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Master's Thesis
Academic Year 2022

Umbrella-based Novel Multimedia Platform Using Physiological Data as an Integrated Feedback Loop

Keio University
Graduate School of Media Design

Kanyu Chen

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Kanyu Chen

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Abstract of Master's Thesis of Academic Year 2022

Umbrella-based Novel Multimedia Platform Using Physiological Data as an Integrated Feedback Loop

Category: Science / Engineering

Summary

Recently, sensors have become more unobtrusive, eccentrically located, and less expensive. Together with the popularity of Internet of Things (IoT), wearable sensing brings more potential in affective computing and emotion regulation. In this thesis, we introduce a novel system (Affective Umbrella) to record and stream physiological data in real time. Moreover, we implemented biofeedback loop design in the system triggering color changes to reflect and influence emotional feelings. We reported the methodologies, processes, and results of data reliability and feedback design impacts.The statistical results proved the potential of applying biofeedback and color changing to regulate emotional arousal and dominance.

Keywords:

Human Computer Interaction, Affective Computing, Emotion Regulation, Physiological Sensing, Biofeedback

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Chapter 1
Introduction

1.1. Motivation

Emotions involve complex processes of changing in the domains of subjective experience, behavior, and physiology. Dealing with emotions is not always easy and emotions can be either helpful or harmful depending on the contexts [4]. Therefore, emotion regulation has raised people's attention to explore an effective communication between one's body, mind, and internal feelings [5]. Among all the factors, weather related to daily life living conditions could be one of the common reasons. Considering the contexts of exploring the emotions, people are also directly or indirectly affected by the weather, especially during the continuously rainy season from May to July every year in Japan. Regarding the related works about the connections between the weather and emotions, it is not hard to find that there has not been any empirical verification of the existence of different types of affective weather reactivity [6–8]. However, one related result shows the possibility of rainy preferences which suggests that some individuals are fairly resilient to the weather, while others are sensitive to it [8]. Therefore, this research would start from augment the interaction between one and the weather with the media of umbrellas to explore the possibilities of emotion regulations.

Umbrellas are one of the most ubiquitous accessories available to us for sunshade and rain protection. In Japan, where 120 to 130 million umbrellas are sold every year[1]. The motivation of Affective Umbrella is to explore ways of our emotional connection to nature. Affective Umbrella presents opportunities for a novel and unobtrusive means to gather physiological data. Umbrella redesign related research focuses on energy conversion [9–11], sound space [10,12], umbrella surface

1 http://www.jupa.gr.jp/pages/faq

as an Internet interactive screen [13–15] , etc. We are unaware of any umbrella redesign embedded with physiological sensors [16–18].

To help people become more aware of their internal states, biofeedback loop will be implemented to recognize and reflect their real time emotions. In order to apply the umbrella-based feedback loop system in natural, no-implicated contexts, we propose an in-the-wild study to access the feedback loop system and assess the relationship between the internal short-term emotion change with external stimulus events.

1.2. Contributions

The main contributions of this paper are:

- (1) We present a novel feedback loop system – Affective Umbrella, which can measure EDA (Electrodermal Activity) and BVP (Blood Volume Pulse) data from an umbrella handle and stream the visualization of biofeedback on the umbreblla cloth. This thesis summarizes the design and evaluation process to validate the sensing availability and feedback effect on emotional feelings.

- (2) We compared the signal collected from the umbrella handle and the wristband and contributed a dataset of 47 participants according to tests and experiments, which is available under the anonymized google drive link[2]. The analysis and comparison between the two types of signals proved the feasibility to use Affective Umbrella to collect EDA and BVP data in real time.

- (3) We tested the influence of Affective Umbrella's biofeedback design on people's experience emotional changes. The statistical results proved the potential of applying biofeedback and color changing to regulate emotional arousal and dominance.

2 https://drive.google.com/file/d/1CfrYq4YySX6ctSjNVFvawRrUWN0PRkN_/view

1.3. Structure of the Thesis

The thesis is consist of 8 Chapters in total. Following this Chapter, literature review about Emotions Theory, Psycho-physiology, and Biofeedback are presented in Chapter 2. Next in Chapter 3, the Concept and Hypothesis of the whole Feedback Loop Study are explained. Chapter 4 describes Data Collection Methods of a mixed measuring methodology including 3 stages of Implementation setup of Iterative Prototyping and Experiment Design of three studies. Chapter 5 demonstrates the results by analyzing the collected data from three stages of experiments accordingly and includes the discussions about Feasibility and Implications for Biofeedback Loop Design. Chapter 6 gives a conclusion of the whole study and Limitations in this research and possible Future Works are explored. The surveys used to measure the level of FoC (Feeling of Control) and relationship between the weather and emotions in the Feedback Loop Study, and results of interview transcripts in the Feedback Test are attached in the Appendix as well.

Chapter 2
Literature Review

2.1. Background of Emotions Theory

In this section we will cover some emotions definitions and concepts in the field of psychology and physiology.

2.1.1 Modeling the Emotions

Emotion essentially is a series of events, with effective stimuli events triggering the senses, dynamic changing of the level of cognitive load and physiological arousal, then reacting as the behaviors. It's a challenging direction of research because people have individual differences of biofeedback in their emotional responses. But one important direction is to chart the immediate and longer-term consequences of different forms of emotion representation and changes in the context of different emotional states.

Emotion usually involves a complex process thus is too ambiguous to measure and communicate. Therefore, model-making is useful to understand and quantify emotions [1]. There are several model of emotions that are widely accepted and validated. Mehrabian and Russel developed the PAD (Pleasure, Arousal, and Dominance) emotional state model to represent all emotions. the PAD model uses three dimensional scales: Pleasure/Valence, Arousal and Dominance [19]. PAD is also used by Lang and colleagues to develop a non-verbal pictorial self-assessment also known as SAM [20]. In my research, I adopted the PAD model and SAM to measure participants' emotional states during both of the online survey and experiments. Especially, the Circumplex Model developed by Russell et al. which is based on the PA part of PAD has been utilized as my main evaluation to represent arousal and valence dimensions [21]. In order to enhance the happiness

of people, there are two major directions: minimize the overwhelming negative emotions and increase the positive emotions.

2.1.2 Emotions and Weather

Emotions can be either helpful or harmful, depending on the context [2]. It's a challenging direction of research because people have individual differences of biofeedback in their emotional responses. But one important direction is to chart the immediate and longer-term consequences of different forms of emotion representation and changes in the context of different emotional states [4].

Considering the context using the umbrella-based system, we explores the research related to the relationship between the emotions and the weather. The case for a link between the two begins to emerge in the late '70s and early '80s. A 1984 study [6] that looked at a variety of mood variables (from anxiety and depression to optimism and aggression) in the context of several weather variables showed that the amount of sunlight, temperature, and humidity had the greatest impact on mood. A 2005 study [7] found that spending more time outdoors in pleasant weather is associated with higher mood and better memory.

But there is also evidence to suggest otherwise. A 2008 study [22] found that weather had essentially no effect on positive mood. Explained another way, more sunlight and better temperatures didn't make a happy person happier. However, the affective impact was very minor between some components (sunlight, wind and temperature) and negative moods (like tiredness). Besides, it's worth noting that while the aforementioned 2005 study did show a link between spending time outdoors in pleasant weather and improving mood, the effects were not always significant. In fact, the effect was very mild.

Therefore, through conducting further research at the physiological and psychological level of emotions, umbrella-based system can be potentially taken as a form factor to explore the relationship between the weather and the emotions.

2.2. Psycho-physiology

Psychophysiology is a field focuses on the interrelationships between mind and body. An important characteristic of psychophysiology is that it's top-down ap-

Table 2.1 Responses when two branches of ANS (PSNS and SNS) activate.

Category	**PSNS Branch**	**SNS Branch**
Emotional Reaction	Arousal level decreases	Arousal level increases
Activated Responses	Rest and digest	Fight or flight
Cardiovascular System (BVP)	HR decreases pNN50 increases	HR increases
Sweat Glands (EDA)	Less sweat More smooth EDA	More sweat More EDA peaks

proach to the study of organismic-environmental transactions, complimentary to the bottom-up approach of psycho-biology.

Although the field of psychophysiology utilises a vast lineup of measurement tools, this work only focuses on the ones suitable for daily use in small form-factor. Thus, the measurement tools have to be reasonably small, easy to use and be safe even if misused. With this in mind we will not discus complex lab equipment used for e.g. neuron-imaging (MRI, PET) as well as any other tools requiring highly trained medical personnel to be used.

Emotions that humans experience while interacting with their environment are associated with varying degrees of physiological arousal where ANS plays a crucial role [23, 24]. ANS is mediated by two branches: 1) the sympathetic nervous system (SNS), and 2) the parasympathetic nervous system (PSNS) [25]. Parasympathetic nerves can exert their effect more rapidly (<1s) compared to sympathetic nerves (<5s) and mediate sudden large changes in HR [26–28]. Emotional states associated with ANS responses can be inferred using physiological data like Electrocardiography (ECG), Electroencephalography (EEG), EDA, and BVP [29,30]. In our study, we used BVP and EDA, which are described below.

2.2.1 Electrodermal Activity (EDA)

Electrodermal Activity (EDA), also referred to as Skin Conductance (SC) or galvanic skin response (GSR), refers to the change of the electrical conductance properties of the skin in response to the change of the sweat secretion rates by

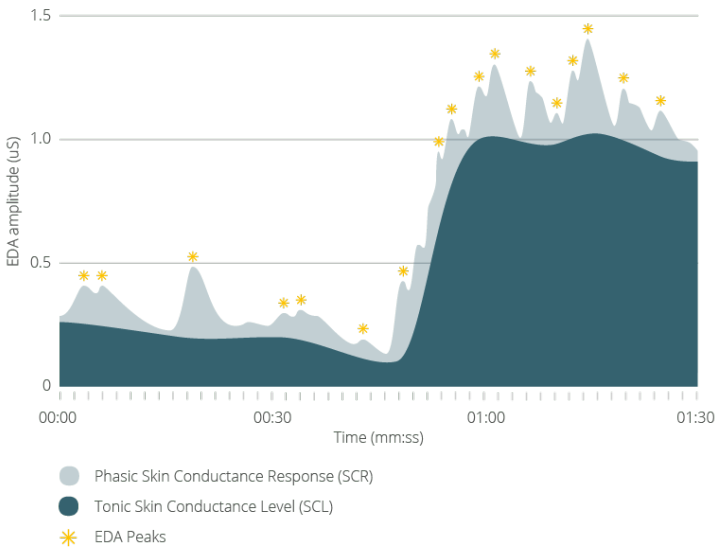

Figure 2.1 Electrodermal Activity (EDA)-example-graph

sweat glands [31,32]. EDA measurements mostly concentrate on two parameters: Skin Conductance Response (SCR) - quick changes (on the scale of seconds) in response to emotional or stress stimuli; and Skin Conductance Level - slow changes (within minutes and hours) commonly associated with the general condition of the subject (fig2.1[1]).

A very common knowledge application scenario, in addition to the massive body of research in laboratory related to skin conductance and emotions, is that the modern polygraph systems (also known as lie detectors) rely on it to assess the unconscious emotional response and its effect on the physiological readings, as a reaction to the investigator's questions.

ElectroDermal Activity (EDA) tracking has a very long history in psychological research [33]. One of the first mentions of EDA usage for psychophysiological research was Carl Jung's book "Studies in Word Association" published in 1906 [34]. Nowadays it remains one of the very widespread tools in psychology and psychotherapy for measurement of autonomic nervous system responses [33, 35].

1 https://imotions.com/blog/skin-conductance-response/

In recent decades, Skin Conductance (SC) is one of the most sensitive markers and frequently used to assess emotional arousal, as the skin conductance response activity increases as the emotional arousal grows. [31, 36–38].

2.2.2 Heart Rate Variability (HRV)

HRV describes the changes in time intervals between each consecutive pair of heartbeats [39] (fig2.2)[2]. HRV is based on the analysis of the patterns in the Inter-Beat Intervals (IBI), also referred to as the RR-interval. The earliest references to Heart rate variability (HRV) go back to 1733, when the Rev. Stephen Hales noted that respiration effects the heart contractions and blood pulsation. Carl Ludwig was the first to ever record and define the respiratory sinus arrhythmia (RSA) in 1847. RSA characterizes the increase in heart rate during inhalation and its decrease during exhalation [40].

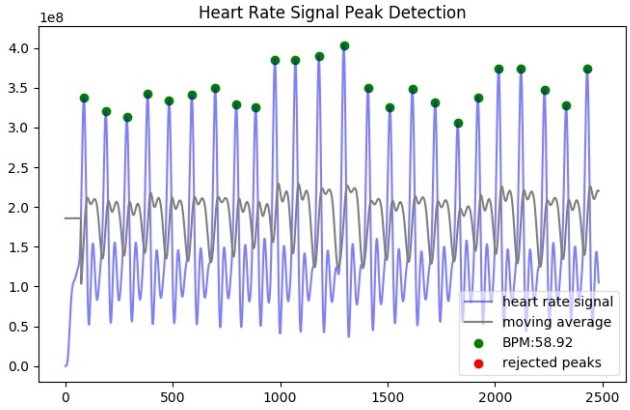

Figure 2.2 Heart rate signal peak detection graph

Heart rate variability (HRV) has been used to approximate vagus nerve outflow. It represents the beat-to-beat variation in the duration of the R–R interval (heart period), reflecting complex interactions between parasympathetic, sympathetic, mechanical and other factors on the pacemaker located at the sinoatrial node of

2 https://python-heart-rate-analysis-toolkit.readthedocs.io/en/latest/quickstart.html

the heart [40].

HRV is often used to evaluate the activity of the autonomic nervous system, namely two of it branches, the sympathetic (SNS) and parasympathetic nervous systems (PSNS). Simply put, it demonstrates how the neural structures of the prefrontal cortex regulate the activity in limbic structures which modulate the balance between PSNS and SNS by inhibiting the PSNS and activating SNS neural circuitry. Since the prefrontal cortex activity is tightly linked with cognitive and psychological processes, it is possible to see the reflections of cognitive and emotional states of a subject in its HRV. When the value of these HRV features go up it indicates the participant is getting more relaxed. In contrast, when they go down, the participant is getting less relaxed and more tense, as it signifies the activation of sympathetic nervous system moderating the fight-or-flight response [41]. Below are several standard HRV measures with their measurement units and respective descriptions. Standard metrics rely only on normal to normal beat intervals, meaning that abnormal heart beats caused by arrhythmia or other diseases or artifacts in the recordings are not counted.

2.3. Biofeedback

Biofeedback is a concept that express the idea of externalizing physiological signals [42]. Physiological signal such as electroencephalography (EEG) [43, 44], galvanic skin response (GSR) [45], and heart rate (HR) [46, 47] can be applied to biofeedback design to reflect emotional situations. What I'm trying to improve from previous work is to bring more routinely available biofeedback visualization methods using ubiquitous form factors rather than clinical devices in the lab.

Colors effect as an important element to reflect emotions were applied in my design [3]: Blue, etc were the most pleasant, with red being rated at an intermediate value of pleasantness. In comparison, far weaker results were obtained relating hue to arousal or to dominance. The most arousing hue was green-yellow, followed by blue- green and green, whereas the least arousing hues were purple-blue, etc.

Chapter 3
Concept and Hypothesis

3.1. Concept of the Feedback Loop System

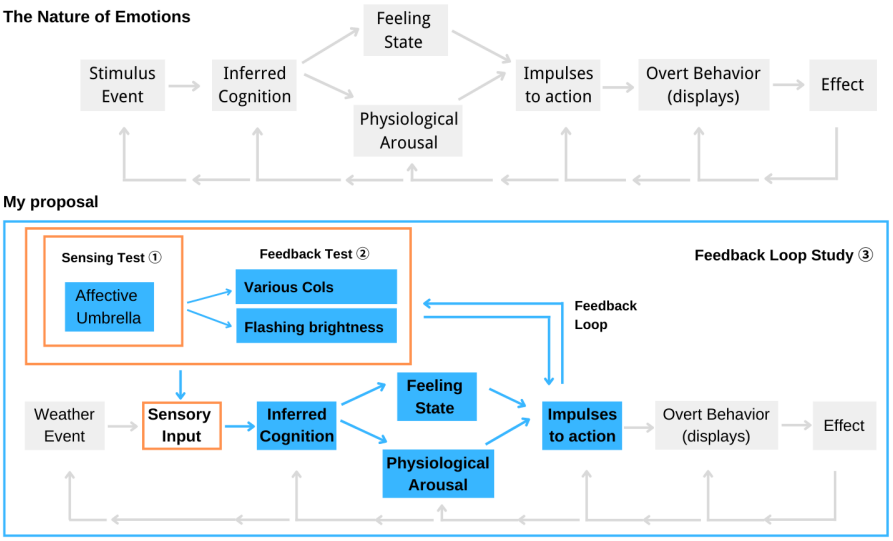

Figure 3.1 Umbrella-based feedback loop in my proposal shows how sensory information is evaluated and translated into action based on the theory of the nature of emotion [1]

3.1.1 Emotion Definition in Feedback Loop

Emotions are an essential part of who we are and how we survive [1]. The process of emotion (fig3.1) is a complex chain of loosely connected events, triggering from the stimulus, dynamic changes on the level of cognitive load and physiological

arousal, then reacting as the specific, goal-directed behaviors [1].

Considering the affective feedback loop framework, regarding the hierarchical conception of affect (fig3.2), emotions refer to more specific negative and positive affective states, whereas stress responses typically refer to negative (but otherwise unspecified) affective states occasioned by an inability to manage situational demands [48] and moods often last longer than emotions and seem to bias cognition more than—or at least as much as— they bias behavior [49, 50]. Besides, several studies provided evidence that three independent and bipolar dimensions, pleasure-displeasure, degree of arousal, and dominance-submissiveness, are necessary and sufficient to adequately define emotional states [51].

Therefore, we define the term 'emotion' in this study as short-term emotions rather than long-term status moods, with three dimensions based on Russell Circumplex Model [51]: valence, arousal, and dominance. That is, the emotions in our feedback loop design refer to the short-term fluctuating changes in the emotional state under external influences.

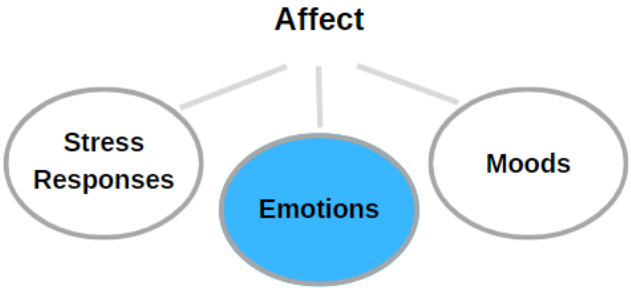

Figure 3.2 A hierarchical conception of affect: Affect and relate terms [2]

3.1.2 Proposal

The system that we are going to build is trying to improve an individual's Feeling of Control (FoC) so as to help us get more self-awareness and control our emotions under the external influences based on the feedback loop using physiological sensing and the visualization of the biofeedback. The system also helps to assess the relationship between the internal short-term emotion change with external stimulus events in laboratory (3.2,3.3) studies and to explore the relationship between

the visualization of biofeedback with FoC in in-the-wild (3.4) study.

3.1.3 Context Design

In order to apply our affective feedback loop system, there are two main types research settings: laboratory environments (3.2, 3.3) or real life environments (3.4). In the laboratory environments, it has more control of internal validity whereas In-the-wild Study has higher external validity in real life environments. Internal validity means to which degree a causal relationship between variables can be confidently inferred. External validity means to which extent the findings can be generalized in the real-world environment.

3.1.4 Bottom-up Implementation

Considering the different contexts design, we proposed an umbrella-based novel multimedia platform using physiological data as an integrated feedback loop.

In order to verify the rationality and effectiveness of the feedback loop system, we conducted three stages of tests and experiments accordingly during my master project(fig3.1): Sensing Test(4.2), Feedback Test(4.3), in-the-wild Study (4.4).

3.2. Sensing Test

3.2.1 Concept

Umbrellas are one of the most ubiquitous accessories available to us. The motivation of Affective Umbrella is to explore ways of our emotional connection to contexts. Affective Umbrella presents opportunities for a novel and unobtrusive means to gather physiological data. Umbrella redesign related research focuses on energy conversion [9–11], sound space [10, 12], umbrella surface as an Internet interactive screen [13–15] , etc. We are unaware of any umbrella redesign embedded with physiological sensors [16–18].

3.2.2 Research Question

The research question for the first study is whether we are able to derive meaningful data from the umbrella handle in both stationary and dynamic contexts compared with a more conventional finger sensor placement in the lab, to understand the potential value of Umbrella-based feedback loop system as the ubiquitous multimedia platform.

3.2.3 Hypothesis

Umbrella handle can collect meaningful data in a dynamic environment compared with a more conventional finger sensor placement in the lab.

3.3. Feedback Test

3.3.1 Concept

What kind of feedback design of expressive bio-signals is supposed to easy to notice, reflect or influence our emotion so as to dynamically form a feedback loop is important in the phase of Feedback Test.

In the previous works, research results show that the visualization most preferred by participants was the Light compared to other visualizations (Graph, Sliders, Swirl, Colors, Emoji) [52]. Besides, Moodlight, as an interactive ambient lighting system related to an individual's current level of arousal, provides greater understanding of the ways in which the representations of personal informatics, with a focus on ambient feedback, influence our perceptions of ourselves [53].

Therefore, in order to to measure the valence and arousal level of different color of lights as the visualization feedback of umbrella in the lab environment, we presented our second step to explore the color of light effects on emotions in the umbrella context, in which black, blue and red colors were selected in the experiment which aims at increasing the level of valence, decreasing the level of arousal based on the general study [3].

3.3.2 Research Question

To explore different effects of the visualization on the psy-physiological level, we present two conditions in the experiment: the umbrella with the red or blue color of lights. The research question for the second study is whether the presence of emotion status information is able to change subject's emotional perception in both conditions, and how the feedback of the visualization can be measured and mapping with related bio-patterns.

Besides, we present various interactive ways using Affective Umbrella.

3.3.3 Hypothesis

Blue color of light can represent lower arousal status whereas red color of light can represent higher arousal status of emotions.

3.4. Feedback Loop Study

3.4.1 Concept

In Japan, umbrellas are ubiquitous accessories for sunshade and rain protection. People are also directly or indirectly affected by the weather, especially during the continuously rainy season from May to July every year. Regarding the related works about the connections between the weather and emotions, it is not hard to find that there has not been any empirical verification of the existence of different types of affective weather reactivity [6–8]. However, one related result shows the possibility of rainy preferences which suggests that some individuals are fairly resilient to the weather, while others are sensitive to it [8].

In order to apply the umbrella-based feedback loop system in natural, no-implicated contexts, we propose an in-the-wild study to access the feedback loop system and assess the relationship between the internal short-term emotion change with external stimulus events.

3.4.2 Research Questions

- RQ1 How is the relationship between the weather and emotion? Can it provides a natural environment as stimulus event for testing the feedback loop system in In-the-wild study?
- RQ2 How does feedback loop system affect the short-term change of emotion in a natural environment?
- RQ3 To which degree does the visualization (color and brightness) of biofeedback effects affect the short-term change of emotion?
- RQ4 Can umbrella-based system improve the Feeling of Control (FoC)? what are possible reasons of individual differences over emotions in the natural contexts?

3.4.3 Hypothesis

Contexts related

- H1 Different weather types can provide a natural environment as either positive or negative stimulus events of emotions.

Feedback loop related

- H2 Participants would show higher score in terms of three emotional dimensions (valence/arousal/dominance) when they are experiencing biofeedback loop than without it.

Feeling of Control (FoC) related

- H3 Participants with higher internal score of Locus of Control (LoC) experience more emotional arousal.
- H4 Participants with different LoC level would experience different feelings of control (FoC) over three feedback of visualization conditions.

Chapter 4
Implementation and Experiment

4.1. Data Collection Methods Overview

Regarding the collection of data, we concludes a mix of measurement methods in three stages of studies (Sensing Test4.2, Feedback Test4.3, Feedback Loop Study4.4), divided into two categories: quantitative and qualitative. Quantitative Methods of data collection includes experiments, physiological sensing from iterative prototyping, statistic surveys; Qualitative methods includes Observation, Interviews and debriefing of drawing. Three stages of data collection were organized around the Feedback Loop Study (fig4.1).

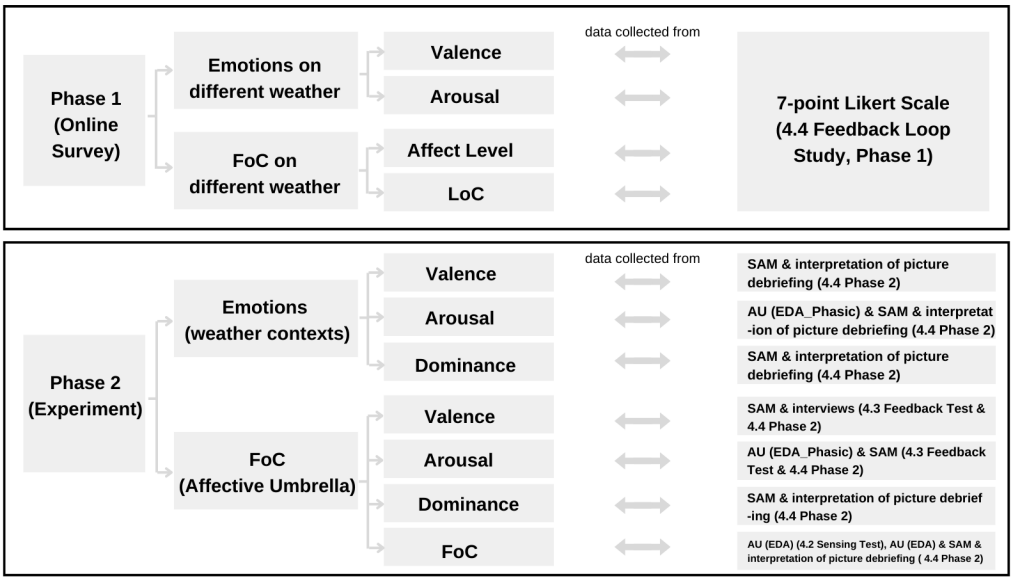

Figure 4.1 Overview of data collection of Feedback Loop Study 4.4

4.1.1 Inclusion and Exclusion Criteria

In all phases of this research, we use non-invasive umbrella-based sensing device and general surveys to collect emotions related self-report and physiological data. Considering the visualization of color of lights in the feedback loop system, we excludes the participants with visual impairment. Besides, we concern properties of the target population including factors such as the subject's age, sex, nationality, resident areas for the Feedback Loop Study .

4.2. Sensing Test

First, in the Sensing Test, we recorded EDA (4.54 Hz) and BVP (50 Hz) data alongside the SAM Scale (Self-assessment Manikin Scale) to different contexts by the audio effects (rain sound and jump-scare effects) and movement states (stationary or walking around) in the experiment (fig4.2).

The Sensing Test has been publish as the poster paper on MUM2021 Conference, the 20th International Conference on Mobile and Ubiquitous Multimedia [54].

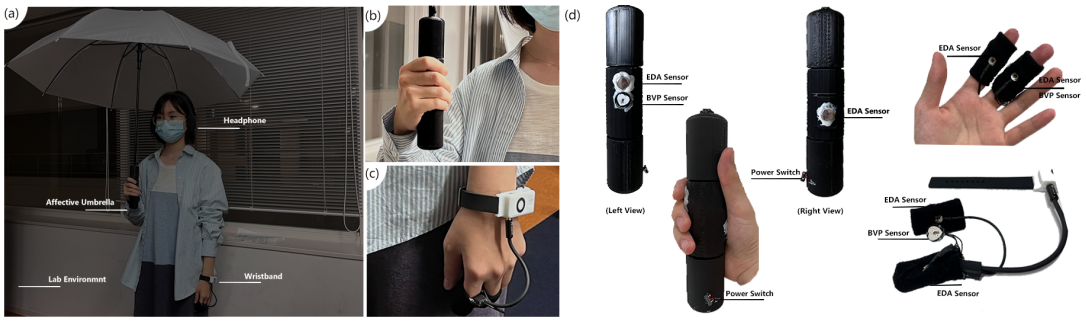

Figure 4.2 Affective Umbrella: to accompany and understand us more deeply. (a) Overview of the experimental environment and devices used (b) the dominant hand holding the umbrella during the experiment (c) Wearing a wristband with the other hand for a baseline recording (d) Comparison of the sensor((blood volume pulse) BVP and (electrodermal activity) EDA sensors) placement design of the umbrella handle with the fingers.

4.2.1 Umbrella Prototyping V1.0

Taking into account the product design that conforms to usage habits, it is also conducive to improving the stability of data collection. We consider of the handle material, weight, and appearance. The prototyping of Affective Umbrella (fig4.3): (a) Sensor placement design -(b) Modeling-(c) Printing-(d,e) Soldering circuit board-(f) Assembling the umbrella (fig4.4). The material is made of Polylactic Acid(PLA), a light, hard, and environmentally friendly polymer, which will not bring more burden to users.The handle uses the same (blood volume pulse) BVP and (electrodermal activity) EDA sensors as the wristband used in similar research [55–58]. Placement of the EDA electrodes was chosen to be in line with our habits of holding umbrella, EDA sensors are placed diagonally on the umbrella handle, matching the position of the palm: under the thumb, and under the pad of the index finger; the BVP plethysmograph is located under the middle finger. To check the rationality of sensor placement and the viability of data collection, we conducted the following experiment (4.2.3).

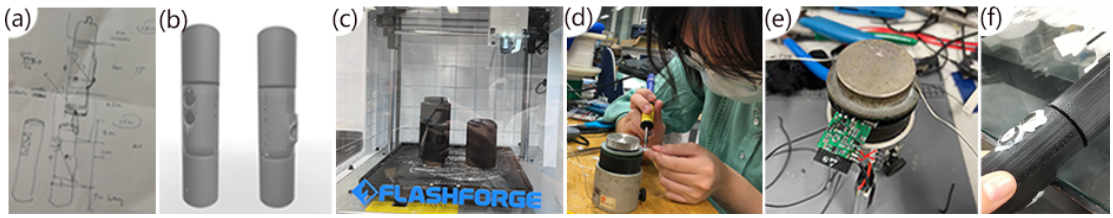

Figure 4.3 Affective umbrella setup: (a) Original sketch (b) Model and render effect (c) Fabrication in a 3D printer (d,e) Circuit board soldering (f) Using hot melt glue to assemble the umbrella handle

4.2.2 Materials

This section descibes the materials used as emotion stimulus, emotion measurement methods in the experiment of the Sensing Test.

Audio Effects

The audio effects[1][2] was used based on the related database on affective sounds [59].

Self-Assessment Manikin Scale

This system for nonverbal pictorial assessment, devised by Lang (1980) (also seen in Bradley Lang, 1994 [60]) to measure emotional ratings in the three dimensions of valence, arousal, and dominance, was used (fig4.8).

Physiological Sensing

Both the umbrella and wristband device used the same analog front-end PCB circuitry, with a wheatstone bridge connected to a differential ADC that communicates to an ESP32 chip over I2C. The resulting data is streamed wirelessly to a nearby computer running in-house software as a data receptacle.

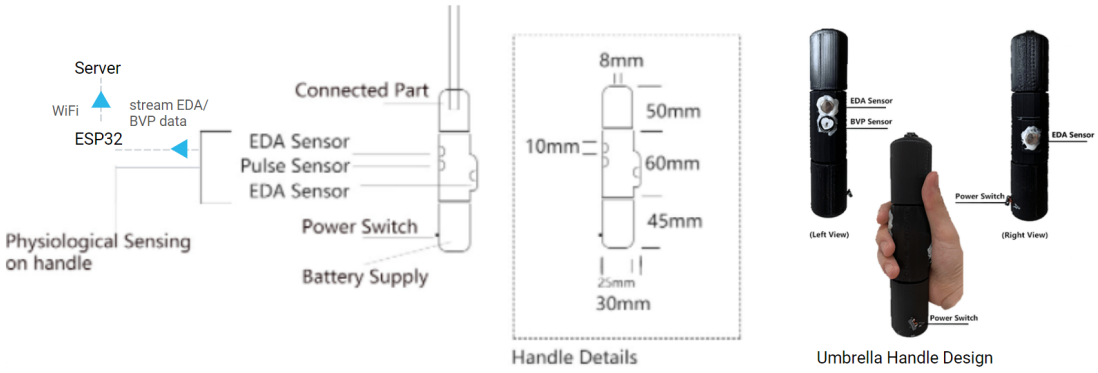

Figure 4.4 Overview of Umbrella Handle System

1 Jump-scared audio effects link: https://www.youtube.com/watch?v=ZWI2hMO6LNM

2 Rain sounds link: https://www.youtube.com/watch?v=ZWI2hMO6LNM

4.2.3 Experiment

Participants

8 participants aged from 23 to 32 years old (mean: 27.125, SD: 2.666, female:4, male:4) were recruited for this study. Every participant received a 1000 JPY gift-card as a compensation for their time, since the whole experiment takes each participant around 45 minutes.

Procedure

The experiment included two 7-minute sessions (Table4.1), before and after each resting and experimental period, participants were asked to fill out the SAM (Self Assessment Manikin) questionnaire, finally received an 8-minutes interview. During the experiment, participants were required to hold the affective umbrella with their dominant hand and wear the wristband on the other hand (Fig4.2), being exposed to audio stimuli listed to over wireless blue-tooth headphones.

Table 4.1 The experimental procedure in the Sensing Test

Baseline+Rating	First session+Rating	Second session+Rating
3min+30s	3min(quiet)+30s+3min(audio)+30s	3min(quiet)+30s+3min(audio)+30s

4.3. Feedback Test

Next, we recorded EDA (4.54 Hz) and BVP (50 Hz) data alongside the SAM Scale to different contexts with different color of lights conditions. In addition to the experiments, we also conduct a short 5min interview in the end.

4.3.1 Iterative Umbrella Prototyping V2.0

Pilot study

Before moving into the next phase of Feedback Test, I have conducted a pilot study using TouchDesigner and wristband in MDR1.

(1) Pilot Study1: initial data collecting progress in the period of MDR1 phase.
(2) Pilot Study2 shows the arousal and valence level of red and blue color.
(3) The showcase was demonstrated at plenary 2021 Fall meeting, initially collected users' expected interaction ways to the rains.

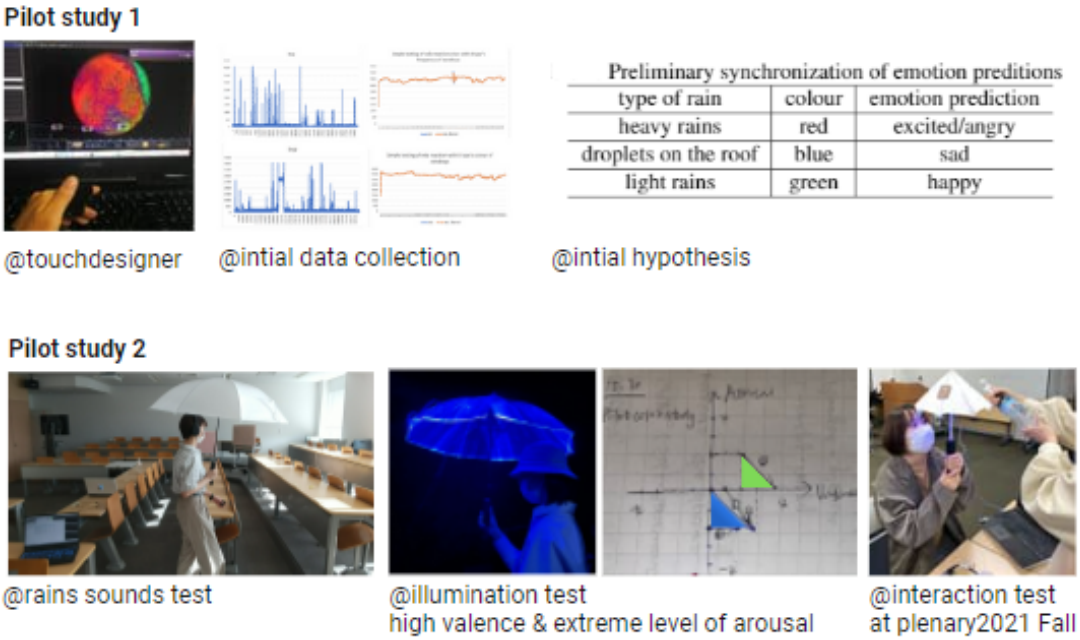

Figure 4.5 Pilot Study Overview

Based on initially successful data acquisition from biometric sensors on the umbrella handle in the Sensing Test, in order to measure the valence and arousal level of different color of lights as the visualization feedback of umbrella in the lab environment, we also conducted the experimental Feedback Test using the iterative Affective Umbrella in MDR2. Besides, we have developed some umbrella models to develop possible affective ways of interactive feedback (fig4.5).

Umbrella Prototyping V2.0

(1) Design Overview (fig4.6)includes three views of umbrella structure, sensors and visualization of the fabric using in the prototype. (2) The iteration of prototyp-

ing is from mini paper-folding model, waterproof fabric model to real assembled umbrella using optic fiber cloths connected LEDs.

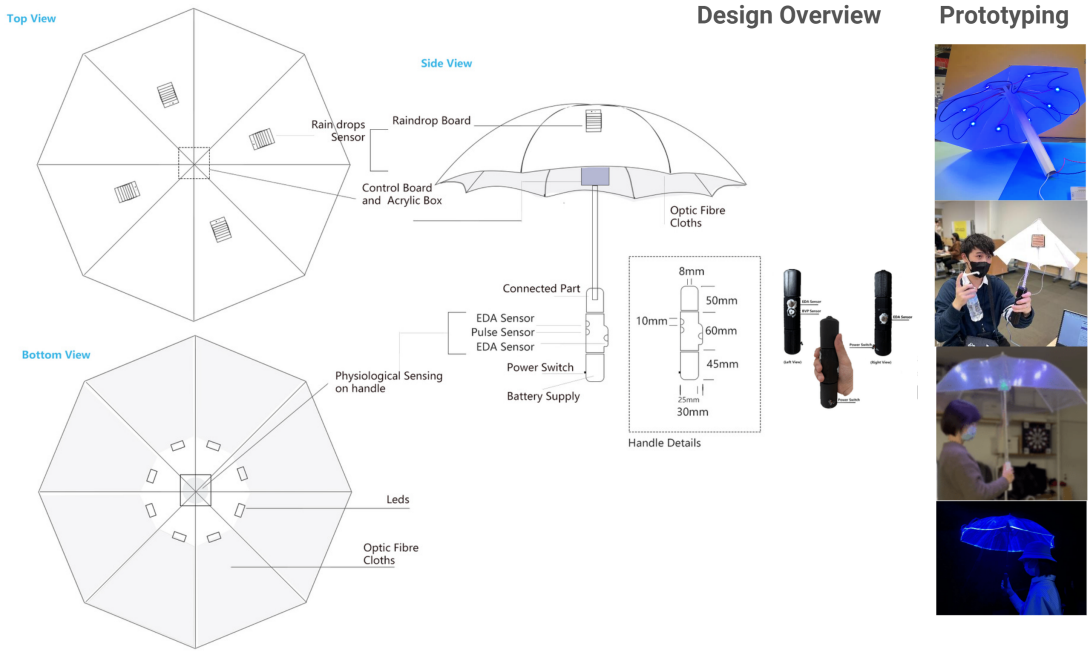

Figure 4.6 Umbrella Prototyping V2.0

4.3.2 Materials

This section describes the materials used as emotion stimulus, emotion measurement and assessment tools.

Physiological Sensing

The V2.0 Umbrella Prototyping has been utilized in the experiment of Feedback Test (fig4.6).

Conditions of color of Lights

Both blue and red color of lights were selected in the experiment which aims at increasing the level of valence, decreasing the level of arousal based on the general

study [3].

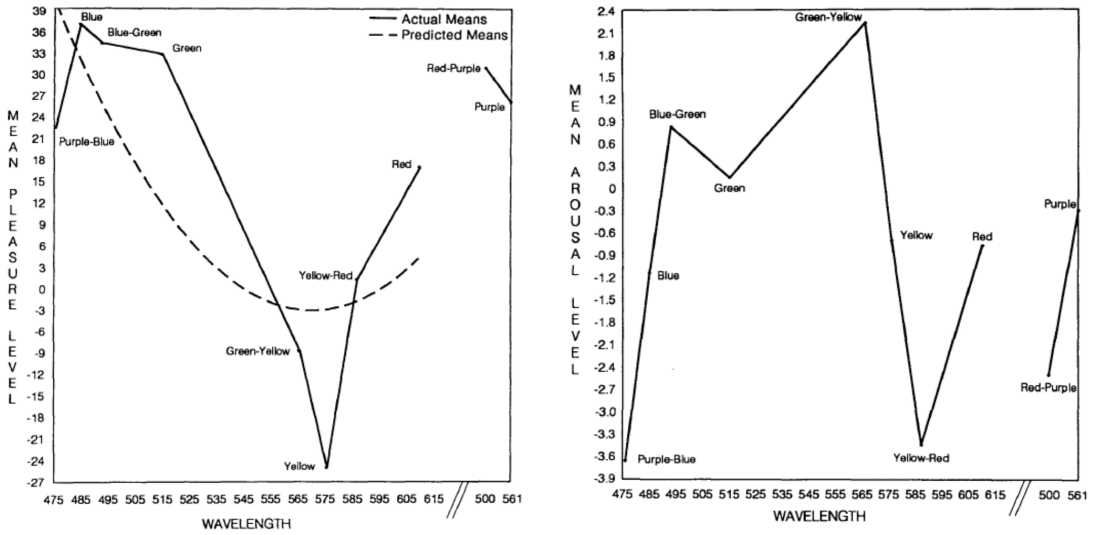

Figure 4.7 Colors Effects on Emotions [3]: Blue, etc were the most pleasant, with red being rated at an intermediate value of pleasantness. In comparison, far weaker results were obtained relating hue to arousal or to dominance. The most arousing hue was green-yellow, followed by blue- green and green, whereas the least arousing hues were purple-blue, etc.

Table 4.2 The experimental procedure in the Feedback Test

Break	no-viz session+Rating	Break	Blue session+Rating	Break	Red session+Rating
3min	30s+3min+30s	3min	30s+3min+30s	3min	30s+3min+30s

Self-Assessment Manikin Scale

Same as in the 4.2.2section (fig4.8).

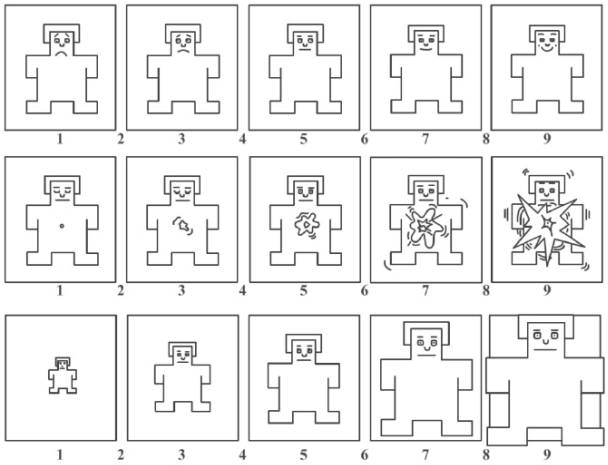

Figure 4.8 The Self-Assessment Manikin (SAM). SAM scale used in the experiment to capture participants' emotional reactions on three dimensions: (from the top row to the bottom row) the manikin representations to express values of Valence (top), Arousal (mid), and Dominance (bottom).

4.3.3 Experiment

Participants

18 participants aged from 21 to 38 years old (mean: 26.8, SD: 3.258, female:9, male:9) were recruited for this study. Every participant received a 1000 JPY gift-card as a compensation for their time, since the whole experiemnt takes each participant around 30 minutes.

Procedure

The structure of the study was the following:

1. Written informed consent form following the ethical guideline.

2. The experiment procedure has three main sessions using Lattin-square to avoid section order effect during the experimental procedure, 6 min per session: no-viz session, blue session and red session (Table4.2).

3. The participant needs to hold the handle with the dominant hand exposed by the stimuli of color of light. Before and after each session, they were required

to do the rating on the SAM Scale for 30s.

The total duration of the test with each participant was around 30 minutes. In the end, the experimenter would take a 5min interview with the participant.

4.4. Feedback Loop Study

Last, we collected the data about the relationship between the weather and emotions through online survey to provide supportive references for the In-the-wild Study. Before the final experiment in the wild, we collected the participants' scores of PERS (Perth Emotional Reactivity Scale) and Locus of Control (LoC) Scale as the baseline of emotions reactivity and internal scores of LoC. During the experiment, we recorded EDA and BVP data (sample-rate of both data: 100Hz) alongside the SAM Scale and Likert-scale regarding the measurement of emotions and Feeling of Control (FoC). In addition to the surveys, we collected the qualitative data of participants' debriefing of drawing with interpretations.

Phase 1: Online Survey about Weather Reactivity

In order to collect the data on people's emotions about general weather reactivity (the four main types:sunny, rainy, cloudy, snowy), compared the emotions to rains with other weather conditions, and know whether rain could be a rich stimulus for the in-the-wild study. Besides, to generally collect people's responses about the relationship between the weather and emotions, and initially figure out the potential reasons behind it. (resident area, age, gender, habit, outdoor activities, locus of control, etc.)

Phase 2: Feedback Loop Study In-the-wild

In order to apply the umbrella-based feedback loop system in natural, no-implicated contexts, we propose an in-the-wild study to access the feedback loop system and assess the relationship between the internal short-term emotion change with external stimulus events

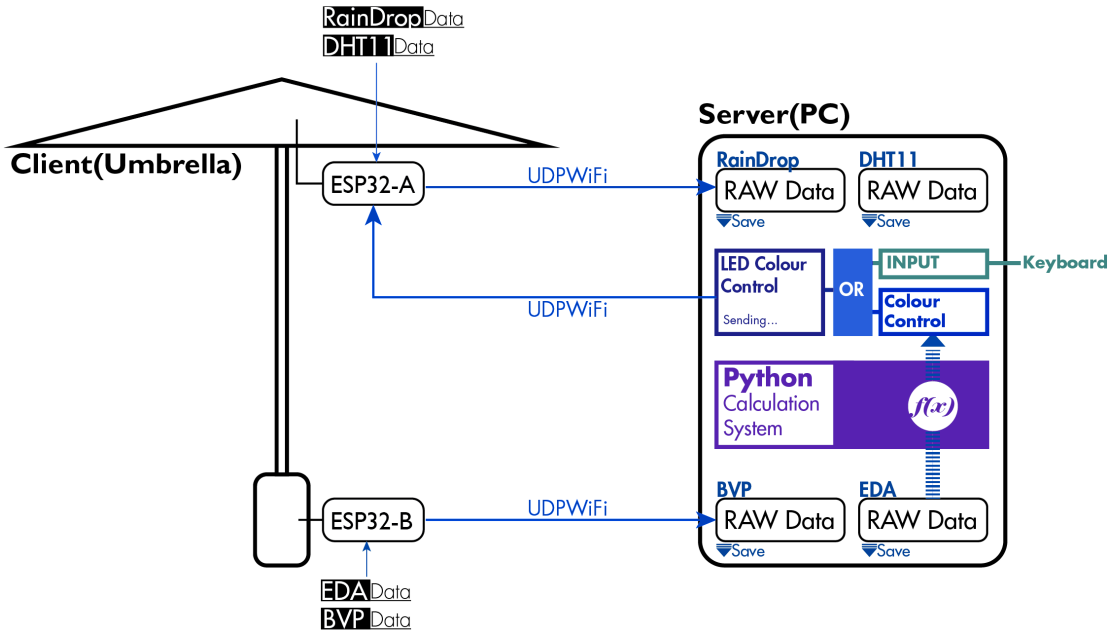

Figure 4.9 Data in Communication System of Umbrella-based Feedback Loop

4.4.1 Final Prototype

By applying the Client-Server Model, the final prototype functions as a storage and streaming system for data communication. Through UDPWiFi, the client of umbrella, collecting the weather related data collected from raindrop sensor and dht sensor on the ESP32-A and physiological data from GSR (galvanic skin response) sensor and BVP (Blood Volume Pulse) sensor on the ESP32-B, can send message packets to the server of the pc. The umbrella consists of two pieces of M5Stick CPlus Board (ESP32-A, ESP32-B) to receive weather related data (temperature, humidity, rainfall data) and physiological data (EDA and BVP data) accordingly. The pc as the server can record the raw data saving as csv file and real-time stream the feature from the raw EDA data. The real-time calculation can send back the message to control the digital input of LED on the ESP32-A so as to control the colour of light on the optic fiber cloths connected LEDs.

4.4.2 Materials

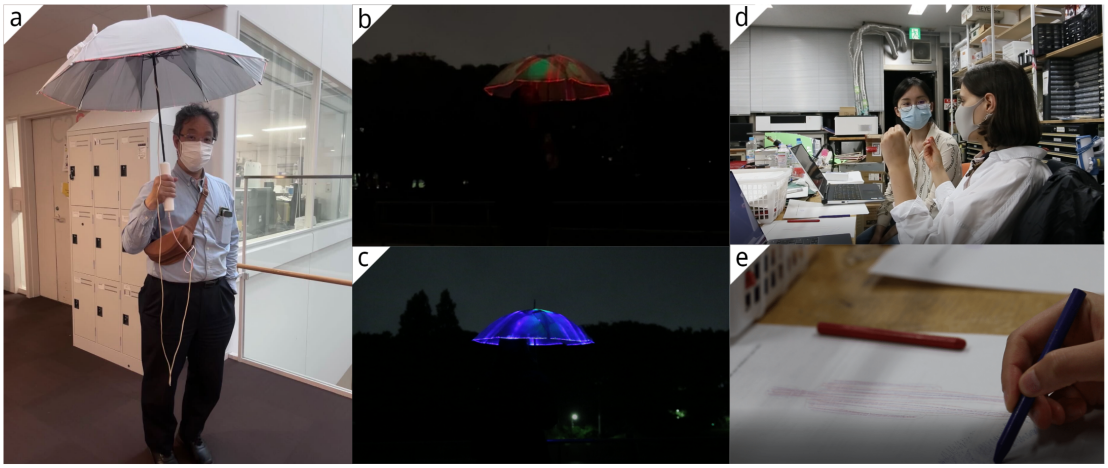

Figure 4.10 In-the-wild Study Setup. (a) Experimental setup. (b-c) Feedback Effects. (d-e) Debriefing interpretation.

Umbrella-based Sensing

Each participant will be required to hold the latest Affective Umbrella, in which the handle is embedded with two biometric sensors (GSR and pulse sensors), and the upper part of the umbrella is designed to install with a board for weather-related data sensing and collecting and some LEDs with fiber clothes showing the visualization of biofeedback. We will use the pc as a server to streaming the data.

Self-Assessment Manikin (SAM) Scale

Same as in the 4.2.2section (Figure 4.8).

Locus of Control (LoC) Scale

The original Multidimensional Locus of Control IPC Scale [61] consists of 24 items that measure an individual's locus of control. All items are scored on a six-point Likert scale, ranging from 3 (Strongly Disagree) to +3 (Strongly Agree). The scale yields three distinct factors.

Perth Emotional Reactivity Scale (PERS)

The Perth Emotional Reactivity Scale (PERS) [62] is a newly developed 30-item self-report measure of emotional reactivity (affective style). The PERS measures the typical ease of activation, intensity, and duration of one's emotional responses, and importantly does so for negative and positive emotions separately.

Beta Amylase density in Saliva

The saliva amylase concentration, which considered as a factor strongly related to stress, it is known that salivary amylase become higher along with the increase of the stress. To measure the salivary amylase, we used the commercial device[3].

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チップ (20 枚入り) 価格：4,000 円 (税別) 1 枚約 200 円

(Source: Kajiura's Master thesis)

Figure 4.11 Salivary Amylase Activity Monitor.

3 https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara$_id = KO40001001 - 0000201$

4.4.3 Experiment

Participants

21 participants aged from 21 to 40 years old (female:10, male:11) were recruited for this study. Every participant received a 1000 JPY gift-card as a compensation for their time, since the whole experiemnt takes each participant around 60 minutes.

Table 4.3 The experimental conditions in the in-the-wild Study

condition group	condition types	condition description
Condition 1	baseline	no visualization
Condition 2	viz of random data	visualization with pre-recording data
Condition 3	viz of emotion reflection	visualization with real-time representation of biofeedback
Condition 4	viz of regulated effects	visualization with regulated effects based on biofeedback

Procedure

The structure of the study was the following:

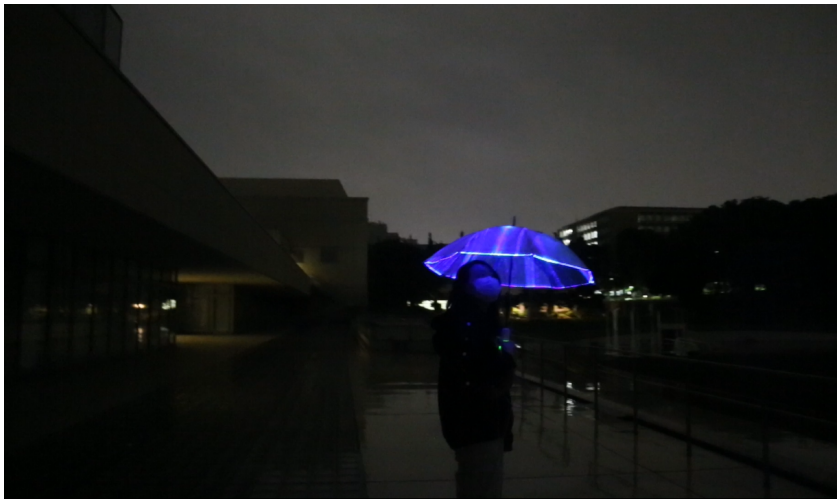

Figure 4.12 Experimental environment in the wild

1. Written informed consent form following the ethical guideline.

2. Participants have completed the Locus of Control Scale [61](a 24-item version of Levenson Multidimensional Locus of Control Scale) and Perth Emotional Reactivity Scale (PERS) before the experiment.

3. SAM Scale rating, self-assessment and saliva testing (Figure 4.11) before and after each session. Participants were also required to complete the picture debriefing in the end of each session (Figure 4.10).

There are four sessions using Lattin-square to avoid section order effect during the experimental procedure. Each session was lasting for 5min with no specific tasks but each participant was required to hold the umbrella with dominant hand, freely walking or standing around in the outdoors environment (Figure 4.12).

The total duration of the test with each participant was around 60 minutes.

Chapter 5
Evaluation

5.1. Data Analysis Overview

Regarding the data analysis, in total throughout 2 tests (Sensing Test with 8 participants, Feedback Test with 18 participants) and Feedback Loop Study with 21 participants for the experiment in the wild and 146 participants for the online surveys (Table5.1), only the data related to develop the feedback loop system reliably recorded from start to finish were used for further analysis.

Table 5.1 Evaluation Overview of Hypothesis and Results

Stage	Study Type	Hypothesis	Results	Data Collection
1	Sensing Test	Section3.2.3	R5.2.1	Resources collecting from 4.2
2	Feedback Test	Section3.3.3	R5.3	Resources collecting from 4.3
3	Feedback Loop	Section3.4.3 (H1)	R5.4.1	Resources collecting from 4.4
	Feedback Loop	Section3.4.3 (H2)	R5.4.2	Resources collecting from 4.4
	Feedback Loop	Section3.4.3 (H3, H4)	R5.4.2	Resources collecting from 4.4

5.2. Sensing Test

This section presents results of analysing the feasibility of platform using physiology (EDA and BVP) and SAM scale.

5.2.1 Results: Physiological Data (EDA and HRV) and SAM

We extracted two commonly used EDA [37] and HRV features [39] from the recorded physiological data.We initially extracted two different features as detailed below: Peaks, pNN50.

- **Peaks**: the SCR is often referred to as a "peak" of activity (and thus, a "GSR peak") as it appears as a rapid increase in the signal value
- **PNN50**: the percentage of adjacent normal-to-normal intervals that differ from each other by more than 50 ms

EDA Data Analysis

Each participant's raw EDA data was passed through a 2^{nd} order Butterworth low-pass filter from the *scipy.signal* package (0.01 Hz) [63] to clean the signal. We also decompose the EDA signal into its Phasic Skin Conductance Response (SCR) and Tonic Skin Conductance Level (SCL) components and mainly focus on the fast changes in EDA response (fig5.1). A Pearson correlation coefficient was computed to assess the linear relationship between the cleaned data from sensors placement on the umbrella handle and the wristband. There was a moderately positive correlation between the two variables, $r(6) = .48$, $p < .001$.

The different patterns of EDA across different sessions of experiment are expected. And we picked (subject07) sub07 and (subject08) sub08's EDA as an example to show the difference. It shows the extreme values of EDA located under the sound effect stimulus in session 1. Through the audio decibel peak corresponding to the extreme EDA peak, we found that **the overall accuracy of the data collected from the umbrella handle is higher than data from the fingers,** (sum amounts of peaks with jump scared effects from sub07 and sub08) is 25 which is larger than 6 (peaks from sub07 + sub08 with jump scared effects).**This can potentially be explained by stronger gripping force participants use to hold the umbrella.**

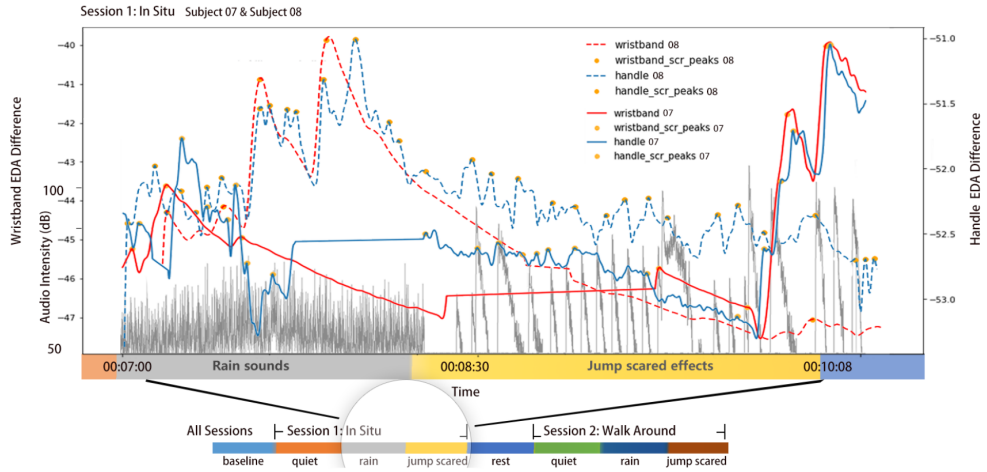

Figure 5.1 EDA changes with EDA extrema counts,EDA extrema peaks (highlighted in orange), trends in subject07 and subject08 from wristband(Left Y scale) and handle(Right Y scale), corresponding with audio effects

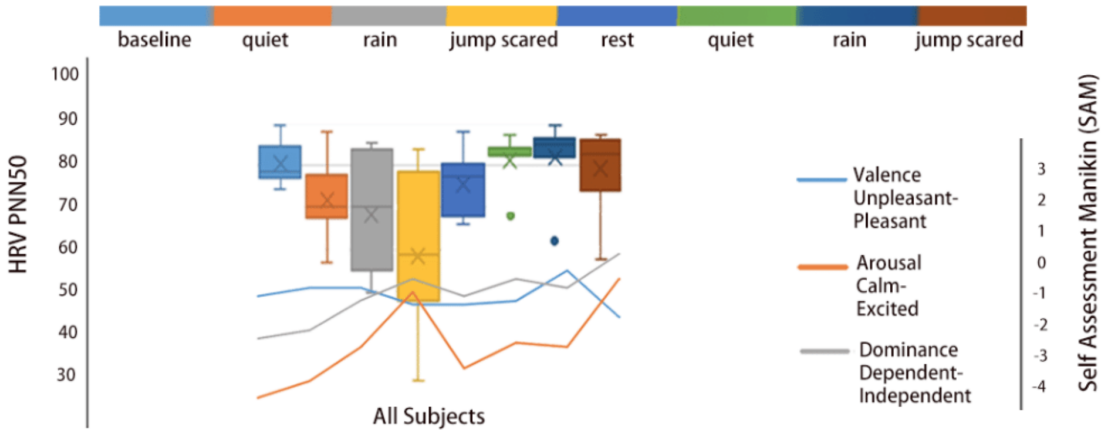

Figure 5.2 Trends in all subjects of HRV PNN50 (Left Y scale) and value from Self Assessment Manikin(SAM) (Right Y scale).

HRV and SAM Data Analysis

HRV feature was extracted from BVP data. For simplicity, the changes (fig5.2) in PNN50 (strongly related to PSNS, less affected by SNS (related to excitement) [26, 27, 64],) and SAM arousal were used to analyze the average changes of all subjects. It is not difficult to find that the two verify each other. Therefore, **the sensor placement and the physiological sensing of Affective Umbrella are both reasonable and effective, that is, the umbrella handle can be used as an functional prototype measuring EDA and HR data.**

5.3. Feedback Test

This section presents results of analysing the feasibility of feedback design using physiology (EDA and BVP), SAM scale, and interviews.

5.3.1 Results: Physiological Data

We extracted three commonly used EDA [37] and HRV features [39] from the recorded physiological data.We initially extracted three different features as detailed below: BPM, pNN50, SCL.

- **BPM**, beats per minute (bpm) is the number of heartbeats detected during one minute.
- **PNN50**: the percentage of adjacent normal-to-normal intervals that differ from each other by more than 50 ms
- **SCL**: slowly-changing Skin Conductance Level

SCL, BPM and pNN50

From the graph below, initial results of physiological data show two main SCL trends of arousal level of emotions on color effect (fig5.3), it shows this individual difference to color stimuli but we could found the similar range of emotion changing to the color. It could also be inferred through the b and c 's box range of BPM and pNN50 value (fig5.4) which the lower value of bpm shows lower arousal

physiologically status whereas the higher value of pnn50 shows higher arousal level.

In three different sessions, through the data of pNN50, we found that the degree of arousal was lower than that of the break state, and the degree of arousal was reduced to varying degrees; through the box plot data of BPM, we found that compared with no effect of color light feedback, blue negatively affects BPM reduction, and red positively affects the extent of physiological changes. The individual differences of red color on the physiological effects of the subjects were smaller compared to the blue color of light.

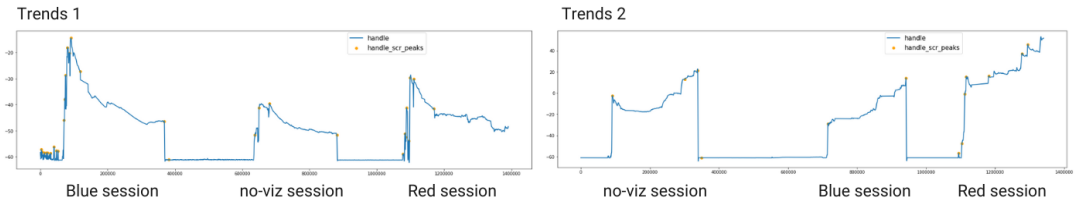

Figure 5.3 Trends in SCL (Y scale) in different sessions

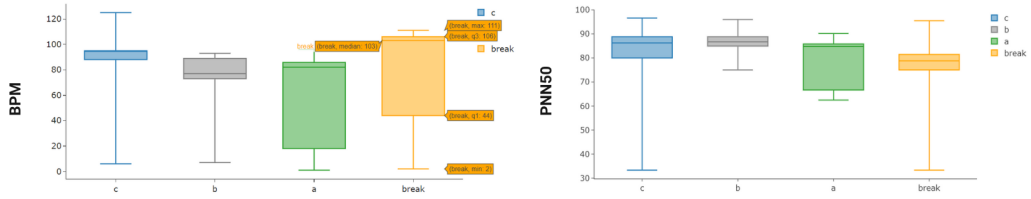

Figure 5.4 Trends in all subjects of BPM and HRV PNN50 (Y scale) in different sessions (X scale, c: Red Session; b: Blue Session; a: No-viz Session).

5.3.2 Results: Self-report

Combined with the relative objective reporting of physiological data for further analysis, further interpretation of the color light of different session settings was collected through SAM Scale and a 5-minute short interview.

- Using nltk package for sentiment analysis.
- Score the trends of color using SAM scores.

Through semantic sentiment analysis (fig5.5), we found that the emotional report of the blue session is positive valence; the emotional report of the red session is negative. Combined with the trend changes of SAM scores, it is mutually confirmed with the results of physiological data analysis.

To further analyze the interpretation of interview transcript (appendixB), we initially using the methods of CloudWord to look over the word frequency about Blue Session and Red Session (fig5.3.2).

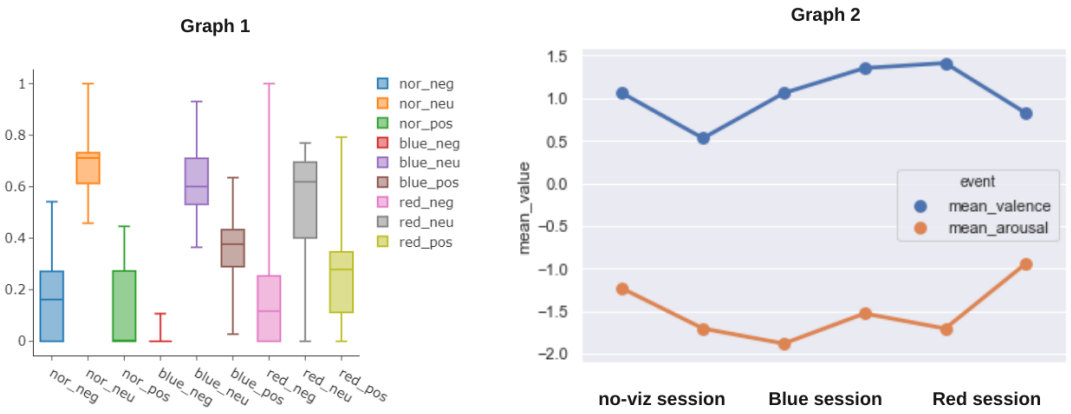

Figure 5.5 Graph1. Three Components about Interview Transcripts: negative, neutral, postive. Graph2. Trends of SAM Scores Changing over the Sessions

Figure 5.6 Blue Effect CloudWord

Figure 5.7 Red Effect CloudWord

5.4. Feedback Loop Study

5.4.1 Online Survey Results of General Attitudes Towards Weathers

H1 Different weather types can provide a natural environment as either positive or negative stimulus events of emotions.

An online survey using 7-point Likert scale (appendixA)was conducted of 146 people (100 female and 46 male) to measure the relationship between people's weather reactivity and their emotional responses. The scale involves a series of statements in order to rate the emotion about four main weather types (sunny, rainy, cloudy, and snowy), individual's emotion on the affect and the control level. Besides, the questions included the living residence, age, gender, possible affective reasons by weather, and open-ended questions about special experiences regarding the rainy days. The distribution of people' nationalities includes 91 Chinese, 46 Japanese, 1 Singaporean, 1 Vietnamese, 3 Germans, 1 Switzer, 1 British, 1 Scottish, and 1 American.

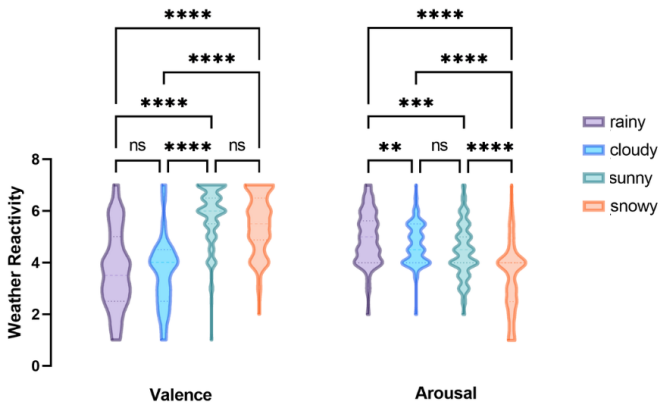

Figure 5.8 Col: One-way ANOVA

Regarding the weather reactivity (fig5.8), we found statistically significant differences between the four weather types on the Valence level ($F\ (2.475, 358.9) = 118.2$, $P<0.0001$) and on the Arousal level ($F\ (2.313, 335.3) = 62.96$, $P<0.0001$) by Repeated Measures one-way ANOVA. Besides, from the Table 5.2, it is no

difficult to find that the rainy and cloudy can be categorised as relatively negative on the Valence level compared to the weather types of sunny and snowy. Thus, this results support H13.2.3.

Table 5.2 Overview Online Survey Results about the Weather Reactivity

Measurements	Rainy (Mean(SD))	Cloudy (Mean(SD))	Sunny (Mean(SD))	Snowy (Mean(SD))	F-value(p-value)
Valence	3.726(1.51)	3.616(1.35)	5.832(1.12)	5.521(1.17)	1.8 (<0.001)***
Arousal	4.959(1.03)	4.699(0.81)	4.442(1.05)	3.435(1.30)	1.5 (<0.01)**

Considering the rainy and cloudy contexts, we found that there was a statistically significant difference between groups of three control level of participants as determined by one-way ANOVA($F(6.434, 933.0) = 144.7$, $P<0.0001$). It means the individual with **different level of locus of control** (we defined the LoC(Locus of Control) in the online survey's question roughly as how much they would agree with that they can well control the environmental effects on them) would **response significantly different on emotionally reaction**. Besides, there was a statistically significant difference between groups of three affect level ($F(2.826, 409.7) = 140.4$, $P<0.0001$). From the results of the relationship between the rainy frequency in a area and emotions rating on rainy days, there was a significant difference between different level of rainy frequency ($F(1.599, 231.9) = 30.94$, $P<0.0001$). Above all, **it provides a good condition to conduct the Feedback Loop Study in the wild (on a rainy/cloudy day)**.

5.4.2 Experiment Results of Biofeedback Loops' Experience

To evaluate the experiment results and quantify participants' biofeedback loops' experience in different conditions (see Table 4.3), we conducted statistical analysis on both the survey answers (appendixA.3,A.2,A.4)and the physiological data collected (specifically on EDA data that was used to trigger color feedback during the experiment). Moreover, we collected qualitative feedback by inviting participants to debrief while drawing on their bodily experience [65]. The results are summarized and reported according to three hypothesis in the following sections.

H2 Participants would show higher score in terms of three emotional dimensions (valence/arousal/dominance) when they are experiencing biofeedback loop than without it.

We calculated the changes of valence, arousal, dominance scores during each condition and conducted statistical analysis to test the hypothesis. According to a repeated measures of ANOVA, mean changes at the dimensions of arousal (F (2.419, 48.39) = 5.632,P=0.0040) and dominance (F (2.081, 41.62) = 3.743, P=0.0305) significantly differed across the four conditions. **The visualization on the umbrella can increase people's valence while there is no significant difference in terms of valence changes (F (2.781, 55.63) = 0.2428, P=0.8522).** We further conducted pairwise comparisons (see Figure 5.9) and found the arousal change in the condition with biofeedback (condition 3) is significantly higher than that in both condition 1 (p=0.0022) and condition 4 (p=0.0277). For the changes in dominance level, condition 1 is significantly higher than that in both condition 3 (p=0.0479) and condition 4 (p=0.0268).

The result of psychological arousal change (p=0.0022) based on visualization of emotion reflection and previous research [66] verify each other, indicating that **the data processing method we used for emotion reflection is confirmed**. Besides, participants would show **a significantly lower score in terms of emotional arousal** when they are experiencing **the visualization of regulated effects (p=0.0277)** than the visualization of emotion reflection. Participants would show **a significantly higher score in terms of emotional arousal** when they are **experiencing the visualization of emotion reflection (p=0.0022)** than without it.

H3 Participants with higher internal score of Locus of Control (LoC) would experience more emotional arousal.

We further investigated whether this emotional experience, especially the emotional arousal, would differ when people have different LoC. According to the survey answers of LoC, we divided the pariticipants into high LoC group and not high LoC group. We compared the experienced emotional arousal via both the SAM score and the count of SCR peaks proved to be related to arousal [37].

Figure 5.10 shows the results and we found that experienced arousal in condition

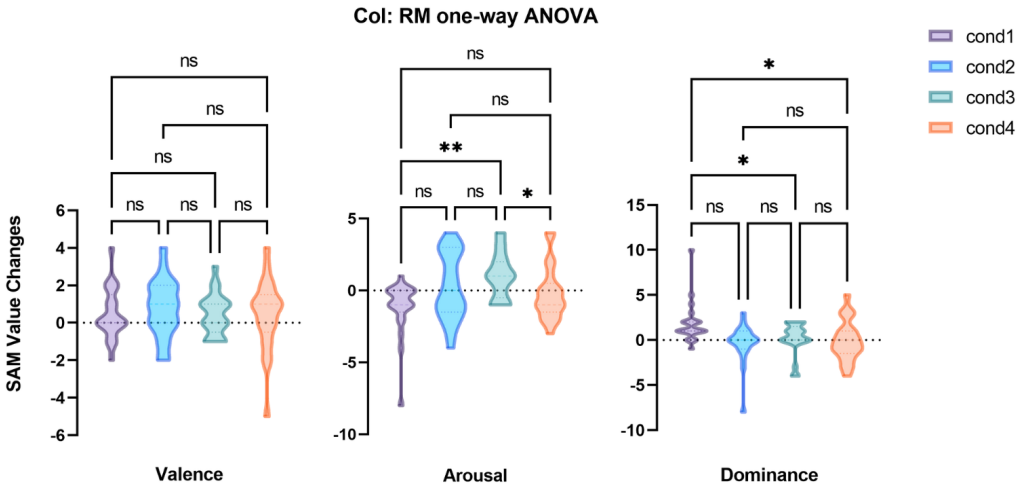

Figure 5.9 SAM changes over four conditions. (cond1: no visualization; cond2: visualization of random data; cond3: visualization of emotion reflection; cond4: visualization of regulated effects)

3 is significantly higher than that in condition 4 for the participants without high LoC (p= 0.0254). While for participants who are with higher scores of LoC, the significant higher experience arousal exists in condition 3 comparing with condition 1 (p= 0.0088). Besides participants subjective feedback, we calculated and compared the SCR peaks. However, we did not find statistically difference across four conditions (F (1.900, 38.00) = 0.8806, P=0.4180).

H4 Participants with different LoC level would experience different feelings of control (FoC) over three feedback of visualization conditions.

As an important element when designing biofeedback loop, FoC levels have been calculated and compared. However, there is no significant difference of psychological arousal change across four conditions ((F (1.886, 37.71) = 1.816,P=0.1783)) either for the difference between high LoC group (F (1.832, 20.15) = 1.869 P=0.1821) and not high LoC group (F (1.686, 13.49) = 0.3435, P=0.6798). Besides, compared the SCR peaks across four conditions (F(1.900,38.00)=0.8806,P=0.4180), it also shows no significant difference of physiological arousal change across different conditions.

Therefore, combined with the results from H2-4, we found that:

- The data processing method we used for emotion reflection is confirmed.
- Two patterns of visualization feedback were explored: (1) the visualization of regulated effects; (2) the visualization of emotion reflection. The visualization of regulated effects decreases the arousal level of emotion; The visualization of emotion reflection increases the arousal level of emotion; Both visualization patterns can increase the valence level of emotion.
- People with different levels of Locus of Control (LoC) show significantly different emotional responses to the visualization of biofeedback. The visualization of biofeedback has a significantly positive regulation effect on the arousal level of emotion for people who are easily affected by environmental influence whereas no significance for people who well control over their emotions by external influence.

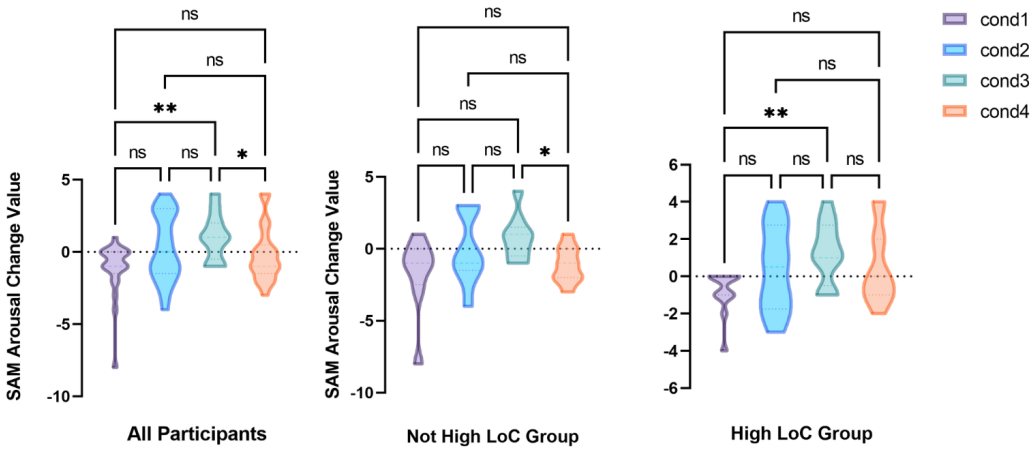

Figure 5.10 Experienced arousal across four conditions for participants with different LoC. (cond1: no visualization; cond2: visualization of random data; cond3: visualization of emotion reflection; cond4: visualization of regulated effects)

5.4.3 Debriefing

The methods was inspired by the body-maps in medical practices to locate pain in and around the body [65]. Complementary to the picture debriefing (fig5.11), interview transcripts were recorded with each participant. The pictures and transcripts below illustrates the potential power of tools for self reflection mediated by biofeedback technologies and facilitated through further reflection-on-experience.

In the figure 5.11, participants debrief their physical and psychological relationship between their feeling of internal state and external environment across four conditions. Take the figures in the first row as examples, it clearly shows the visualization with random data (in the second column) was aware as an accessory whereas different reflection-on-experience under the visualization of emotion reflection (in the third column) and regulated effects (in the fourth column).

Figure 5.11 Body maps produced by participants during the Sessions (From left to right: cond1 - no visualization; cond2 - visualization of random data; cond3 - visualization of emotion reflection; cond4 - visualization of regulated effects)

Participants' reflection-on-experience

session cond1

"My upper body is a bit cold, and the color i used corresponded to the body temperature; my lower limbs are not very sensitive to the outdoor temperature; orange because i felt warm from surrounding environment; black is just dark environment.."

"Feel the dark, but stop by the umbrella.."

session cond2

"I tried to control the color changing but failed, and the actual application scenario was simulated after giving up, very good, with a commercial future, my mood returned to the feeling before the experiment.."

session cond3

"I feel that I can control the umbrella; Most of the time I feel my way; color-sanity is overwhelming; the umbrella is my shell, the upper part covers me and expresses me; the lower part passively accepts"

"energy low, confusing, calming down. too much thoughts. (trying to figure out the reason of the color changing)."

session cond4

"I mainly feel the feeling of following the changes of the umbrella, and there is a feeling of shaking under the street light; I feel that I am in the world, shrouded in light, small and existing.."

"make sure of calmness, with some level of empty, felt some part of me is falling down. I feel like in transition between good and bad emotions. Like in between. .."

5.5. Discussions

Based on the evaluations and results of a series of studies, we tested the potential of using Affective Umbrella as a biofeedback system. In the following sections, we discussed over the feasibility of emotion reflection and influence. We further summarized the implications of similar designs and studies related to biofeedback loop.

5.5.1 Feasibility of Emotion Reflection and Influence

First of all, the results of sensing test proved the sensing availability of the Affective Umbrella's handle. Comparing with the EDA signal collected from the established sensing device (the wristband), signal from the handle could perform similar trends and key SCR peaks (see Figure 5.1). The feedback test showed participants have different emotional feelings (see Figure 5.2) under the blue color and red color, which proved the feasibility of using color feedback to reflect and influence people's emotional feelings.

After a few rounds of prototype iterations, we developed the final version of Affective Umbrella that used in the feedback loop study. In terms of experienced emotions in three dimensions (valence/arousal/dominance), this system could bring different experiences in arousal and dominance level. While valence level turned to be rarely affected. Comparing with the controlled condition where the color changing was triggered randomly, biofeedback that reflected and influenced the emotional feelings in real time were able to cause higher arousal and lower dominance (see Figure 5.9). For participants who had relatively lower LoC level, the difference of emotional arousal between biofeedback reflecting and influencing emotions is obvious. This could imply that for people with not high LoC, reflecting their own emotions and intentionally leading their emotions could receive quite different results. On the contrary, participants who are in high LoC reported relatively higher arousal level as long as the biofeedback existed. Among three conditions, reflecting the emotion is the most effective way to increasing arousal compared with the baseline condition.

5.5.2 Implications for Biofeedback Loop Design

In the biofeedback loop study, we not only compared between the condition without and with the visualization, but also explored the potential biofeedback types: reflection and influence. The two types of loop design could bring different experience in terms of emotion interpretation and regulation. Our initial results tend to prove the reflection type could be more effective to increase arousal level.

Moreover, as a bodily experience, biofeedback loop could bring different experience. Therefore, we suggested the design of biofeedback could also take individual's personality into considerations especially the locus of control.

Chapter 6
Conclusions

In this thesis, the definition of emotions in our feedback loop design refer to the short-term fluctuating changes in the emotional state under external influences, and we presented an umbrella-based feedback loop system to explore the complex information in the emotion processing. We introduced the iterative implementation and experimental setups to test the potential of using Affective Umbrella as a biofeedback system. Based on initially successful data acquisition from biometric sensors on the umbrella handle in the Sensing Test, we moved our steps to the feedback loop system of interaction design. Besides, we have developed some umbrella models to develop possible affective ways of interactive feedback. We discussed over the feasibility of emotion reflection and influence. A Pearson correlation coefficient was computed to assess the linear relationship between the cleaned data from sensors placement on the umbrella handle and the wristband. There was a moderately positive correlation between the two variables, $r(6) = .48$, $p < .001$. Using color of lights as the visualization of biofeedback, we conducted the final Feedback Loop Study in the wild under the contexts of natural rainy and cloudy days, which provides a good condition based on the online survey results we found statistically significant differences between the four weather types on the Valence level ($F(2.475, 358.9) = 118.2$, $P<0.0001$) and on the Arousal level ($F(2.313, 335.3) = 62.96$, $P<0.0001$) by Repeated Measures one-way ANOVA. For the results in the final study, we found that reflecting the emotion is the most effective way to increasing arousal level whereas the visualization of regulated effects decreases the arousal level of emotion compared with the condition of no visualization. Both visualization patterns can increase the valence level of emotion while can not significantly improve one's FoC over emotion. Furthermore, we summarized the implications of similar designs and studies related to biofeedback loop.

6.1. Limitations

Firstly, we collected both EDA and BVP data during the feedback loop study. However, as a movement sensitive sensing modality, BVP data turned to be too noisy to analyze. In the future, we could test other positions to collect and use BVP data (e.g. head or ear) in terms of stability. Moreover, the current feedback was triggered by calculating SCR peaks in certain period. There could be further explorations to design the feedback actuation such as implementing machine learning model to automatically predict emotional states. There could be also improvement when designing for the prototypes in terms of battery storage and weight. We would keep working on streaming data via cloud instead of UDP communication to provide better user experience.

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Appendices

A. The questions of surveys for emotions and FoC evaluation in the Feedback Loop Study

The questions of online survey consisted of demographic questions and perceptions towards the interaction states between two people suggested by the animated visuals. Participants were asked to rated their agreement using Likert scale (1-Strongly disagree, 7-Strongly agree) about the statements to answer the questions about perceptions.

B. Interview Transcripts: Feedback Test

Table B.1: Interview Transcripts: Feedback Result of Color Effects

subject ID	No-viz session	Blue session	Red session
01	taking the umbrella with no color is also calm	the blue umbrella cloths is the most comfortable and relaxed	red umbrella cloths looks a bit bloody; red is not scary but not calm
02	when no lighting, (kind of random thinking..)	blue, felt dreamy, a bit of a cosmic and starry -sky being inside, or inside the ocean or universe, the sense is like under a jellyfish, and the shape also looks like a flower; seems blue one creates a safe and peace dream..	red, related to his game experience, like a warning color, also can clearly realize the umbrella itself
03	when nothing colored, just felt so so, being in her own space and expected to have sth coming up, random thinking..	blue looks better and felt a calming down to it , she got a feeling of more submerged in some seconds	she worried before about any nervous under the red light but felt homesick instead

Table B.1: Interview Transcripts: Feedback Result of Color Effects

subject ID	No-viz session	Blue session	Red session
04	when no color, he didn't feel anything, just standing in the dark.	he felt reassured when it turned blue, felt like being boxed up, in a little house with a blue frame in the dark, feeling peace of mind and slightly gained a sense of peace of mind. looks good.	when it changed to red, he intuitively didn't want to stand down there any longer, having a strong sense of warning. ' why i am holding the umbrella up high, i don't want me to be covered in this red frame.' it gave me too good of an association, police cars, just less positive, i felt very uncomfortable.
05	when no color also good, thinking about things to reflect in the silence. she appreciated the silence, getting really calm down, pretty relaxing.	no expect to see it light up with blue colors, looks like the sky full of stars, pretty cool, enjoyable.	when turning to red, she felt a little uncomfortable reminding Hong Kong colon? (bad images), pretty scary.
06	when no color, feel sleepy	the blue one seems like an aquarium, blue more focus(sense of control)	the red one is gorgeous, she would like to take the umbrella to walk down the red carpet.
07	not too much specific feeling	he felt more relieved	annoying
08	blackness one just not too much feeling.	blue is the most comfortable, reminding her of a rainy day when walking home and neon light reflecting on the pavement over the water. bring her into the atmosphere of the rain day, of the wetness and the experience at once, immersive.	she associated the red one with a lot of neon lights, though doesn't feel very comfortable, doesn't seem to brings any certain negative emotions.
09	he felt a bit strange; stupid to stand there when it was a zero light holding the umbrella.	warm and safe, reminding him when he was a kid, he was scared to go outside when it was dark to throw out the rubbish. Because in New Zealand, usually half as many street are very dark; blue feels more metropolitan; kind of alertness due to his background, associated to a technology color from computer screen, or shibuya scrabble square.	he felt quite, content, standing with the red umbrella. feel more like secure in complete darkness with the red light; red umbrella may has some implications, like adult services, more playful. quite calm; red just makes him relaxed, more associated of some bar place or feeling of safety.
10	when no lights, she was feeling a bit anxious. but felt somehow warm, enveloped inside of the umbrella.	blue gets her delighted because the fabric is beautiful and the light looks amazing. she did deep breathing exercise	red is more joyful, more excited about compared to the blue.

Table B.1: Interview Transcripts: Feedback Result of Color Effects

subject ID	No-viz session	Blue session	Red session
11	not too much specific feeling	blue is more comfortable compared to both others, but not sure is the feeling of relaxed	less comfortable
12	she felt more horrible in the no color one also in all black environment.	the blue one may be calm, images of sea feelings. the blue is calming, more healing feeling, like the jellyfish in the ocean	the red one make her feel a little anxious. red would have a more scary kind of vibe especially being isolated in the black environment. reminds her of an erupting volcano.
13	when it was all black, a little bit of anticipation at first, but it's okay no light, very quiet and comfortable, she thinks no particular change about emotions	blue, a little bit of a feeling of being under the stars, like the milky way, beautiful, she enjoyed those two minutes of watching the milky way. blue helps to have a more layer of richer imagination, comfortable, smooth and peaceful situation.	red, she felt warm, like holding leaves to block the rain, or holding a very large red flower to block the rain, is happy, comfortable.
14	senseless.	blue umbrella is stunning to see at the first time, then also feel it a romantic color	red, a cool feeling
15	not too much specific feeling	excited and curious, calm. a pool aside with blue lights and kind of relaxing	excited and curious, red, may images of violent game but not like anger feeling
16	black, a little scary at first, not quite comfortable, a little lonely.	blue, gives a lot of calm, like a jellyfish or a sea creature. felt nice and calm, feels of being on the surface of a jellyfish and cold	more intense, surprised, and a very warm color.
17	black, out of expectation and felt quite nice to see through the ceiling, kind of enjoyed.	blue, nice, enjoying the pattern, looks like a jellyfish	like about to halloween, cool with this kind of red lights on an umbrella.
18	no much emtion changes.	blue indeed gives the relaxation for the mind; blue one is nice, because it looks cool.	red seems excited, but he didn't become so excited if just affected by color.

Table A.1 Survey of the relationship between the weather and emotions

Category	Question	Answer
Demographic	What gender do you identify as?	Single Choice
Demographic	How old are you?	Single Choice
Demographic	In which country/city do I currently live?	Single Choice
Demographic	I currently live in a city with a relatively ( ) climate.	Single Choice
Demographic	I prefer to live in a city with a ( ) climate.	Single Choice
Dominance	I can control my emotions over the environmental change.	Likert Scale
Valence	On a sunny day, I usually feel pleased.	Likert Scale
Valence	On a sunny day, I usually feel sad.	Likert Scale
Arousal	On a sunny day, I usually feel calm.	Likert Scale
Arousal	On a sunny day, I usually feel excited.	Likert Scale
Valence	There is too much rain per month in city I live.	Likert Scale
Valence	On a rainy day, I usually feel pleased.	Likert Scale
Valence	On a rainy day, I usually feel sad.	Likert Scale
Arousal	On a rainy day, I usually feel calm.	Likert Scale
Arousal	On a rainy day, I usually feel excited.	Likert Scale
Valence	On a cloudy day, I usually feel pleased.	Likert Scale
Valence	On a cloudy day, I usually feel sad.	Likert Scale
Arousal	On a cloudy day, I usually feel calm.	Likert Scale
Arousal	On a cloudy day, I usually feel excited.	Likert Scale
Valence	On a snowy day, I usually feel pleased.	Likert Scale
Valence	On a snowy day, I usually feel sad.	Likert Scale
Arousal	On a snowy day, I usually feel calm.	Likert Scale
Arousal	On a snowy day, I usually feel excited.	Likert Scale
Dominance	Weather conditions affect my emotions a lot.	Likert Scale
Dominance	If you are more sensibly affected by weather, what could be possible reasons?	Likert Scale
Dominance	If you are less sensibly affected by weather, what could be possible reasons?	Likert Scale
Debriefing	Do you have any special relationship or experiences regarding rain or rainy days? Please feel free to share.	Open-ended

Table A.2 Questions in Condition 1 - Before session

Category	Question	Answer
Emotions	(Q1- Q3) Valence, Arousal, Dominance	SAM Scale
Valence	I felt pleased about the temperature in the air now.	Likert Scale
Arousal	I felt calm about the temperature in the air now.	Likert Scale
Valence	I felt pleased about the humidity in the air now.	Likert Scale
Arousal	I felt calm about the humidity in the air now.	Likert Scale

Table A.3 Questions in Condition 1 - After session

Category	Question	Answer
Emotions	(Q1- Q3) Valence, Arousal, Dominance	SAM Scale
Valence	I felt pleased about the temperature in the air just now.	Likert Scale
Arousal	I felt calm about the temperature of the weather just now.	Likert Scale
Valence	I felt pleased about the humidity in the air just now.	Likert Scale
Arousal	I felt calm about the humidity in the air just now.	Likert Scale
Debriefing	Please draw here freely to describe how you felt your emotions in your body.	Somaesthetic

Table A.4 Questions in Condition 2-4

Category	Question	Answer
Emotions	(**Before Session**)(Q1-Q3) Valence, Arousal, Dominance	SAM Scale
Emotions	(**After Session**)(Q1-Q3) Valence, Arousal, Dominance	SAM Scale
FoC	How do you think about the change of the visualization?	Likert Scale
FoC	How do you interpret the change of the visualization during the session?	Likert Scale
FoC	The visualization moved just like I wanted to, as if it was obeying my will.	Likert Scale
FoC	I felt as if I was controlling the movement of the visualization.	Likert Scale
FoC	I felt as if the visualization was controlling my will.	Likert Scale
FoC	I felt as if the visualization was controlling my movements.	Likert Scale
FoC	I felt as if the visualization had a will of its own.	Likert Scale
FoC	I felt as if I was causing the movement I saw.	Likert Scale
FoC	I feel my emotions in my body.	Likert Scale
Debriefing	Please draw here freely to describe how you feel your emotions in your body.	Somaesthetic