It was a task related to a behavioral change. The second location was a corner of the corridor leading to the laboratory where has to space for larger signage. The third place was a shelf of shoes where lab members stop when they wear or take off shoes. We believe that this position is the most suitable for interacting with a user. Besides, it is the best location to confirm the state of the seminar room (A407), which is next to the shelf of shoes. Similar to a weight scale, the task related to a behavioral change was posted to a user

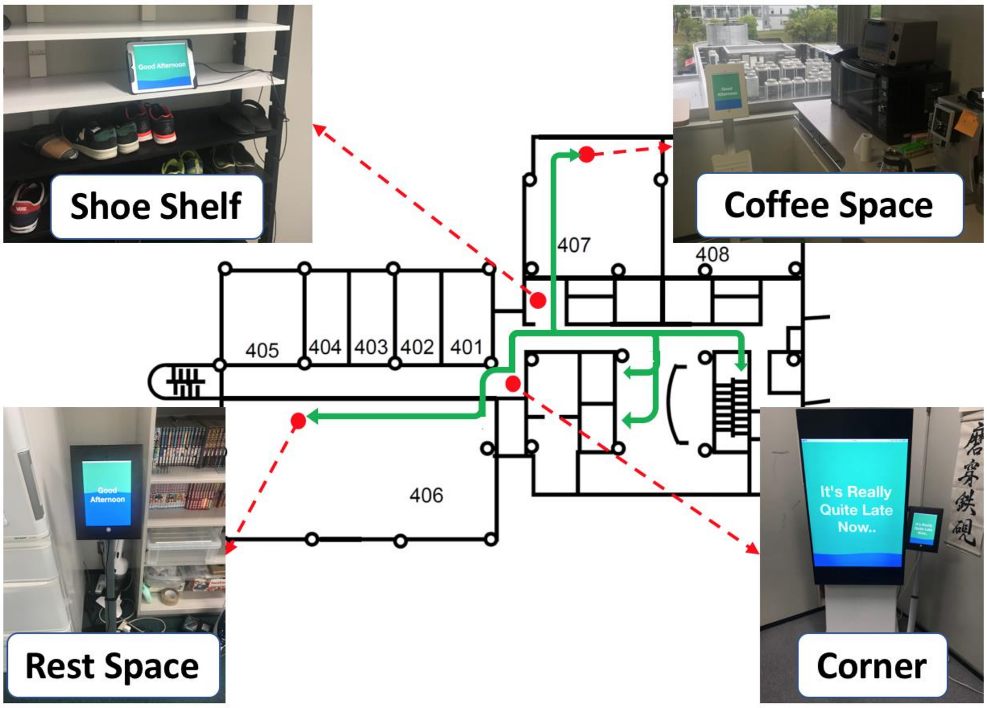


Figure 3.3: Location of Interactive Signage

at this location. For example, digital signage asked about the usage of A407 or the status of room lights in A407, and promote the next behavior for saving energy. If the user turned off the light in case no one was in A407, we can say that digital signage succeeds to change the user's behavior. The last place was a coffee space. This coffee space has an oven, a microwave, a coffee maker, and a hot water pot. Members who want to drink coffee or heat food up often come here and stay for several minutes. We think that this pocket of time is a good chance to interact with a user and promote a different behavior such as checking the remaining amount of consumables.

3.7.2 User Setup

15 participants participated in our experiment. We asked all the participants to carry a name tag with a BLE beacon. The transmission frequency of the beacon signal is 1 Hz. Also, we registered the name, language (English or Japanese), and

ID of the beacon assigned to each participant on the server.

3.7.3 Scenario

Tables 3.3 and 3.4 [55] show the lists of the scenarios we prepared for this experiment which is the core part of the stimulation of our system. To explore users' acceptance degree to interactive signage and the effectiveness of the system on inducing behavior change, we prepared 5 different sets of scenarios (Personal Task, Check Task, Personal+ Task, Check+ Task, and Action Task) in advance.

A personal Task is a task with the aim to collect personal data from the user. Before inducing a behavior change, it is essential to recognize the user's life patterns. Therefore, besides the inquiries of the basic personal information (gender, age, nationality, height, and weight), we also prepared the inquiries that collect users' diet, sleep, and mental status. Moreover, for each signage deployed in the rest space, corner of the corridor, and coffee space, we set one inquiry checking the reason why the user goes there to recognize users' life patterns. In order not to cause misunderstanding, in Table 3.3, we add comments in parentheses for these three inquiries. The contents presented to the user during the experiment do not contain the comment part.

Personal+ Task is a particular Personal Task that combined with an Action Task and system judges whether presents the Action Task to the user or not based on users' response to the Personal+ Task. In this experiment, we prepared a Personal+ Task that asks whether the user has checked his or her weight recently. If not, the system presents the Action Task that encourages the user to use the weight scale near the signage to measure their weight.

The ultimate goal of Check Task is to lead users to finish the tasks that improve the environment like cleaning the office, cleaning the waste from the coffee maker, or replacing the water in the humidifier. However, due to the high cost of time and labor, it is hard to realize this goal immediately. Therefore, we set several scenarios which have a lower cost of time and labor to investigate users' reactions to this kind of task. We believe the result can guide our future work.

Check+ Task is a particular Check Task that is combined with an Action Task. With the same as Personal+ Task, the system judges whether presents the Action Task to the user based on the user's response to the Check+ Task. We prepared

Table 3.3: The List of Tasks Prepared (Part.1); Difficulty 0–3: 0=Able to Complete Immediately; 1=Cost a little bit of time and labor to Complete; 2=Cost a longer time and more labor to Complete; 3=Cost a great amount of time and labor to Complete

Task Category	Content	Time Cost	Labor Cost	Difficulty (0~3)
Personal	Should I call you Sir or Madam?	Instant	Push Button	0
Personal	Could you please tell me your age?	Few Seconds	Input Text	1
Personal	What country are you from?	Few Seconds	Input Text	1
Personal	Could you please tell me how tall are you?	Few Seconds	Input Text	1
Personal	Could you please tell me your weight?	Few Seconds	Input Text	1
Personal	Are you feeling stressful now?	Instant	Push Button	0
Personal	Have you eaten your breakfast yet?	Instant	Push Button	0
Personal	Have you eaten your lunch yet?	Instant	Push Button	0
Personal	Have you eaten your dinner yet?	Instant	Push Button	0
Personal	Did you sleep well last night?	Instant	Push Button	0
Personal	The reason you come here is? (*For Rest Space)	Instant	Push Button	0
Personal	Where are you going? (*For Corner of Corridor)	Instant	Push Button	0
Personal	You come here for? (* For Coffee Spcae)	Instant	Push Button	0

Table 3.4: The List of Tasks Prepared (Part.2); Difficulty 0–3: 0=Able to Complete Immediately; 1=Cost a little bit of time and labor to Complete; 2=Cost a longer time and more labor to Complete; 3=Cost a great amount of time and labor to Complete

Task Category	Content	Time Cost	Labor Cost	Difficulty (0~3)
Personal+	Have you check your weight recently?	Instant	Push Button	0
Action	Do you want to use the weight scale to check your weight?	Few Seconds	Push Button & Use Weight Scale	1
Check	Is Mizumoto-San in Lab now?	Few Seconds	Check & Push Button	1
Check	Are Secretaries in their Office now?	Few Seconds	Check & Push Button	1
Check	Does the water pod have enough water?	Few Seconds	Check & Push Button	1
Check	Does the coffee maker have enough water?	Few Seconds	Check & Push Button	1
Check	Are there many people in lab now?	Few Seconds	Check & Push Button	1
Check+	Is there anyone in A407 now?	Few Seconds	Go to A407 & Check	1
Action	Could you please turn off the light if it's on?	Few Seconds	Go to A407 & Turn Off the Light	1

a Check+ Task letting users check if someone is using Room A407. If nobody is using the room, the system presents the Action Task that encourages users to close the light of A407 for saving energy.

Users can respond to the task through a touchscreen. The number of tasks in those task sets was 13 (Personal), 1 (Personal+), 5 (Check), 1 (Check+), 2 (Action) respectively. The total number of tasks was 22. Both Japanese and English descriptions were prepared for all the tasks so that the international students who cannot understand Japanese also participated.

Table 3.3-3.4 also show the difficulty of each task. The standard for measuring the difficulty is basing on the cost of time and labor of finishing the task. We set four levels to evaluate the difficulty of each task. Level 0 means users can finish the task immediately without any difficulty (e.g., Push a button on the screen). Level 1 means users need to spend a little bit of time and labor to finish the task (e.g., Check the amount of water left in the hot pot first, then push the button to respond). Level 2 means users need to spend a long time and more labor to finish the task (e.g., clean the waster from the coffee maker, replacing the water in the hot pot). Level 3 means users need to move a long distance and use more power to finish the task (e.g., clean the office room, collect the garbage and throw it to the designated location). However, in this experiment, we didn't prepare the task of Level 2 and Level 3.

After the 3-week experiment, we asked all participants to answer a questionnaire about the timing of an inquiry, the impression of each task, and their opinion of the voice message function.

3.7.4 Result and Discussion

During the experiment, we collected a total of 2447 responses, of which 18 responses were rejection, and 337 responses were ignorance [55]. Figure 3.4 shows the ratio of response types (Answered, Rejected, Ignored) of 15 participants. The average number of responses from each participant was 61.1 times during the first week (forced to respond) and 78.3 times during the next two weeks (free to respond). The average response rate during the next two weeks was 84.49% and the response rate of each task type was 84.35% (Personal Task), 83.33% (Personal+ Task), 85.18% (Check Task), 86.67% (Check+ Task), 88.24% (Action Task), in-

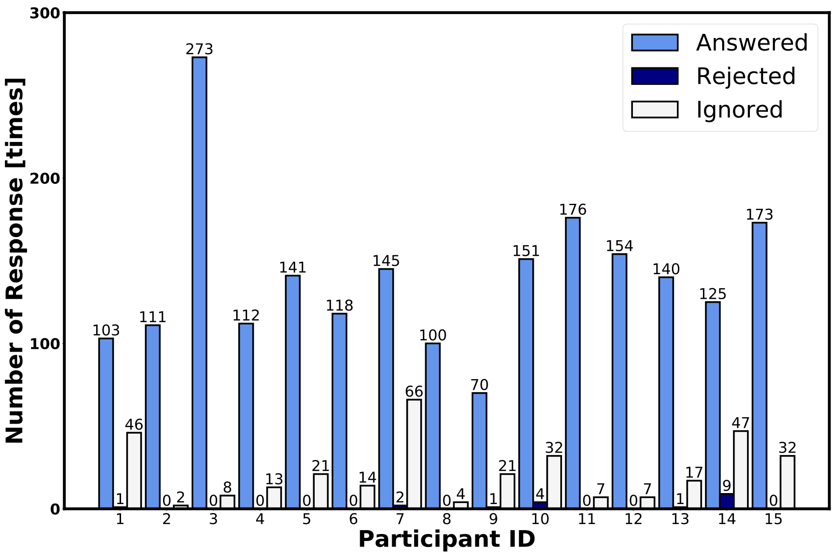


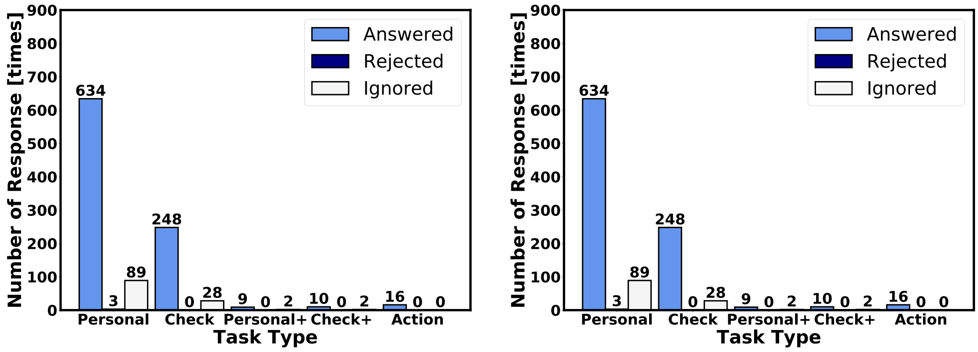
Figure 3.4: Response Results of 14 Participants

dicating that people responded to the inquiry from interactive signage with high probability.

Result and Discussion of Each Task Type

As shown in Figure 3.5, the percentage of Personal tasks is much higher than the other tasks. The reason for this is that we prepared 13 kinds of Personal Tasks in this experiment, which is much more than the other task type (Personal+ Task:1, Check Task: 5, Check+ Task: 1, Action Task: 2) and participants can answer 9 of the Personal Task easily by pushing a button. Besides, since the system only presents Personal+ Task, Check+ Task, and Action Task when a participant goes to a fixed location during a fixed time of a day, it is reasonable for the low number of records of these three types of tasks during the experiment. For example, the Check+ Task for checking the status of the light in Room A407 can only appear in the interactive signage set on the shoe shelf after 8 pm.

The response rate of Personal Task was 87.74% with bias and 84.35% without bias, while the response rate of Personal+ Task was 81.82% with bias and 83.33%



(First Week) (Second-Third Weeks)

Figure 3.5: Response Result of Each Task Type

Table 3.5: The breakdown of response of action tasks

Contents	Result	Times
If the light in A407 is on, could you please turn it off?	No, I'm kind of busy now	1
	It's off now	10
	Someone is using A407 now!	1
Do you want to use the weight scale to check your weight?	Ignore	2
	No,thanks	2
	Sure,let's see	1

without bias, indicating that the interactive signage can collect personal data without bias to a certain degree.

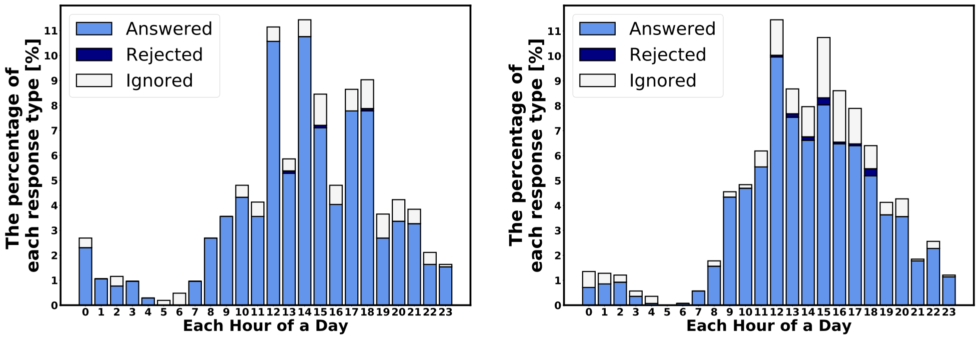
Table 3.5 shows the breakdown of responses to Action Tasks during the next two weeks. To the task of checking the status of light in A407, we managed to collect 12 answers from the participants. However, since we did not use sensors for checking the light status, we could not confirm that the light was turned off or not by the stimulation from our system. To the task of using a weight scale, we got 5 responses (1 answered, 2 rejected, 2 ignored), which indicated that our system managed to induce behavior change at least one time.

Table 3.6 shows the breakdown of Check Tasks. Since Participants need to go to the related places and check the status of lab members and equipment which

Table 3.6: The Breakdown of Response of Check Tasks

Contents	Results	Times	Response Rate
Are secretaries in their office now?	Ignore	16	86.55%
	Yes, they are	75	
	No, they aren't	28	
Is Mizumoto-San in Lab now?	Ignore	9	59.09%
	Yes, he is	9	
	No, he isn't	4	
Does the coffee maker have enough water?	Ignore	4	80.95%
	It's lower than 30%	4	
	Yes, like 30%~80%	7	
	Yes, it's over 80%	6	
Does the water pot still have enough water?	Ignore	3	87.5%
	It's lower than 30%	5	
	Yes, like 30%~80%	9	
	Yes, it's over 80%	7	
How many people are there in lab now?	Ignore	24	87.56%
	Over 15 people	72	
	About 10 people	52	
	About 5 people	34	
	Other	4	

cost the user a little bit of labor and time, the difficulty of Check Tasks is Level 1. Except for the low response rate to the question "Is Mizumoto-San in Lab now?", Check Tasks obtained a high response rate, indicating that our system can promote low time and labor cost behavior change effectively. The reason for the exception task is that the system presented this task to the participants who were sleeping on the sofa in the rest space and could not respond to the question.



(First Week) (Second-Third Weeks)

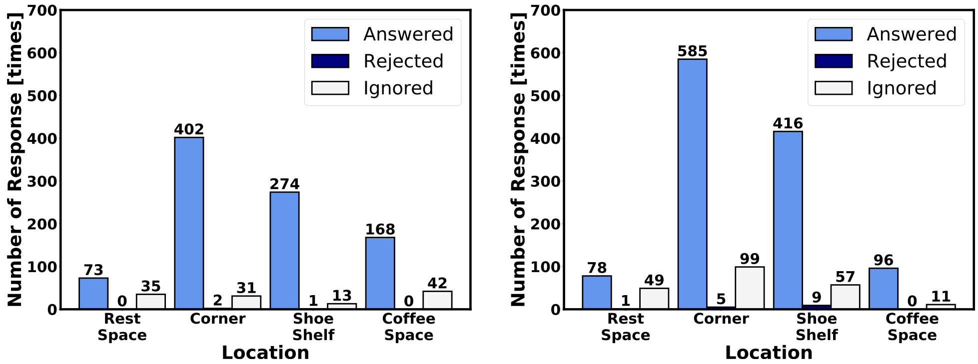
Figure 3.6: Response Result of Each Time of Day

Result and Discussion of Each Time of Day

Figure 3.6 shows the response result of each time of a day during the first week and the next two weeks, respectively. The x-axis stands for the time of a day, and the y-axis stands for the number of responses. As shown in the graphs, the ignorance rate and rejection rate raised in the latter two weeks of the experiment. Besides, according to the graphs, the rate of answered reached the highest level between 8:00 am and 10:00 am and decreased to the lowest level 15:00 pm and 16:00 pm. There are two reasons that could be considered for this result: (1) the participants were getting busy in the afternoon and had no time to respond to the task; (2) participants may have got tired of the task since they had already answered many tasks in the morning.

Result and Discussion of Location

Figure 3.7 shows the number of responses for each location of interactive signage during the first week and the next two weeks respectively. The x-axis stands for each location, and the y-axis stands for the number of responses. The rate of ignorance of the signage deployed in rest space was 32.41% and 38.28% respectively. Since our system recognizes participants based on RSSI, it was difficult to distinguish whether the participants are working, sleeping, or resting. Due to this limitation, our system presented tasks to participants who were working



(First Week) (Second-Third Weeks)

Figure 3.7: Response Result of Each Location of Signage

or sleeping, which was the reason for the high ignorance rate in the rest space. Meanwhile, the signage deployed on the shoe shelf obtained a high answered rate during the whole experiment. The reason for this is that participants always stop there to wear or take off shoes which creates opportunities for the digital signage to send stimulation. The signage set in the coffee space was down several times and the data was not collected completely due to technical problems. However, based on the collected results, we did not found any rejections even during the later two weeks. It is because those participants had to wait for the preparation of the coffee and answering the inquiry from the signage is a way to spend their spare time.

Result and Discussion of Questionnaire

In this subsection, we summarize the result of the questionnaire asked after the three-week experiment. We collected the answer from 14 participants. Table 3.7 shows the breakdown of part of the questionnaire.

In order to effectively induce a behavior change, it is necessary to be aware of user context requiring the system to collect any personal data from users, which always accompanies by privacy issues. In this experiment, we tried to collect low sensitive personal data (basic personal data and the purpose of movement) from participants, and the result of the questionnaire showed that most of them were willing to provide this low sensitive personal information.

Table 3.7: Breakdown of Questionnaire

Question	Option	Result
How did you feel when you heard the question about your personal data (Age, Weight, Height, Country, Gender)	It's OK to tell my personal information to the system	10
	I don't want to let the system knowabout my personal information	2
How did you feel when you heard the question for checking the purpose of your movement	It's OK to tell the system where I'm going or what I'm going to do.	13
	I feel uncomfortable when someone ask me this kind of question	1
How did you feel when you heard the question for checking the statement of members or equipment	It's OK for me to check the statement out	7
	It's troublesome and I don't want to check the statement of members or equipment	6
	It's troublesome but it's good to know how many water left	1
How did you feel when you heard the question about your mental state	I think it's good that someone cares about my mental state	6
	I feel stressed when I heard this task	8

In order to effectively induce behavior changes, we believe that it is necessary to identify users' life patterns, which means that we need to collect a lot of personal data from users. In addition, privacy issues have always been accompanied by the development of BCSS. In this experiment, we tried to collect participants' low-sensitive personal information (basic personal information and travel purpose) to investigate users' acceptance degree to personal data collection. The results of the questionnaire showed that most participants are willing to provide this low-sensitive personal information to the system.

Mental health is always been an important part of the quality of life (QoL) and has been increasingly getting attention in recent years. Based on this background, we designed a task for our experiment to check their stress degree. However, due to the stiffness of the content, participants reported that they even felt more stressed when they heard the task. Therefore, it is necessary to design content with more humanity.

While we prepared 5 Check Tasks in this experiment to induce behavior changes that cost people a little bit of labor and time, there were 6 participants who reported that they did not want to check the status of members and equipment. Lack of attractive feedback could be a reason for this since the system only sends a text message "Thank You", for finishing the Check Task. Therefore, to improve users' motivation, more effort on the feedback in improving users' motivations is needed.

Lastly, we asked participants what they thought about the active interaction via sending voice and text messages and let them free to answer. 9 participants gave a high score and said it was fascinating. Moreover, 4 participants reported that the voice message could remind them to respond. Based on this feedback from participants and the high response rate (84.49% without bias) to the inquiries, we confirmed that the voice message function could raise users' attention and interest with a high probability. Besides, we also got a report that he felt stressed when he always hears the same voice message. Therefore, the diversification of content is needed.

Based on the above results, we could say that the active interaction through sending voice and text messages could raise users' attention with a high probability. Also, we found that the interactive signage system can effectively induce low time and labor costs behavior changes like pushing a button and checking statements of members and equipment. We also found that the interaction with the consideration of users' daily routines is useful for raising the rate of answering. Besides, the results also confirmed that most participants are willing to provide their personal information to the system indicating their high acceptance of personal data collection.

3.8 Study 2: Users' Response Time and Reaction to The Voice Feedback

Based on the results gained from study 1, we updated our interactive signage system by adding two functions: response time collection function and voice feedback function [55]. Since the response time (the time passed from showing task until users respond) is a part of users' reactions and the effect of stimulation, it is necessary to evaluate the response time. Also, some of the participants reported in study 1 that they would like to hear the voice feedback, therefore we add the voice feedback function to improve participants' motivation. To collect response time and users' reactions to the voice feedback, we conducted an additional experiment in addition to the previous experiment described above. The period of the additional experiment was one week. All participants were asked to answer a questionnaire about their opinions on the upgraded system.

3.8.1 User Setup

We invited the participants who joined the previous experiment, and 14 of them joined in our additional experiment. As the same as the previous experiment, we asked all the participants to carry the name tag with a BLE beacon during the experiment period. However, due to one participant went on a business trip and quit our experiment, there were only 13 participants finished the experiment.

3.8.2 Scenario

In the previous experiment, each Check Task was assigned to all participants and one participant's response does not affect the presentation of the same task to other users. However, this rule put a burden on participants as there were some participants who complained that they had to do the task again even other participants had done the task already. Therefore, in the additional experiment, we changed the rule of Check Task to "Once there is someone respond the task, then the same task would not be presented to other users again until the cooldown is finished" to reduce the burden of participants.

3.8.3 Response Time Record Function

To evaluate the response time, we upgraded our system by adding a response time record function. Response time means the time passed from showing task until users respond. After participants responded to the inquiry (including ignorance and rejection), a task record containing response time is sent to the server. When a user ignored the inquiry, the response time is the preset time for digital signage that goes back to the initial screen.

3.8.4 Voice Message Feedback Function

To improve participants' motivation, we set several patterns of voice feedback for participants which changes based on the amount of response of the user. For example, at first, participants only hear "Thank You". After they respond to some tasks, they can hear "Mr.(users' name), thank you very much for responding".

3.8.5 Result and Discussion

During the additional experiment, we collected a total of 753 responses, of which 10 responses were rejection, and 158 responses were ignorance [55]. Figure 3.8 shows the ratio of response types (Answered, Rejected, Ignored) of 14 participants. However, 1 participant exit for a business trip, and only 13 people finished the additional experiment. The average number of responses for each participant

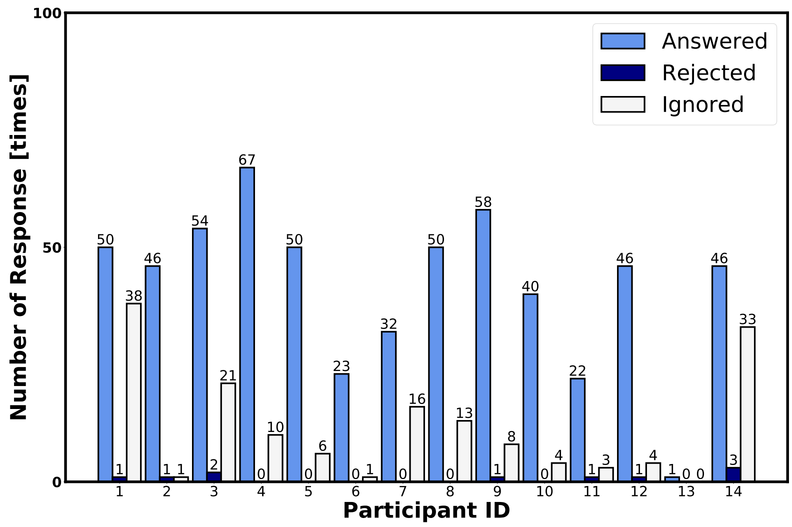


Figure 3.8: Response Results of 14 Participants

was 45.8 which is close to the average number of responses in the 3-week experiment (46.5 times per week). The average response rate in the additional experiment was 79.01%. Although it is lower than the previous experiment, we can still say that people respond to the inquiry from the interactive signage with high probability.

Result and Discussion of Each Task Type

Figure 3.9 shows the number of responses for each task type during the additional experiment. The x-axis shows the type of task, and the y-axis shows the number of responses. There are 3 types of response: Answered, Rejected, Ignored. The response rate of each task type was 78.85% (Personal Task), 83.33% (Personal+ Task), 81.30% (Check Task), 100% (Check+ Task), 54.55% (Action Task) respectively. As the same with the previous experiment, there were only a few times that Personal+ Task, Check+ Task, and Action Task were triggered due to the serious conditions and few patterns. Besides, since we changed the trigger rule of Check Task from "one's response to a task does not affect the presentation of the

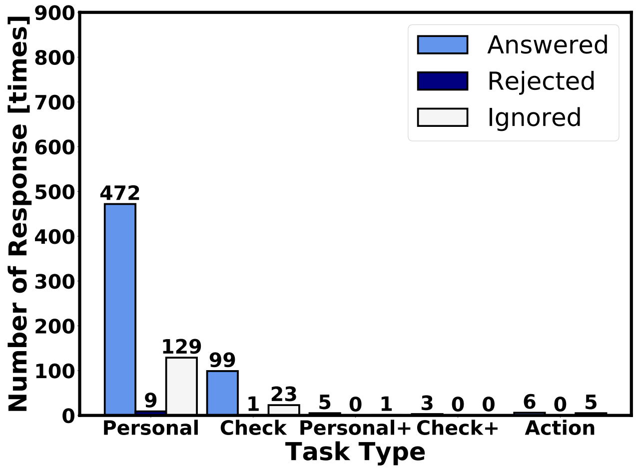


Figure 3.9: Response Result of Each Time of Day

same task to others" to "once one responded to a task, then the system does not present the same task to others until the cooldown time expires", the percentage of Check Task was lower than in the previous experiment. However, the response rate of Check Task was still high enough indicating that the upgraded interactive signage system can promote low labor and time cost behavior change effectively. During the additional experiment, all the Action Tasks triggered were the Action Tasks combined with Personal+ Task which only appears when people are near to rest space. However, as the same with the previous experiment, the system

Table 3.8: The response rate of each task type in previous and additional experiment

Type	First Week	Second Third Week	Additional
Personal	87.74%	84.35%	78.85%
Personal+	81.82%	83.33%	83.33%
Check	89.86%	85.18%	81.30%
Check+	83.33%	86.67%	100%
Action	100%	88.24%	54.55%

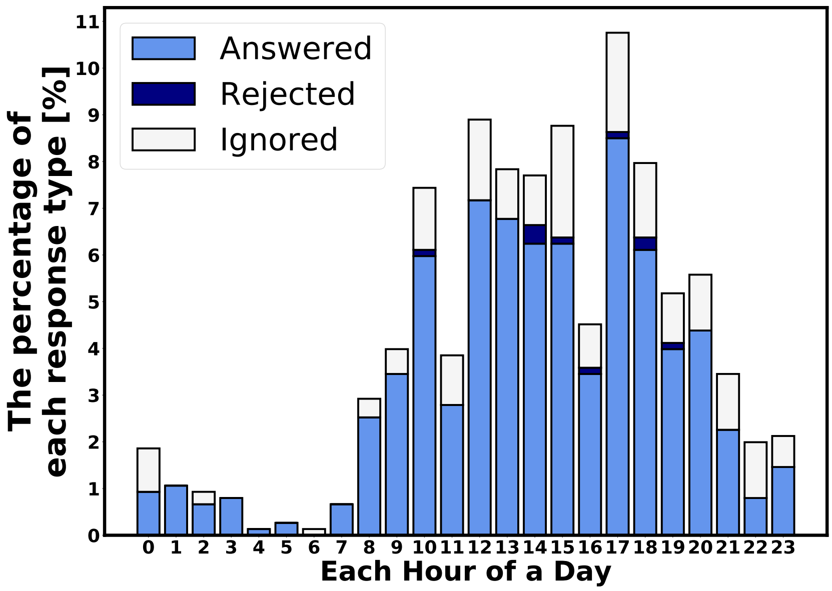


Figure 3.10: Response Results of Each Task Type

could not distinguish whether the user is working or resting and may present contents to participants who were sleeping, which is considered as the reason for the low response rate of Action Task. Table 3.8 shows the response rate of each task type in previous and additional experiment.

Result and Discussion of Each Time of a Day

Figure 3.10 shows the response result of each time of a day in the additional experiment. The x-axis stands for the time of a day, and the y-axis stands for the number of responses. Through the observation of the graph, we found that the rate of rejection and ignorance were higher than in the previous experiment. We also found that the rate of answered reached the highest level between 8:00 am and 10:00 am, and it reached the lowest level between 15:00 pm and 18:00 pm, which is close to the result we obtained in the previous experiment.

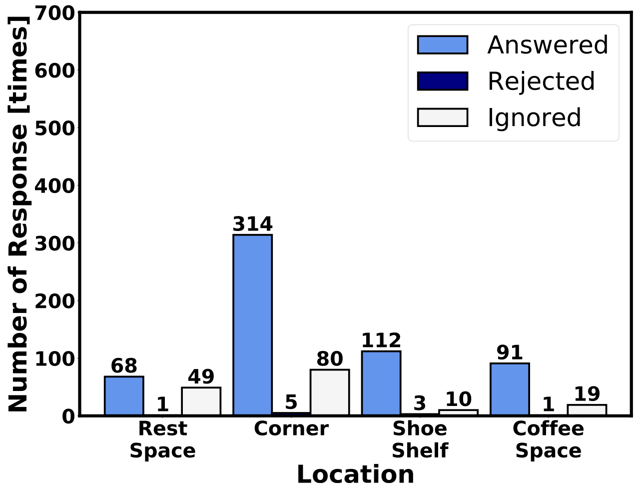


Figure 3.11: Response Result of Each Location of Signage

Result and Discussion of Each Location

Figure 3.11 shows the number of responses for each location of interactive signage in the additional experiment. The x-axis stands for each location, and the y-axis stands for the number of responses. Compared with the previous experiment, the signage deployed in the rest space got a higher rate of ignorance which was 41.53%. Meanwhile, the answered rate of the signage on the shoe shelf was still high (92%) during the additional experiment as same as before. As for the signage deployed in the coffee space, we found that rejection happened only one time indicating. Table 3.9 shows the response rate of each task type in previous and additional experiment.

Based on the above result, the correctness of the conclusion we got from the previous experiment has been proved.

Result and Discussion of Response Time

Table 3.10 shows the result of the average response time of each task type and each location. Since participants need to confirm the status of members and equipment before responding to a Check Task but only need to push a button

Table 3.9: The response rate of each location in previous and additional experiment

Type	First Week	Second Third Week	Additional
Rest Space	67.59%	61.72%	58.47%
Corner	92.87%	85.63%	79.95%
Shoe Shelf	95.49%	88.17%	92.0%
Coffee	80.0%	89.72%	82.88%

Table 3.10: Result of Average Response Time of Each Task Type and Each Location

Content	Details	Average Response Time [seconds]
Each Task Type	Personal Task	4.7
	Check Task	5.6
	Personal+ Task	6.4
	Check+ Task	4.33
	Action Task	5.0
Each Location	Rest Space	5.39
	Corner	4.84
	Shoe Shelf	3.81
	Coffee Space	5.88

to respond to most of the Personal Tasks, the response time of Personal Task is shorter than Check Task. Besides, due to the sample size of Personal+ Task, Check+ Task, Action Task is too small, we do not discuss their response time here. The signage set on the show shelf got the shortest response time since participants approach the signage whenever wear or take off their shoes so they can respond to the inquiry by the way. Figure 3.12 shows the result of the average response time of each time in a day. The average response time between 8 am to 18 pm was 5s and the average response time between 19 pm to 7 am the next day was 4.1s.

Based on the result above, we did not find a difference in response time among the type of tasks, location of signage, and time zone in a day.

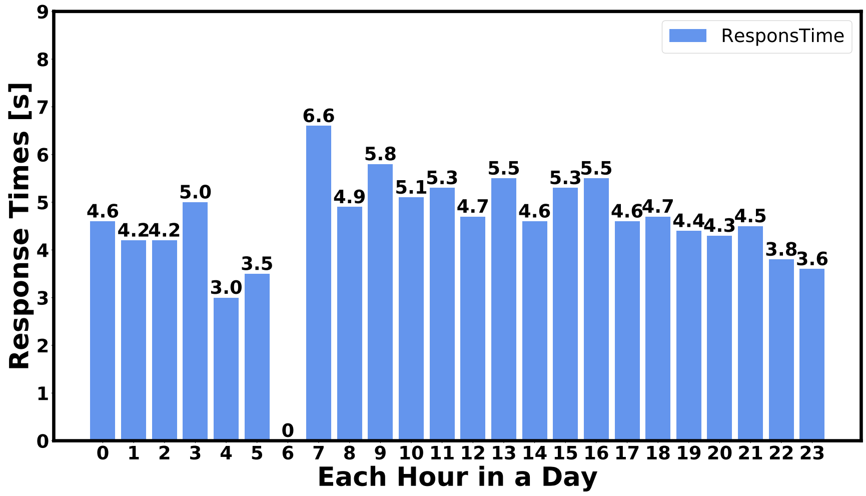


Figure 3.12: Result of Average Response Time in Each Time of a Day

Result and Discussion of Questionnaire

According to the result of the questionnaire, 9 participants reported that they felt interesting to hear the voice feedback in the response to the question about their feeling about the newly added voice feedback, indicating that the voice feedback function can raise users' interest. However, there were also 3 participants who reported that they felt embarrassing since some patterns of the voice feedback were too long and they preferred a "Thank You" as feedback. Meanwhile, there were 3 participants who reported that their motivation was improved by hearing the voice feedback, indicating that the voice feedback function can raise the interest of users and may be able to improve the motivation of users.

Effect of the Day Passed on Response Rate

A common issue with BCSSs is the effectiveness of the system decreases as time passes. We assume that users' motivation for using the system decreases over time, which increases tiredness as well as ignorance of the trigger. To verify the correctness of our guess, we conducted an analysis between the response rate and day passed based on the task record collected in two experiments. Since the type

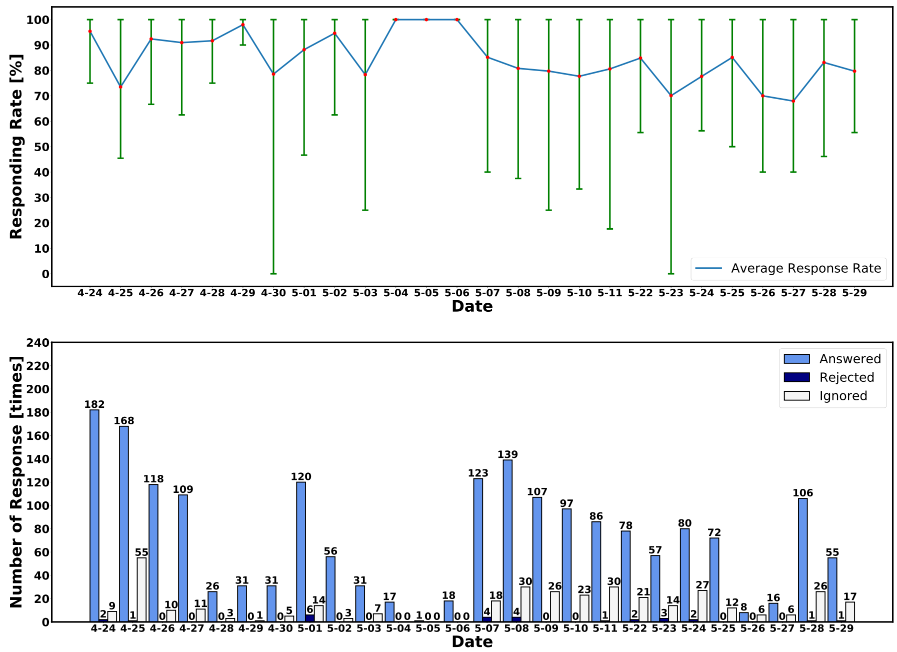


Figure 3.13: Response Result of Personal Task by Date

of task is also a variable, we did the analysis for each task type.

Figure 3.13 shows the response result of Personal Task by date. In the upper graph, the x-axis stands for the date, and the y-axis stands for the responses rate. Besides, the line stands for the average response rate in each day, and the error bars stand for the highest and lowest response rate of participants on that day. In the lower graph, the x-axis stands for the date, and the y-axis stands for the number of responses. There are three types of responses: Answered, Rejected, Ignored.

The first week started on April 24th and ended on April 29th (6 days in total). During the first week, participants were asked to respond to the tasks whenever they noticed the voice message, therefore the response rate (including rejection) naturally did not decrease. From the second week started from April 30th, par-

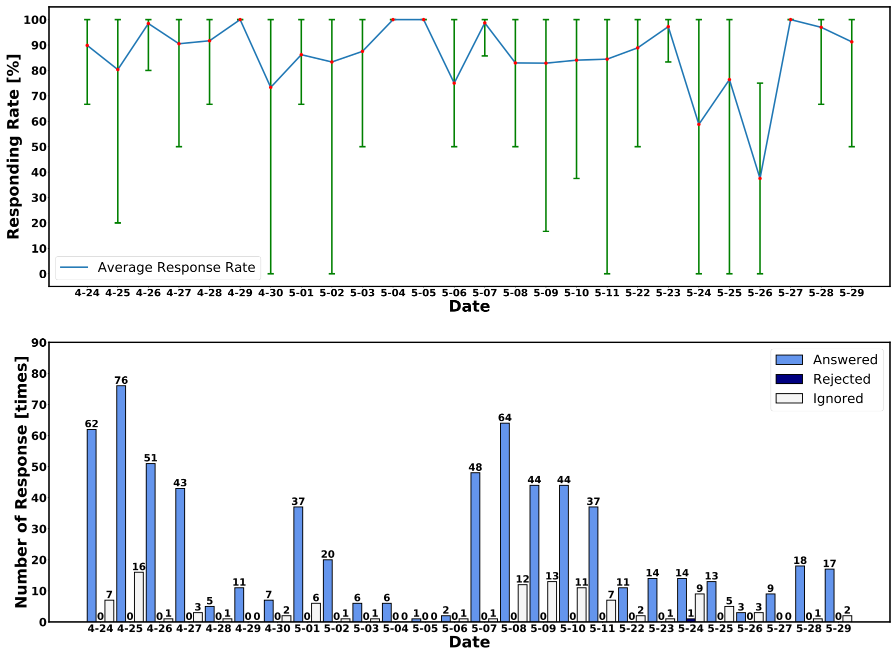


Figure 3.14: Response Result of Check Task by Date

ticipants were not asked to respond to the tasks definitely, and the response rate went down a little bit and become stable at around 80%. Although the lowest response rate in a day tends to go down, according to the lower graph, the number of ignorance has not risen as time passes. The additional experiment started on May 22nd and ended on the 29th. Participants were free to respond to the tasks during this period. As time goes by, the response rate fluctuates drastically, but according to the lower graph, the number of ignorance is almost the same as the previous experiment. The reason for the fluctuation was the total number of triggered tasks during that day was small. Based on the result above, the number of ignorance of Personal Task doesn't rise even as the time passes has been proved.

Figure 3.14 shows the response result of the Check Task by date. In the upper graph, the x-axis stands for the date, and the y-axis stands for the responses rate.

Besides, the line stands for the average response rate in each day, and the error bars stand for the highest and lowest response rate of participants on that day. In the lower graph, the x-axis stands for the date, and the y-axis stands for the number of responses. There are three types of responses: Answered, Rejected, Ignored.

During the first week, due to the controlled condition, the response rate did not go down naturally as time passed. During the second and third week without the controlled condition, the response rate went down a little bit and became stable around 83%. According to the lower graph, the number of ignorance has not risen. During the additional experiment, since we changed the rule of presenting Check Task, the amount of Check Task triggered decreased a lot. Although the response rate fluctuates drastically as time goes by, according to the lower graph, this is because the number of tasks triggered on that day was small. The number of ignorance is much smaller than in the previous experiment. Based on the result above, the number of ignorance of Check Task does not rise even as the time passes has been confirmed.

Since the sample data of Personal+ Task, Check+ Task, Action Task are too small and scattered, we do not discuss them here.

3.9 Discussion

To evaluate the effect and availability of the proposed design of active BCSS, we developed a prototype and conducted a 3-week experiment. Based on the result of each task type and participants' answers to the questionnaire, we found that participants responded to the inquiry from the interactive signage with high probability. It is one of the results of inducing behavior change since there is no such system in users' daily routines before the experiment and responding to an inquiry from such a system is a new behavior. Moreover, according to the result of the response of the Personal Task and participants' answers to the question about their opinions to personal data collection, we found that people are willing to provide their low sensitive personal information to the system. Besides, through the result of the Check Task, we found that the interactive signage can induce low labor and time cost behavior change effectively.

Although we obtained several positive results, we also found some limitations of our system. First, some participants reported that they did not want to do the Check Task. To improve the motivation of these people, more effort on the attractive feedback and content is needed.

Based on the result we got from the previous experiment, we upgraded our system by adding a voice message feedback function (improve users' motivation) and a response time record function (collect the response time). To reduce the burden on users, we changed the trigger rule of Check Task. To collect the response time and users' reactions to the voice feedback function, we conducted an additional experiment with the same participants of the previous experiment. Eventually, 13 participants completed the additional experiment. Through the result of the additional experiment, we found the same conclusion as the previous experiment. Moreover, through the analysis of the response time, we did not find a significant difference in response time among each task type, each location of signage, and each time of the day. Besides, we assume that users' motivation for using the system decreases over time, which increases tiredness as well as ignorance of the trigger. To verify our guess, we held an analysis based on the task record collected in two experiments to investigate the relationship between the ignorance rate and the day passed. As a result, we found that the number of ignorance of Personal Task and Check Task does not increase as time passes. However, it is necessary to hold longer-period experiments to explore whether this finding is also true in the longer term. Due to the sample size of other task types was too small and scattered, we could not draw any conclusion from them.

3.10 Limitation

Although we got some positive results from the experiment, we also found some limitations of our system. 7 participants reported that they did not want to do the check task after the 3-week experiment. The reason for this can be considered as the content of the task was less related to the participant and there was no attractive feedback but only a text message, "Thank you!". And there were also some people who reported that they felt stressed when they heard the mental check task since the content was too strict and less humanized. They also said that they felt bored and stressed when they always hear the same content due to the patterns of the inquiry are limited.

3.11 Summary

With the widespread of smart devices equipped with many sensors, people have conducted many developments and research for recognizing users' life patterns with the cooperation of smart devices. Especially in the medical field, using smart devices has been taken as the treatment of lifestyle diseases such as diabetes, obesity, hypertension which are usually caused by patients' poor daily habits by reviewing their lifestyle and leading them to better life patterns. This kind of system is also called a behavior change support system (BCSS). The majority of BCSSs available on the market tend to apply a passive approach that rarely interacts with users and only report users' status upon opening the app, which may limit the effectiveness of the system in inducing behavior change. Therefore, an alternative approach is needed.

In this chapter, we proposed a design of active BCSS. The design aims not only the reinforcement of users' behavior but also the form and altering of users' behavior. The design focuses on the common issues that people meet with during their daily lives including the improvement of health conditions (e.g., diet, sleep, stress) and the environment (e.g., save energy, keep the environment clean). To realize these goals, our design targets the enclosed environment such as a company or a university where people nowadays usually spend a long time in. As long as people are staying in the environment, our system is expected to be able to send stimulation to them and promote behavior change continuously, so that we can improve the efficiency of digital intervention and the quality of behavior change.

To evaluate the effectiveness of the design on inducing behavior, we developed a prototype of the proposed approach and evaluate its effectiveness. For the prototype, we developed an interactive signage system to present information to users due to three reasons: 1) it has a larger screen so that we can show more content; 2) it is independent of users' operations (such as turning smartphones to silence mode) so that we can better investigate users' reactions; 3) it is able to interact with multiple people instead of only a specific one. The interactive signage system can actively talk to the passing users for nudging their behavior change. To identify the person who is passing, we used a BLE beacon (coin-size, weight 8 grams) and embedded it in a nameplate. After identifying the user, the interactive signage provides visual and auditory messages to him/her to stimulate them trying to induce behavior change.

We conducted a 3-week experiment and an additional experiment to investigate the effect and availability of our proposed system. As the first step of promoting behavior change, we prepared 5 check tasks that cost the user a little bit of time and labor to investigate users' reactions to the simple tasks. Through the result, we proved the usefulness of our interactive signage on promoting low time and labor cost behavior change. Also, we showed the effectiveness of active interaction through sending voice and text messages in attracting users' attention and interest through the result of the questionnaire of the experiment. Besides, we investigated the effect of the fatigue factor by analyzing the relationship between the day passed and the response rate. We found that the number of ignorance of Personal Task and Check Task does not rise even as the time passe, indicating that users' motivation did not decrease as we assumed while using the interactive signage system. For the rest of the task types, due to the sample data were too small and scattered, we could not get any conclusion from them.

4 Active And Adaptive Behavior Change Support System

4.1 Introduction

In this chapter, we build upon our work in Chapter 3. The work described in this chapter has been done in cooperation with Dialogue System Research Group, UUlm and already been published in [57]. We previously considered a design of the active behavior change support system. To evaluate the effectiveness of the proposed approach in inducing behavior change, we developed a prototype that actively sends voice and text messages to the passing users. Through two experiments, we showed that the proposed approach can effectively induce behavior change at low labor and time costs. However, we also found several limitations of our system including too strict and less humanized content, and no attractive feedback, which brings us to the consideration of the representation methods while presenting content.

To induce behavior change effectively, it is necessary to select the appropriate contents, timing, and ways of representation. Using a quantitative approach involving charts, graphs, and statistical reports are the common ways of representation applied in the majority of existing apps. However, there are some pieces of evidence showing that the quantitative approach can be difficult for users to understand [11, 12] and thereby lower users' motivation and result in a failure to induce a behavior change [13]. To cope with this issue, it is necessary to provide explanations of quantitative data as a supplement. Through the provided explanations, users can be aware of their situation more clearly, so that the system can induce a behavior change more likely. Meanwhile, many reports are showing that different descriptions of the same data may lead to different outcomes. For instance, Pragst *et al.* [14] demonstrated that different levels of elaborateness and indirectness can influence users' perceptions of the information provided. Therefore, to enhance the effectiveness of a BCSS, it is necessary to take consider the effects of different communication styles during the design process.

In the rest of the chapter, we firstly present a review of related literature, then we describe the design of active and adaptive behavior change support systems. Afterward, we describe the prototype of the proposed approach and evaluate its effectiveness in inducing behavior change.

4.2 Literature Review

For Human-Human Interaction (HHI), it has been shown that people tend to adapt their interaction style (e.g., tone, amount of information, directness) to each other when they communicate [31–35]. Therefore, many researchers suggest adapting systems to users in a similar way in Human-Computer Interaction (HCI) [36–40]. By adapting the system's behavior to the user, the system may appear more familiar and trustworthy, and the interaction may be more effective, which is the reason why the research in the field of Spoken Dialogue Systems currently focuses on user-adaptive systems [41–45].

The hard adaptation approach is a common adaptation approach that utilizes dedicated system actions to deal with certain conditions such as reacting to an angry user by asking what is wrong [58–60]. For instance, to ensure drivers' safety, Kousidis *et al.* [61] developed an in-car dialogue system that pauses the conversion entirely when drivers meet the situation that requires their full attention. Jaksic *et al.* [62] developed a dialogue system that provides different responses based on users' emotions. Meanwhile, the system developed by Bertrand *et al.* [63] provides four kinds of emotional feedback to users.

In contrast, soft adaptation is only rarely considered. Soft adaptation means keeping the propositional content of a system action the same and changing only the way it is presented, i.e., the communication style. Through a user study, Pragst *et al.* [14] proved that different levels of elaborateness and indirectness can influence users' perception of dialogue, which makes the level of elaborateness and indirectness valuable candidates for adaptive dialogue management. The level of elaborateness refers to the amount of additional information provided to the user. In response to a question concerning the current day's weather forecast, an answer with a low level of elaborateness might be providing only the requested information, whereas an answer with a high level of elaborateness provides additional information including the weather forecast for the next few days. The level of indirectness describes the concreteness of the information addressed by the system. For example, a direct answer to the question concerning the current weather would be an accurate description of the weather, such as "It is raining", whereas an indirect answer would be advised to take an umbrella or a raincoat. The meaning of an indirect answer can be inferred from the given information even when it does not mention the weather directly. Through a user study, Miehle *et al.* [41, 46] found that the level of elaborateness and indirectness of the system influences users' satisfaction and perception of the dialogue and they did not found a general preference for the communication style of the system.

Although these studies have shown that different communication styles affect users' perception of interaction in spoken dialogue systems, the impact of communication style on inducing behavior change remains unclear. Therefore, further investigation is needed to improve the effectiveness of behavior change.

4.3 Architecture of Active and Adaptive Behavior Change Support System

In this section, we describe the updated form of our design with the consideration of communication style. There are four stages in our design as shown in Figure 4.1.

The recognizing stage is mainly for identifying and classifying the user. In this stage, the system starts to observe all the smart devices carried by users and deployed in the environment side such as a smartwatch, interactive signage, smart belt [64], BLE beacon. These devices continuously send a package containing the information of the UUID of the device and data to the receiver in the system to identify and classify the user. Each type of device has an independent receiver that decides whether the system goes to the executing stage based on the data in the package. For example, when the package is from a BLE beacon, which

Figure 4.1: Form of Proposed Active and Adaptive Behavior Change Support System

means there is a user in the vicinity (good timing for presenting information [65]), then the system checks the physical data of the user, including age, weight records, BMI (Body Mass Index), sleep status, and so on. If the package is from a smartwatch which means there is an abnormal heart rate, then the system checks the heart rate records of the user. When the package comes from the smart belt indicating the user is sitting too long or in a wrong posture, the system checks the sitting posture records and time records of the user. After getting users' status, the system goes to the executing stage.

The executing stage is the stage where we try to induce a behavior change. In this stage, the system selects a proposal based on the records obtained in the recognizing stage. The selection contains three parts: Topic, Method, and Reward. Topic means the content to propose. For example, based on users' weight records and the amount of movement, the content could be the tendency of weight and propose users to do more exercise. The method means the approach to propose the content, including platform (e.g., interactive signage, smartwatch, a chatbot in social media), media (e.g., voice message, text message, chart), and communication style (e.g., indirectness, elaborateness). Reward means the type of reward given from the system to the user (e.g., messages, points). The proposal selection depends on users' status (e.g., location, amount of movement) and the group of the user.

In the reviewing stage, we record the user's reaction toward the proposal from the system. For the behavior related to movement and location, we estimate the user's reaction through the users' data, whereas, in other behavioral patterns, we confirm the result through the response to the inquiry and notifications of the user. We regroup users again based on the result.

The feedback stage is for keeping and improving users' motivation. If the user responded to the proposal presented by the system, the system sends users rewards in the selected proposal as feedback. The rewards could be virtual gold coins or points. Also, a ranking table and a chart of the progress of the whole group are a part of the feedback. A blog (or report) about the progress of an individual or a group is sent to social media periodically. The content of feedback depends on the group of the user.

4.4 Prototype of Active and Adaptive Behavior Change Support System: Walkeeper

To investigate the effect of different communication styles on inducing behavior change, we designed and developed a prototype based on the architecture mentioned above. We this time focus on users' physical activity. According to WHO's report, 81% of adolescents globally aged 11-17 years were insufficiently physically active and one in four adults do not meet the global recommended levels of physical activity, which is considered as a reason for the growth of obesity and overweight [2,3]. More than 75% of adults lack exercise in the United States [66,67]. Meanwhile, it is estimated that just increasing physical activity can prevent over five million annual deaths worldwide [2,68,69]. Therefore, promoting users to exercise more has always been an important area of BCSSs. However, these BCSSs are precisely the ones that rely most heavily on the quantitative representation approach which has been suggested may reduce the motivation of users and result in a failure to improve health [13] since it is difficult to understand the mean-

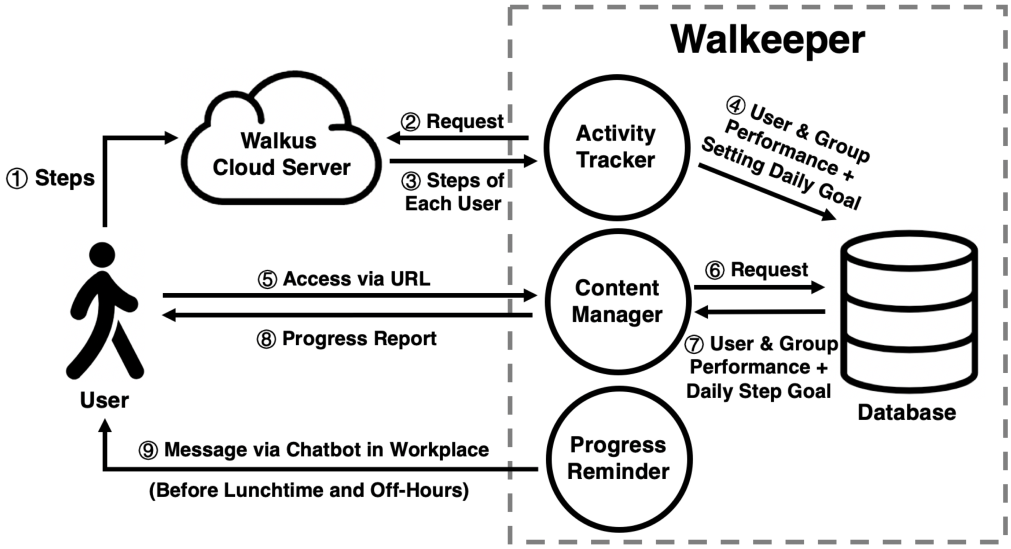


Figure 4.2: The web-based application called Walkeeper consists of three parts: the activity tracker, the contents manager and the progress reminder.

ing of the quantitative data [11, 12]. To offset the shortcoming, we believe it is necessary to provide explanations along with the quantitative data so that users can be aware of their situation more clearly and thereby change their behavior. Meanwhile, since different descriptions of the same data may lead to different outcomes, it is necessary to explore the impact of different communication styles on users' performance. To this end, we developed Walkeeper [57], a Web-based application that provides explanations of users' daily step counts based on different levels of elaborateness and indirectness, to examine how the explanation style affects the user's walking performance. As can be seen in Figure 4.2, Walkeeper consists of three parts: an activity tracker, a content manager, and a progress reminder. The activity tracker tracks the users' activity and sets the daily step goal for each user. Based on the data collected by the activity tracker, the contents manager selects the content to be provided to the user, including the contents of the explanation, the facial expression of the emoji, the graph of historical records, and the group ranking table. The progress reminder sends messages to the users before lunchtime and off-hours every weekday in an attempt to promote the users to walk more by reminding them of their walking progress. In the design of Wal-

Table 4.1: Software Features in Walkeeper.

Feature	Way to Apply
Reduction	Gradually increase the goal of daily steps
Self-monitoring	Providing information on the user's walking progress
Praise	Congratulating the user when the daily goal has been reached
Suggestion	Promoting the user to walk more when the user has not reached the daily goal
Reminder	Sending messages to the user before lunchtime and off-hours
Comparison	Showing the average number of steps of the whole group in a historical records graph
Competition	Showing the rank of other users in a ranking table

keeper, we applied BCSS theory by importing reduction, self-monitoring, praise, suggestions, reminders, comparisons, and competition from a list of BCSS software features [9] shown in Table 4.1 to improve users' motivation. These features have also been widely applied in other existing BCSSs and got positive results.

In the following, we describe the main features of Walkeeper, including how the system tracks the activity, sets the daily step goal, selects the contents of the explanation to be provided, and reminds the user of his/her walking progress.

4.4.1 Activity Tracking and Goal Setting

To track the number of steps of each user, we used a mobile app called Walkus [70] which can track the activity of users and upload the data to its cloud server. To obtain users' data from Walkus' cloud sever, we developed an activity tracker function that accesses Walkus's cloud sever every five minutes and store the data in the Walkeeper database automatically. The activity tracker function identifies

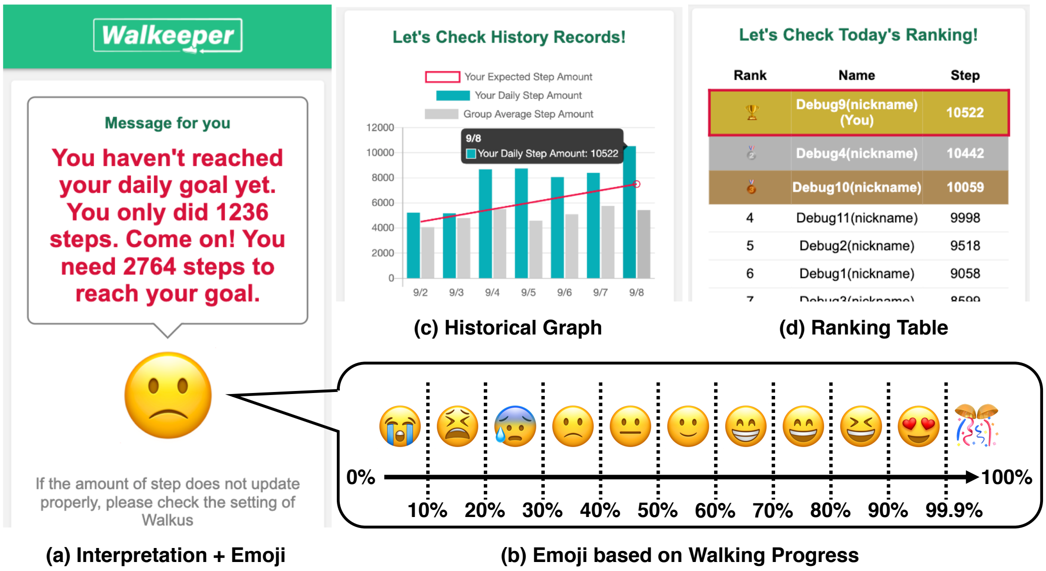


Figure 4.3: The Walkeeper Interface

users through their Walkus IDs. After getting data of all the users, the activity tracker calculates the average number of steps of the whole group which is taken as the group performance at that time, and stores it into the database. At the end of each day, the activity tracker checks the number of steps of users and updates their daily goal of steps for the next day based on their performance on that day. If the user has reached the daily goal of step, then the activity tracker increases the number of the daily goal of step for the next day by 500 steps, otherwise, the activity tracker keeps the same goal for the next day.

4.4.2 Progress Reporting

For each user, Walkeeper provides a unique URL containing a token that allows Walkeeper to identify users directly without requiring a login. Through the URL provided, users can check their walking progress at any time. As shown in Figure 4.3, by accessing the URL, users can see their progress report containing an explanation of the current step count, an facial expression emoji, a historical records graph, and a ranking table.

To deal with the selection of the contents provided to the user when they access Walkeeper, we developed a content manager function in the cloud sever of Walkeeper. When a user opens his/her progress report, the content manager chooses contents according to the following steps:

1. identifies the user through the token embedded in the URL
2. calculates the user's walking progress
3. checks the communication style set for the user
4. formulates an explanation based on the communication style and performance of the user
5. selects the facial expression emoji, historical records graph, and ranking table based on the performance of the user and the whole group

There are four different communication styles in Walkeeper for the situation that the user has and has not reached his or her goal, as shown in Table 4.2. The contents of templates were designed by the collaboration between the Ubiquitous Computing Systems Lab at NAIST and the Dialogue Systems Group at Ulm University, Germany based on the definitions provided in Section 4.2. Hence, the concise explanations contain only the most important information, while the elaborate explanations contain some additional information, such as the exact number of steps taken or the number needed to reach the goal. The direct explanations state concretely whether the daily goal has been reached, while the indirect explanations provide positive or negative feedback only based on the walking progress.

The explanation is displayed as a speech bubble next to an emoji, as shown in Figure 4.3 (a). Eleven different emoji facial expressions are used to represent the user's walking progress rate, as can be seen in Figure 4.3 (b). To maintain the user's motivation, Walkeeper also provides a graph showing the daily step records, daily step goal, the average number of daily steps of the whole group for the past week (see Figure 4.3 (c)), and an overall ranking table containing the user's rank, nickname, and current step count (see Figure 4.3 (d)). For Japanese-speaking users, all contents are provided in Japanese. To ensure the accuracy of translations, the translations were conducted by a native Japanese speaker with a high TOEIC score (915/990).

Table 4.2: Different communication styles for the explanations, where <X> is the user's number of steps at that time and <Y> is the number of steps remaining to reach the goal.

Status	Communication Style	Content
User has reached goal	Direct & Elaborate (DE)	You have reached your daily goal. You already did <X> steps today. Well done! You improve your health with physical activity.
	Direct & Concise (DC)	You have reached your daily goal. Well done!
	Indirect & Elaborate (IE)	You did it. <X> steps are fantastic! Your health is benefiting from physical activity.
	Indirect & Concise (IC)	You did it. Fantastic!
User has not reached goal	Direct & Elaborate (DE)	You haven't reached your daily goal yet. You only did <X> steps. Come on! You need <Y> steps to reach your goal.
	Direct & Concise (DC)	You haven't reached your daily goal yet. Come on!
	Indirect & Elaborate (IE)	You still need to do some steps today. <X> steps are a good start. Get going! <Y> are all that is needed.
	Indirect & Concise (IC)	You still need to do some steps today. Get going!

4.4.3 Progress Reminder

To realize the active interaction with users, we developed a progress reminder function that sends messages to users twice a day by a chatbot developed in Workplace Chat [71]. The message sent by the progress reminder consists of a text ("Please access the URL and check your performance") and the unique URL for the user. For Japanese-speaking users, Walkeeper provides the reminder in Japanese. The progress reminder sends the first message at 11:30 and the second message at 16:30 so that users receive their progress report before lunchtime and before leaving the office. In this way, users can consider whether to have an active lunch break (e.g., use the stairs instead of the elevator when going to the canteen, take a walk after having lunch) or plan to walk more in the evening (e.g., walk to the train station instead of taking the bus, exercise after arriving home).

4.5 Experiments and Evaluation

To evaluate Walkeeper, we conducted a 6-week user study. Through the user study, we investigated the answers to the following research questions:

1. How do people react to Walkeeper?
2. How do different communication styles affect the attitudes and behavior of users?
3. How does the browsing duration affect the behavior of users?

4.5.1 Participants and Procedures

The user study was conducted from June to July 2020. We recruited 24 participants (21 men, 3 women; mean age, 29 years; age range, 22–52 years) from the members of Ubiquitous Computing Systems Laboratory at the Nara Institute of Science and Technology. Eighteen participants were Japanese speakers and 6 remaining participants were English speakers. Before the experiment, we assisted all the participants with the installation and setup of Walkus, Workplace, and Walkeeper.

The first two weeks were the period of confirming the functionality of the system including whether the system can track participants' steps continuously. Moreover, we estimated the activity levels of each participant based on the step records collected to set an appropriate daily goal and obtain a comparative value for the evaluation. During this period, we asked participants to use the Walkus only so that we can collect participants' performance while using the common exercise assistant application that does not have active and adaptive function. Based on the collected data, we calculated the average number of steps of each participant and set it as the initial daily goal of step.

The following four weeks were the period for collecting participants' reactions to Walkeeper. Through the 4-week study, we tried to investigate how the Walkeeper affects participants' attitude and behavior toward physical activity, and the overall experience of the different communication styles. During this period, Walkeeper only interacted with the participants on workdays (from Monday to Friday) to keep the same conditions for the data collection during the course of the study. Besides, at the beginning of each week, the daily goal of the step of each participant was reset to the initial average number of steps to keep the starting point identical. At the end of each week, all the participants were asked to complete a 3–4-minute questionnaire on their impressions of the interface and explanations. The questionnaire was hosted on Google Forms and sent to all participants by a text message containing the link to it every Friday evening during the experiment period. Besides, we collected analytic data about the times of accessing the Walkeeper and the duration of browsing the main interface of Walkeeper since they are the parts of participants' reactions. At the end of the 4-week study, all participants were asked to complete a final questionnaire on their overall experience with the Walkeeper app. As a reward for participating in this study, we give participants a gift card worth 2000 JPY (around 19 USD). To ensure the reliability and accuracy of the experiment, we did not mention the reward in the experiment introduction at the beginning, and only after the end of the experiment, we informed the participants about the reward and gave it to them.

Table 4.3: All participants were randomly assigned to one of four teams.

Team	Number of Participants	Week 1	Week 2	Week 3	Week 4
1	7	DE	IC	IE	DC
2	6	DC	IE	IC	DE
3	4	IE	DC	DE	IC
4	7	IC	DE	DC	IE

4.5.2 Study Groups

At the beginning of this experiment, all the participants were randomly assigned to one of four teams. To investigate the effects of different communication styles in Walkeeper, each team experienced a different communication style each week as shown in Table 4.3. Through this setting, we ensure that the weather would have no impact on the data collection of each communication style every day. Six participants were assigned to Team 3 at the beginning of the study among whom two participants failed to participate fully due to personal reasons. Therefore, the afterward data analysis excluded the data of these two participants. At the beginning of the first week, we assigned one of four communication styles to each team and make sure no team got the same communication style. For the second week, Walkeeper reversed the communication styles of each team (direct $\leftrightarrow$ indirect, elaborate $\leftrightarrow$ concise) to strengthen the differences. In the third week, the level of indirectness was maintained as the same as the second week, and the level of elaborateness was changed (elaborate $\leftrightarrow$ concise). In the final week, Walkeeper reversed the communication styles used in the third week.

4.6 Findings

In this section, we first present the evaluation method used to investigate the effect of different communication styles. Then we describe the results of statistical analysis of the effect of Walkeeper on promoting behavior change, the influence of different communication styles on behavior change, and the overall impression of the participants on the Walkeeper interface design.

4.6.1 Data Filtering and Calculation of the Step Increase Rate

We conducted a statistical analysis to examine the correlation between the step counts and communication styles. To ensure the reliability of the data, we filtered out the incorrect data owing to technical issues based on the following conditions:

1. The daily step count had to be at least 500.
2. For each participant, at least three data records had to be available for the first experimental phase (i.e., the average number of steps for this phase had to be reliable).

We excluded all the data which did not fulfill these conditions from the subsequent analysis. Through the data filtering, we obtained 89 data records for the first experimental phase and 400 for the second (DE: 96, DC: 99, IE: 103, IC: 102). To compare the step counts, we calculated the step increase rate (SIR) for each day of the second experimental phase by using each participant's average number of steps during the first experimental phase M. The calculation was conducted as follows:

$$SIR(\%) = \frac{\#DailySteps - M}{M} \times 100 \tag{4.1}$$

SIR represents how different the participant's daily step count is compared with the average number of steps before receiving a reminder from the Walkeeper system. When the SIR of that day is positive, it means the user walked more than the average number of steps during the first experimental phase; when the SIR of that is negative, it means the participant walked less than the average number of steps during the first experimental phase.

4.6.2 Impact of Communication Styles on the Participants' Behavior

Table 4.4 shows the average SIR for each communication style (DE: Direct & Elaborate, DC: Direct & Concise, IE: Indirect & Elaborate, IC: Indirect & Concise). According to Table 4.4, every communication style obtained a positive SIR

Table 4.4: Results of a one-way ANOVA showing significant differences between communication styles.

	Sample Size	Average Step Increase Rate (SIR)	p-value (ANOVA)
DE	96	4.82%	0.017*
DC	99	5.07%	
IE	103	32.79%	
IC	102	13.38%	
Best	101	47.57%	-

indicating that the participants reacted positively to the Walkeeper system and walked more during the second than during the first experimental phase when only the steps were tracked and Walkeeper did not send any messages or URLs to the participants so that they could check their progress. The highest average SIR of 32.79% was obtained for IE, whereas the lowest average SIRs of 4.82% and 5.07% were obtained for DE and DC, respectively. We also calculated the average SIR of the "Best" style (the number of participants who got best performance under each style: DE:3, DC: 0, IE: 12, IC: 6) which refers to participants' performance under the most appropriate communication style. The result was 47.57%, indicating the potential improvement of applying adaptiveness into the system.

We conducted a one-way analysis of variance (ANOVA) to assess the effects of the different communication styles. The results of the statistical analysis revealed statistically significant differences between communication styles ($p = 0.017$). Tukey's posthoc analysis revealed a significant difference DC and IE ($p = 0.030$) and between DE and IE ($p = 0.030$), as shown in Table 4.5.

To explore further the impact of the different communication styles on the participants' behavior, the two dimensions of elaborateness and indirectness were considered independently. A t-test demonstrated that the participants had a significantly higher SIR with an indirect compared with a direct communication style ($p = 0.011$), but no significant difference was found between the elaborate and concise communication styles ($p = 0.164$). This result was confirmed in a

Table 4.5: Results of Tukeyś all-pairs comparison test showing significant differences between DC and IE and between DE and IE.

	DE	DC	IE	IC
DE	-	1.000	0.030*	0.833
DC	1.000	-	0.030*	0.842
IE	0.030*	0.030*	-	0.209
IC	0.833	0.842	0.209	-

Table 4.6: Results of the two-way non-repeated measures ANOVA.

	p-value
Indirectness	0.012*
Elaborateness	0.164
Indirectness:Elaborateness	0.168

two-way non-repeated measures ANOVA. The results are shown in Table 4.6. Figure 4.4 visualizes the correlation between the average SIR and different levels of elaborateness and indirectness. Additionally, the two-way ANOVA showed no interaction between elaborateness and indirectness that influenced the participants' average SIR ($p = 0.168$).

4.6.3 Impact of Browsing Time on the Participants' Behavior

We conducted a statistical analysis to examine whether there was a correlation between the SIR and the time participants spent browsing the Walkeeper website. To achieve this, we extracted the access records for the Walkeeper website and calculated the total browsing time for each day. Next, we filtered out the data records with a total browsing time of zero (meaning that the participant did not access the Walkeeper website that day) or longer than 90 seconds (assuming that the participants did not actively check the information for more than 90 seconds), leaving 288 data records for the analysis. To examine the correlation between the SIR and browsing time, we calculated the Spearman rank-order correlation

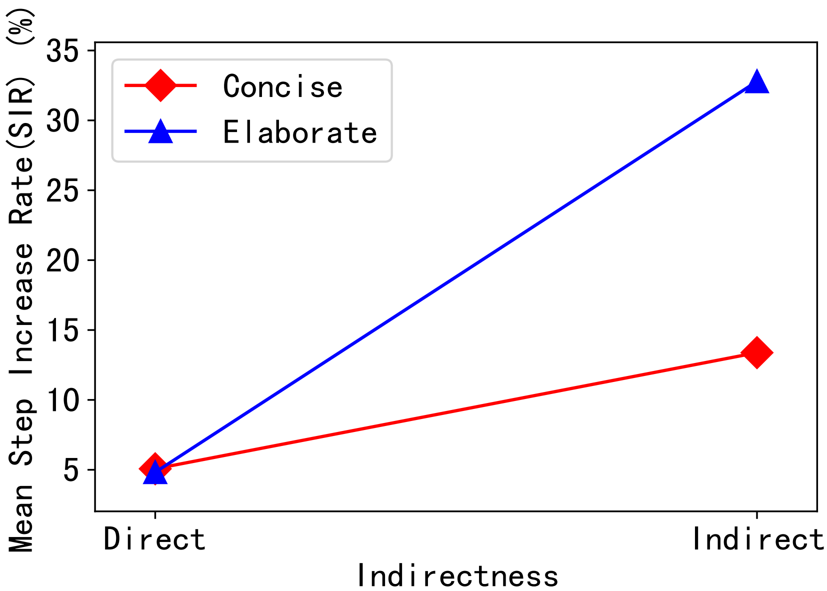


Figure 4.4: The correlation between the SIR of participants and different levels of indirectness and elaborateness.

coefficient. The results revealed no significant correlation ($p = 0.54$).

4.6.4 Impressions of the Interface Design of Walkeeper

Using the weekly survey and final questionnaire of the second experimental phase, we obtained the participants' (N=24) impressions about the interface design of Walkeeper, including the explanations, emoji facial expressions, a graph of historical records, and a ranking table.

Table 4.7: Results of all weekly questionnaires.

Statement	Metric	DE	DC	IE	IC
1. The system seemed polite.	Median	4	4	4	4
	Average	3.81	3.73	3.65	3.69
	SD	0.85	0.86	1.06	0.74
2. The system seemed unfriendly.	Median	2	2	2	2
	Average	2.23	2.15	2.04	2.00
	SD	0.99	1.05	1.08	0.75
3. The system seemed professional.	Median	3	3	3	3
	Average	3.00	3.15	3.00	3.00
	SD	0.80	0.83	1.10	0.94
4. The system provided more information than I needed.	Median	3	3	2	3
	Average	2.85	2.62	2.42	2.69
	SD	0.83	1.02	0.99	1.09
5. The system provided the right amount of information.	Median	4	4	4	4
	Average	3.54	3.50	3.50	3.46
	SD	0.99	0.96	1.10	1.03
6. I would have preferred to get more details.	Median	3.5	3	3.5	3.5
	Average	3.58	3.27	3.46	3.38
	SD	0.95	1.12	1.24	1.17
7. I got the information I wanted.	Median	3	4	4	3
	Average	3.38	3.54	3.38	3.19
	SD	0.94	0.99	0.85	1.06
8. I always knew what the system wanted to tell me.	Median	4	4	4	4
	Average	4.19	4.23	4.12	4.04
	SD	0.75	0.82	0.99	0.82
9. The system provided imprecise information.	Median	2	1	2	2
	Average	2.12	1.96	2.42	2.00
	SD	0.86	1.09	1.30	1.02

Table 4.8: Results of the final questionnaires regarding the emoji facial expressions, graph of historical records, and ranking table.

Element	Statement	Average	SD	Median
Emoji	1. I knew my progress clearly from the face expression.	3.67	1.40	4
	2. I felt happy when I saw a happy face.	4.17	0.87	4
	3. A happy face encouraged me to walk.	3.33	0.87	3
	4. I felt upset when I saw a sad face.	3.50	1.02	4
	5. A sad face encouraged me to walk.	3.00	1.06	3
Graph of History Records	1. I was glad to see my daily amount of steps.	4.67	0.56	5
	2. Checking my daily amount of steps encouraged me to walk.	3.92	0.88	4
	3. I was glad to see the expected amount of steps.	4.25	1.03	5
	4. I felt like to walk more since I wanted to reach the expected amount of steps.	3.67	0.87	4
	5. I was glad to see the group average amount of steps.	4.46	0.98	5
	6. I felt like to walk more since I wanted to walk more than the group average amount of steps.	3.42	1.02	3
Ranking Table	1. I was glad to know my rank.	4.33	0.76	4.5
	2. I was glad to know the others' rank.	4.17	0.76	4
	3. I felt like to walk more since the others can see my rank.	3.46	1.06	3
	4. I felt like to walk more since I wanted to get a higher rank.	3.63	0.97	3

Impressions about the overall system

Using the weekly questionnaire, we obtained the participants' opinions about the overall Walkeeper system according to each communication style. The questionnaire contained statements that had to be rated on a five-point Likert scale (1=fully disagree, 5=fully agree). Table 4.7 shows the results of all weekly questionnaires. Even though the communication style of the explanation had changed, most of the participants considered the system to be friendly and to provide the appropriate amount of precise information that was easy to understand. Meanwhile, most of the participants disagreed with the statement that the system provided more information than needed when using the indirect and elaborate style.

The final questionnaire included one open-ended question that asked the participants whether the Walkeeper system helped them with their exercise. In total, 19 participants reported that the Walkeeper system was useful for their exercise, nine of whom answered that it was because the Walkeeper system could track their steps in real-time and show the distance to the daily goal directly, six appreciated that the Walkeeper system sent messages to them regularly so that they could remain aware of their exercise progress, and seven reported that competition (e.g., group performance, ranking table) encouraged them to walk more (some overlap was seen because some participants mentioned two or three aspects). By contrast, five participants reported that the Walkeeper system was not useful for their exercise. The main reason mentioned for this was that the Walkeeper system could only track and show the step count, not other types of exercise information.

Impressions about the explanations

The final questionnaire contained three questions about the participants' impressions of the explanations. The first question was whether they noticed any changes in the explanations. Eighteen participants reported "Yes" and six reported "No". The second question was an open-ended question about how the participants described the differences. Among the 18 participants who noticed changes in the explanations, nine reported that they noticed changes regarding whether exact numbers were shown, five reported that they noticed changes in the tone of the explanations, and four reported noticing both. The third question was an open-ended question on the aspects of the explanations that the participants found most important. The most frequently mentioned aspects were: (1) showing the exact number of steps, (2) using a soft tone for the explanations, (3) providing sufficient information, including the benefits of walking more, and (4) using an appropriate sentence length.

Impressions about the emoji facial expressions

In the final questionnaire, we asked the participants to rate five statements (based on a five-point Likert scale) regarding their opinions of the emoji facial expressions. The details and results are shown in Table 4.8. Most of the participants could understand their progress from the emoji; they felt happy when the emoji had a happy face and sad when the emoji had a sad face. However, neither the happy nor sad face encouraged the participants to walk more.

Impressions about the graph of historical records

The participants were also asked to answer six questions about their impressions of the graph of historical records (Table 4.8). Most of the participants reported that they were glad to see their daily step count, daily step goal, and group average. However, while the participants felt encouraged to walk more when seeing their daily step count and goal, the group average did not have the same effect.

Impressions about the ranking table

Finally, we asked the participants four questions about their impressions of the ranking table (Table 4.8). Most of the participants reported that they were glad to see their and the other users' rankings, but did not feel encouraged to walk more by these elements.

4.7 Discussion

In this chapter, we explored how the communication style of a supplemental explanation in a quantitative approach-based BCSS can affect users' behaviors and attitudes toward walking. The following section discusses the findings of our user study, including how Walkeeper helps people with their daily exercise and how the communication style affects their behavior, thereby contributing new knowledge for the design of quantitative approach-based BCSSs.

4.7.1 Effect of Walkeeper in Inducing Behavior Change

Despite the adverse weather during the rainy season in the study region, we obtained a positive SIR for each communication style, indicating that overall, the participants reacted positively to the Walkeeper system and walked more. One reason for this might be that Walkeeper regularly sends messages to users to remind them of their walking progress. The majority of apps currently available on the market tend to adopt a negative approach that rarely interacts with the user and only reports the user's status upon opening the app.

For example, the well-known fitness app Google Fit [10] sends notifications to users to inform them that they have achieved a certain exercise level. However, if the user constantly lacks exercise, Google Fit does not send any notifications to promote the user to exercise more, even though the user should care more about his/her health. In addition, numerous applications (e.g., Walkus [70]) only report the user's status at the end of the day, which is too late for the user to engage in exercise, even if he or she thinks that their exercise amount was insufficient. By contrast, Walkeeper actively sends messages to users before lunchtime and off-hours to remind them of their status. Hence, the users can understand their progress more clearly and have enough time to change their plans, thereby increasing the possibility of walking more.

The results of the final questionnaire support our conclusion. In total, 19 participants reported that the Walkeeper system was useful for their exercise. The reasons given were that the Walkeeper system can track the users' steps in real-time and show the distance to the daily goal directly and that it reminds them of their exercise progress regularly, which increases their awareness.

4.7.2 Impact of Communication Styles on Behavior Change

The result of the statistical analysis regarding the correlation between the number of steps and the communication style led us to the conclusion that the communication style of the explanations in the Walkeeper system influences the behavior of the user. Among the four communication styles, the indirect and elaborate styles had the highest SIR. This reflects two issues that were also emphasized by the users in the questionnaire. First, compared with the concise style, the elaborate style includes more details, such as the exact number of steps that have already been achieved at the current time and information about the benefits of being more active and playing more sports; this helps the users understand their progress more clearly and motivates them to achieve their goal. Second, the indirect style is usually perceived as being more friendly than the direct style because it uses a softer tone and does not concretely address (negative) information. If the Walkeeper system has to address an issue such as the user not being active enough, it is easier for the user to accept it if the system does not mention it directly. Considering these aspects when designing explanations of quantitative data for BCSSs could influence behavior change among users and encourage them to be more active. These results also confirm that different levels of elaborateness and indirectness can influence users' perceptions of the information provided [14] in inducing behavior change. Besides, the result of the SIR of "Best" style has shown the potential improvement on users' performance by applying the appropriate communication style in the system.

The results mentioned above have shown the impact of different levels of elaborateness and indirectness of contents and the potential improvement of applying appropriate communication style in the system. Based on these results, we believe that not only for walking but also for other types of exercise, we could collect users' performance and try to provide the most appropriate style of information for the user including the duration of exercise, the times of exercise, the strength of exercise, etc. to encourage them to start/keep doing the exercise.

4.8 Limitation

Through the development and evaluation of Walkeeper, we have obtained some positive results. However, we also found some limitations of our system. The first limitation we found is the timing of sending the message to users. Some participants reported that they were used to walk during late-night such as 9 pm or 10 pm but Walkeeper only sends messages at noon and afternoon which did not consider different exercise habits of people. Another limitation we found is about goal setting. Walkeeper sets a daily goal of steps based on participants' average step count and raises the goal when the participant reached the goal. However, two participants reported that they prefer to set goals by themselves. One participant said that he/she prefers a fixed goal such as 8000 or 10000 steps instead of a changing one. Besides, although we have obtained several positive results of the effect of Walkeeper on users' performance, longer-period experiments are needed to explore whether the Walkeeper can maintain the same outcome over a longer period of time and whether Walkeeper can induce attitude change.

4.9 Summary

To promote a healthier lifestyle, numerous technologies have been conducted by researchers and developers. However, while these technologies gain positive results in inducing behavior change, the majority of existing systems heavily rely on the quantitative representation approach which has been suggested that may lower users' motivation and fail to promote behavior change since it is difficult to understand the meaning behind the quantitative data. Therefore, an explanation of quantitative data needs to be provided as a supplement. However, different descriptions of the same data may lead to different outcomes. To enhance the effectiveness of the behavior change support system, it is necessary to investigate the impact of different communication styles of explanations in inducing behavior change.

To this end, we proposed a design of active and adaptive behavior change support system with the consideration of communication styles. Since physical inactivity is a major cause of chronic diseases and the systems developed for promoting users to walk more are the ones heavily relying on quantitative representation, we focused on physical activity and developed Walkeeper, a Web-based app that provides explanations of users' daily step counts using different levels of elaborateness and indirectness.

To evaluate Walkeeper, we conducted a 6-week user study with 24 participants. We prepared four patterns explanations for users who reached the goal and users who have not reached the goal (8 patterns in total) based on four different levels of elaborateness and indirectness. The results indicated that Walkeeper had a positive effect on increasing the users' daily step count. The results also revealed that the communication style of the explanations of the quantitative data affects the users' walking performance. The indirect and elaborate communication style led to the highest SIR, while the direct and elaborate and direct and concise communication styles led to the lowest SIRs. This might be explained by the fact that the elaborate style includes more details, which makes it easier for users to get a clear picture of their progress accompanied by an increased sense of achievement and motivation. The indirect style has a softer tone than the direct style and does not concretely address (negative) information, thereby making it easier to accept. Therefore, BCSSs that applies a quantitative approach should consider different communication styles when explaining quantitative data to users; this could lead to enhanced behavior change among users. This work is done by the collaboration between two research institutes, namely the Ubiquitous Computing Systems Lab at NAIST, Japan, and the Dialogue Systems Group at Ulm University, Germany.

5 Conclusion

5.1 Summary

In this dissertation, we presented the design of an active and adaptive behavior change support system, based on the Persuasive System Design (PSD) Model and Behavior Change Support System (BCSS) Theory. Although positive results have been gained by using BCSSs, the majority of the existing BCSSs still have two major issues: (1) tending to adopt a passive approach that rarely interacts with users and only report users' status upon opening the apps; (2) heavily relying on the quantitative representation approach, and even though these systems provide explanations for the quantitative data, they would face another issue that different communication styles of explanations for the same data may lead to different outcomes. Therefore, a BCSS that is more active and more adaptive is needed. To realize an active and adaptive BCSS, two challenges have been tackled in this dissertation:

(1) how to design an active BCSS?

(2) how to design an active and adaptive BCSS?

Since there was no such system before, we believe it is necessary to investigate the impact and feasibility of active BCSS in inducing behavior change first before realizing the active-and-adaptive approach.

For the first challenge, we presented an active BCSS design (Chapter 3) that focuses on the enclosed environment where people spend a long time during their daily routines so that our BCSS can send stimulation to users and promote behavior change continuously as long as people are staying in that environment. To evaluate the effectiveness of the design in inducing behavior change, we developed an interactive signage system that actively sends voice and text messages to the passing user to promote behavior change. We then conducted a 3-week experiment and an additional experiment with 15 participants to investigate the effect and feasibility of our proposed system. As the first step of promoting behavior change, we prepared 5 check tasks that cost the user a little bit of time and labor to investigate users' reactions to the simple tasks. We also consider pushing a button (including the rejection button) as a behavior change since there was no such system before. Through the result, we proved the usefulness of our interactive signage on promoting low time and labor cost behavior change (average response rate: 84.35% for the 3-week experiment and 79.01% for the additional experiment). Also, we showed the effectiveness of active interaction through sending voice and text messages in attracting users' attention and interest through the result of the questionnaire of the experiment. Besides, we investigated the effect of the fatigue factor by analyzing the relationship between the day passed and the response rate. We found that the number of ignorance of Personal Task and Check Task does not rise even as time passes, indicating that users' motivation did not decrease as we assumed while using the interactive signage system.

For the second challenge, in Chapter 4, we presented the design of an active and adaptive BCSS. This work is done by the collaboration between two research institutes, namely the Ubiquitous Computing Systems Lab at NAIST, Japan, and the Dialogue Systems Group at Ulm University, Germany. Since physical inactivity is one of the major causes of chronic diseases and the systems developed for promoting users to do more exercise are the ones heavily relying on quantitative representation, we focused on physical activity and developed a prototype, named Walkeeper, which is a Web-based app providing explanations of users' daily step counts using different levels of elaborateness and indirectness. We then conducted a 6-week user study with 24 participants. The results indicated that Walkeeper had a positive effect on increasing the users' daily step count. The results also revealed that the communication style of the explanations of the quantitative data affects the users' walking performance. The indirect and elaborate communication style led to the highest SIR (33%), while the direct and elaborate and direct and concise communication styles led to the lowest SIRs (5%). This might be explained by the fact that the elaborate style includes more details, which makes it easier for users to get a clear picture of their progress accompanied by an increased sense of achievement and motivation. The indirect style has a softer tone than the direct style and does not concretely address (negative) information, thereby making it easier to accept. Therefore, BCSSs that applies a quantitative approach should consider different communication styles when explaining quantitative data to users; this could lead to enhanced behavior change among users.

From the interaction approach aspect, the common BCSS available in the market tend to apply the passive approach that rarely interacts with users until they open the app. The problem with the passive approach is, for the users who constantly lack motivation or awareness of their self-condition, they may never open the apps so they will not be aware of their health conditions and the systems will miss the timing of inducing behavior change. By applying the active interaction approach, the system can support not only the people who have high motivation, but also the users with low motivation or self-awareness and try to lead them to a better lifestyle. Through the 4-week and 6-week experiment, we have proved the usefulness and feasibility of this approach in inducing behavior change.

From the representation approach aspect, the common BCSS tends to use quantitative data representation. But there are some pieces of evidence showing that this approach might harm users' motivation since they cannot understand the meaning behind the data. By providing the explanation of the data, users can understand the meaning of the data and be aware of their self-condition more clearly, so that they can change their behavior or attitude. In addition, we explored the impact of different levels of elaborateness and indirectness on users' behavior and obtained some positive results.

Finally, the contributions of this dissertation to academic knowledge are summarized with the following three aspects. First, as a scientific aspect, this is the first study that clarified the feasibility and appropriate overall design of the active and adaptive behavior change support system. Next, as a technical aspect, the active interaction function and adaptive expression with different levels of elaborateness and indirectness were implemented into an application to build a system that can be operated in practice. Finally, as a practical aspect, we conducted 4-week and 6-week experiments using that system to investigate our hypothesis and demonstrate the effectiveness of the system with 15 and 24 participants in total.

5.2 Future Work

Adjustment of the Timing of Sending Message

Walkeeper sends messages at noon (11:30 am) and afternoon (4:30 pm) so that users receive their walking progress before lunchtime and before leaving the office. In this way, users can decide whether to have an active lunch break or plan to walk more in the evening. However, through the experiment, some participants reported that they were used to walk during the late-night time such as 10 pm but Walkeeper did not consider different exercise habits of people. Therefore, we will consider the upgrade of the progress reminder function with the consideration of users' exercise habits. For example, estimating users' exercise time based on their step records collected then adjusting the timing of sending messages.

More Flexible Goal Setting

Walkeeper sets a daily goal of step for each participant based on their average step and raises the goal for the next day when the participant reached the goal during that day. However, two participants reported that they prefer to set goals by themselves. One participant said that he/she prefers a fixed goal such as 8000 or 10000 steps instead of a changing one. Besides, according to Jung *et al.* [72]'s work, compared withdrawing a goal achievement line, setting a flexible goal achievement zone that recognizes users have reached the goal as long as their performances have entered the zone can improve users' motivation. However, Walkeeper only recognized users' performances as reaching the goal when they were equal to or more than the daily goal of step set by the system. Therefore, in the future, we will consider adding a goal-setting function that allows users to set their daily step of goals by themselves and a flexible goal achievement zone to investigate whether it can improve users' motivation.

Exploring The Impact of Different Aspects of People

Since most of the participants of the two experiments were master and doctoral course students of NAIST who have similar age, education level, and rich experience in using electronic products. Therefore, we could not draw any conclusions about the impact of age, experience, and education level from the data of the two experiments. However, it is undeniable that these aspects may affect the outcome of our systems. For example, elder people may have different reactions to the active and adaptive BCSS or different preferences for communication styles compared to the younger generation as young people are more receptive to electronic products, and their understanding of information is faster than that of the elderly, so young people may be more inclined to concise contents while the elderly need more detailed and easy to understand content. Also, people who have rich experience of using electronic devices may understand the quantitative representation better than those who do not have much experience, which may also affect their understanding of the information and thereby influence the outcome of the system. Similarly, people with different education levels may have different understandings to the same contents and communication styles, which may lead to different performances. Meanwhile, it has been shown that patterns of language and culture are matter in Human-Computer Interaction and it is necessary to consider the cultural bias while designing a dialogue system [73, 74]. Miehle *et al.* [75] presented a study in which significant differences have been found between German and Japanese to different communication styles. However, in the study of Walkeeper, most of the participants were Japanese so we could not investigate the impact of different cultures. Thus, to investigate the impact of different aspects of people on their behavior and attitude, we will hold experiments with more participants from different cultural background, age, education level, experience, and so on.

Exploring the Effect of Other Adaptation

In this dissertation, we explored the impact of the contents with different levels of elaborateness and indirectness on users' walking performance and obtained positive results, which is a part of the expression adaptation. In addition to expression adaptation, there are also other categories of adaptation such as tone adaptation, content adaptation, etc. For example, if a user is not good at walking, the system could promote other exercises than walking. In the future, we will explore more about the effect of other adaptations.

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In 2000, when I was a primary school student, I read a book about Einstein. It said “Einstein, a great scientist.” That was the first time I knew the word “scientist.” My parents told me that if I want to become a scientist, I must first become a Ph.D. Since then, I have always dreamed of becoming a Ph.D. one day and then becoming a great scientist, even though I did not know that a scientist is not a specific profession, and being a Ph.D. does not mean that I can become Einstein. With the increase of age and knowledge, I gradually realized the cruelty of reality and forgot my childhood dreams as time passed. It was not until 2018, when I was about to go to work in the company after graduating with my master’s degree, that I remembered my past dreams. I realized that although I cannot be Einstein, I can still make some contributions to academics, even if it is just a little bit of work. I like to discuss research with my supervisors and colleagues, and I also like the moment I finish writing the paper, which makes me think maybe I am suitable for research. In order to fulfill my childhood dream, I chose to decline offers from companies and continue my doctoral study at NAIST. Now, I am writing an acknowledgment for my doctoral thesis, which means that my doctoral career is coming to an end. It was a long journey, during which I met many difficulties, but I got through them successfully with the help of my family, friends, and Professors.

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Publication List

Peer Review Journal Paper

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