

# **Dispositional Flow-Related Measures Associated with Diurnal Heart Rate Parameters for the Promotion of IoT-based Mental Health Assessment Systems**

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# Structured abstract

**Background:** With considerable advancements in the field of technology, it is now more convenient and easier to acquire biomedical signals. These signals not only can be used in the evaluation of physical wellness but also may be helpful in the assessment of mental health if applied properly and precisely. With psychological measures to track mental wellness, and searching for relevant physiological parameters to reveal the underlying physiological bases of mental health, it may be possible for individuals to be healthy both physically and mentally in order to achieve full health and high life expectancy in an ageing society.

**Objectives:** This study investigated whether six dispositional psychological measures, *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* are associated with physiological parameters of diurnal heart rate rhythm. Psychological measures are evaluated by questionnaires related to the psychological attributes of a person that can be based on either the experienced sampling method or the dispositional method. The dispositional approach, as the main focus of this study, is designed to quantify one's personality with a long-term psychological nature whereas the experienced sampling approach is for short-term measures to quantify the psychological state of a person during specific short activities. These methods have different questionnaires with experienced sampling using nine items for *Frequency of Flow Experience* while the dispositional method is only containing four items.

**Methods:** The association of four physiological parameters of diurnal heart rate rhythm—24-hour and 12-hour periodic component amplitudes, diurnal heart rate range over a day and autonomic switching rate with six dispositional psychological measures were analyzed. The physiological parameters were extracted using conventional double cosinor rhythmometry and smoothing of splines methods from heart rate data continuously recorded at one-minute intervals by a wrist device. The double cosinor method is a well-known signal processing technique in heart rate variability. The spline method was considered an alternative approach to capture a more detailed trend pattern of the heart rate diurnal change and address the multicollinearity issue in heart rate parameters. The experiment was conducted on 20 healthy Japanese engineers aged 25–60. Four physiological datasets (weekday only, weekday and weekend data each with mean and median values) were used.

**Results:** The dataset containing weekday-only data with median values gave better results. One reason was that median values were generally suitable for small-size sample. The main reason was that circadian rhythm showed a regular pattern on weekdays since participants spent most of their time in desk work or indoor meeting which corresponded to mental activities. However, during the weekends, there were inconsistent patterns heart rate patterns due to extreme physical activities. Therefore, eliminating the effect of extreme physical activities was important for an accurate mental health assessment. The Spearman single regression analysis revealed a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, and *Trait-Coping*, a trend of significant correlation ( $p < 0.1$ ) of *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* while showing no correlation ( $p > 0.1$ ) of *Self-Image* with spline-based parameters. The regular single regression analysis revealed a significant correlation of *Frequency of Flow Experience*, *Trait-Coping*, and *Will for Meaningful Life*, a trend of significant correlation of *Self-Image*, while showing

no correlation of *Self-Awareness* and *State-Trait Anxiety* with spline-based parameters. The only negative psychological measure; *State-Trait Anxiety* showed a negative correlation in both Spearman and regular single regression analyses. The regular multiple regression analysis showed a significant correlation of *Frequency of Flow Experience*, *Trait-Coping*, and *Self-Image*, a trend of significant correlation of *Will for Meaningful Life*, while showing no correlation of *Self-Awareness* and *State-Trait Anxiety* with cosinor-based parameters. Principal component analysis extracted one to three orthogonal components with which single component regression analysis showed a significant correlation of *Frequency of Flow Experience*, *Trait-Coping*, and *Self-Image*, a trend of significant correlation of *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* with cosinor-based parameters. Finally, multiple components regression analysis yielded better scores by showing a significant correlation of *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, and *Will for Meaningful Life*, a trend of significant correlation of *Self-Awareness*, while showing no correlation of *State-Trait Anxiety*. Generally, cosinor-based physiological parameters gave better scores in regular multiple regression and multiple principal components regression analyses since more heart rate parameters were used to improve the correlation results. Therefore, for regular single regression and Spearman analyses, spline-based heart rate parameters are to be considered as they are a more detailed representation of heart rate change.

**Conclusion:** Dispositional psychological measures were associated with physiological parameters of diurnal heart rate rhythm introduced by this study, representing long-term characteristics of autonomic nervous activity. Integrating such psychological measures and heart rate parameters may lead to a comprehensive understanding of the psychological characteristics of people. The research outcome may be applied to the development of ubiquitous healthcare monitoring systems that integrate both physiological bio-signals and psychological measures.

**Keywords:** dispositional flow experience, positive psychological measure, mental healthcare, heart rate variability, biomedical signal processing.

# Chapter 1: Introduction

The Internet of Medical Things (IoMT) and the Internet of Things (IoT) with cloud-based services have been at the centre of attention over the past number of years [1]. The significance of continuous monitoring of health during routine physical activities has also been extensively recognized to counter physical health problems such as diabetes, cardiovascular disease, sleep apnea, and certain cancers [2, 3]. In addition, nowadays, wearable devices are considered an efficient way to acquire biomedical data for the evaluation of physical health at home or office as these devices are easy to operate and often don't require much training time [4]. As a result, data from bio-signals can be transmitted to a cloud system for future evaluations by a professional medical staff to provide appropriate treatments to the patients [5, 6].

In the past few decades, people have been persistently having difficulties in maintaining a balance between their physical and mental health states. According to a report conducted by the Ministry of Health, Labor, and Welfare in Japan, more than 55% of Japanese workers have been suffering from mental stress each year [7]. An unhealthy mental state is mainly caused by complications in the social environment and a considerable amount of stress felt during daily work activities [7]. Moreover, the annual rate of suicides in the past decade has been over 20,000 due to acute mental stress and an unhealthy mental condition [8]. To sustain a healthy life in an ageing society, it is required to be healthy, both physically and mentally. The Health Adjusted Life Expectancy (HALE) is an important index to be tracked in the field of global healthcare [9]. In HALE estimation, the years of healthy life lost due to disability have also been used to adjust the life expectancy for measuring the life span with "full health". Therefore, to achieve a high HALE index, in addition to maintaining physical wellness, holding mental wellness is also to be considered.

This study introduces psychological measures to track mental wellness and searches for relevant physiological parameters to reveal the underlying physiological bases of mental health. Psychological measures are evaluated by questionnaires related to the psychological attributes of a person. These questionnaires can be based on either the Experienced Sampling Method (ESM) or dispositional studies. On the other hand, the physiological criterion is acquired by a Holter ECG device through the time-domain index and frequency-domain index of the RR interval introduced in Heart Rate Variability (HRV) [10]. However, wearable devices are an alternative for obtaining such biomedical data because they are significantly cheaper, easier to use, and sometimes have an accuracy level close to that of a clinically used Holter ECG device [11, 12].

Psychological *Flow* is defined as an optimal state of experience in which a person is entirely immersed in a particular activity without reflective self-consciousness but with a profound feeling of control [13]. Various measures of *Flow* related personal psychological characteristics such as *Trait-Coping*, *Self-Image*, *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* are important elements to characterize the *Flow* experience [14–18]. There are two types of psychological *Flow* studies. One type is to assess *Flow* characteristics during a certain activity period. Another type is to measure the general tendency to experience *Flow*. The questionnaire used for studying the first type is called the state version questionnaire, whereas the questionnaire used for the second type is called the dispositional *Flow* questionnaire [19].

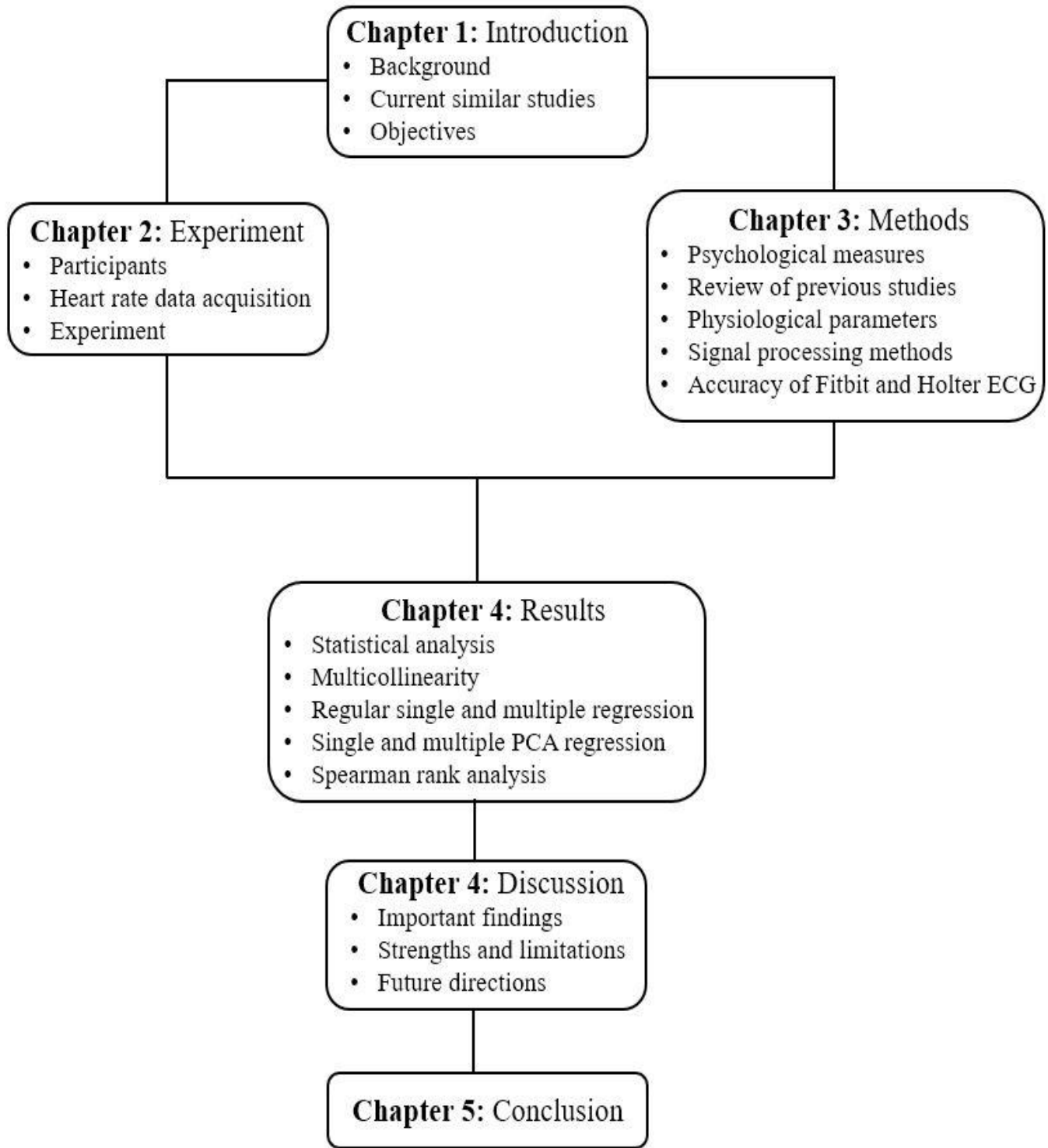
There is the same distinction for other *Flow*-related psychological measures. Our research focuses on the dispositional psychological nature of people.

Recently, studies associating the *Flow* experience of the first type with physiological data such as heart rate, respiration, and skin conductance, which quantify the autonomic nervous activity, have emerged [20–24]. Among them, HRV, an established non-invasive quantitative index for probing the autonomic nervous activity, has received increasing attention. In analyzing HRV, frequency domain parameters are typically used, and the key parameters are high-frequency band power (HF; 0.15–0.4 Hz) representing the parasympathetic activity and the ratio of low-frequency band power (LF; 0.04–0.15 Hz) to HF (i.e., LF/HF) associated with the sympathetic nervous activity [25, 26]. They are short-term parameters characterizing HRV during a certain activity period. However, research that relates the second type of dispositional *Flow* tendencies and related psychological characteristics to physiological data is still rare [27].

This study, thus, examined whether dispositional *Flow* and related psychological measures are associated with HRV. To that end, physiological parameters that indicate the long-term characteristics of HRV must be introduced. Four parameters—24-hour and 12-hour periodic heart rate rhythm amplitudes, diurnal heart rate range, and the newly defined parameter named the autonomic switching rate that represents the transition speed of autonomic nervous activity—were extracted from diurnal heart rate time series and utilized in this study. Our research question was whether the average rhythm pattern that reflects the sensitivity of autonomic nervous activity over a sufficiently long period is associated with dispositional psychological characteristics.

For heart rate data acquisition, continuous heart rate recordings at a sampling interval of one minute were obtained using a wrist device connected to the cloud data system. By introducing such an IoT device for continuous monitoring of heart rate, this research envisions the development of an integrated ubiquitous healthcare system that continuously monitors physiological data using IoT devices and psychological measures using web-based questionnaires at prescheduled appropriate times to provide timely feedback of the analysis results to users.

**Fig. 1.1** outlines this dissertation, which consists of seven chapters; Introduction (chapter 1) highlights the importance of mental health, previous psychological flow-related studies, and the use of HRV in mental health. Experimental schemes (chapter 2) describes participants and tools used during trials. Methods (chapter 3) which covers the description of each psychological measures, reviewing previous studies regarding psychological measures and the relevant questionnaires, signal processing techniques used to extract physiological parameters, and the accuracy of the IoT device used in this study. Analytical results (chapter 4) will show a series of correlation and statistical analyses for psychological measures and heart rate parameters. Discussion (chapter 5) will describe important findings, future directions, strengths, and limitations of this study. Finally, concluding remarks are in Conclusion (chapter 6).



**Figure 1.1** Outline of this doctoral dissertation.



# Chapter 2: Experimental scheme

## 2.1 Participants and experiment

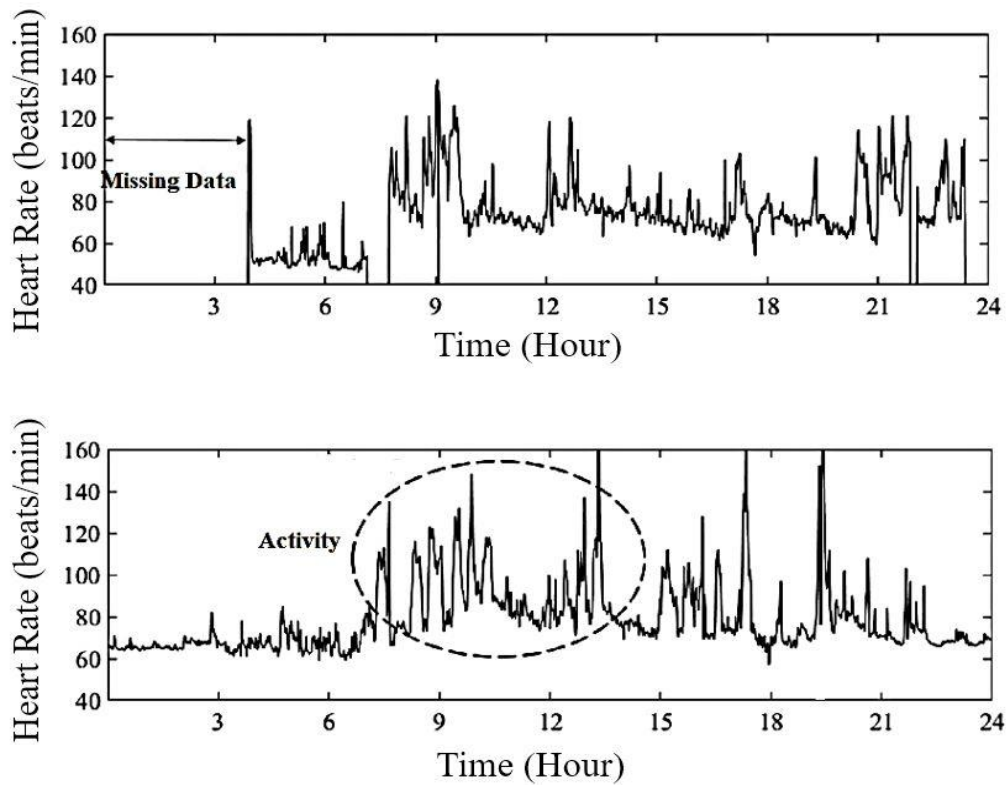
Twenty healthy Japanese employees (12 males, 8 females aged 25–57 years) from an IT and software development company in Tokyo (ISID-AO Co. Ltd., Tokyo, Japan), with no signs of physical or mental disorders and taking no medications (sleeping pills, anti-depressants,  $\beta$ -blockers), volunteered to participate in this study. They were asked to answer six questionnaires once at the beginning of the study. The questionnaires were on dispositional *Flow* proneness and five other measures related to psychological well-being characterizing the dispositional personality of the participants. The questionnaires and their scoring methods are provided in the Appendix. The study period was four weeks, including 20 weekdays and 8 weekends for continuous heart rate measurement to extract nominal long-term heart rate rhythm parameters. During this period, the participants' main activities were routine desk work and indoor meetings. This study investigated the association between dispositional psychological measures and diurnal heart rate rhythm through a series of correlation analyses. This study was approved by the Ethics Committee of the Biological Experiment carried by Professor Mitsuhiro Kimura, Hosei University, Japan (Approval Number: 2019–9). All human participants provided informed consent for participation in the experiment.

## 2.2 Heart rate sequence acquisition

The heart rate data of each participant were continuously recorded every one minute using Fitbit Charge 2 smartwatch (Fitbit, LLC., San Francisco, CA, USA). The device was wrapped around the arm and collected heart rate data continuously at one-minute intervals for four weeks, except for the battery charging period of approximately 10-20 minutes. Battery charging is necessary once every few days. The charging time is not strictly specified. However, such occasional short-term missing data will not affect the estimation of the parameters of interest, i.e., long-term diurnal heart rate rhythm. Data recording was not restricted to controlled normal daily activities, but was restricted to weekdays when the participants were mainly engaged in desk work i.e., mental tasks, to avoid the heart rate changes by physical activities. Note that studies of long-term dispositional psychological characteristics are often conducted in an uncontrolled environment by its nature [28]. The total measuring time was 20 days for each subject.

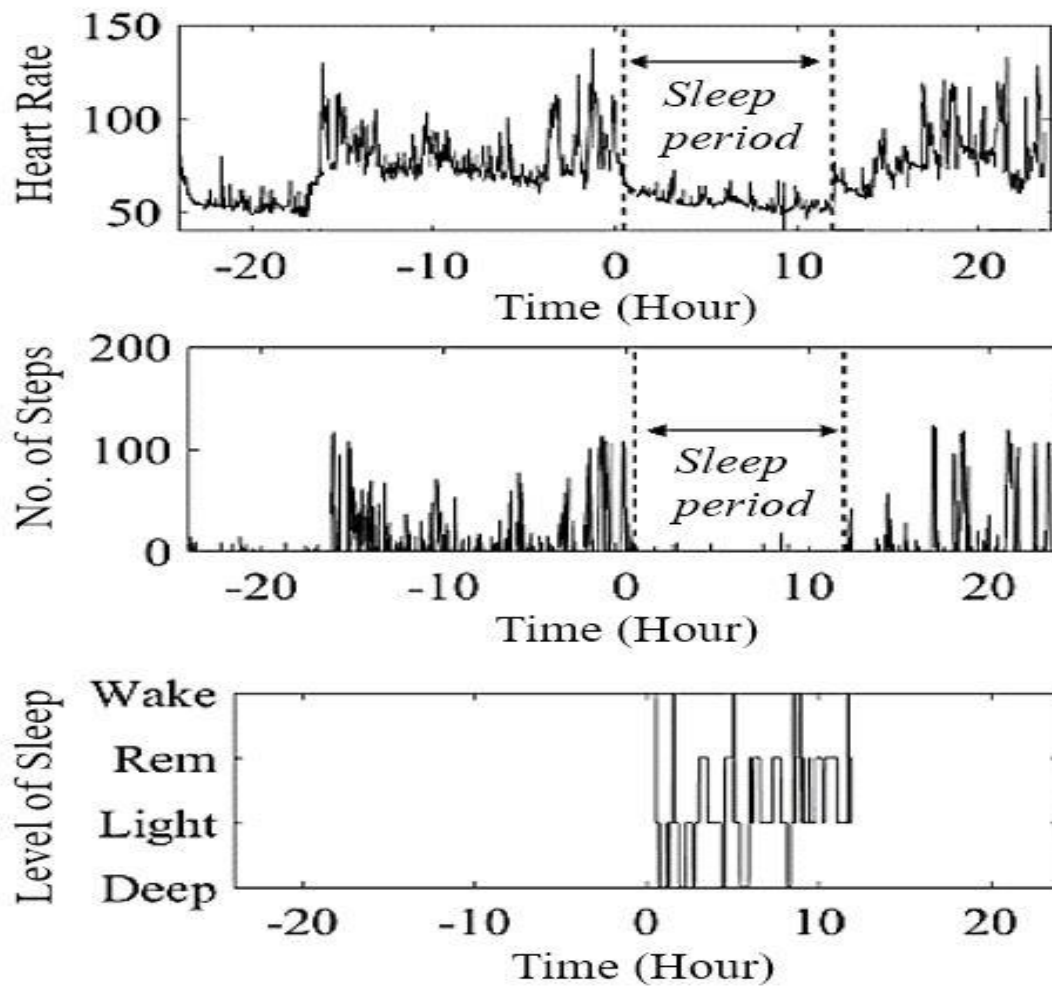
The heart rate measurement accuracy of Fitbit Charge 2 has been validated previously [29–31]. In one of the studies, Fitbit Charge 2 shows a mean absolute error of 5.96% in the measurement of 24-hour data for heart rate compared to the measurement based on the standard ambulatory electrocardiograph (ECG) monitoring system [29]. Another study evaluated the estimation accuracy of the double cosinor curve, which we utilized in this study, based on the wrist device measurements [30]. It found a relative error of 3.9% compared to the estimation by the clinically used Holter ECG device. **Fig. 2.1** shows the graphs of heart rate sequence measured by the Fitbit charge 2 device. Whenever a subject disconnects the device (upper trace), the missing data will appear for that specific period. In addition, when a participant

performs a physical activity (lower trace), heart rate changes will be more apparent. Such variations in heart rate sequences were used to investigate the accuracy of Fitbit Charge 2 in comparison to a Holter ECG device in this study which will be described in chapter 3 in detail.



**Figure 2.1** Sample heart rate sequences measured by Fitbit Charge 2.

In addition to heart rate sequences, Fitbit can generate graphs for the number of steps and sleep stages. In regard to sleep measurement, four stages are supported by the device. In this study, we also used step data to analyze the severity of physical activities in relation to mental health assessment. **Fig. 2.2** shows different recordings of physiological data by the wearable device.



**Figure 2.2** Heart rate, step, and sleep recordings generated by Fitbit Charge 2.

	A	B	C	D
1	db_id,date,time,value			
2	20,2017/08/13,00:00:00,68			
3	20,2017/08/13,00:01:00,68			
4	20,2017/08/13,00:02:00,68			
5	20,2017/08/13,00:03:00,68			
6	20,2017/08/13,00:04:00,67			
7	20,2017/08/13,00:05:00,67			
8	20,2017/08/13,00:06:00,67			
9	20,2017/08/13,00:07:00,66			
10	20,2017/08/13,00:08:00,69			
11	20,2017/08/13,00:09:00,66			
12	20,2017/08/13,00:10:00,68			
13	20,2017/08/13,00:11:00,70			
14	20,2017/08/13,00:12:00,68			
15	20,2017/08/13,00:13:00,68			
16	20,2017/08/13,00:14:00,66			
17	20,2017/08/13,00:15:00,67			
18	20,2017/08/13,00:16:00,67			
19	20,2017/08/13,00:17:00,66			
20	20,2017/08/13,00:18:00,68			
21	20,2017/08/13,00:19:00,68			
22	20,2017/08/13,00:20:00,67			
23	20,2017/08/13,00:21:00,67			
24	20,2017/08/13,00:22:00,67			
25	20,2017/08/13,00:23:00,68			
26	20,2017/08/13,00:24:00,69			
27	20,2017/08/13,00:25:00,68			
28	20,2017/08/13,00:26:00,68			
29	20,2017/08/13,00:27:00,67			
30	20,2017/08/13,00:28:00,70			
31	20,2017/08/13,00:29:00,70			
32	20,2017/08/13,00:30:00,71			
33	20,2017/08/13,00:31:00,68			
34	20,2017/08/13,00:32:00,66			
35	20,2017/08/13,00:33:00,66			
36	20,2017/08/13,00:34:00,66			
37	20,2017/08/13,00:35:00,66			
38	20,2017/08/13,00:36:00,65			

**2017-08-13\_HRminData**

	A	B	C	D
1	db_id,date,time,value			
2	20,2017/08/12,00:00:00,0			
3	20,2017/08/12,00:01:00,0			
4	20,2017/08/12,00:02:00,0			
5	20,2017/08/12,00:03:00,0			
6	20,2017/08/12,00:04:00,0			
7	20,2017/08/12,00:05:00,0			
8	20,2017/08/12,00:06:00,0			
9	20,2017/08/12,00:07:00,0			
10	20,2017/08/12,00:08:00,0			
11	20,2017/08/12,00:09:00,0			
12	20,2017/08/12,00:10:00,0			
13	20,2017/08/12,00:11:00,0			
14	20,2017/08/12,00:12:00,0			
15	20,2017/08/12,00:13:00,0			
16	20,2017/08/12,00:14:00,0			
17	20,2017/08/12,00:15:00,0			
18	20,2017/08/12,00:16:00,0			
19	20,2017/08/12,00:17:00,0			
20	20,2017/08/12,00:18:00,0			
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22	20,2017/08/12,00:20:00,0			
23	20,2017/08/12,00:21:00,0			
24	20,2017/08/12,00:22:00,0			
25	20,2017/08/12,00:23:00,0			
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28	20,2017/08/12,00:26:00,0			
29	20,2017/08/12,00:27:00,0			
30	20,2017/08/12,00:28:00,0			
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32	20,2017/08/12,00:30:00,0			
33	20,2017/08/12,00:31:00,0			
34	20,2017/08/12,00:32:00,0			
35	20,2017/08/12,00:33:00,0			
36	20,2017/08/12,00:34:00,0			
37	20,2017/08/12,00:35:00,0			

**2017-08-12\_stepdata**

**Figure 2.3** A raw heart rate and step data provided by Fitbit Charge 2 in Microsoft Excel (Microsoft, Co., San Redmond, WA DC, USA).

# Chapter 3: Methods

## 3.1 Dispositional Flow and related psychological measures

The primary tools designed for discovering and examining *Flow* were intended at investigating the psychodynamic features and the variability of the incidences of *Flow*-related experiences. During the early stages of the *Flow* research studies, qualitative tools were employed, such as the *Flow* questionnaire items, which furnished rich explanations and calculations of various experiences related to *Flow* [32]. Such an instrument with its universal and subjective characteristics made it possible to describe the optimal experience.

Another medium that has been focal and extensively used in *Flow*-related research study development is the ESM [19]. This approach is a considerably interesting method since it makes it possible for the frequent measurement of a participant's activity and the relevant psychological states in a more normal diurnal setting. On the other hand, there is a major downside to this instrument as the activity has to be disrupted in order to fill in the diary-related items. In addition, it must be collected in a randomized fashion across several days due to its nature [19].

A particular research study made the preliminary effort to construct a compounded questionnaire that would eliminate some of the restrictions of the current tools and could be utilized with a central approach for special research studies [32]. As a result, the Flow State Scale (FSS) questionnaire was developed in order to measure *Flow* in specific activities mainly during sports and exercises [32]. This type of questionnaire is conducted at the end of a sport-related experiment, to reveal the sensation of *Flow* in the task that the athlete has just completed. FFS scales *Flow*-related experiences and describes their peculiar features in quantitative settings in regard to the following nine items that have been proposed by a study conducted by Csikszentmihalyi in 1990 [13]: (Item 1) The balance between skill and challenge: individuals view the situation as breath-taking or challenging but they realize that their resources are sufficient and balanced for the current circumstance. (Item 2) The association between activity and conscience: individuals' sense that they are completely immersed in the activity. During this situation, automatizations allow individuals to supply a more solid execution, without neither the realization of a sudden notion nor the realization of an attempt. (Item 3) A transparent set of purposes: obvious, clearly described, and scalable goals deduce from genuine information which considerably enhances motivation. (Item 4) Straightforward and prompt feedback: during the action, individuals obtain a timely and vivid set of feedback from the actual situation. This allows them to monitor constantly how they're performing during the activity. (Item 5) Concentration on the task at hand: precision is merely centralized on the ongoing activity. Hence, there must be no room for any unessential information. (Item 6) Feeling of control: individuals have the sensation of automatic and involuntary control. (Item 7) Absence of self-consciousness: individuals feel to be a portion of the activity they are doing. The energy derived from the psychological angle is completely centralized on the activity and individuals feel free to function without

others' opinions. Moreover, an increased sensation of *Self-Awareness* is felt. (Item 8) Alternation of time: The sensation of time in regard to *Flow* is transformed: in some instances, people feel the time is passing quickly, while in others it is viewed as slowed down. (Item 9) An experience that is autotelic: this concept is about the internal euphoria that an individual has when performing a task, regardless of the anticipated outcomes. Intrinsic euphoria appears from the administration of the task at hand, without considering the need to receive a reward in return.

The FSS is mostly considered in academic research studies as well as sports psychology [33]. The 36-item questionnaire scales nine dimensions of *Flow* dimensions in detail. The questions in this instrument are based on a 5-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5) and are commonly either operated by asking the subject to recall a particular *Flow*-related experience or as post-activity *Flow* evaluation [33]. A few sample questions are shown below:

- 1) I was challenged, but I think my skills would let me meet those challenges.
- 2) My attention was focused completely on what I was performing at that time.
- 3) I was really pleased with the experience.
- 4) I felt I was worthy enough to meet the high demands of the task.
- 5) I was not worried about how I was presenting myself.
- 6) My skill and the challenge were at an equally high level.
- 7) I performed things automatically without thinking.
- 8) I have a feeling of self-consciousness.
- 9) Even though the goals are challenging, they are clear and reachable.

To improve the quality of the *Flow* measurement method, Jackson and co-authors have also designed another questionnaire that, instead of evaluating *Flow* in the here-and-now situation, can measure the preparedness and pre-disposition of individuals to discover *Flow* as a constant representation of their personality. This instrument is called the Dispositional Flow Scale (DFS) [27]. The ultimate versions of DFS and FSS have been released by a research study conducted in 2008 [27]. Both instruments were legitimized in two versions: short and long. Thirty-six questions are available in the long version, portioned equally based on nine items defined by Csikszentmihalyi [13] while the short version is composed of nine questions, representing one question per item. Over the last decade, both DFS and FSS measurements have been validated and provided in various languages. In addition, they were employed in a variety of cultural grounds, particularly with samples taken from the sports sessions [32]. Such research studies revealed the cross-cultural reliability and practicality of the questionnaires. There were also other studies that exclusively utilized DFS in other types of experiments, such as study, outdoor activity, and online gaming, showing that this scale can be used for situations other than sports.

Since its initial making, FSS has been adjusted to increase its sufficiency to scale particular dimensions, resulting in the shorter version of FSS, also known as FSS-2 as well as the Dispositional Flow Scale (DFS). In our research, we used a shorter version of DFS (DFS-2) which measures *Flow* using a 4-item questionnaire based on a 7-point Likert scale [34]. All three of the instruments hold up considerably well as psychometrically authentic and trust-worthy *Flow* questionnaires [33].

The purpose of our research study is to first investigate the psychometric characteristics of the Japanese version of DFS and to propose a unique method that can be helpful both in cross-cultural experiments as well as in research studies related to the development of healthcare systems for the evaluation of both physical and mental soundness with the introduction of physiological parameters of heart rate rhythm. We are also measuring other psychological measures such as *Trait-Coping*, *Self-Image*, *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* based on the dispositional scaling methods that were specifically designed for each psychological measure. Another purpose of this study is to show that dispositional questionnaires, which are mainly used for psychological studies during sports, are also beneficial to be applied in other areas of research especially when planning to measure the subjects' various psychological tendencies during a day regardless of what activity they are performing. For these very reasons we were significantly precise in the translation of the questionnaire items from Japanese into English, and we utilized a considerable number of Japanese employees for the validation procedure.

### 3.1.1 Frequency of Flow Experience

The *Frequency of Flow Experience* was used as the dispositional *Flow* scale to measure how often participants experience *Flow* during daily activities [35]. This dispositional measure was proposed by Csikszentmihalyi [35, 36] who originally introduced the notion of *Flow*, and has been adequately validated. The measure has been widely adopted in *Flow* studies [34, 37–39]. The questionnaire consists of four questions, asking how often a participant experiences one of four types of typical *Flow* states. The answer to each question is rated on a 7-point Likert scale from 1 (several times annually) to 7 (several times daily). The measure of *Frequency of Flow Experience* is obtained as the average score of the four questions.

Psychological *Flow* takes the positive mental state of being thoroughly absorbed, concentrated, and involved in an activity at a particular time, as well as deriving pleasure from being involved in that activity. Being involved can be described as a state of concentration in which an individual is completely absorbed in a task. The concept of the *Flow* state, also known as being “in the zone”, was first described and popularized by Csikszentmihalyi in one of the earliest points of *Flow* research [35]. This concept became of interest to Csikszentmihalyi as a positive psychology scholar when he was checking the creative process during the 1960s. Watching artists at their job, Csikszentmihalyi became curious by their single-minded, unique concentration, and tenacity to continue with the dancing, painting, or musical play, despite any inconvenience, exhaustion, hunger, and boredom. It turned out that the *Flow* experience was brought about by two major key things: purpose and feedback [35].

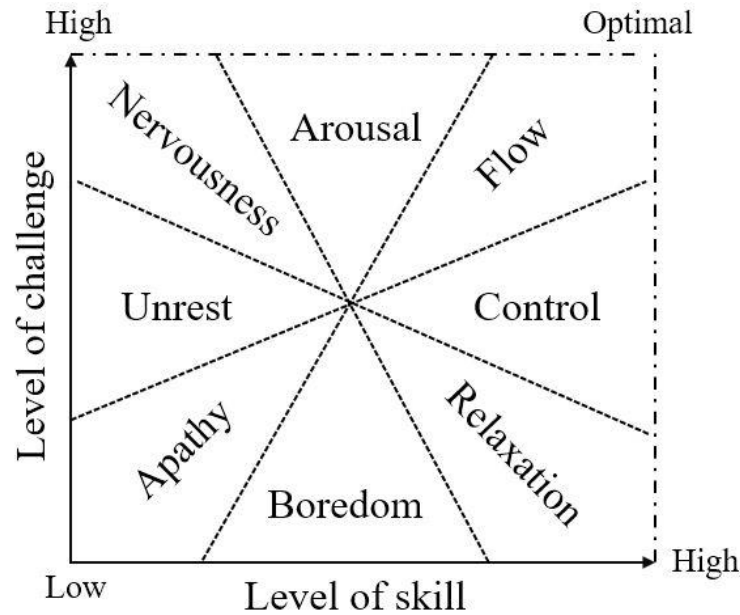
First, an optimal state of *Flow* was developed when individuals coped with challenges that they figured out to be at only the right level of severity for their actual skill sets. Simply put, the challenges were neither too difficult nor too simple as to be boring. Second, they had unequivocal short-term goals and gained immediate feedback on their improvement. This helped them to be informed of their actual progress and allowed them to change their actions accordingly. Throughout the whole experience, people considered *Flow* as an extremely enjoyable state of mind. They were pleased for being in control of the task at hand mainly due to the continuous feedback they acquired [40]. It can be said that they realized whatever they were performing to be considerably rewarding. In reality, the feeling of reward and happiness is associated with the *Flow* experience even though the activities that people do to enter this state might be different.

Naturally, the next stage of fondness for positive psychologists became how the Flow state could be made, controlled, and perceived in relation to other characteristics of the self that let people prosper. The concept of *Flow* became interesting to positive psychologists already looking at feelings, performance, ingenuity, purpose orientation, attention, and motivation. In addition, *Flow* has been viewed as a great part of modifying the human experience for its role in *Will for Meaningful Life* [17]. This is a life in which people use their virtues and capabilities for something much bigger and spend less time being anxious about the mundane and invalid things. Perceiving how to feel the *Flow* experience, and keep it, hence, is considered a significant way to be pleased about engaging activities.

The *Flow* state is often described autotelic experience. An experience is called autotelic if it is enjoyable and significantly motivating [34]. To easily understand *Flow* as an autotelic experience, it is better to look at the nine dimensions of the *Flow* state developed by Csikszentmihalyi. According to Csikszentmihalyi, *Flow* experience includes the meaningful examples in life that make it worth living and enjoyable. Humans can enrich their lives by getting involved in things they love doing. In other words, instead of doing boring tasks, or getting tired by over-complex challenges, doing the things they highly enjoy within the *Flow* zone allows them to enter into a meaningful life. There is also another term called autotelic personality which is sometimes used to highlight distinguished potency to experience *Flow* at work. Compared with other research studies about the concept of *Flow* [37–39], measuring *Flow* at work is considered less popular and there are a few research studies about it. Basically, an autotelic personality explains the propensity of people to engage in tasks for reasons relevant to internal motivation. As a result, those individuals may derive more pleasure from the activity itself instead of being driven by a future goal, and simply be able to concentrate on an activity without much effort at hand [20].

In the Flow Experience Model, there are eight different zones as shown in **Fig. 3.1**. The main dimensions to pay attention to can be seen in the axes of the chart—understanding the balance between skill and challenge. When these two are at an optimal-high level, conditions are suitable for feeling the *Flow* state. The description of each dimension is as follows: (Apathy) there is no interest, people are apathetic. (Boredom) people are bored and maybe run-down. (Relaxation) people have a feeling of calmness, but also lack of excitement. (Unrest) if peoples’ focus is on worry, their problems grow and become harder. (Control) – people have a feeling of dominance. Their activity is hard, but they are in command of the situation. (Nervousness) – if people are anxious, they may freeze or shut down. (Arousal) in this state people approach their surroundings more attentively. (Flow) people focus completely on the task or activity, leading to the most successful results.





**Figure 3.1** Flow experience model.

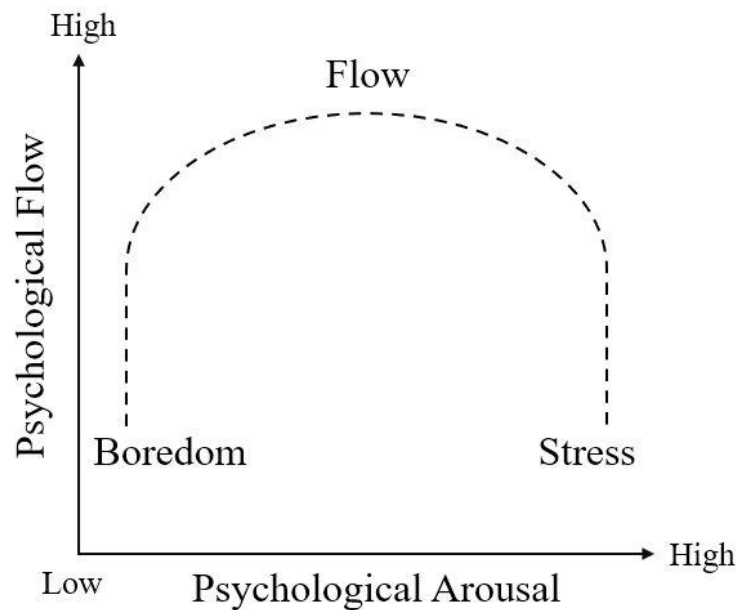
Experiencing the *Flow* state of mind can be performed in various ways, and everyone has different triggers and tasks that they are quite skilled in or love doing. The triggers which *Flow* can be driven from are mainly (1) Psychological (deep concentration, obvious goals, instant feedback, and skill-challenge balance), (2) Environmental (rich surroundings and deep visualization), and (3) Social (serious focus, oriented and shared goals, communication, and creativity). The benefits of *Flow* are increased creativity, skill development, improved performance, greater motivation, happiness, and fulfilment. Popular physical activities to feel *Flow* are playing a musical instrument, doing yoga, swimming, jogging, and mountain climbing. People who have experienced the state of *Flow* reported the following cases:

1. I appreciate the *Flow* state because it encourages me to deal with challenges in a unique way.
2. *Flow* allows me to experience like I am at one with my surroundings.
3. Allows me to share wonderful moments with others.
4. I often find myself in this state when I am alone.
5. I enter the *Flow* state when I focus on something deeply.
6. I feel *Flow* when my heart beats faster or adrenaline is pumping.
7. *Flow* happens when everything around me is beautiful and without effort.
8. I lose myself in the activity as hours pass by.

When it comes to exercises, sports, or doing tasks at the office, the comprehension of the actual mental state, skills, challenges, and performance are all associated with *Flow* theory. To deal with the negative characteristics of performers and workers' experiences, such as stress and anxiety, many psychologists have been centralizing their attention around the positive conditions that can improve performance during

sports or work activities, and therefore, *Flow* is considered one of the solutions [40]. In a detailed experiment on the predictive features of *Flow* on athletes' performance, there are two major factors: the balance between the realized difficulty of the sports activity against the performer's realized skill set, and the existence of clear, and oriented goals. When it came to workers enjoying the activity itself, it is significant that they become completely immersed in an autotelic experience to further increase their pleasure and productivity. It can be said that task-oriented office workers are more likely to have a more positive experience in terms of *Flow* dimensions which generally leads to a greater sense of focus and control over certain work-related activities.

According to **Fig. 3.2**, if people are too bored, they cannot enter the *Flow* state because their arousal level is not high enough. Conversely, if they are anxious or stressed for whatever reason, it means they are in an over-aroused state and again the chances to get into the *Flow*-state are quite low. Practically, it seems that performance anxiety and being in the *Flow* state can exist simultaneously. *Flow* proneness (the ability to get into *Flow*) is associated with lower levels of performance anxiety. This also makes sense. In *Flow* state, musicians experience a smaller number of disturbing thoughts. So, they sense stage fright less frequently as well as less intensely.



**Figure 3.2** The relationship between Flow and physiological arousal under stress.

### 3.1.2 Trait-Coping

*Trait-Coping* refers to one's capacity to reconcile with and persevere in the face of stressors [41]. A Japanese *Resilience* scale was used to measure participants' psychological *Trait-Coping* [42]. It consists of 21 questions rated on a 5-point Likert scale, ranging from 1 (not applicable) to 5 (true). *Trait-Coping* and four other *Flow*-related measures; *Self-Image*, *Self-Awareness*, *Will for Meaning Life*, and *State-Trait Anxiety*, were selected from Comprehensive List of Psychology Measures I, II, V and VI [43–46]. The book series includes more than 300 psychology measures validated by rigorous criteria of reliability and efficiency. The books are widely recognized by the psychological research community. The *Trait-Coping* scale has also been validated by another study [47].

The term coping or resilience is sometimes mentioned on its own to show overall coping and adjustability to the situation, but it can be broken down into four different categories: (Psychological Coping) This is about the ability to adapt to challenges, stressors, and uncertainties mentally. It is often referred to as Mental Resilience or Mental Coping. Individuals who demonstrate psychological resilience build up coping skills and abilities that allow them to stay calm and concentrate during hardship and continue moving forward without thinking about long-term negative outcomes too much. This version of coping was adopted in this research study. (Emotional Coping) There are different grades of how well an individual copes emotionally with catastrophic events. For instance, some individuals are sensitive to change by nature which may unleash a flood of emotions. People who are emotionally resilient realize what they are experiencing or feeling. They utilize a sense of pragmatic optimism which may help them to be proactive in using both inner and outer resources. This allows them to manage stressful situations effectively and control their emotions to stay positive and healthy. (Physical Coping) This is about the physical body's ability to adjust itself to challenges and maintain increased strength and stamina to recover fast. It mainly happens when a person recovers from disease, accident, or some physical solicitations. This kind of resilience plays a significant role in healthy aging since individuals usually face physical stressors and medical problems during life. Building up physical coping is possible through making good connections with others, deep breathing, participating in enjoyable activities, having a healthy lifestyle, and spending time for recovery. (Community Coping) This type of resilience refers to the ability of several individuals within a group to tend to and recover from a stressful situation such as an economic crisis, violence, and natural disaster within the community. It involves connecting with other people and working together in order to solve problems and overcome difficulties that may have an impact on people both individually and collectively.

*Trait-Coping* is considered as the process and result of prosperously adapting to hardships or challenging life events, especially through passionate, mental, and behavioral flexibility as well as adaptation to both internal and external demands [14]. A challenging life event or stressor can be basically the death of a loved one, financial problem, divorce, disease, loss of job, and natural disaster. There are a number of key factors which contribute to how well individuals adapt to difficulties such as the ways in which they see and engage with the world, certain coping techniques, and the quality and accessibility of social resources. Psychological research studies demonstrate that the skills and resources related to the

more positive adjustment, in other words a greater sense of resilience, can be promoted and rehearsed which ultimately leads to greater response and performance [41]. It can be said that *Trait-Coping* is some kind of psychological quality that let some individuals be affected by the stressors of life and come back at least as powerful and solid as before. Rather than allowing hardships, stressful events, or failures to overcome them and pull out their purpose or intention, extremely resilient individuals discover a way to change the course of action, emotionally meditate, and continue moving toward their purposes.

Traumas and hardships do not necessarily make people less resilient. In fact, people who have experienced trauma at some point in their lives can be often highly resilient. However, in some instances, traumatized individuals may often bring up malformed and abnormal coping techniques such as drug use that can have a negative effect on them and as a result, undermine their capabilities to cope with future hardships. There are several factors that can define *Trait-Coping* such as luck, experiences at the early stages of life, and genetics [48]. These factors cannot be modified but there are some particular coping-development techniques that can be learned such as finding the benefits in life, past challenges and failures as well as stopping negative thoughts through different cycles of life. Psychological resilience is not a constant trait. Tenacity, adjustability, and flexibility can aid people to enter this mental state by changing specific behaviors and thoughts. There are basically five factors that can describe *Trait-Coping*: acceptance, acknowledgment, sympathy, forgiveness, and meaning [41].

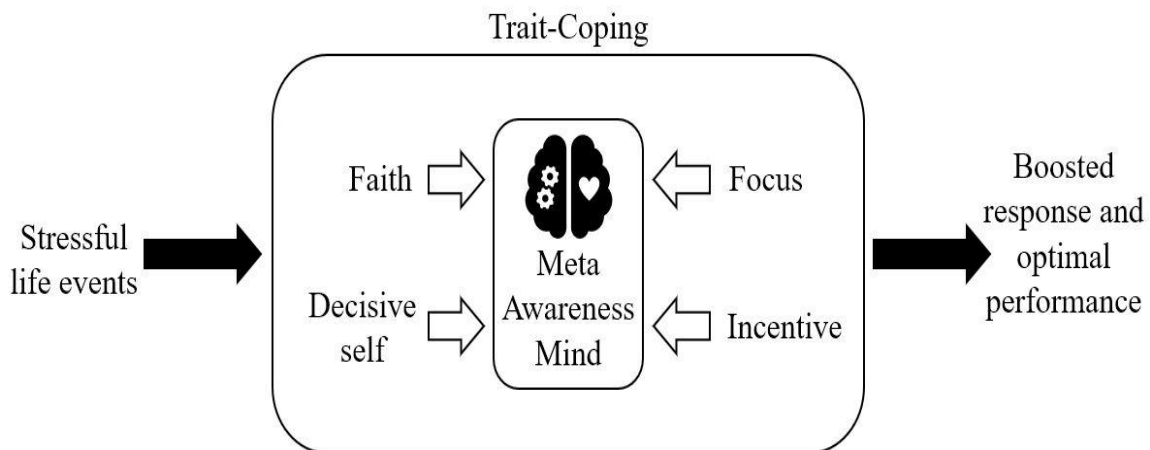
Building *Trait-Coping* is both complicated and personal. It consists of a combination of internal resistance and external resource. All individuals are different, for example, one person might develop symptoms of sadness or anxiety following a stressful event, while another person might not report any symptoms at all. As mentioned previously, there is a combination of factors that contribute to developing this psychological trait. In one specific research study, protective factors for young individuals at risk for anxiety, for instance, family solidarity, positive self-assessment, and pleasant interpersonal relations, were related to resilient outcomes in adolescents. While people deal with trauma and stressors in various ways, there are particular protective measures that aid in developing *Trait-Coping* by enhancing coping strategies. Such factors are:

1. **Social Assistance:** social systems that prepare support and aid in times of hardship or trauma may build up resilience in people. Social assistance can also be support from a family member, community, friend, and place of work.
2. **Pragmatic Planning:** this is the ability to make and carry out realistic schemes in order to help people meet their strengths and concentrate on achieving their goals in life.
3. **Self-Image:** a positive psychological sense of control and self-confidence in own abilities and strengths.
4. **Increased Optimism:** optimistic people usually feel more in control of the consequences. To build up optimism, it is very important to identify problem-solving steps before facing the actual challenge.
5. **Coping Strategies:** problem-solving techniques to help strengthen an individual who has to work through a stressor and overcome difficulties.
6. **Communication Abilities:** being able to communicate effectively and efficiently allows people to pursue support, organize resources, and take the necessary action. Maintaining, and strengthening

current social connections as well as finding opportunities to build new ones would be helpful as well.

7. Emotional Arrangement: the valence to administer potentially overwhelming feelings or seeking support to deal with them which may help individuals maintain concentration when overcoming a trauma.
8. *Self-Awareness*: knowing how to typically deal with a stressor is the first step toward learning more adaptive techniques. It first begins with the understanding of both weaknesses and strengths.

*Trait-Coping* is what gives people the emotional stability to cope with trauma, stressor, and difficulty. Resilient individuals use their resources, abilities, and skills to deal with challenges and work through barriers. On the other hand, those who lack this trait are more likely to feel devastated and rely on unpleasant coping strategies for example substance use, elusion, and isolation. In the study [48], it was suggested that people who had tried suicide had considerably lower resilience scores compared to those who had never tried suicide. It is clear that resilient people do experience stress and hard emotions. However, they utilize their strengths and seek support from the system or relatives to overcome difficulties and find a way through problems. Therefore, *Trait-Coping* strengthens them to accept and adjust themselves to a situation and continue moving forward. A complete model of psychological resilience includes connection, competence, confidence, character, coping, contribution, and control [41]. **Fig. 3.3** depicts that numerous psychological factors (relating to a positive personality, motivation, confidence, focus, and perceived social support) protect the individuals from the potential negative effect of stressors by influencing their challenge appraisal and meta-cognitions. These processes promote facilitative responses that precede optimal sport performance.



**Figure 3.3** A grounded theory of psychological coping/resilience and optimal sport performance.

### 3.1.3 Self-Image

Positive traits such as confidence, honor, and note-worthiness are attributed to people who develop *Self-Image* [15]. It is a measure of how much individuals appreciate and value themselves. Rosenberg's *Self-Image* scale with 10 items was used to evaluate this psychological trait [49]. Participants rated each item on a 5-point Likert scale, ranging from 1 (not applicable) to 5 (applicable). The scale of *Self-Image* has been validated by some studies [45, 50].

In the field of psychology, the word *Self-Image*, also known as Self-Esteem, Self-Regard or Self-Report is used to describe an individual's overall subjective feeling of personal worthiness or value. In other words, it may be defined as how much people appreciate and like themselves regardless of the situation. Many factors are responsible for defining *Self-Image* such as self-confidence, identity, sense of security, belonging, and competence. *Self-Image* tends to be the lowest amount possible during childhood and it gradually increases during adulthood, ultimately reaching a considerable amount. There are many reasons why *Self-Image* is very important. It can have a great impact on decision-making skills and improve emotional wellness as well as overall health. It also can have an effect on motivation which helps people to positively view themselves and understand their capabilities when taking on challenges. Usually, people with a healthy amount of *Self-Image* have some characteristics such as a firm comprehension of their actual abilities and skills, being able to have a healthy and stable relationship with other people, having expectations that are suitable and realistic, and understanding their needs and be able to discuss them.

Individuals with low *Self-Image* tend to doubt their skills and may be unsure about their decision-making capabilities. They may not be motivated to attempt new things because they don't think that they're qualified for achieving their goals. Moreover, they may have problems with relationships and discussing their needs. Gradually, they are going to lose self-confidence and feel they are not worthy. *Self-Image* should be at an optimal or healthy level. For example, people with an extremely high amount of *Self-Image* may overestimate their skills and may feel entitled to succeed, even without the skill to back up their thoughts and beliefs. They may also have difficulties in their relationships with others and deny themselves personal improvement since they are almost certain to see themselves as perfect human beings.

Only with an optimal level of *Self-Image* people can be motivated and work toward reaching their goals. Such individuals can set boundaries in their relationship, keeping it healthy with others. In general, *Self-Image* can be affected by age, disability, genetics, disease, physical skills, and social status. It is also suggested that racism and discrimination can negatively affect *Self-Image* [15]. Factors related to genetics are considered a major factor to shape an individual's personality but experiences during life are also important for *Self-Image*. For instance, people who frequently receive negative and critical judgments from their family members or friends, are most likely going to experience a low amount of *Self-Image*.

Detailed characteristics of people with a low *Self-Image*:

1. They may think or believe that others are better than them.
2. They may find it difficult to express their needs.
3. Focusing on their weaknesses all the time.

4. Constantly experience fear, anxiety, and doubt.
5. Lack of control over life.
6. Severe fear of failure.
7. Having difficulties accepting positive feedback from others.
8. Lack of confidence.
9. Feeling extreme depression and anxiety.
10. Having suicidal thoughts.

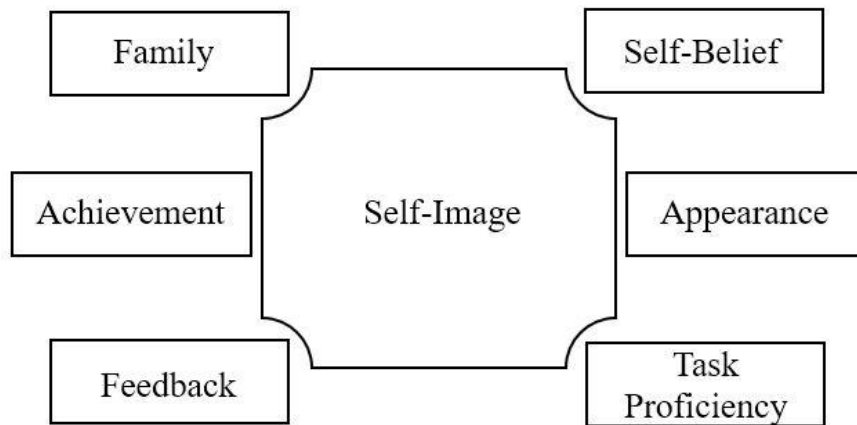
Detailed characteristics of people with an excessive *Self-Image*:

1. May concentrate on being right all the time.
2. May think they must not fail.
3. Are preoccupied with being a perfect individual.
4. Believing that they are better than others in terms of skills or abilities.
5. Inability to accept criticism from others.

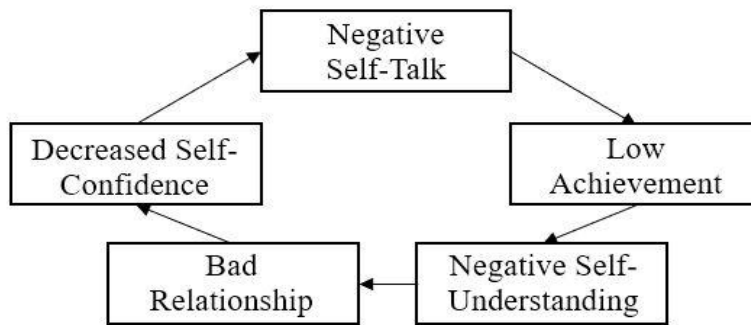
Detailed characteristics of people with an optimal *Self-Image*:

1. Avoid thinking about past bad experiences.
2. Believing that they are equal to everyone.
3. Expressing their needs and opinions clearly.
4. Have the self-confidence to make decisions.
5. Have a positive view of life.
6. Have realistic expectations.
7. Maintaining secure and honest relationships.
8. Accepting their strengths and weaknesses.
9. An accurate view of oneself.
10. More resilient, be able to counter stress and setbacks.

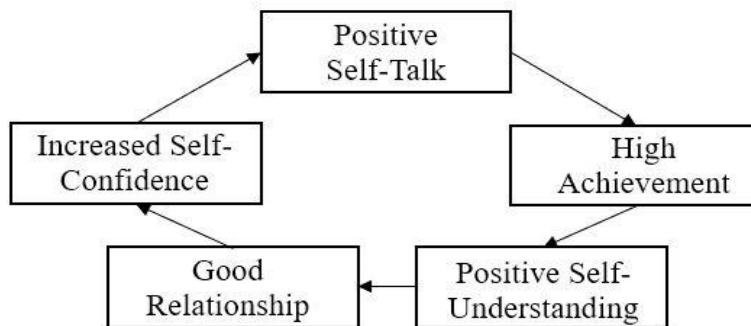
There are several ways to address the problems with *Self-Image* and be able to improve it over time. Individuals should become more informed about negative thoughts and beliefs. It is also important to counter negative patterns of thinking by having realistic and positive thoughts. In addition, practicing self-talk and self-compassion can be useful in improving *Self-Image* by reciting positive affirmations, learning from past mistakes, and moving forward with a new plan.



**Figure 3.4** Factors influencing Self-Image.



(1) Low Self-Image



(2) High Self-Image

**Figure 3.5** Cycles of low and high Self-Image trait.



### 3.1.4 Self-Awareness

*Self-Awareness* reflects confidence in the ability to control one's own social environment, motivation, and manners, and increases the desire for achievement [16]. Consequently, people can effectively perform necessary actions if they have faith in their ability to face challenges. The trait *Self-Awareness* scale which consists of 23 questions rated on a 5-point Likert scale from 1 (I do not think so) to 5 (I think so) was used [51]. The scale of *Self-Awareness* has been validated by some studies [43, 52].

*Self-Awareness* or Self-Efficacy is referred to individuals' belief in their ability to be successful in a certain situation. It basically determines how they think, behave, and feel. *Self-Awareness* can play a major role in not only how people feel about themselves, but whether or not they accomplish their goals in life successfully. The concept is closely related to the concept of social cognitive, which focuses on the role of learning through observations, social experience, and mutual determinism in personality development. *Self-Awareness* is considered an essential part of the self-system containing a person's orientation, cognitive skills, and abilities, allowing them to understand different situations and behave in response to those situations.

According to the study [16], *Self-Awareness* is the belief in one's abilities to arrange and perform the courses of action necessary to manage futuristic conditions. It can have an effect on everything from psychological states to motivation and attitude. In addition, it determines what goals people choose to follow, how they go about reaching those goals, and how they reflect upon their own performance on the way. Implicitly all individuals can identify goals they want to reach as well as things they would like to modify in life. On the other hand, most of them may also perceive that putting their plans into action is not quite as easy as they expected it to be. An individual's *Self-Awareness* plays a key role in how goals, activities, and challenges are approached.

Characteristics of people with a low *Self-Awareness*:

1. Avoiding challenging and difficult activities
2. Thinking that challenging tasks are beyond their skills
3. Focusing only on negative outcomes
4. Quickly lose confidence in their own personal capabilities
5. Giving up fast
6. Having extreme feelings of depression and anxiety
7. Less resilient individuals overall

Characteristics of people with a high *Self-Awareness*:

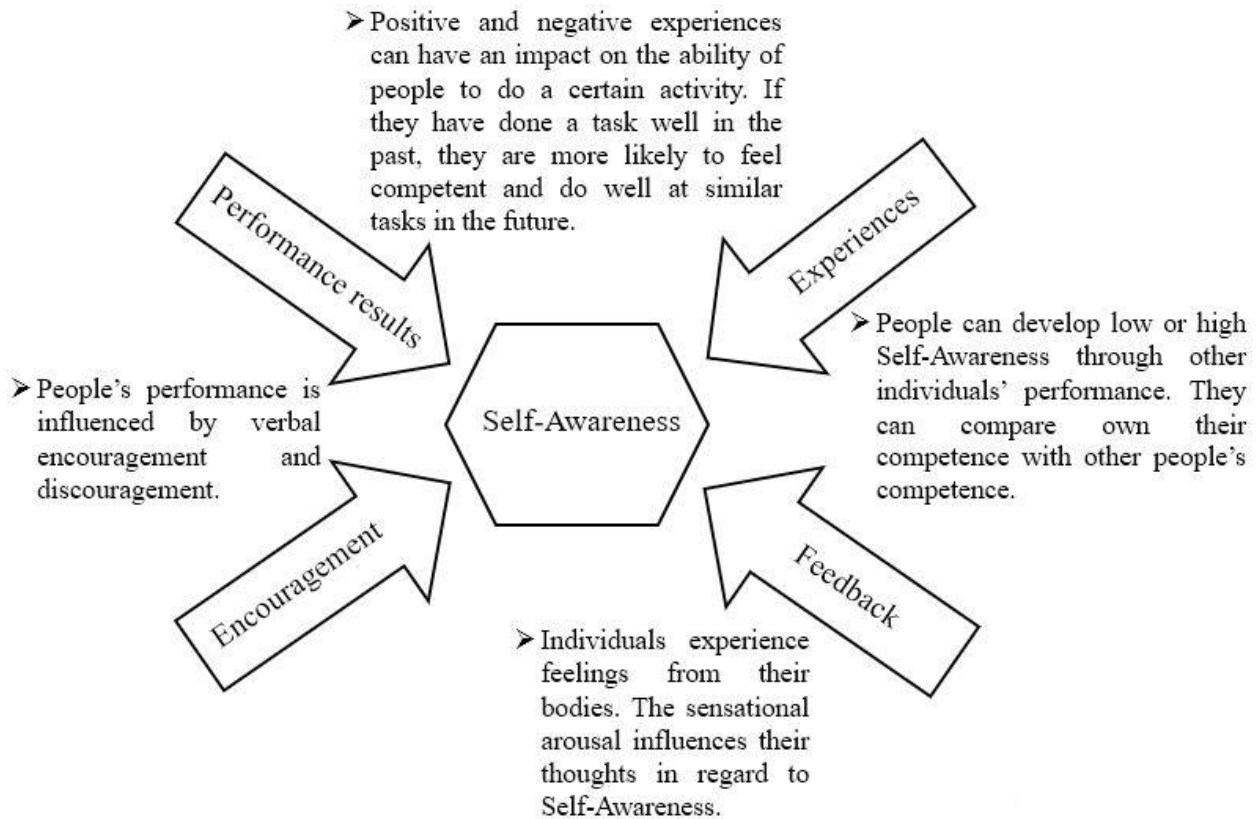
1. Developing a deeper enthusiasm for the tasks they participate
2. Forming a strong and steady sense of commitment to their tasks
3. Quickly recover from setbacks and failures
4. Considering challenging tasks as opportunities to be mastered
5. Improving their health by working hard and following recommendations

*Self-Awareness* also plays a significant role in health psychology and how people maintain their wellness in regard to nutrition and disease. For instance, having a strong sense of *Self-Awareness* trait can

aid people to stick to their plans when trying to quit cigarettes [43]. Controlling a weight loss, managing severe pain, giving up alcohol drinks, showing commitment to an exercise schedule, and following a healthy diet can all be affected by an individual's levels of *Self-Awareness*. Since people with a good level of *Self-Awareness* look at hardships as challenges instead of threats, they tend to be more naturally interested in the activities they follow. These individuals believe that difficulties and failures don't necessarily mean defeat and therefore, they increase the number of their endeavours and seek new ways to overcome.

People start shaping their sense of *Self-Awareness* during childhood by dealing with a wide range of experiences, activities, and conditions but the growth of *Self-Awareness* does not end during young age but rather continues evolving throughout personal life as individuals gain new skills, experiences, and thoughts. It can be identified from the several sources: (Mastery Experience) This is perhaps the most effective and efficient way of a strong *Self-Awareness* development. Doing activities successfully makes the sense of *Self-Awareness* stronger but failure to deal with challenges can undermine it. (Social Modeling and Encouragement) Seeing other people performing and completing a task successfully can build a strong sense of *Self-Awareness*. By doing so, the observers may think that their skills are equivalent to the performer's abilities and hence, it makes them think that they have the necessary capabilities to complete the task and succeed. Receiving positive feedback from others helps individuals to overcome doubts and fully concentrate on the task at hand. (Psychological Response) Peoples' responses and emotional reactions to circumstances also be important in developing a sense of *Self-Awareness*. Things such as psychological moods, emotional expressions, physical responses, and stress can all have an impact on how individuals feel about their personal skills in response to a certain situation. For example, an individual who becomes extremely anxious before a public-speaking event may develop a weak sense of *Self-Awareness*. However, it is not the absolute severity of physical and emotional responses that are important but instead how they are understood and interpreted by people. By learning how to control the progression of stress and elevate psychological moods when facing a challenging event, people can reach a good level of *Self-Awareness*. (Celebrating success) Mastery experiences play a major role in the development of *Self-Awareness*. This is identified as the single most effective method to build a strong sense of self-belief. When people succeed at something, they can create a powerful thought in their own abilities. On the other hand, failures and disappointments can weaken such feelings, particularly if individuals are still in the early stages of developing a sense of personality. However, it can be said that the ideal types of successes are not particularly those that come easily. For instance, if people experience a lot of easy successes, they may find themselves giving up more easily when they finally face a failure. Therefore, working on setting goals that are reachable, but not necessarily easy is very important. (Looking for positive affirmations) Listening to positive feedback and encouragement from other individuals can also help build a strong sense of *Self-Awareness*. It is also essential to try to avoid asking for feedback from those who generally may have a negative or critical view. In general feedback from family members, friends, supervisors, doctors, and people whom an individual respects, can help increase self-confidence. It can be said that social feedback alone is not sufficient to create a sense of self-belief, but it can be a helpful war when people need a little extra encouragement in their life.

*Self-Awareness* is different from *Self-Image* and *Self-Regulation* though they all have some similar properties. *Self-Image* is considered a type of general sensation of one’s worth or value that is more focused on “being”, for example feeling that you are perfect while *Self-Awareness* is conceptualized more on “doing”, for example feeling that you can take a challenge. *Self-Regulation* is about a person’s self-generated beliefs, emotions, and actions that are shaped to have an impact on learning systematically. On the other hand, *Self-Awareness* is more related to a person’s realized and understood abilities. *Self-Regulation* is considered a strategy to achieve goals in life especially when learning is involved but *Self-Awareness* is the belief that a person has to succeed. Both *Self-Regulation* and *Self-Awareness* can be built simultaneously. **Fig. 3.6** briefly explains how to build up the trait of *Self-Awareness*.



**Figure 3.6** Factors that can contribute to the increase of *Self-Awareness* trait.

### 3.1.5 Will for Meaningful Life

*Will for Meaningful Life* is the desire for self-preservation, normally coupled with expectations for further improvements in a person's social life [17]. It can also be related to either an individual's attempt to survive or find meaningful ways to continue life. The *Will for Meaningful Life* scale was used, and it consists of 10 questions rated on a 4-point Likert scale, ranging from 1 (No) to 4 (very much so) [53]. The scale of *Will for Meaningful Life* has been validated by some studies [44, 53].

Satisfaction with life is a multidimensional topic that depends on a lot of subjective and objective characteristics such as emotional state, physical status, and cognitive function. Generally, it can be said that people with anxiety tendencies always show considerably lower degrees of satisfaction with life compared to those who are not anxious regardless of their cognitive state [17]. In addition, individuals who share their decisions and whose opinions are important for daily life decisions reported significant levels of life satisfaction. According to the study [17], various health problems demonstrated a low level of correlation with life satisfaction while personality, independent life, physical activities, and satisfaction with friends showed a high level of life satisfaction. Alongside the traditional medical goals for the identification, prevention, and treatment of medical problems, it is also important to simultaneously concentrate on the quality of life, autonomy, and functional independence in order to achieve a good level of satisfaction in life.

Amongst the factors that have an impact on the satisfaction of life in individuals are memory complaints and cognitive functions. Various research studies have shown that the spread of memory complaints among individuals ranges from 20% to 60% and is mainly associated with dementia and a low level of education which ultimately leads to having distressful life with feelings of uncertainty, isolation, fear, loss, loneliness, and worthlessness [53]. Physical activity is an important factor in determining life satisfaction. This is due to the fact that maintaining a physical function will increase individuals' capacity for moving independently, using daily tools, and performing other self-care activities to maintain health. Fulfilling such functions independently represents autonomy which is sometimes reflected in people who are studied with their lives.

Another factor that affects satisfaction with life is sharing in the decision-making and remarks of one's decision regarding his/her action toward a healthy life [53]. Making such a decision in regard to health is considered one of the most difficult processes that can greatly have an impact on satisfaction with life because it is normally accompanied by conflicting feelings such as anxiety, depression, shock, stress, fear, and resistance during life events. Reaching a considerable level of comfort with a health-related decision and maintaining life satisfaction of people with their coping and adaptation to the new environment is a very hard challenge. Hence, detailed studies and extensive knowledge are needed about these factors that are contributing to the growth of life satisfaction.

The frame of subjective well-being has been mentioned as consisting of two major components: emotional and cognitive components. The cognitive component has also been referred to as *Will for Meaningful Life* which is closely related to life satisfaction. Even though the sensual component of subjective well-being has gained a considerable amount of attention from various research studies, *Will for Meaningful Life* has been relatively neglected. It was basically designed as an instrument to measure

the cognitive component of subjective well-being. It is a well-validated, reliable, and predictive tool to measure satisfaction in life [39]. Moreover, the high isotropy of self and peer-reported scales of subjective soundness and life satisfaction provide powerful evidence that subjective wellness is a relatively universal and constant phenomenon, not just a transient judgment based on fleeting effects.

*Will for Meaningful Life* was designed to scale the satisfaction with the respondent's life in general. This measurement tool does not measure satisfaction with life domains related to health or finances but allows respondents to integrate and weigh such domains in whatever way they prefer. It also shows good convergent validity with other psychological such as *Frequency of Flow Experience* and *Trait-Coping* instruments and with other kinds of evaluations of subjective well-being [54]. It is always measured to demonstrate a degree of temporal consistency and durability with enough sensitivity to be potentially noteworthy to identify changes in life. In addition, the measurement tool shows discriminant validity from sensational well-being measures. *Will for Meaningful Life* is often recommended as a complementary tool to measure psychopathology factors or emotional wellness since it can measure a person's conscious evaluative notion of life employing the individual's own criteria. According to **Fig 3.7** ideally, individuals should look for ways to live their life in quadrant  $\beta$ , in which they are happy, and they are living with integrity. Quadrant  $\gamma$  is basically a bad zone: people may feel miserable, and they are living without integrity. Where it gets complicated is when they have to choose between quadrants  $\alpha$  and  $\delta$ . If they want to live a meaningful life, they would choose quadrant  $\alpha$ : living with integrity, even if this has negative consequences for them.

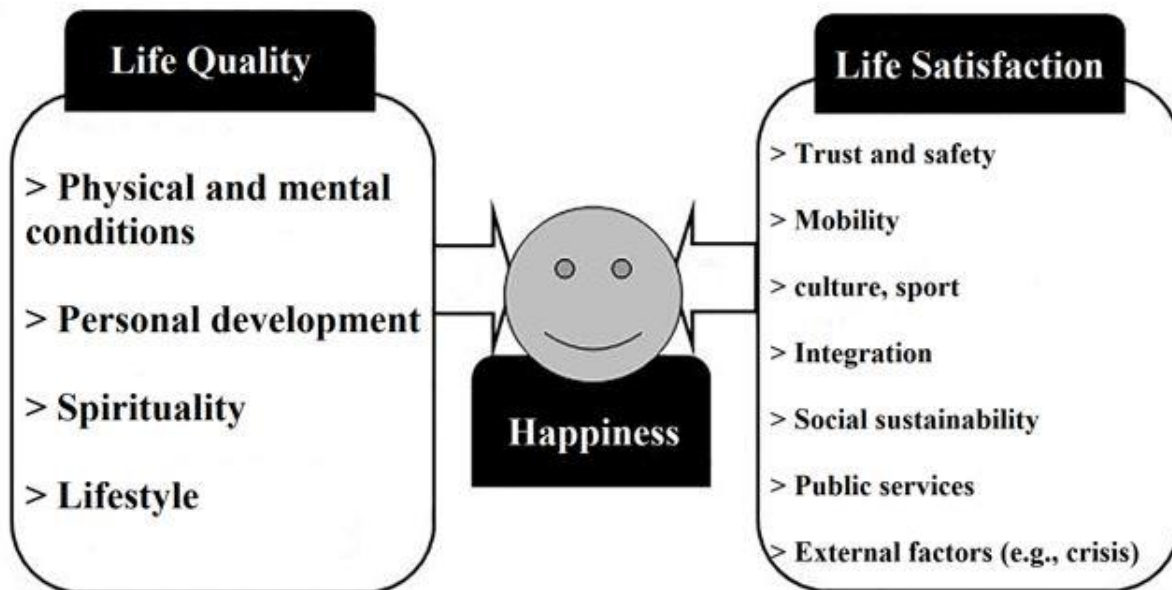
	Grief	Satisfaction
Integrity	$\alpha$	$\beta$
Psychosis	$\gamma$	$\delta$

**Figure 3.7** Quadrants of Will for Meaningful Life.

*Will for Meaningful Life* contains three basic characteristics: goal, understanding, and mattering. Having and attempting to achieve goals are considered important factors to each life satisfaction. It is also essential for people to have the belief that their existence is valuable, and they should make sense of their life events. If life turns out to be meaningful for people, then they will experience the following benefits:

1. Having meaning in their lives finally makes them healthier
2. Increased vitality and energy
3. Easily being able to cope with stressors which makes them more resilient
4. Can become more productive
5. Their self-confidence increases and makes them feel better about themselves
6. Their ability to reach the Flow state increases significantly
7. They will satisfy their human need for value
8. May have a longer life expectancy

*Will for a Meaningful Life* has coherence, significance, and purpose which can be achieved in several ways: (Making life meaningful by having a goal) Begin by identifying strengths and weaknesses, focusing on strengths, and using them in a way that will benefit oneself as well as others. (Reframe the view on occupation) Taking greater pride in occupation, having more responsibility for work-related results, being able to handle stress effectively, and being highly motivated. (Choosing friends wisely) Humans are social beings, and how they feel about themselves is often impacted by the way in which others treat them. Therefore, to have a meaningful life, it is important for an individual to surround himself/herself with people who are worthy and respectful. (Maintaining the balance between meaning and happiness) Happiness sometimes involves doing things that make the person feel good in that particular moment. However, meaningful tasks often involve making sacrifices because they are accompanied by joy and toil. The key is to discover the balance between enjoying moments and going on to reach a crucial goal despite discomforts and hardships. (Being able to express oneself) Many people pretend to be someone they are not since the pressure to fit in and adapt can be powerful. If people do not let themselves be who they are, then they cannot reach satisfaction in life. It is important for them to think of the goals they are currently focusing to accomplish. If those goals are difficult to reach, then they must be changed. It is essential that people reach a meaningful life by focusing on the goals that allow them to express who they are.



**Figure 3.8** Importance of the quality of life and satisfaction of life to reach the ultimate happiness.

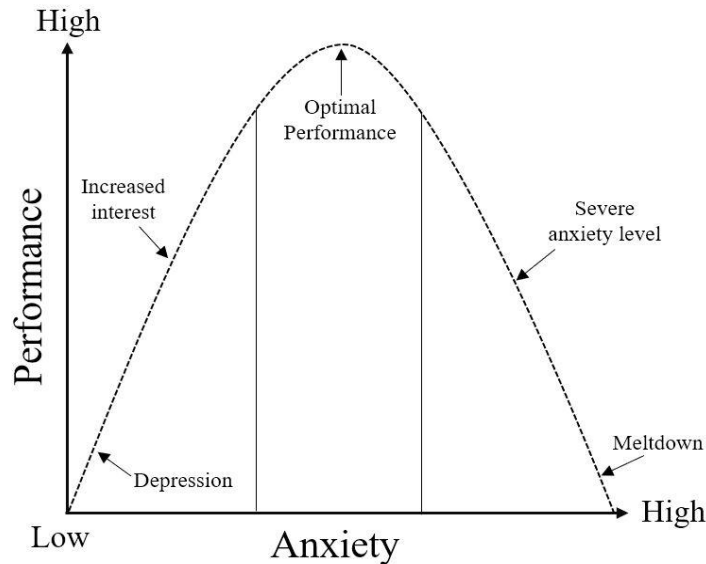
### 3.1.6 State-Trait Anxiety

A modified version of Spielberger's scale of *State-Trait Anxiety* was used to measure individuals' internal tendency to generate anxiety in stressful conditions [55, 56]. It consists of 20 items and participants rate the questions on a 4-point Likert scale, ranging from 1 (not at all) to 4 (quite so). The scale of *State-Trait Anxiety* has been validated by some studies [45, 56].

*State-Trait Anxiety* is considered both a physical and mental state of a negative outlook. Psychologists describe it as an emotion determined by feelings of tension, worried intentions, and physical changes such as high blood pressure [18]. It can turn into a mental health problem that leads to extreme nervousness, panic, and worry as well as a physical health problem through ill-sorted activation of multiple systems of the body in order to respond to an unfamiliar peril whether imagined or real. *State-Trait Anxiety* basically alters how an individual processes feeling and behaves. It can be either mild or severe, affecting day-to-day activities and it is the most common mental illness in every country, especially among young people [45].

In the middle of the curve in **Fig. 3.9**, there is “eustress”. It's the low-to-moderate amount of stress that leads to anxiety. In this context, anxiety doesn't mean a kind of erotic excitement. Rather, it's the combination of stress and motivation that propels people to accomplish a task or rise to a challenge. Some may experience it less as a strain and more as attentiveness galvanized by a crackle of positive energy. This type of good stress is a powerful engine for performance, all the way up to the very top of the chart, where people reach the optimum level. If individuals' stress tips beyond the sweet spot, they enter “distress”—a high-potency agitation that arises due to emergencies, physical threats, overly demanding work, trouble at home, or procrastinating until the do-or-die moment. While useful in an emergency when people need to act quickly, distress can degrade their performance and well-being the more acute it becomes and the longer it sticks around. Throttle down their stress, and they reach “sustress”. This is the low-potency stress they feel when for example, they have a deadline that's several weeks out.





**Figure 3.9** Relationship between State-Trait Anxiety and performance.

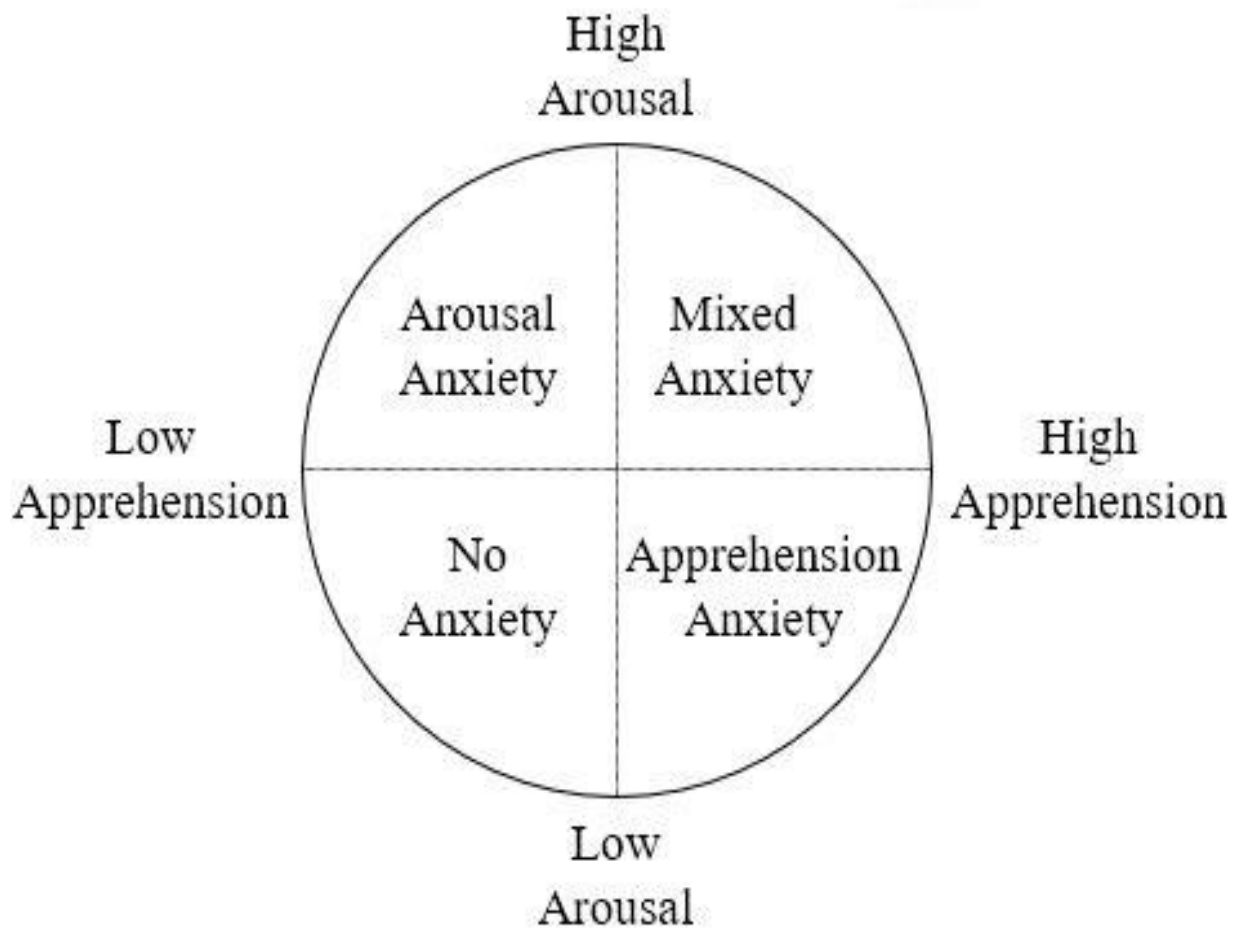
A majority of children and adolescents are diagnosed with Anxiety every year [7, 18]. One of the main reasons for the universal growth in *State-Trait Anxiety* is the burden of doubt in almost every part of modern life, in response to an array of cultural and economic changes [7]. In fact, doubt doesn't cause this negative psychological state, but instead, it furnishes breeding grounds for it. Anxiety is the body's natural response to the occurrence of stress, a generalized term for various disorders that cause anger, dismay, presentiment, and anxiousness. Such disorders have an influence on how people feel and behave. Moderate anxiety is ambiguous whereas high anxiety can seriously affect the person's overall mental state. It is crucial to understand the distinction between normal anxiety and anxiety disorder that needs medical treatment. Experiencing normal anxiety in life is normal. Ever since the earliest stages of mankind, the approach of incoming perils has set off alarms inside the body and let a person take the necessary precautions. Such alarms become notable in the form of increased heartbeat, breathing rapidly, difficulty falling asleep and excessive sensitivity such as sweating. These days, anxiety rotates around the workplace, financial, family, and health issues that require an individual's attention without particularly needing the reaction [7]. On the contrary, individuals with anxiety disorder constantly have severe, extreme, and continuous worrying thoughts and horror about events every day. Most of the time, anxiety disorder involves panic attacks, increased blood pressure, nausea, and phobia.

The causes of both anxiety and anxiety disorder aren't completely understood. Common causes can be drug misuse, alcohol withdrawal, severe pain, trauma, depression, poor quality of life, and social isolation. If both anxiety and anxiety disorders are not prevented soon enough, they will cause some catastrophic incidents such as suicidal thoughts which is a major problem in many developed counties especially in

Japan [8]. Other symptoms are restlessness, uncontrollable emotions, high irritability, difficulties in concentration, and sleep problems. Getting aid early means the person can start to get sedation and recover fast. There are some useful treatments for Anxiety, from cognitive-behavioral therapy (CBT), e-mental health tools using IoT devices to relaxation methods, and medicines [57]. Other approaches such as visiting a psychologist, doing exercises, answering questions related to anxiety, learning ways to handle challenges, and talking to family members can be influential as well.

Anxiety disorder which is caused by the increased feeling of anxiety has several types. It includes several diagnoses: (Generalized Anxiety Disorder) It is considered a severe disorder involving long-lasting feelings of nervousness and worrying thoughts. (Panic disorder) Sudden panic attacks due to intense tension or terror, usually happen due to long-lasting stress or experiencing something frightening. Such attacks can cause shaking, dizziness, nausea, and difficulties in breathing. (Specific phobia) It is an inconsequential fear and avoidance of a certain situation. A person with this type of phobia considers fear as something extreme and cannot control emotions. (Agoraphobia) The fear and avoidance of places such as leaving the house, using an elevator, or public transport. (Separation anxiety) Increased level of anxiety after separating from an individual or a place, especially those which provide a sense of security. It is often accompanied by panic symptoms. (Selective mutism) This type of anxiety is very common among children who do not want to talk in particular places such as schools, or public events even if they have excellent communication skills.

Several strategies are helpful to manage the level of anxiety: (Breathing slowly) When people are anxious, their breathing becomes quicker and shallow. These individuals should intentionally slow down their breathing to gradually decrease the level of anxiety. (Maintaining a healthy lifestyle) Being active, eating healthy foods, going out into nature, spending some time with a partner, family members, and friends, reducing the level of stress, and performing activities which are enjoyable. These are all influential in decreasing anxiety and maintaining both physical and mental wellness. (Practices to replace negative thoughts with positive ones) It is important to create a mental image of successfully facing and overcoming a difficulty as well as thinking about reachable goals to reduce anxiety. (Managing stress) Learning how to manage stress can aid in restricting potential triggers. It is essential to organize future pressures and deadlines, break big tasks into manageable sub-tasks, and commit to taking some time off from stressful activities.



**Figure 3.10** The dimensional elements leading to the formation of anxiety.

## 3.2 Physiological parameters of diurnal heart rate rhythm

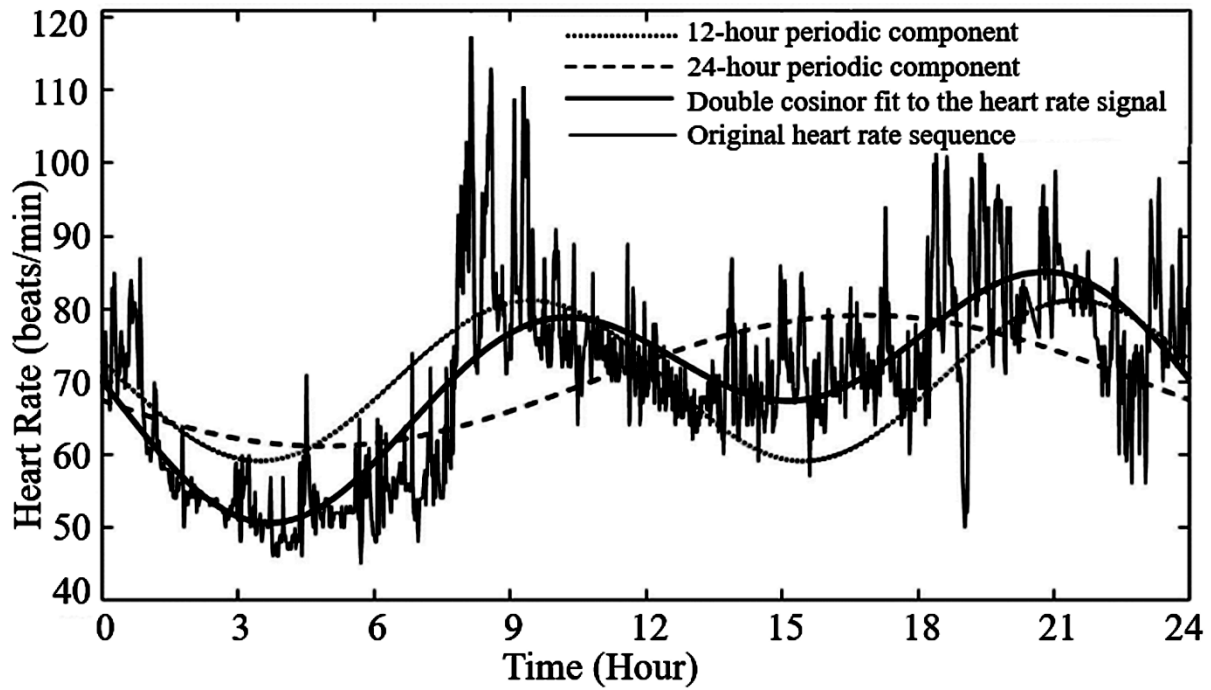
We adopted diurnal heart rate rhythms that reflect the long-term nature of autonomic nervous activities for this study. The mean and median of heart rate rhythm parameters derived from four weeks of continuous heart rate recording were used as nominal values. The heart rate rhythm parameters of each day were extracted by two conventional methods of signal processing; double cosinor rhythmometry and smoothness of splines. As a result, four physiological datasets were acquired for analysis: (G1) Average weekday only data, (G2) Median weekday only data, (G3) Average weekday and weekend data, and (G4) Median weekday and weekend data.

### 3.2.1 Double cosinor rhythmometry method

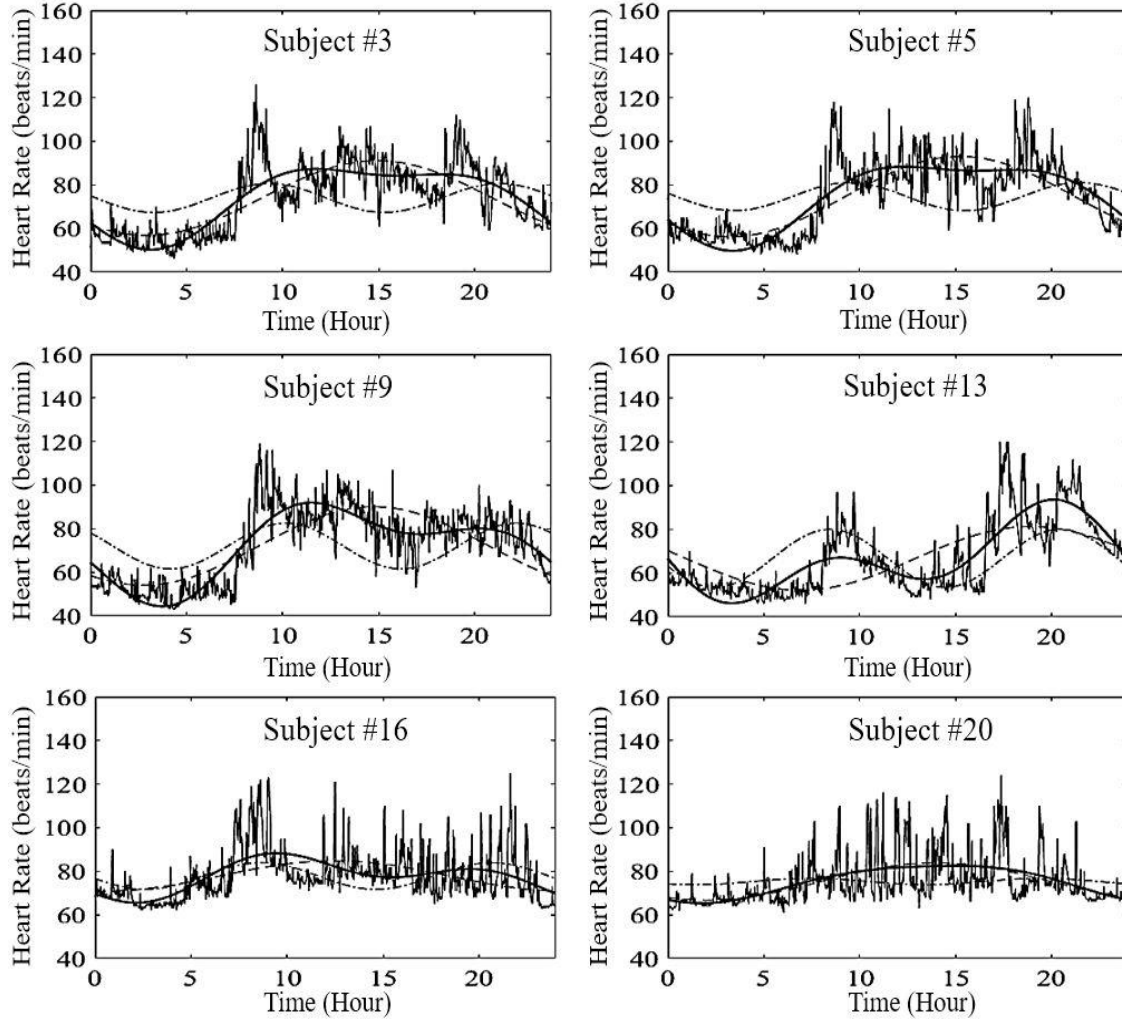
The double cosinor method was used to extract the heart rate rhythm parameters to be studied [58]. The method was applied to the heart rate sequence continuously recorded at one-minute intervals  $\Delta t$  over one day. The heart rate sequence  $H(n\Delta t)$  was fitted by two sinusoids, as shown in the following equation.

$$H(n\Delta t) = M + cA_{24} \left( \cos 2\pi \frac{1}{T} (n\Delta t - t_{24}) \right) + cA_{12} \left( \cos 2\pi \frac{2}{T} (n\Delta t - t_{12}) \right) \quad (3.1)$$

where  $M$  is the average heart rate;  $cA_{24}$  and  $cA_{12}$  are the 24-hour and 12-hour periodic component amplitudes, respectively, of the heart rate rhythm;  $T$  is the fundamental diurnal period, i.e., 24 hours; and  $t_{24}$  and  $t_{12}$  specify the phase shift of 24-hour and 12-hour periodic components, respectively. The parameters were estimated using the least-squares method to minimize residual variance. Typical examples of a fitted cosinor curve are shown in **Fig. 3.11** for a person during a 24-hour period as well as in **Fig. 3.12** for several participants.



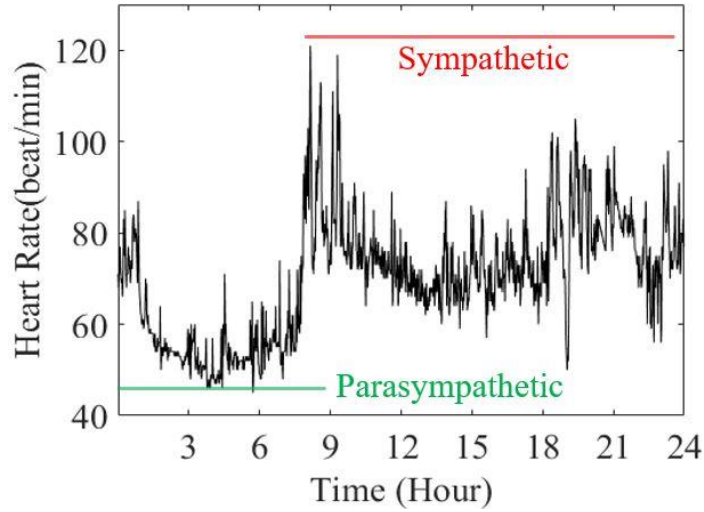
**Figure 3.11** Double cosinor decomposition of the diurnal heart rate changes. Continuously recorded heart rate time series sampled every one minute is decomposed by 24 and 12-hours periodic components into two sinusoids.



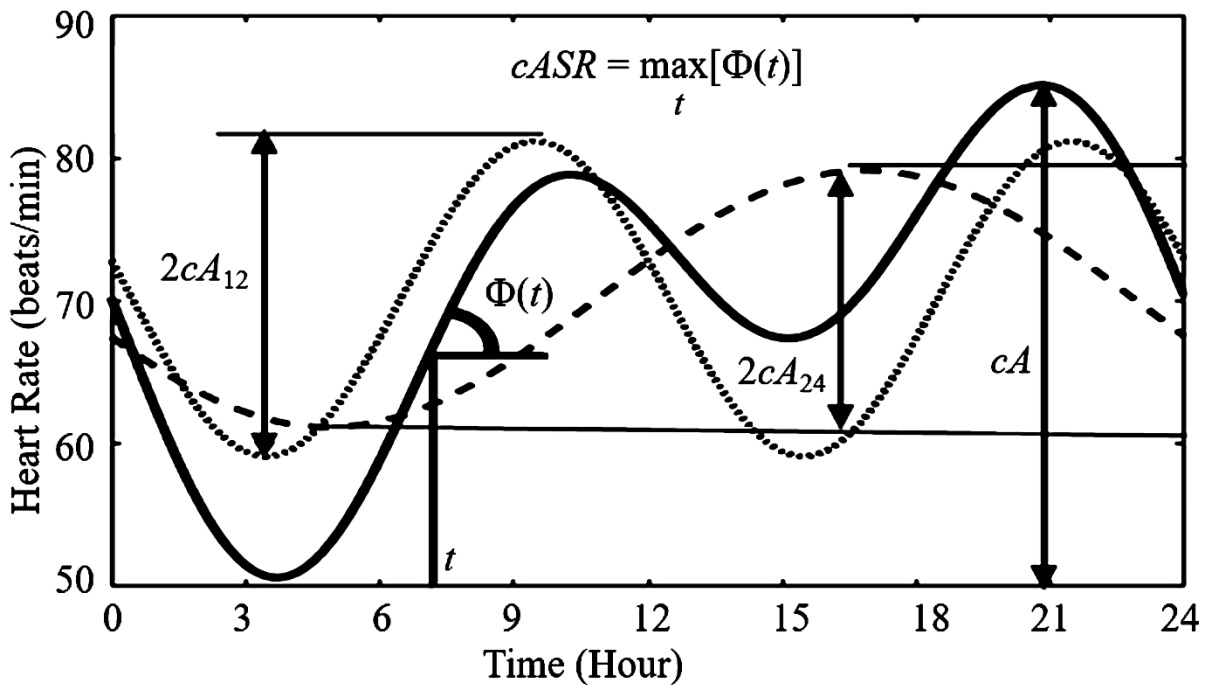
**Figure 3.12** Double cosinor parameters measurement of random participants (Thick solid line: double cosinor fit, Broken line: 24-hour periodic component, and Dotted line: 12-hour periodic component).

After applying the double cosinor fit to the heart rate sequence, two more parameters were introduced in addition to  $cA_{24}$  and  $cA_{12}$ . They were heart rate diurnal range amplitude over one day ( $cA$ ) and a newly defined parameter called the cosinor autonomic switching rate ( $cASR$ ).  $cASR$  represents the switching speed from the parasympathetic dominant state to the sympathetic dominant state as shown **Fig. 3.13**. Such state transition typically occurs when waking up in the morning. It is defined as the maximum value of the derivative of the cosinor representation of the heart rate that shows autonomic responsiveness, as shown in the following equation and **Fig. 3.14**.

$$cASR = \max_t [\Phi(t)], \quad \Phi(t) = \frac{d}{dt} H(t) \quad (3.2)$$



**Figure 3.13** Shift of the autonomic switching rate from parasympathetic state to sympathetic state.



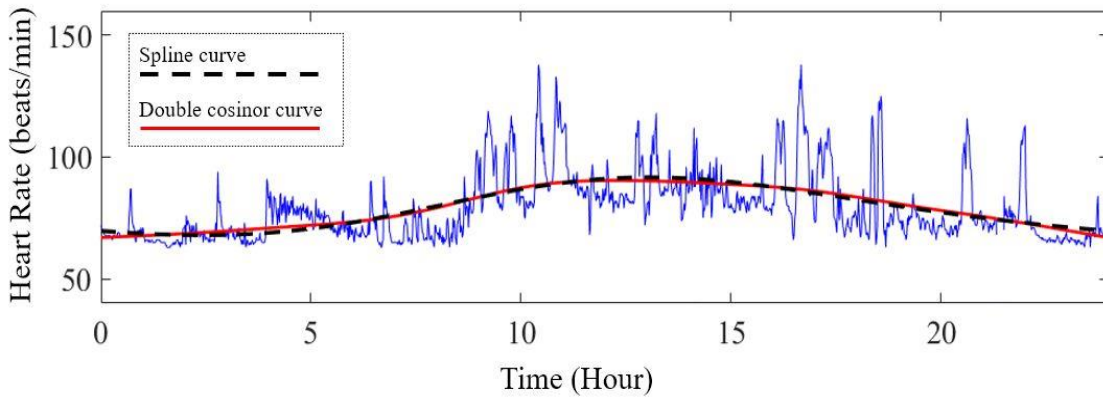
**Figure 3.14** Cosinor heart rate rhythm parameters used in the analysis. Four heart rate diurnal rhythm parameters;  $cA_{24}$ ,  $cA_{12}$ ,  $cA$ , and  $cASR$ , are extracted by the double cosinor heart rate data decomposition.

### 3.2.2 Smoothing of splines method

As an alternative to cosinor-based parameter extraction, the spline-based method was introduced [59]. The spline-smoothed heart rate signal  $s(t)$  is obtained by minimizing the following equation.

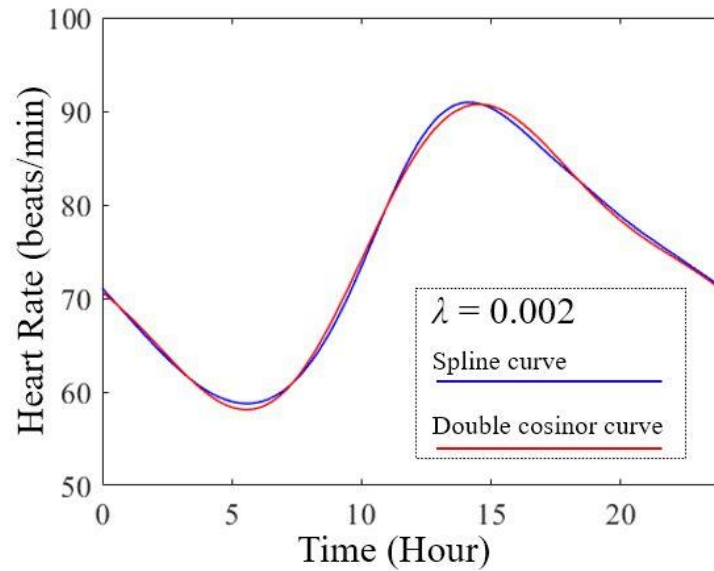
$$(1 - \lambda) \sum_n (s(n\Delta t) - H(n\Delta t))^2 + \lambda \int \left( \frac{d^2 s(t)}{dt^2} \right)^2 dt \quad (3.3)$$

where the smoothing parameter  $\lambda \in [0,1]$  specifies the balance between the smoothness and the goodness of fit. As  $\lambda$  approaches one, the weight of the smoothness; that is, the second term of the equation, increases. The parameter value was set at 0.002, which minimizes the mean square error between the spline-smoothed heart rate estimate and the cosinor curve. The cosinor-based heart rate rhythm parameters and spline-based parameters are differentiated by the respective attached prefixes “ $c$ ” and “ $s$ ”. Parameters  $sA$  and  $sASR$  are obtained as the range of spline-smoothed function  $s(t)$  and as the maximum value of the numerical derivative of  $s(t)$ , respectively.  $sA_{24}$  and  $sA_{12}$  are derived as the amplitude of the fundamental and second harmonic components of the Fourier series expansion applied to  $s(t)$ . **Fig. 3.15** shows a typical example of the fitted spline-smoothed curve. **Fig. 3.16** shows the optimal  $\lambda$  value to perfectly align the spline and double cosinor curves for the extraction of spline-based physiological parameters.



**Figure 3.15** Fitted spline curve applied to the double cosinor curve and the original heart rate sequence.





**Figure 3.16** Perfectly fitted spline and double cosinor curves.

Four techniques to acquire the optimal  $\lambda$  value is provided by this research study: figures observation, single regression analysis, multiple regression analysis, and multicollinearity analysis.

### 3.2.2.1 Figure observations

**Figs. 3.17 (a)** and **(b)** are showing the double cosinor curve (red) and the correspondent spline curve (blue) generated by five  $\lambda$  values for two participants. In **Figs. 3.17 (a)**, it is clear that  $\lambda = 0.002$  is the optimal value since both curves are perfectly fitted. However, in **Figs. 3.17 (b)**, it is complicated to determine the optimal  $\lambda$  value since there is competition between  $\lambda = 0.002$  and  $\lambda = 0.005$ . Other  $\lambda$  values can be discarded at this point.

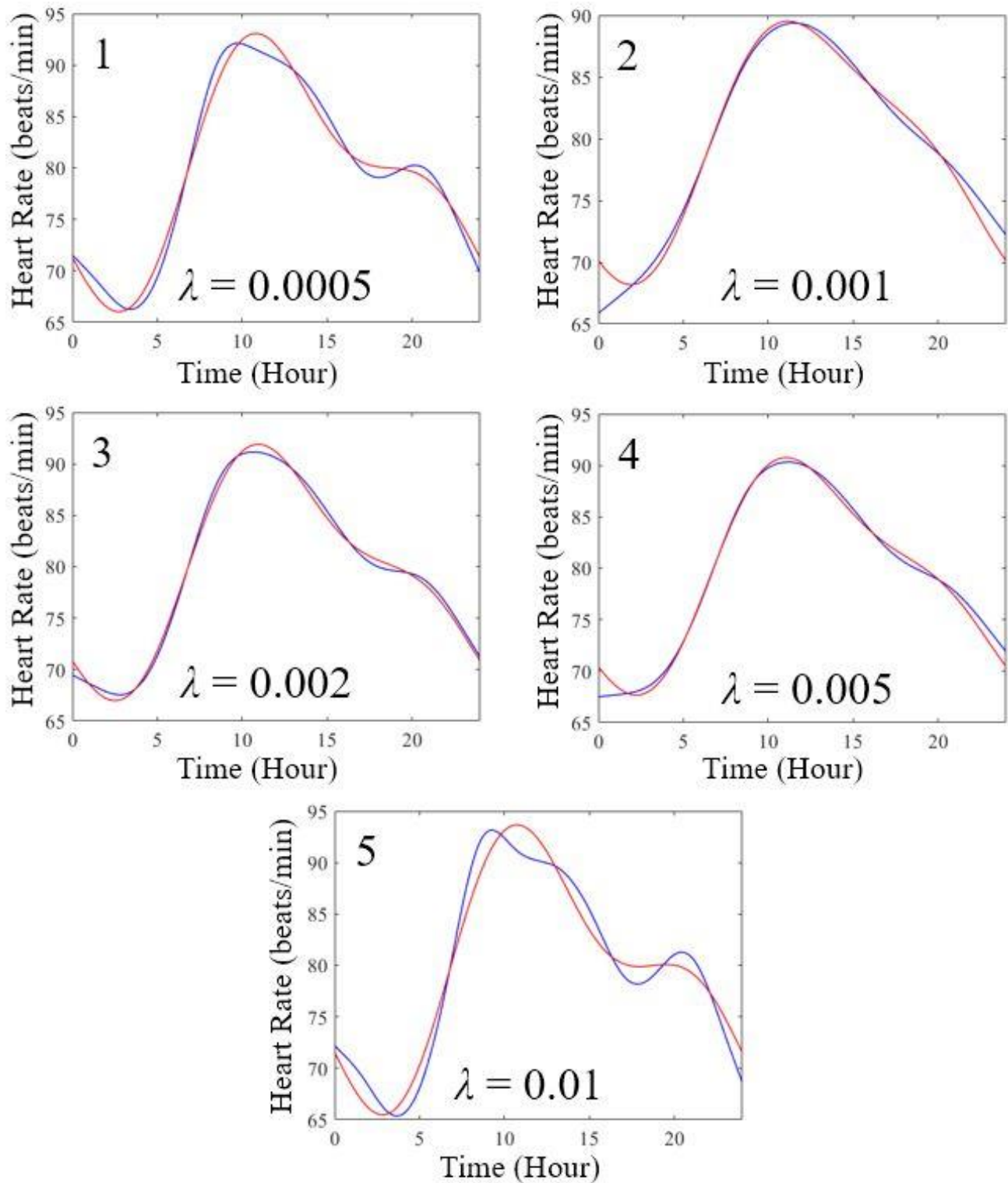


Figure 3.17 (a) Finding optimal  $\lambda$  value.

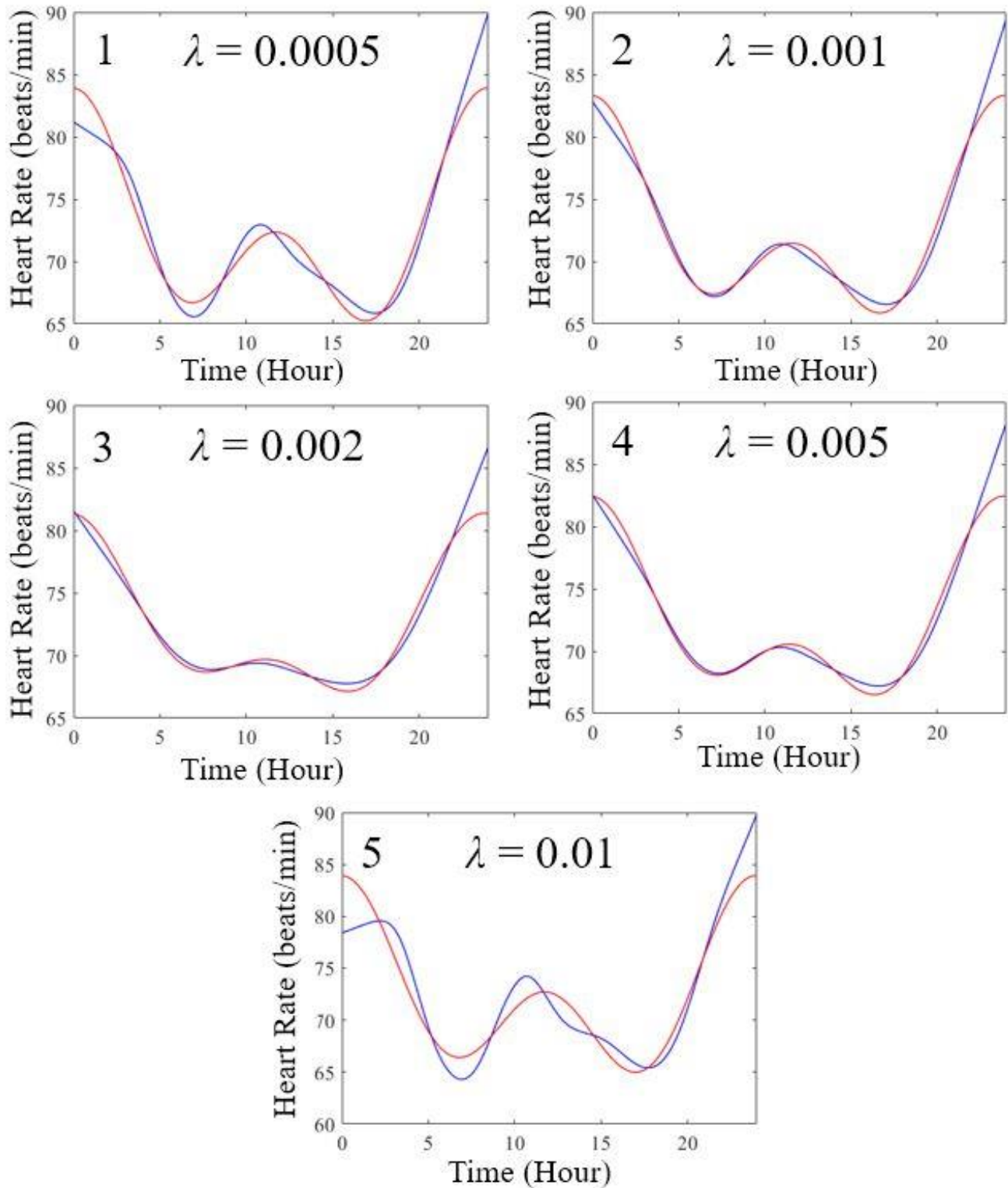


Figure 3.17 (b) Finding optimal  $\lambda$  value.

### 3.2.2.2 Single regression analysis

One way to solve the previous problem, is to extract the spline parameters from the heart rate recordings of all participants and perform a single regression analysis to investigate the correlation results between psychological measures and spline-based parameter. **Fig. 3.18** shows the scores of six psychological measures and the value of spline-based physiological parameters based on five  $\lambda$  values. As mentioned previously, we only need the dataset of  $\lambda = 0.002$  and  $\lambda = 0.005$  to perform the regression analysis methods from now on. Results of single regression are shown in **Fig. 3.19**. Four psychological measures, i.e., *Trait-Coping*, *Self-Image*, *Will for Meaningful Life*, and *State-Trait Anxiety* gave better correlation results by  $\lambda = 0.002$ .

1	2	3	4	5	6
5	53	26	60	16	57
13	89	39	92	33	40
4	71	31	81	21	40
8	72	31	77	23	65
2	61	22	62	22	59
6	63	26	91	36	47
5	71	27	59	24	54
7	44	27	67	15	54
5	55	20	46	18	70
6	83	42	85	27	32
3	48	22	57	15	56
11	83	33	68	30	45
6	73	33	69	27	50
14	82	40	88	29	38
3	73	32	68	24	64
3	64	29	73	26	47

$\lambda = 0.0005$					$\lambda = 0.001$					$\lambda = 0.002$				
Subj No.	sA	sASR	sA <sub>24</sub>	sA <sub>12</sub>	Subj No.	sA	sASR	sA <sub>24</sub>	sA <sub>12</sub>	Subj No.	sA	sASR	sA <sub>24</sub>	sA <sub>12</sub>
3	18.85	2.20	5.39	3.09	3	21.25	2.93	5.42	4.05	3	23.51	3.76	5.37	4.93
4	32.37	3.93	12.48	5.23	4	31.78	4.94	12.86	5.88	4	32.11	6.21	13.15	6.79
5	24.61	3.78	9.54	4.40	5	24.28	4.73	9.72	5.10	5	24.24	6.07	9.83	5.83
6	21.55	2.88	7.95	3.70	6	21.63	3.84	8.09	4.41	6	24.84	4.91	8.21	5.26
7	19.08	2.83	7.35	3.85	7	19.66	3.55	7.48	4.49	7	21.64	4.53	7.57	5.29
8	20.61	3.09	8.38	4.65	8	22.79	4.23	8.54	5.46	8	25.53	5.58	8.66	6.97
9	17.16	2.58	7.20	2.61	9	19.00	3.37	7.75	3.28	9	20.78	4.07	7.79	4.26
10	20.69	2.19	5.74	3.59	10	23.33	2.95	6.45	4.22	10	27.84	3.89	7.22	4.71
13	24.73	3.30	8.88	5.10	13	26.89	4.31	8.97	6.09	13	28.88	5.52	9.06	7.37
14	37.44	4.16	9.38	6.16	14	39.10	4.72	9.44	7.26	14	43.66	6.35	10.03	10.48
15	28.34	3.68	8.96	4.66	15	28.39	4.48	8.95	5.25	15	27.95	5.49	9.00	6.06
16	38.01	4.77	14.55	5.01	16	35.95	5.73	14.84	5.70	16	36.15	6.94	15.14	6.83
17	19.75	2.36	7.33	3.23	17	21.63	3.06	7.02	4.15	17	22.99	3.95	7.54	4.86
18	23.35	3.16	8.41	3.68	18	22.90	3.89	8.57	4.09	18	22.92	4.86	8.77	4.64
19	22.34	3.41	8.75	4.42	19	22.60	4.54	8.80	5.52	19	26.73	5.81	8.53	6.42
20	18.68	2.28	6.81	2.71	20	20.94	3.20	7.04	3.56	20	20.68	4.32	7.19	4.40

$\lambda = 0.005$					$\lambda = 0.01$				
Subj No.	sA	sASR	sA <sub>24</sub>	sA <sub>12</sub>	Subj No.	sA	sASR	sA <sub>24</sub>	sA <sub>12</sub>
3	25.55	5.17	5.29	5.71	3	27.71	6.23	5.65	5.98
4	34.37	8.31	13.40	7.47	4	35.68	10.18	13.52	7.80
5	27.66	8.52	9.90	6.86	5	30.97	10.73	9.93	7.46
6	25.93	6.26	8.31	6.29	6	28.61	7.23	8.35	6.86
7	24.61	6.21	7.66	5.88	7	26.66	7.64	7.70	6.51
8	29.34	7.72	8.81	8.42	8	32.12	9.41	8.88	9.04
9	20.43	5.21	8.09	5.55	9	22.31	6.33	8.20	5.99
10	31.30	4.91	7.74	5.44	10	32.28	6.24	8.16	5.84
13	30.80	7.37	9.16	8.81	13	32.38	9.06	9.21	9.44
14	44.00	7.79	9.97	9.97	14	45.17	9.83	9.96	12.17
15	29.25	7.42	9.08	7.17	15	30.85	9.26	9.13	7.88
16	38.51	8.89	15.36	7.30	16	40.55	10.75	15.44	7.99
17	25.63	5.61	7.64	5.79	17	27.27	7.17	7.68	6.24
18	24.80	6.66	8.88	5.63	18	26.99	8.46	8.92	6.21
19	28.51	8.12	8.81	7.43	19	30.40	10.30	8.87	7.89
20	23.09	5.94	6.52	5.02	20	25.23	7.27	6.53	5.29

**Figure 3.18** Psychological data and spline-based physiological data of 16 participants (1 = Frequency of Flow Experience, 2 = Trait-Coping, 3 = Self-Image, 4 = Self-Awareness, 5 = Will for Meaningful Life, and 6 = State-Trait Anxiety).

**Freq. of Flow Experience**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.313	0.003	0.075	0.089
$R_{corr}$	0.264	-0.069	0.009	0.024
$p$	0.024	0.851	0.305	0.262

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.330	0.001	0.045	0.092
$R_{corr}$	0.282	-0.071	-0.023	0.027
$p$	0.020	0.933	0.428	0.255

**Trait-Coping**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.393	0.101	0.277	0.131
$R_{corr}$	0.350	0.037	0.225	0.069
$p$	0.009	0.229	0.036	0.168

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.370	0.057	0.246	0.104
$R_{corr}$	0.325	-0.010	0.192	0.040
$p$	0.013	0.374	0.051	0.224

**Self-Image**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.185	0.103	0.132	0.214
$R_{corr}$	0.126	0.039	0.070	0.157
$p$	0.097	0.226	0.167	0.071

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.173	0.030	0.095	0.189
$R_{corr}$	0.114	-0.039	0.030	0.131
$p$	0.109	0.522	0.247	0.092

**Self-Awareness**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.102	0.056	0.120	0.048
$R_{corr}$	0.038	-0.012	0.057	-0.020
$p$	0.228	0.378	0.189	0.414

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.093	0.031	0.126	0.071
$R_{corr}$	0.028	-0.039	0.064	0.004
$p$	0.251	0.517	0.177	0.320

**Will for Meaningful Life**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.250	0.067	0.169	0.037
$R_{corr}$	0.197	0.000	0.110	-0.032
$p$	0.048	0.334	0.114	0.475

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.230	0.065	0.180	0.047
$R_{corr}$	0.175	-0.002	0.121	-0.021
$p$	0.060	0.341	0.102	0.419

**State-Trait Anxiety**

Single variable regression				$\lambda = 0.002$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.172	0.090	0.120	0.153
$R_{corr}$	0.113	0.025	0.057	0.092
$p$	0.110	0.260	0.189	0.134

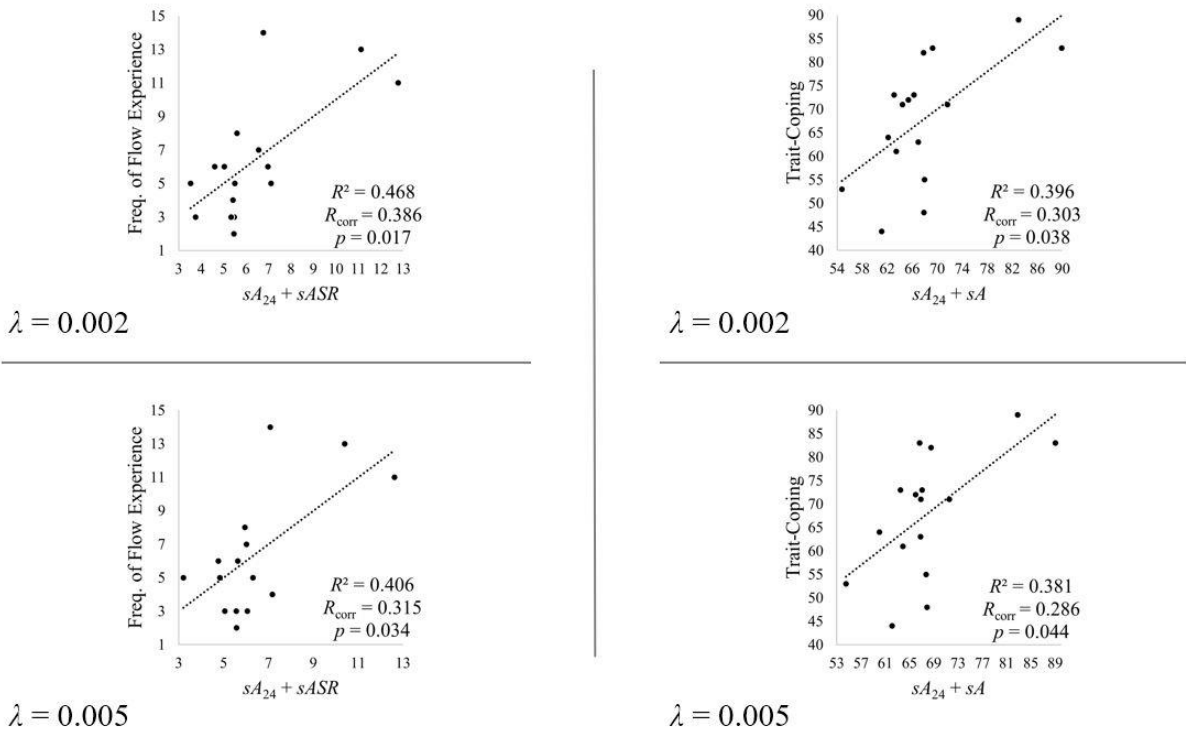
  

Single variable regression				$\lambda = 0.005$
	(1) $sA_{24}$	(2) $sA_{12}$	(3) $sASR$	(4) $sA$
$R^2$	0.148	0.025	0.100	0.171
$R_{corr}$	0.088	-0.045	0.035	0.112
$p$	0.141	0.562	0.234	0.111

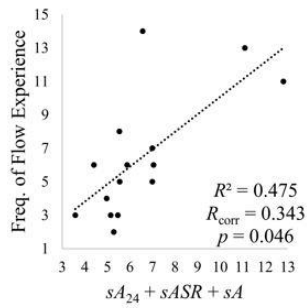
**Figure 3.19** Single regression analysis between psychological measures and spline parameters and two candidates of optimal  $\lambda$  values ( $R^2$  = coefficient of determination,  $R_{corr}$  = adjusted/corrected value of  $R^2$ ,  $p$  = significance level/ $p$ -value).

### 3.2.2.3 Multiple regression analysis

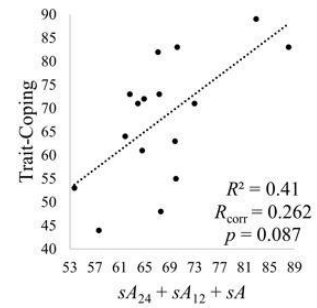
In addition to single regression, multiple regression analysis was performed using two and three spline parameters. Since *Frequency of Flow Experience* and *Trait-Coping* were highly correlated with spline-based parameters in the previous analysis, they were used with 2 and 3 spline-based parameters to further increase the correlation. **Figs. 3.20 (a)** and **(b)** shows the results of multiple regression analysis when 2 and 3 splines-based parameters are used. In this analysis, *Frequency of Flow Experience* and *Trait-Coping* gave better correlation results by  $\lambda = 0.002$  again.



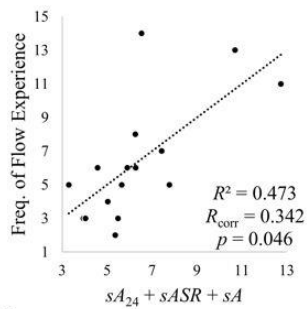
**Figure 3.20 (a)** Multiple regression analysis between two psychological measures and two spline parameters.



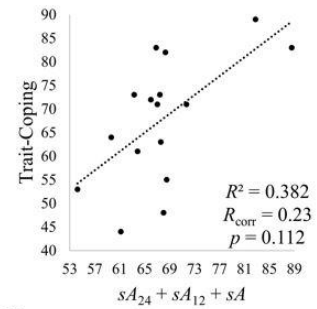
$\lambda = 0.002$



$\lambda = 0.002$



$\lambda = 0.005$



$\lambda = 0.005$

**Figure 3.20 (b)** Multiple regression analysis between two psychological measures and three spline parameters.



### 3.2.2.4 Multicollinearity among spline parameters

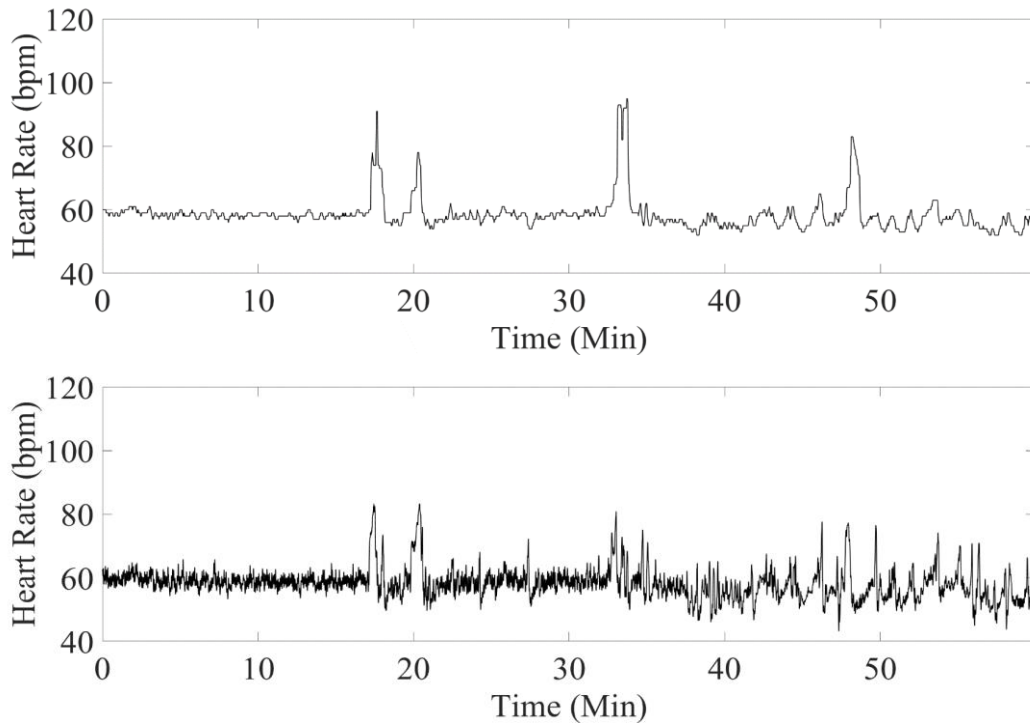
From the previous methods, we can almost conclude that  $\lambda = 0.002$  is the optimal value for our spline-parameters derivation. One final solution to ensure that  $\lambda = 0.002$  is optimal is to analyze the multicollinearity among spline-parameters when  $\lambda = 0.002$  or  $\lambda = 0.005$ . For this analysis, Variance Inflation Factor (VIF) must be calculated for each spline parameter. Many researchers suggest the VIF score of below five while others may debate that VIF scores below 10 is still acceptable. Since our research is promoting the development of medical systems and application for mental health assessment, we took a stricter approach and considered ( $VIF < 5$ ) as the standard. **TABLE 3.1** shows the VIF score of each spline-based physiological heart rate parameter with two different  $\lambda$  values. Since the VIF scores of parameters with  $\lambda = 0.002$  are smaller than five, we can conclude that they are independent variables and hence, must be selected as the final spline parameters for the analysis of psychological measures and physiological parameters

**TABLE 3.1** Multicollinearity analysis for two candidate  $\lambda$  values.

<b>Score of VIF</b>				
$\lambda$	<b>Spline-based physiological parameters</b>			
	<i>sA<sub>24</sub></i>	<i>sA<sub>12</sub></i>	<i>sASR</i>	<i>sA</i>
<b>0.002</b>	2.46	2.51	2.31	2.72
<b>0.005</b>	4.67	6.34	4.83	5.93

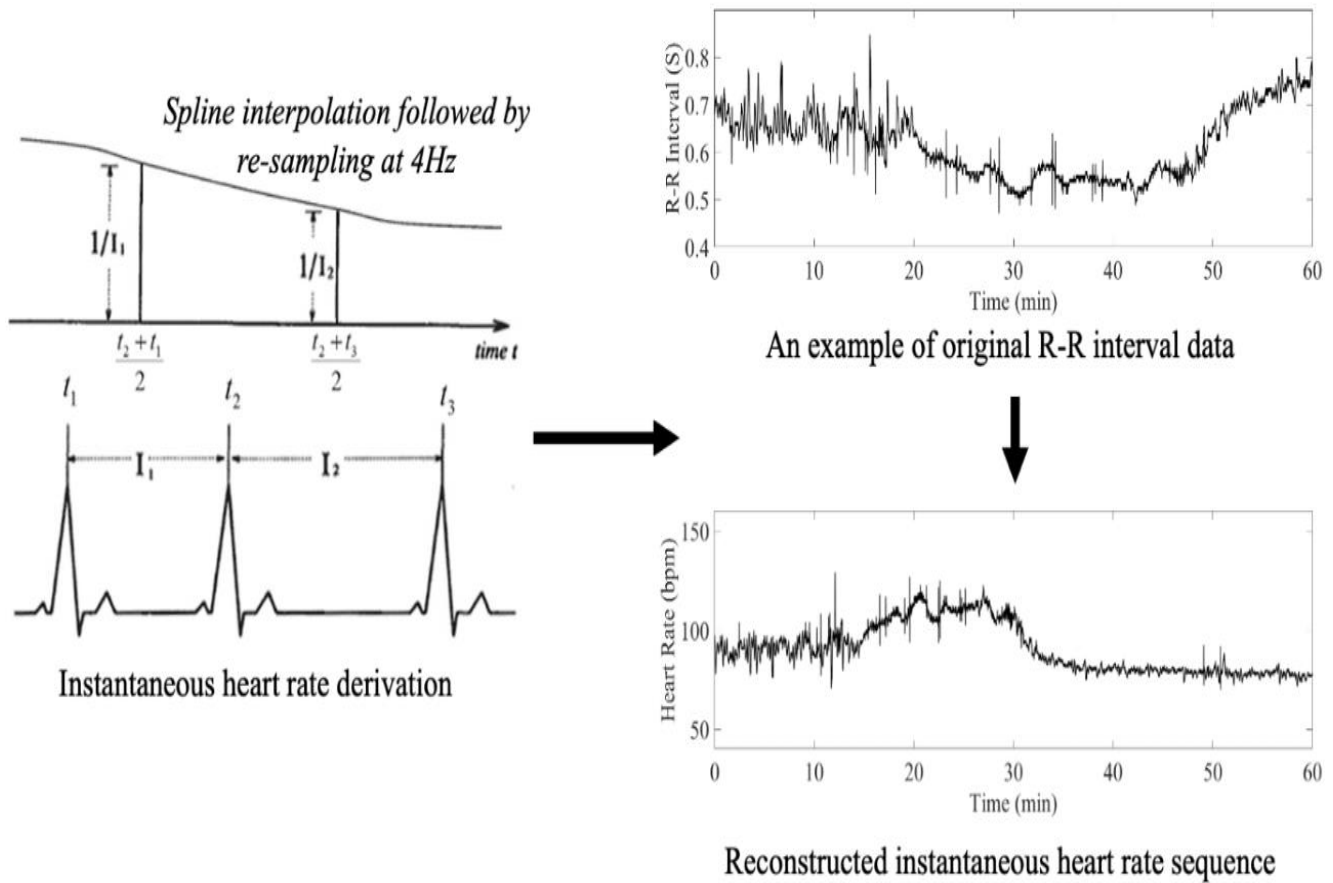
### 3.2.3 Accuracy of Fitbit Charge 2

As mentioned in chapter 2, the heart rate data of each participant were continuously recorded at every one-minute interval using a Fitbit Charge 2 smartwatch. All previous studies [29–31] suggested that the wrist-worn device is sufficient for implementing ambulatory measurement of cardiac activity and the accuracy can be further improved by tightening the sensor placement of a wrist. In addition, we decided to compare the recordings from a Holter ECG device and Fitbit Charge 2 by evaluating their accuracies for the derivation of cosinor-based parameters during two recording modes: activity and normal. The activity mode had a sampling interval between one to three seconds whereas the normal mode had a sampling interval between five and 15 seconds. An example of the original heart rate recording of each device is shown in **Fig. 3.21** for Fitbit Charge 2 (upper trace) and a Holter ECG device (lower trace).



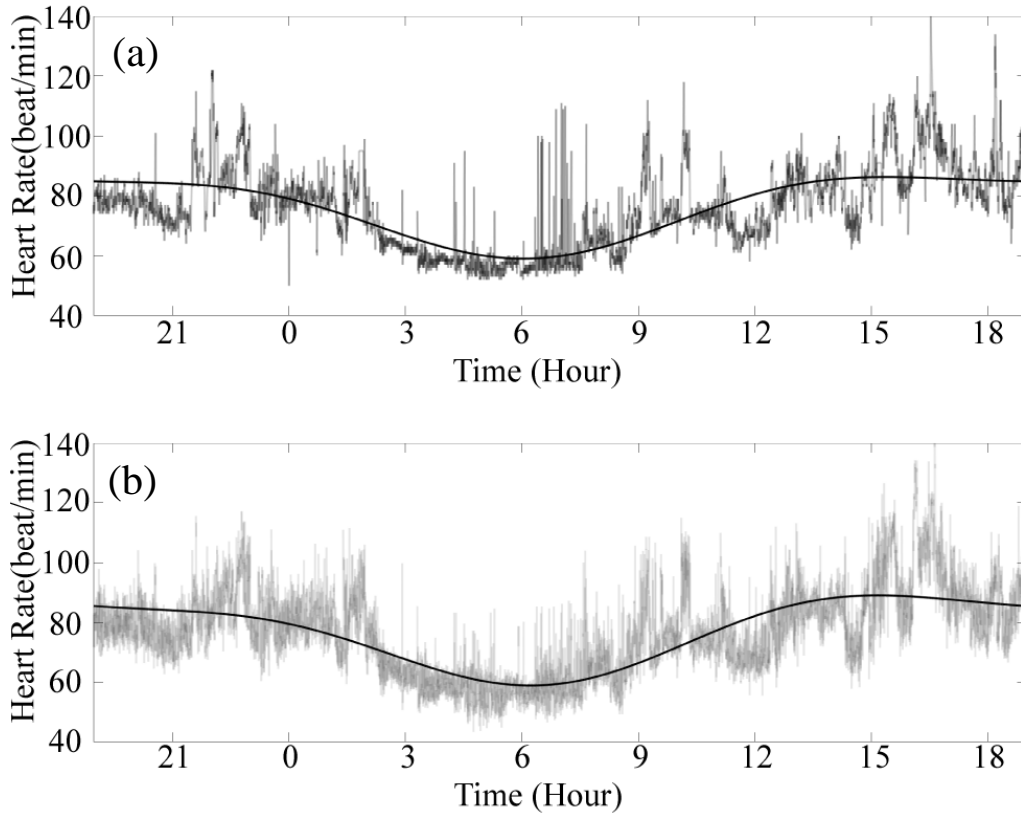
**Figure 3.21** Heart rate sequence recording using Fitbit Charge 2 (upper trace) and Cardy 303 (lower trace, Suzuken Co. Ltd., Nagoya, Japan).

For Cardy 303, the interval between R waves (RRI) was calculated from the ECG signal to calculate the instantaneous heart rate, and spline smoothing was performed to obtain equally spaced heart rate data. When measuring the instantaneous heart rate from the RRI, the reciprocal of the RRI was taken. However, since RRI is unevenly spaced data, it is necessary to make it into evenly spaced data by the smoothing of splines method. The actual operation is shown in **Fig. 3.22**.



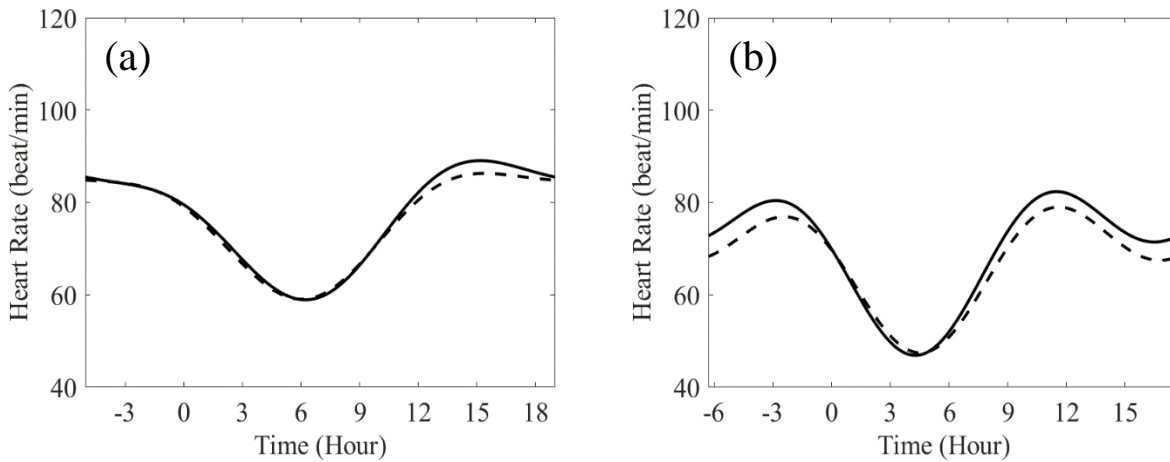
**Figure 3.22** Reconstructed instantaneous heart rate using spline interpolation method for the heart rate data obtained from the Holter ECG device.

We found a relative error of 3.9% compared to the estimation by the clinically used Holter ECG device. **Fig. 3.23 (a)** is the heart rate recording and fitted double cosinor curve from Fitbit Charge 2 during activity and normal mode. **Fig. 3.23 (b)** shows the corresponding heart rate time series reconstructed from the Holter ECG record and fitted double cosinor curve during the same modes.



**Figure 3.23** Double cosinor fit to the heart rate sequence recorded by Fitbit Charge 2 (a) and Cardy 303 during activity mode and normal mode.

The relative cosinor curve error of the circadian rhythm due to activity mode is  $0.0235$  ( $0.023 \pm 0.017$ ), which is considered to be a very small error but during normal mode, it is  $0.039$  ( $0.039 \pm 0.018$ ). **Figs. 3.24 (a) and (b)** show the variations in curve fitting during activity and normal modes respectively. The relative error of the circadian parameter is also about 10%, and the error is smaller in the activity mode. One of the major causes of such an error is the weak tightening of the device belt. The prominent error caused by the rough belt coupling occurs during the exercise. On the contrary, errors are small during sleep.



**Figure 3.24** Variations in curve fitting during activity mode (a) and normal mode (b). The solid line and broken line represent the recordings by Cardy303 and Fitbit Charge 2 respectively.

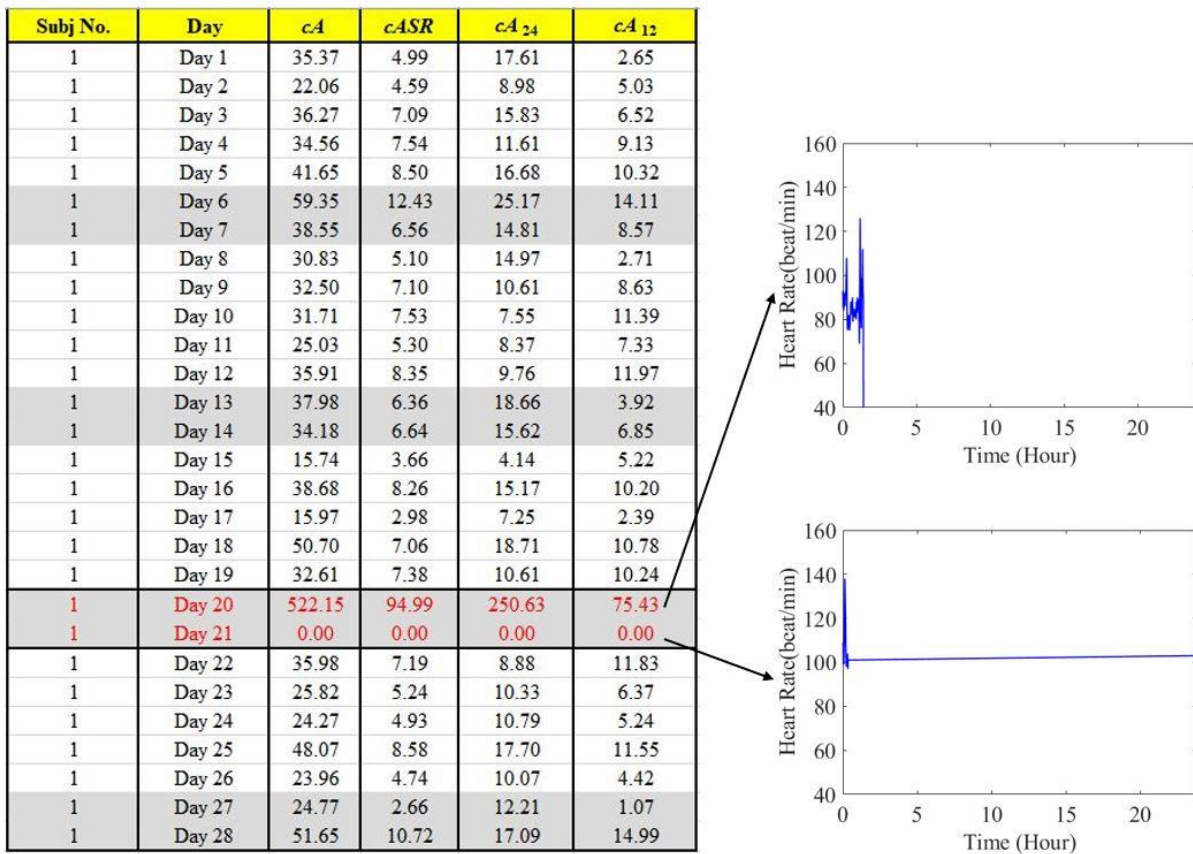
It is worth pointing out that the circadian rhythm of the wrist device in activity mode at a sampling rate of one to three seconds, matches Holter ECG well compared to normal mode at a sampling rate of five to 15 seconds as shown in **TABLE 3.2**. Both devices are useful in healthcare-related research studies.

**TABLE 3.2** Circadian rhythm parameter estimation errors.

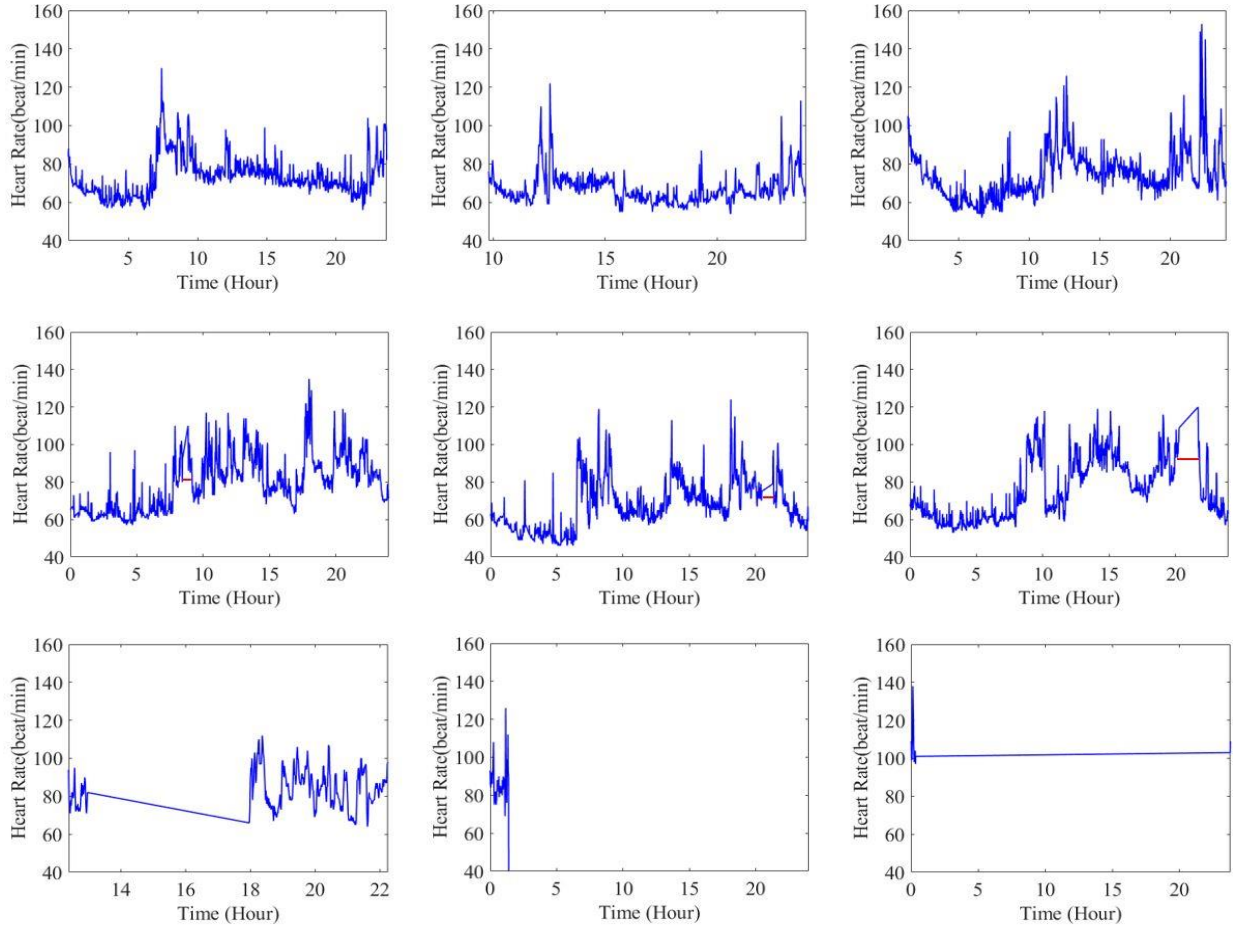
Modes	$M$	$cA_{24}$	$cA_{12}$	$cA$	$cASR$
Activity	$0.021 \pm 0.02$	$0.119 \pm 0.103$	$0.118 \pm 0.096$	$0.072 \pm 0.06$	$0.09 \pm 0.089$
Normal	$0.04 \pm 0.021$	$0.153 \pm 0.071$	$0.087 \pm 0.06$	$0.117 \pm 0.06$	$0.101 \pm 0.055$

### 3.2.4 Physiological parameters processing

All cosinor and spline-based parameters for each participant were calculated by MATLAB R2022b numerical analysis software (MathWorks, Inc., Massachusetts, USA). The mean and median value of each physiological parameter was assessed in 16 out of 20 participants. Four participants who never had any *Flow* experience (questions 1–4 for *Frequency of Flow Experience*) were excluded from the analysis. Some extreme values of the parameters were observed as a result of disconnecting the smartwatch for a long time (more than two hours) by a few participants. Those extreme values (typically for one to three days at most) were also excluded from the analysis. **Fig. 3.25** shows such extreme values observed in cosinor parameters of one participant.



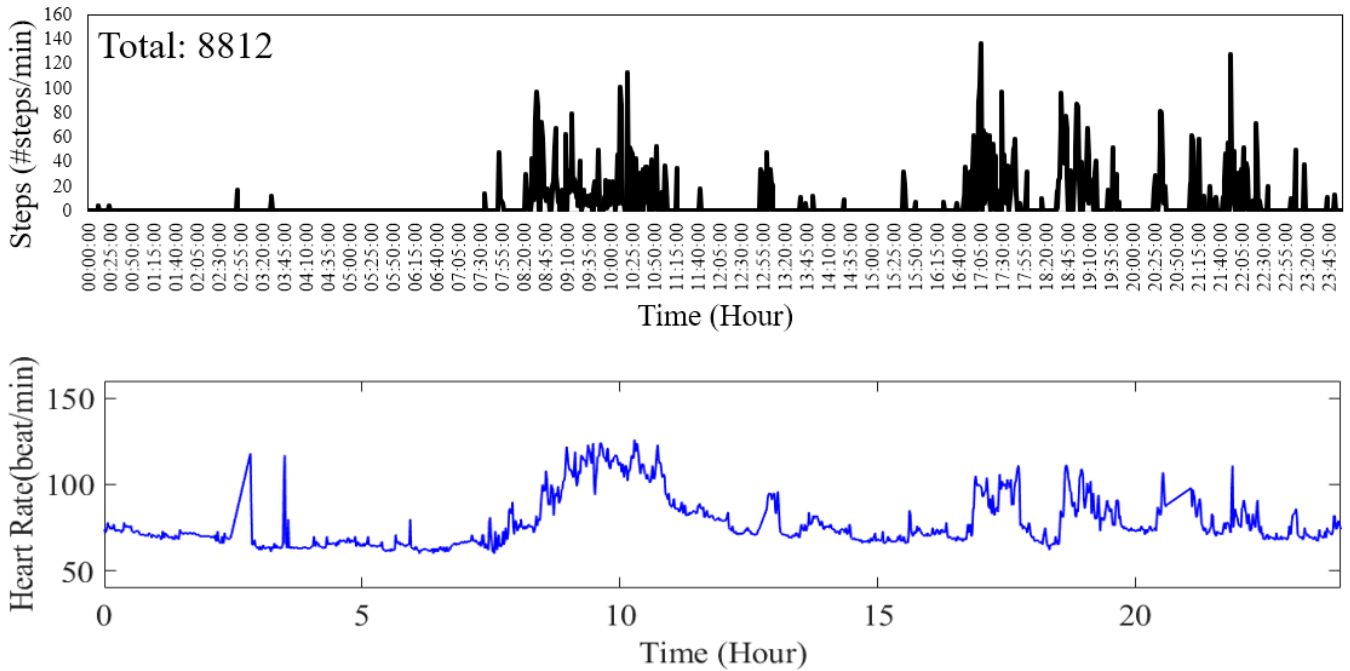
**Figure 3.25** Examples of missing data during weekends. Grey boxes in the datasheet represents weekends.



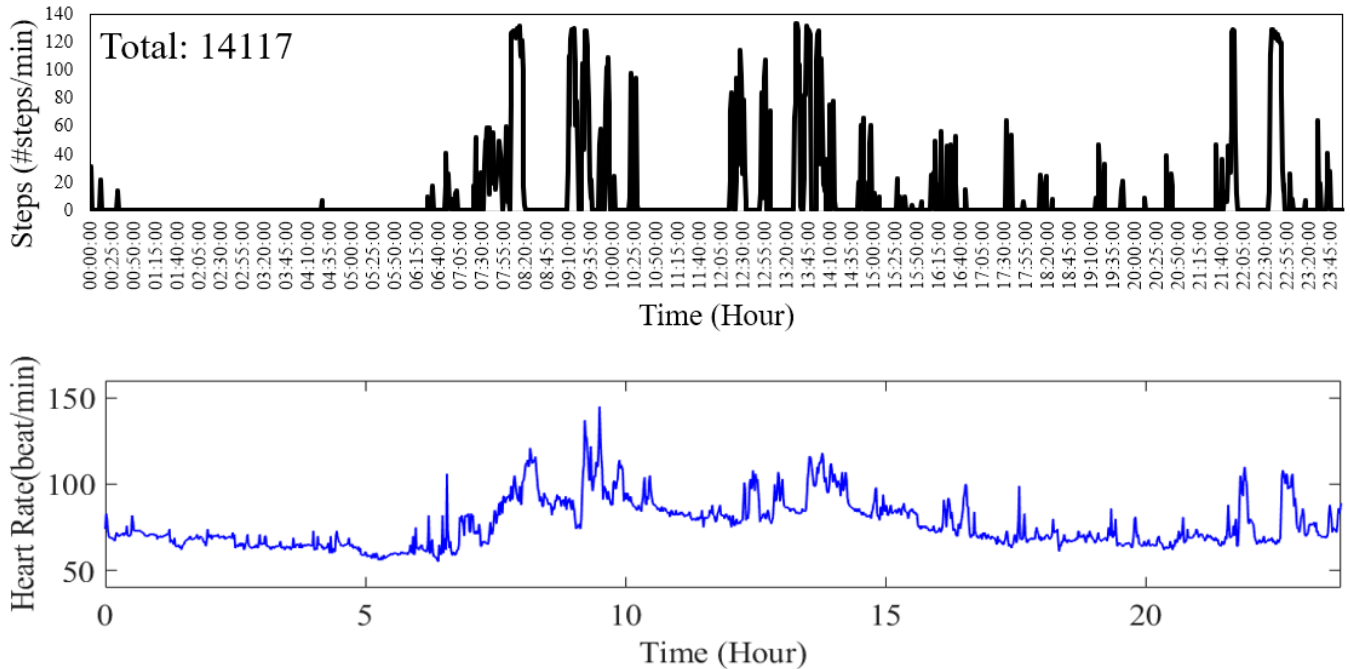
**Figure 3.26** An example of perfectly recorded heart rate sequence (top), still acceptable heart rate sequence with small periods of missing data which happened during battery charging of the wearable device (middle), and unacceptable heart rate sequence due to long missing data (bottom).

We restricted the heart rate measurement to weekdays (G1 and G2 datasets) when participants were mainly engaged in desk work i.e., mental tasks, to avoid the heart rate change by physical activities. This was for keeping the general condition during the measurement period and it is general practice in the study of such long-term dispositional psychological characteristics [27, 28]. **Figs. 3.27–3.29** show the step graph and the corresponding heart rate graph of three random participants during a weekday and weekend. It is apparent that these individuals were more active during weekends based on the total number of steps. Hence, we can conclude that they performed some sort of extreme physical activity during weekends such as exercising. Since extreme physical activities can cause an increase in the amplitude of heart rate and affect mental health assessment, it is better to exclude the physiological parameters recorded during weekends.

### Participant A's steps and heart rate during Monday



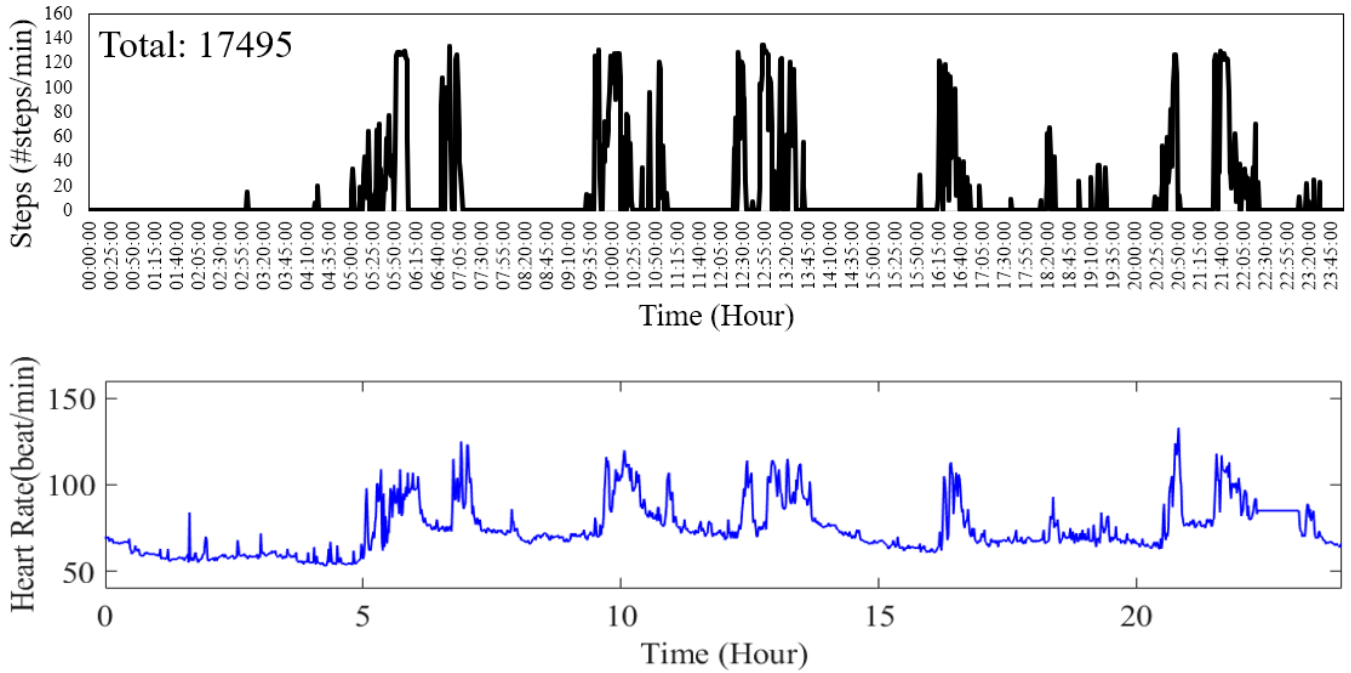
### Participant A's steps and heart rate during Saturday



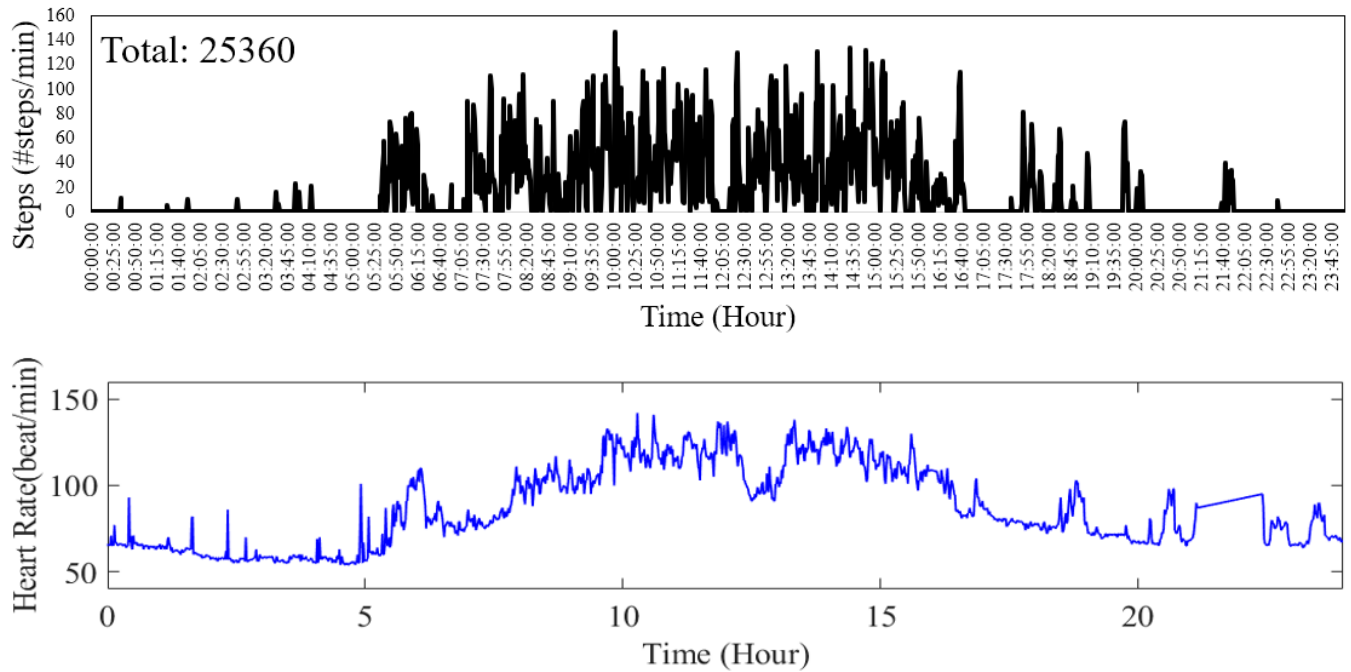
**Figure 3.27** A random participants' step data and corresponding heart rate sequence during a weekday (total number of steps: 8812) and a weekend (total number of steps: 14117).



## Participant B's steps and heart rate during Thursday

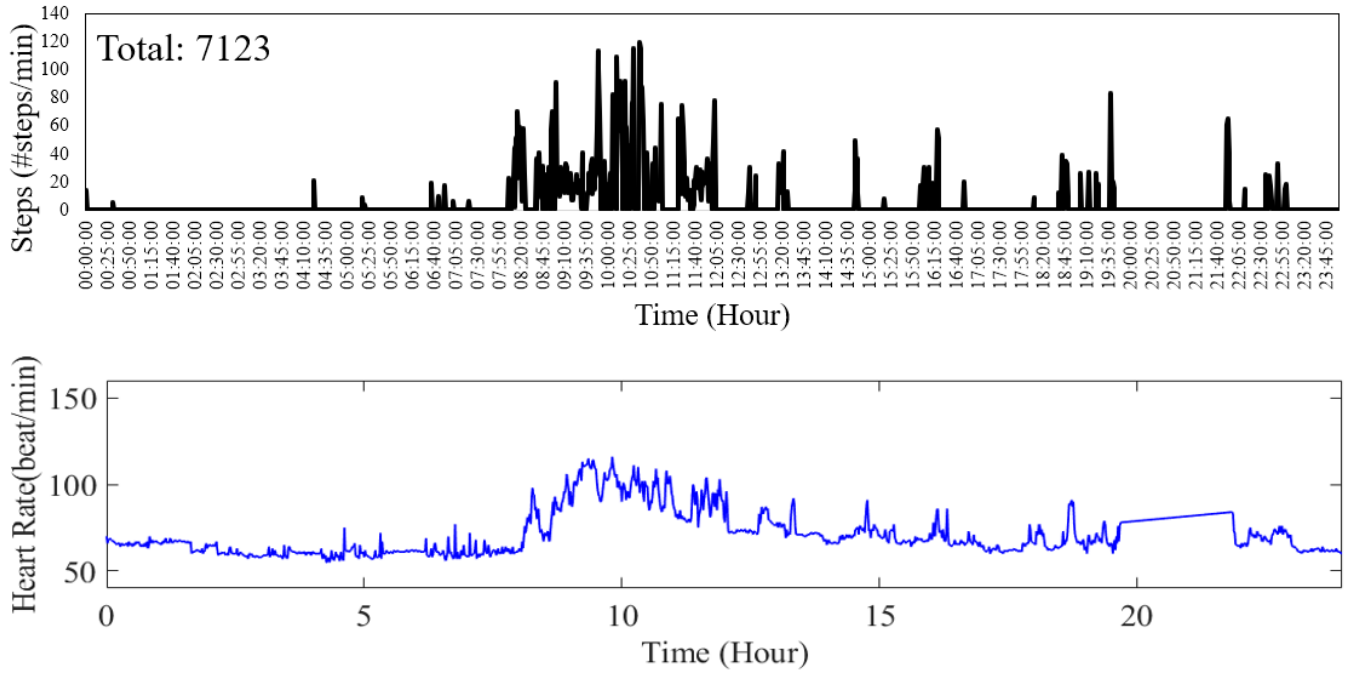


## Participant B's steps and heart rate during Sunday

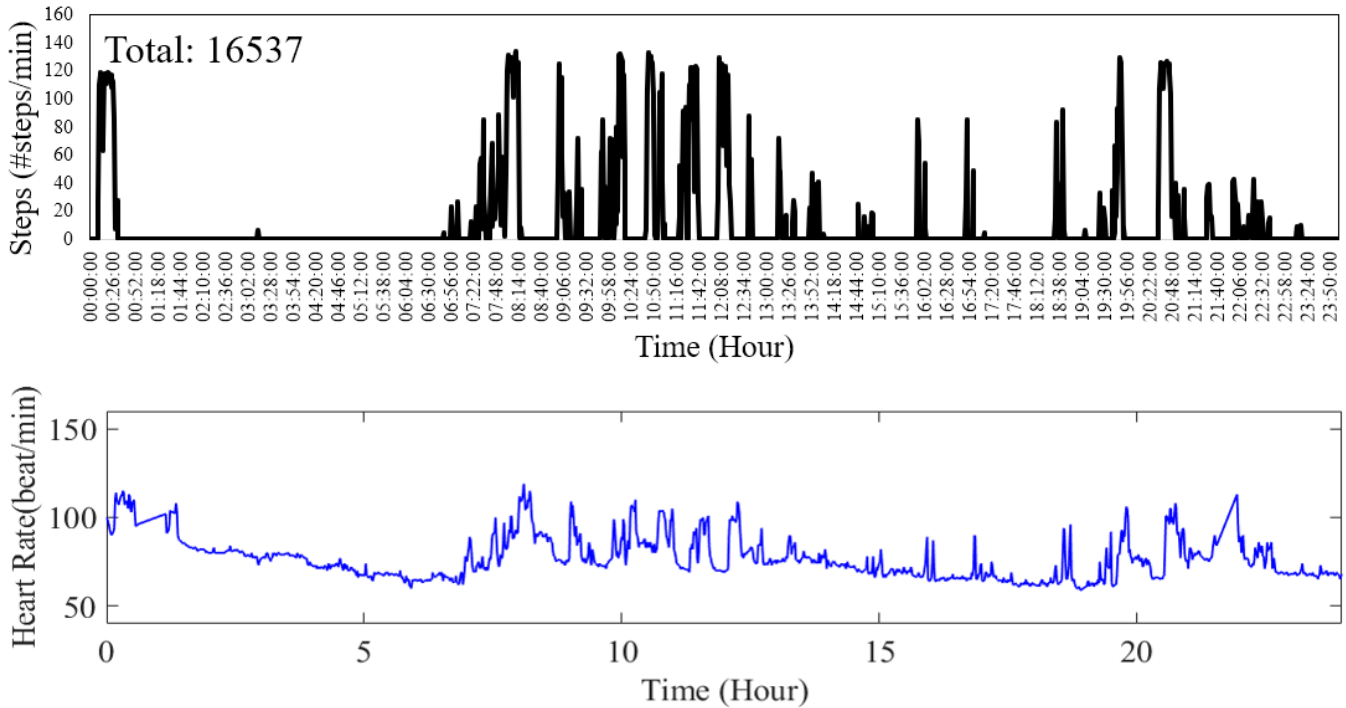


**Figure 3.28** A random participant's step data and corresponding heart rate sequence during a weekday (total number of steps: 17495) and a weekend (total number of steps: 25360).

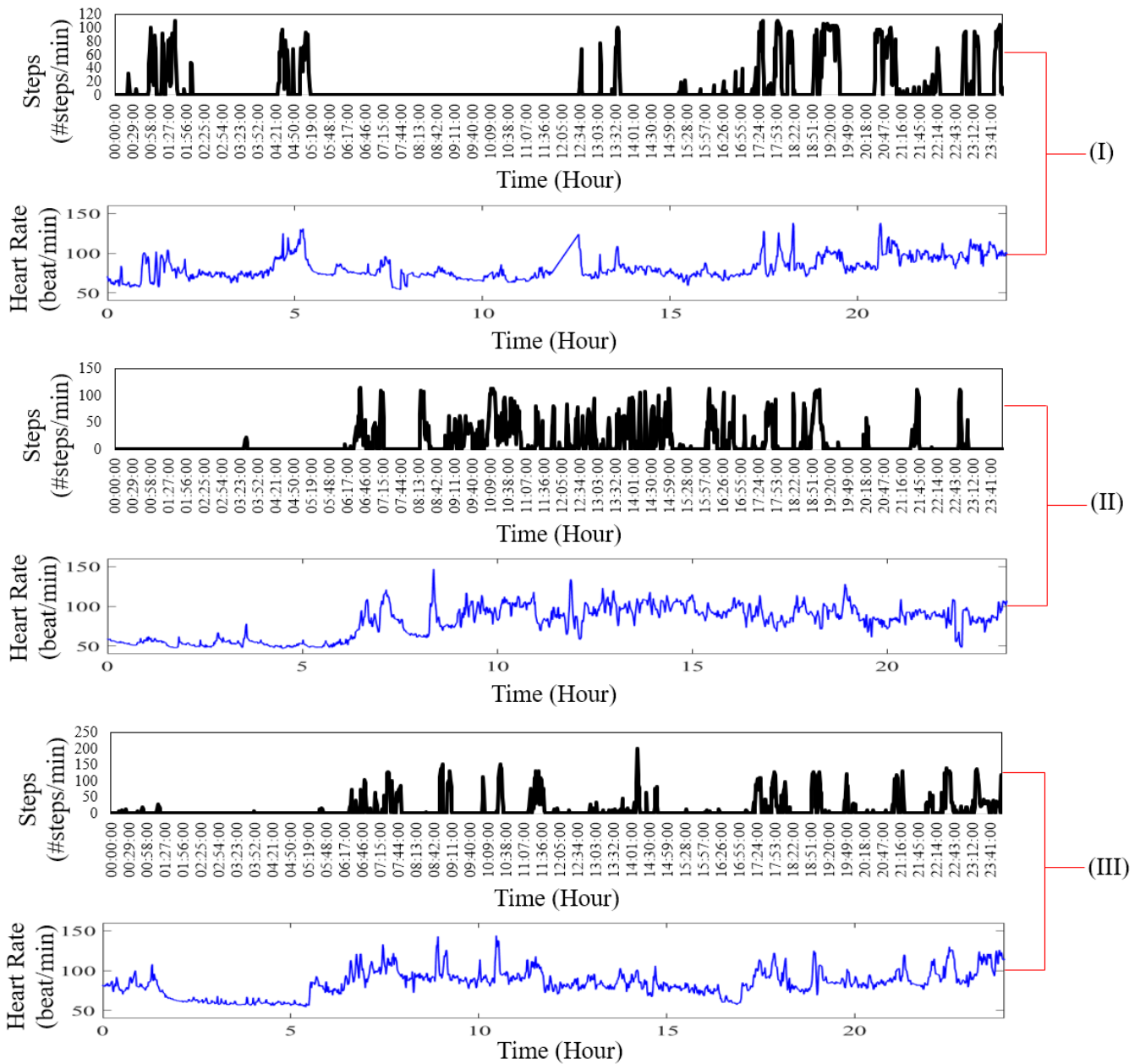
## Participant C's steps and heart rate during Tuesday



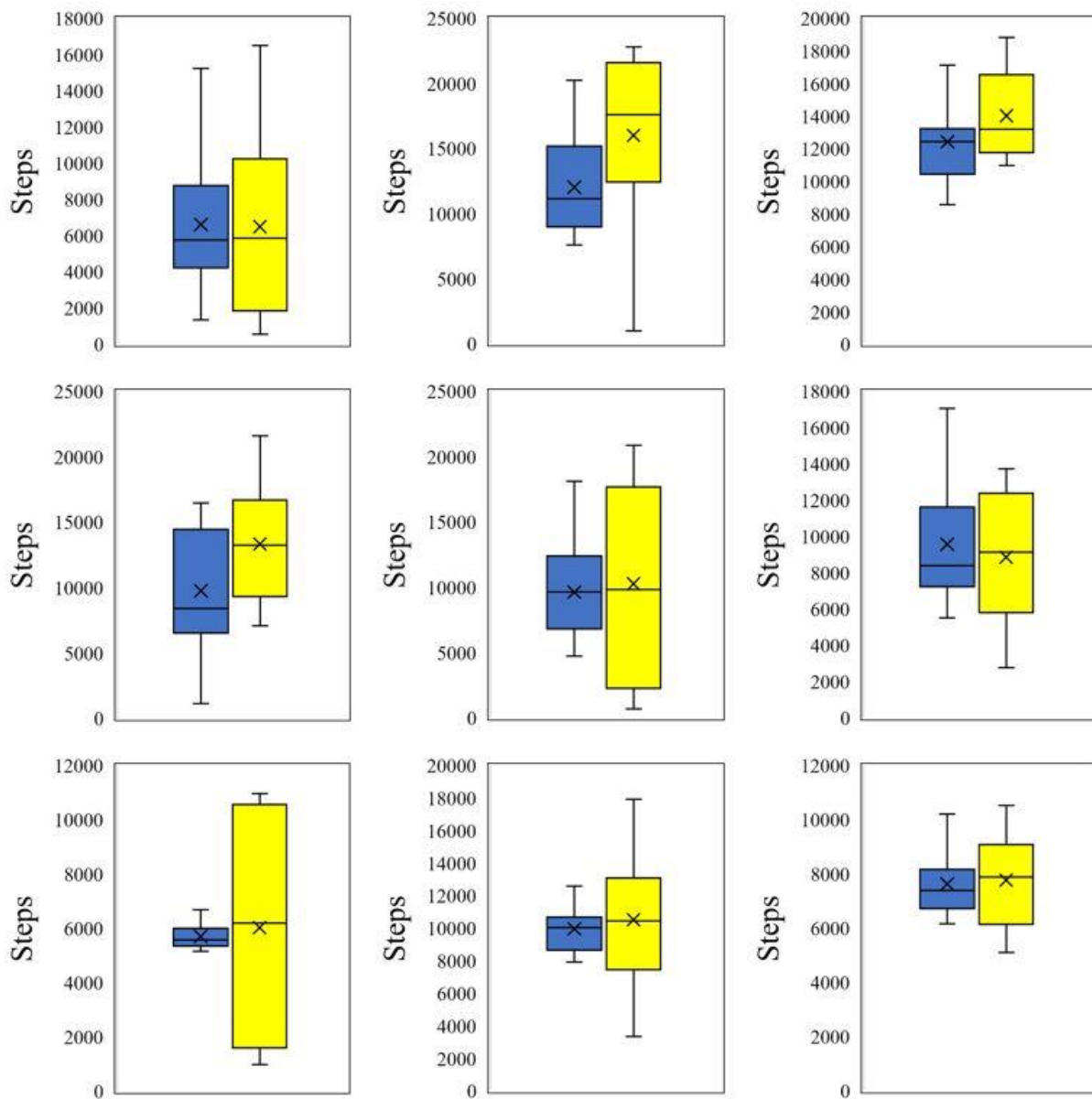
## Participant C's steps and heart rate during Saturday



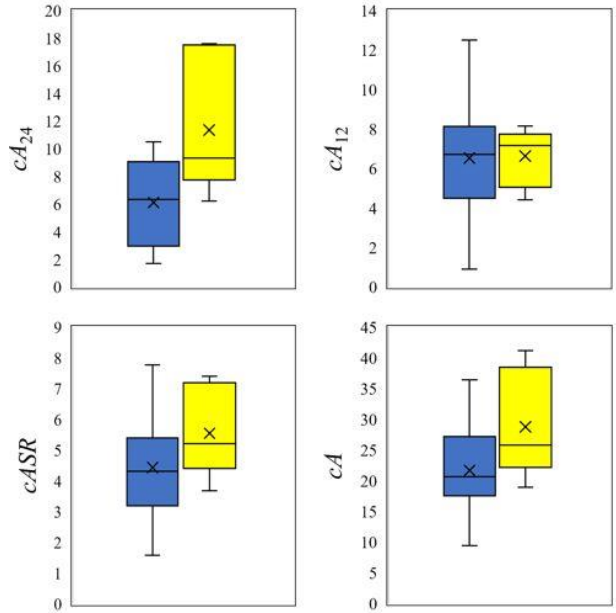
**Figure 3.29** A random participant's step data and corresponding heart rate sequence during a weekday (total number of steps: 7123) and a weekend (total number of steps: 16537).



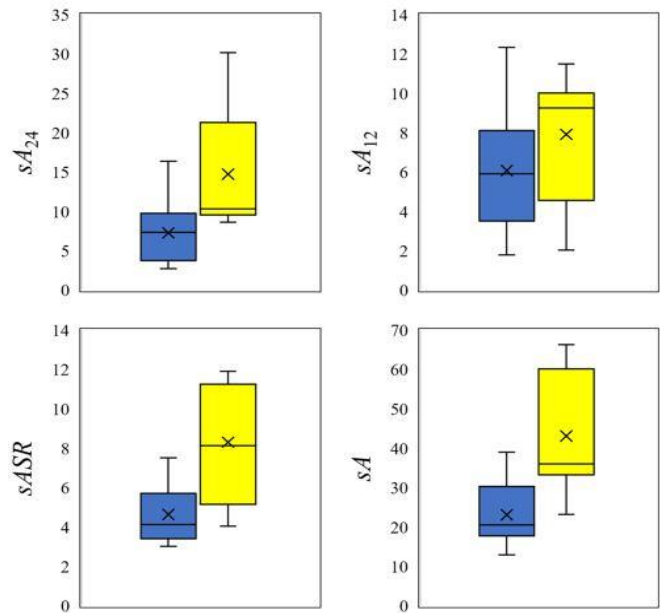
**Figure 3.30** More participants' step data and their corresponding heart rate sequence during weekends. Total number of steps are 17987 for (I), 24802 for (II), and 16493 for (III).



**Figure 3.31** Box-plot analysis for the comparison between step data during weekdays (blue) and weekends (yellow) for nine random participants. The median value of the steps during weekends is generally higher than weekdays. This means that more physical activities were performed during weekends and may cause an increase in physiological parameters.



**Figure 3.32** Comparison between cosinor parameters during weekdays (blue) and weekends (yellow) of one participant. The median value of the parameters during weekends was generally higher than weekdays.



**Figure 3.33** Comparison between spline parameters during weekdays (blue) and weekends (yellow) of the same subject. The median value of the parameters during weekends was generally higher than weekdays.

Subj No.	Day	<i>cA</i>	<i>cASR</i>	<i>cA<sub>24</sub></i>	<i>cA<sub>12</sub></i>	Subj No.	Day	<i>sA</i>	<i>sASR</i>	<i>sA<sub>24</sub></i>	<i>sA<sub>12</sub></i>
20	Day 1	32.53	7.52	7.84	10.50	20	Day 1	25.11	6.74	7.54	6.25
20	Day 2	31.82	6.86	11.18	8.11	20	Day 2	25.52	6.22	10.58	5.66
20	Day 3	45.37	9.89	11.15	15.64	20	Day 3	43.61	6.86	10.26	12.16
20	Day 4	20.84	4.85	3.85	8.10	20	Day 4	29.30	3.24	4.24	5.29
20	Day 5	25.65	5.84	6.59	7.87	20	Day 5	24.16	4.62	6.26	6.22
20	Day 6	61.70	11.38	28.12	8.66	20	Day 6	57.02	9.18	27.18	5.43
20	Day 7	33.43	7.53	9.52	9.86	20	Day 7	26.32	6.60	9.71	5.75
20	Day 8	18.87	3.47	8.64	2.66	20	Day 8	21.59	4.38	8.30	2.57
20	Day 9	20.40	3.40	9.82	1.79	20	Day 9	19.76	3.28	8.27	1.59
20	Day 10	17.65	3.88	2.76	6.92	20	Day 10	22.67	3.40	2.94	5.53
20	Day 11	28.15	5.03	12.77	3.23	20	Day 11	27.35	5.03	11.95	2.90
20	Day 12	16.37	2.49	8.13	1.01	20	Day 12	19.29	3.70	7.74	1.06
20	Day 13	33.52	7.58	9.59	10.06	20	Day 13	27.34	7.21	8.99	6.11
20	Day 14	55.41	10.90	22.97	9.87	20	Day 14	48.26	9.27	22.33	5.72
20	Day 15	39.08	6.61	9.60	12.34	20	Day 15	58.89	7.73	10.39	11.65
20	Day 16	16.17	3.08	3.74	5.36	20	Day 16	19.35	3.05	3.53	4.31
20	Day 17	20.25	4.04	8.08	3.78	20	Day 17	17.67	4.41	7.73	2.85
20	Day 18	18.00	4.21	3.98	6.08	20	Day 18	14.94	4.26	3.45	4.48
20	Day 19	16.09	3.05	6.87	3.44	20	Day 19	15.21	3.25	6.65	2.49
20	Day 20	38.49	8.70	10.71	11.49	20	Day 20	30.39	7.68	10.47	7.16
20	Day 21	66.29	11.91	30.21	7.98	20	Day 21	62.74	10.09	29.31	4.80
20	Day 22	15.51	3.28	5.31	3.62	20	Day 22	13.80	3.89	5.12	2.39
20	Day 23	20.63	5.05	2.92	8.20	20	Day 23	15.49	4.44	2.68	5.42
20	Day 24	25.86	5.31	11.34	5.75	20	Day 24	24.05	4.57	11.03	4.56
20	Day 25	12.96	3.03	2.87	4.37	20	Day 25	10.70	3.46	2.63	3.13
20	Day 26	33.24	4.06	16.38	2.04	20	Day 26	33.84	5.29	15.84	1.99
20	Day 27	33.24	4.06	16.38	2.04	20	Day 27	19.49	3.43	9.44	1.48
20	Day 28	23.19	4.38	9.91	3.42	20	Day 28	20.97	3.55	9.57	2.03



Subj No.	<i>cA</i>	<i>cASR</i>	<i>cA<sub>24</sub></i>	<i>cA<sub>12</sub></i>	Subj No.	<i>sA</i>	<i>sASR</i>	<i>sA<sub>24</sub></i>	<i>sA<sub>12</sub></i>
3	19.94	3.87	5.43	6.72	3	23.51	3.76	5.37	4.93
4	35.08	7.18	13.75	8.18	4	32.11	6.21	13.15	6.79
5	30.12	6.53	9.89	8.34	5	24.24	6.07	9.83	5.83
6	27.14	5.67	8.45	7.66	6	24.84	4.91	8.21	5.26
7	25.17	5.48	7.53	7.12	7	21.64	4.53	7.57	5.29
8	30.88	6.52	8.98	9.77	8	25.53	5.58	8.66	6.97
9	23.22	5.30	8.31	6.34	9	20.78	4.07	7.79	4.26
10	23.63	5.12	7.88	6.97	10	27.84	3.89	7.22	4.71
13	30.86	6.72	9.34	10.53	13	28.88	5.52	9.06	7.37
14	36.74	7.83	9.95	11.74	14	43.66	6.35	10.03	10.48
15	29.07	6.60	9.72	8.75	15	27.95	5.49	9.00	6.06
16	42.23	8.44	15.44	10.37	16	36.15	6.94	15.14	6.83
17	25.00	4.87	7.66	6.86	17	22.99	3.95	7.54	4.86
18	27.25	5.70	8.87	6.87	18	22.92	4.86	8.77	4.64
19	28.92	6.03	8.63	8.50	19	26.73	5.81	8.53	6.42
20	20.33	4.13	7.48	5.56	20	20.68	4.32	7.19	4.40

**Figure 3.34** Cosinor and spline parameters extracted for one participant, in this case Subject No. 20 during 28 days of continuous heart rate recording (upper trace). Final physiological data after data cleaning of 16 participants used as G2 dataset (lower trace).

# Chapter 4: Results

## 4.1 Overview of data acquired

The basic characteristics of the obtained psychological measures and physiological parameters were examined. The mean (M) and standard deviation (SD) of all dispositional psychological measures and physiological heart rate rhythm parameters are shown in **TABLE 4.1**.

**TABLE 4.1** Distribution of psychological measures and physiological parameters of heart rate rhythm.

<b>Psycho-physiological indicators</b>	<b>M</b>	<b>SD</b>
Freq. of Flow Experience	6.31	3.57
Trait-Coping	67.81	13.24
Self-Image	9.21	2.41
Self-Awareness	8.14	1.73
Will for Meaningful Life	28.47	5.96
State-Trait Anxiety	6.00	1.24
<i>cA<sub>24</sub> / sA<sub>24</sub></i>	9.21 / 8.94	2.41 / 2.35
<i>cA<sub>12</sub> / sA<sub>12</sub></i>	8.14 / 5.94	1.73 / 1.57
<i>cA / sA</i>	28.47 / 26.90	5.96 / 6.11
<i>cASR / sASR</i>	6.00 / 5.14	1.24 / 0.99

As mentioned in previous chapters, four physiological datasets were used in this research study to see which one gave better correlation results. The multicollinearity among all parameters for different datasets were analysed. **TABLE 4.2** and **TABLE 4.3** show the VIF value of cosinor and spline-based physiological parameters for four datasets. Results shows that the physiological parameters of G2 dataset have lower VIF scores.

**TABLE 4.2** Multicollinearity analysis of cosinor parameters for four datasets.

Dataset	Score of VIF			
	Cosinor-based physiological parameters			
	<i>cA</i> <sub>24</sub>	<i>cA</i> <sub>12</sub>	<i>cASR</i>	<i>cA</i>
G1	41.4	27.3	17.0	106.4
G2	8.9	6.9	14.2	22.4
G3	51.4	34.3	9.1	152.1
G4	7.9	4.9	22.0	36.1

(G1: average weekdays only, G2: median weekdays only, G3: average all days, and G4: median all days)

**TABLE 4.3** Multicollinearity analysis of cosinor parameters for four datasets.

Dataset	Score of VIF			
	Spline-based physiological parameters			
	<i>sA</i> <sub>24</sub>	<i>sA</i> <sub>12</sub>	<i>sASR</i>	<i>sA</i>
G1	3.1	4.1	3.5	4.0
G2	2.5	2.5	2.7	2.3
G3	3.0	4.0	2.8	4.2
G4	2.8	3.6	2.3	4.5

(G1: average weekdays only, G2: median weekdays only, G3: average all days, and G4: median all days)



## 4.2 Principal component analysis

The principal component analysis (PCA) method was applied to determine the appropriate dimensionality of the parameter space and to extract the orthogonal parameters effective at associating physiological parameters with psychological measures. **TABLE 4.4** shows the contribution ratios of four orthogonal principal components.  $X_k^C$  and  $X_k^S$  ( $k = 1, \dots, 4$ ) denote the  $k$ -th principal components for the cosinor and spline-based original parameter sets, respectively. The first and second principal components showed a cumulative contribution ratio close to 100% (99.55% for the cosinor and 98.50% for the spline-based parameter set).

**TABLE 4.4** Contribution ratios of four double cosinor and spline-based PCA components.

$k$	Contribution ratio (%)	
	$X_k^C$	$X_k^S$
1	95.54	91.36
2	4.01	7.13
3	0.34	1.37
4	0.11	0.13

**Eqs (4.1) to (4.4)** for cosinor-based orthogonal components and **Eqs (4.5) to (4.8)** for spline-based orthogonal components are listed below:

Principal components for cosinor parameter set:

$$X_1^C = 0.330 \cdot cA_{24} + 0.217 \cdot cA_{12} + 0.900 \cdot cA + 0.184 \cdot cASR \quad (4.1)$$

$$X_2^C = 0.728 \cdot cA_{24} - 0.676 \cdot cA_{12} - 0.089 \cdot cA - 0.073 \cdot cASR \quad (4.2)$$

$$X_3^C = 0.577 \cdot cA_{24} + 0.648 \cdot cA_{12} - 0.422 \cdot cA + 0.263 \cdot cASR \quad (4.3)$$

$$X_4^C = -0.169 \cdot cA_{24} - 0.275 \cdot cA_{12} - 0.065 \cdot cA + 0.944 \cdot cASR \quad (4.4)$$

Principal components for spline parameter set:

$$X_1^S = 0.253 \cdot cA_{24} + 0.214 \cdot cA_{12} + 0.936 \cdot cA + 0.117 \cdot cASR \quad (4.5)$$

$$X_2^S = 0.922 \cdot cA_{24} - 0.150 \cdot cA_{12} - 0.247 \cdot cA + 0.257 \cdot cASR \quad (4.6)$$

$$X_3^S = -0.064 \cdot cA_{24} + 0.835 \cdot cA_{12} - 0.235 \cdot cA + 0.494 \cdot cASR \quad (4.7)$$

$$X_4^S = -0.285 \cdot cA_{24} - 0.484 \cdot cA_{12} + 0.085 \cdot cA + 0.823 \cdot cASR \quad (4.8)$$

**TABLE 4.5** shows four datasets that gave the best correlation result in each regression analysis methods conducted in this research study to display the relationship between psychological measures and physiological parameters of diurnal heart rate rhythm. Results show that cosinor and spline parameters from G2 dataset gave the highest results. Therefore, in the following sections, the regression result of this specific dataset will be shown. This is the dataset where we removed weekend data to eliminate the effects of extreme physical activities on mental health assessment.

**TABLE 4.5** Datasets that gave the best result in each correlation analysis method.

Applied methods	Cosinor parameter datasets				Spline parameter datasets			
	G1	G2	G3	G4	G1	G2	G3	G4
Regular single regression		●				●		
Regular multiple regression (×2)		●			●			
Regular multiple regression (×3)		●			●	●		
PCA single regression		●				●		
PCA multiple regression (×2)		●				●	●	
PCA multiple regression (×3)		●			●	●		●
Spearman regression		●			●			
Total Score (#●)	0	7	0	0	4	5	1	1

### 4.3 Relationship between psychological measures

Fig. 4.1 shows the scatter diagrams of *Frequency of Flow Experience* and other psychological measures. Positive psychological measures comprising *Trait-Coping*, *Self-Image*, *Self-Awareness*, and *Will for Meaningful Life* showed significant positive correlations with *Frequency of Flow Experience* ( $p < 0.05$ ), while the only negative psychological measure; *State-Trait Anxiety*, showed a negative correlation with *Frequency of Flow Experience* ( $p < 0.1$ ).

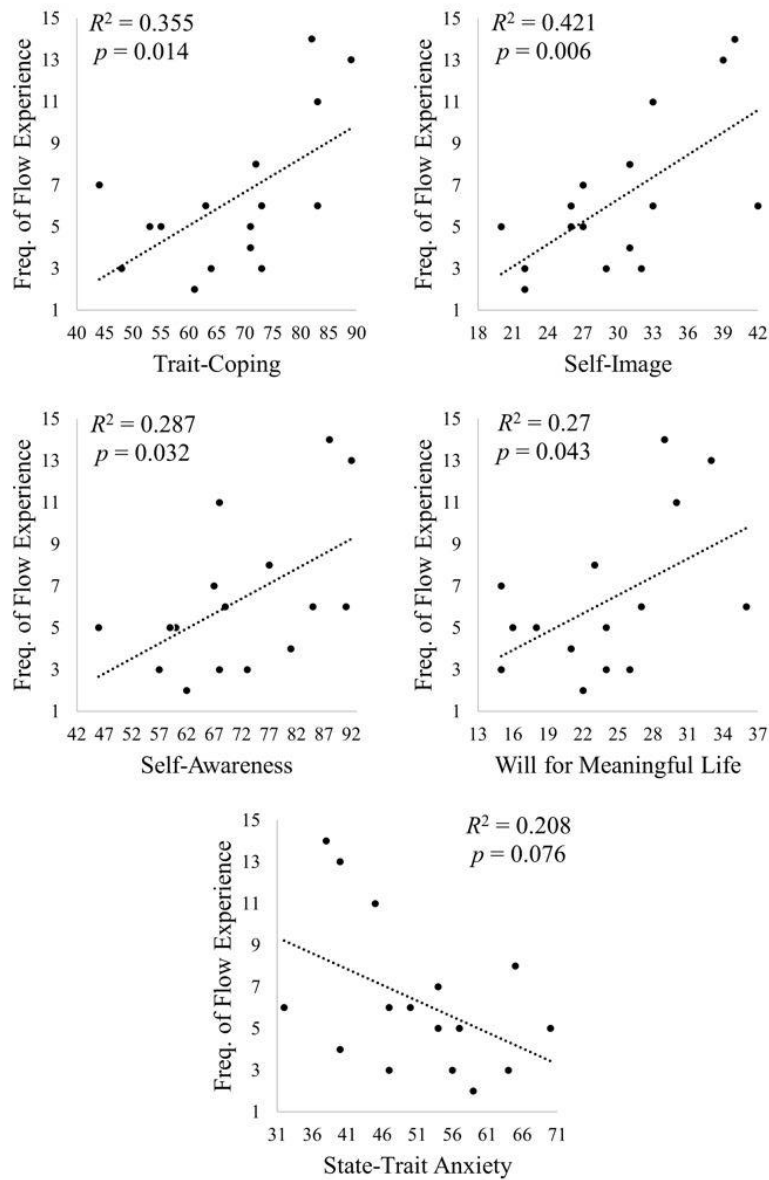
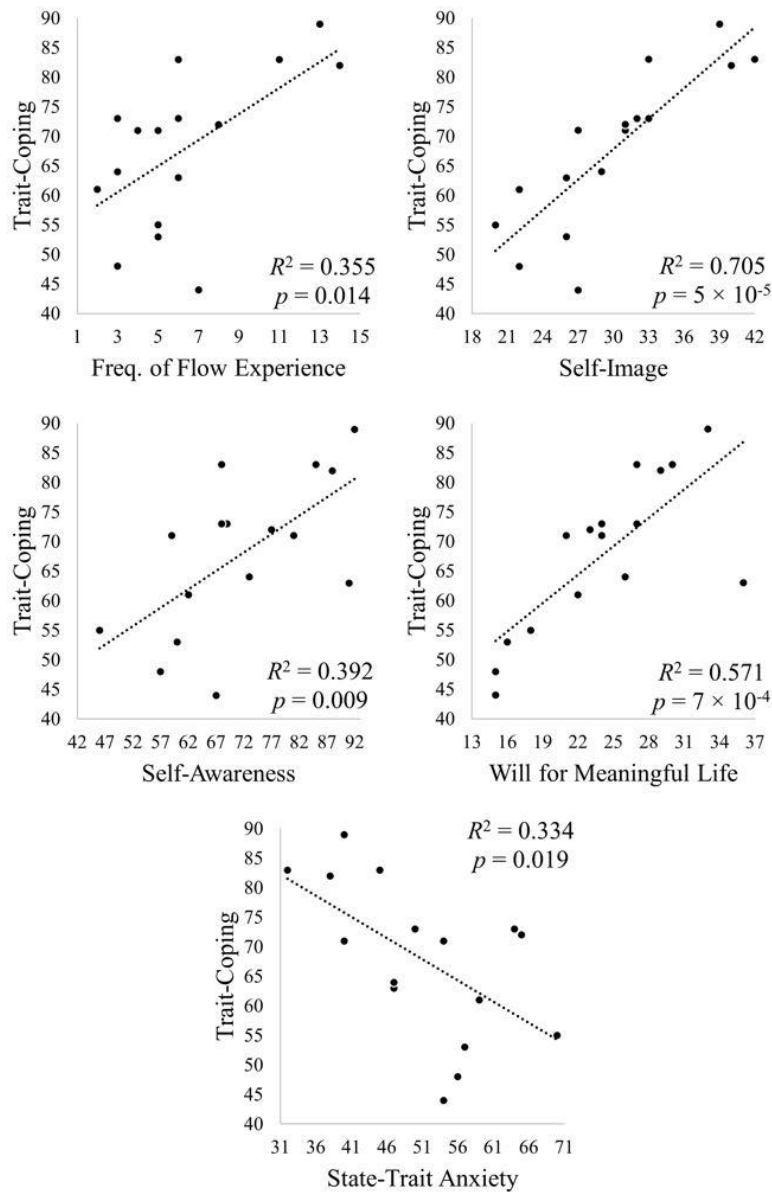


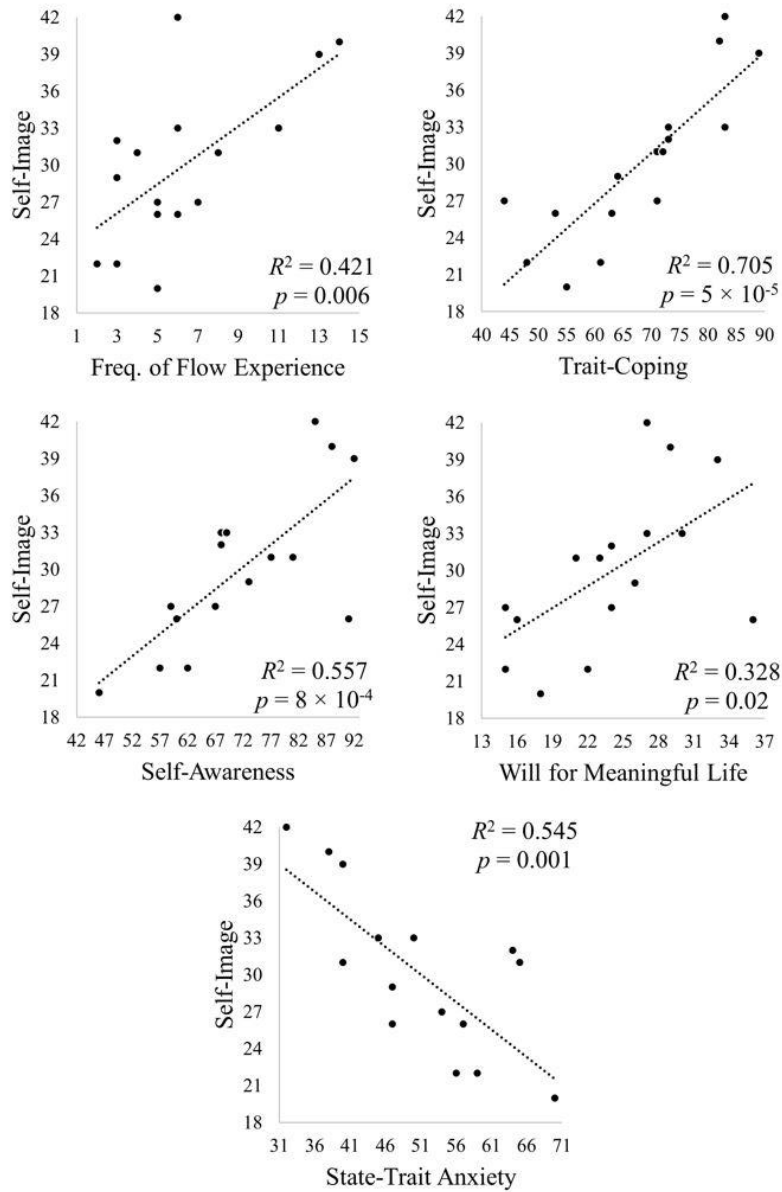
Figure 4.1 Regression analysis showing the relationship between *Frequency of Flow Experience* and other psychological measures.

**Fig. 4.2** shows the scatter diagrams of *Trait-Coping* and other psychological measures. Positive psychological measures comprising *Frequency of Flow Experience*, *Self-Image*, *Self-Awareness*, and *Will for Meaningful Life* showed significant positive correlations with *Trait-Coping* ( $p < 0.05$ ), while the only negative psychological measure; *State-Trait-Anxiety*, showed a negative correlation with *Trait-Coping* ( $p < 0.05$ ).



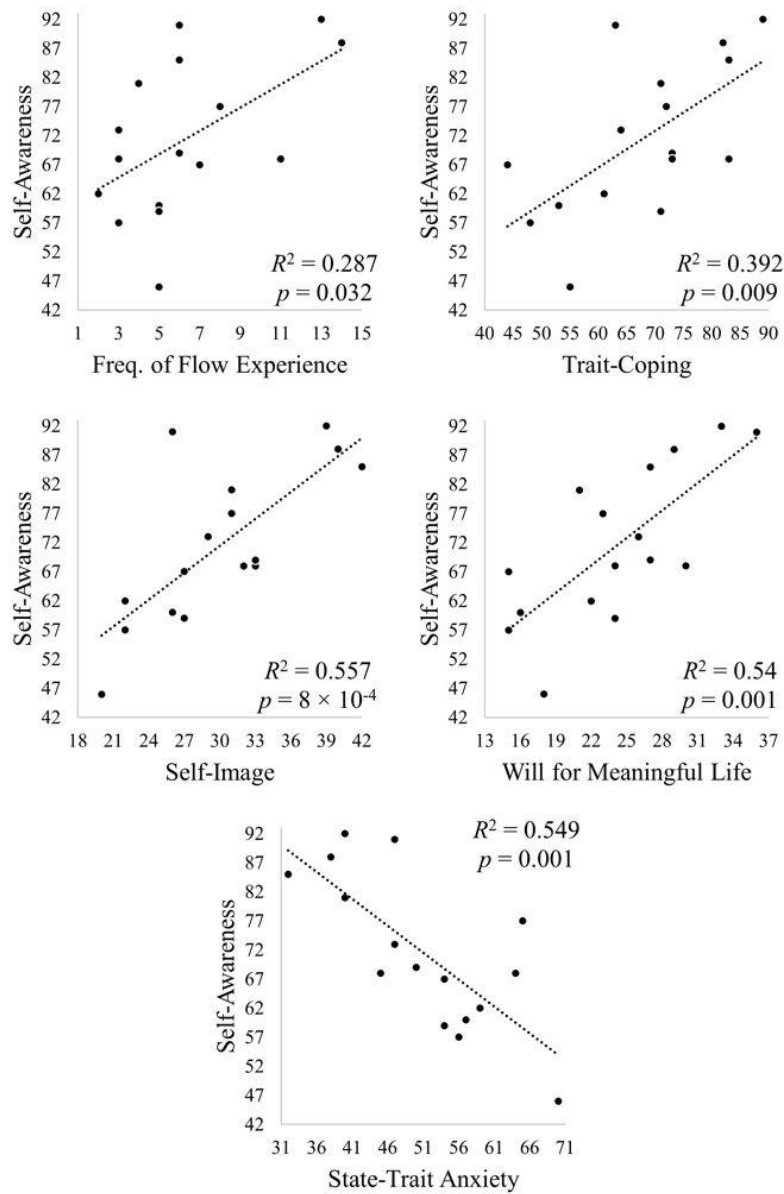
**Figure 4.2** Regression analysis showing the relationship between *Trait-Coping* and other psychological measures.

**Fig. 4.3** shows the scatter diagrams of *Self-Image* and other psychological measures. Positive psychological measures comprising *Frequency of Flow Experience*, *Trait-Coping*, *Self-Awareness*, and *Will for Meaningful Life* showed significant positive correlations with *Self-Image* ( $p < 0.05$ ), while the only negative psychological measure; *State-Trait-Anxiety*, showed a negative correlation with *Self-Image* ( $p < 0.05$ ).



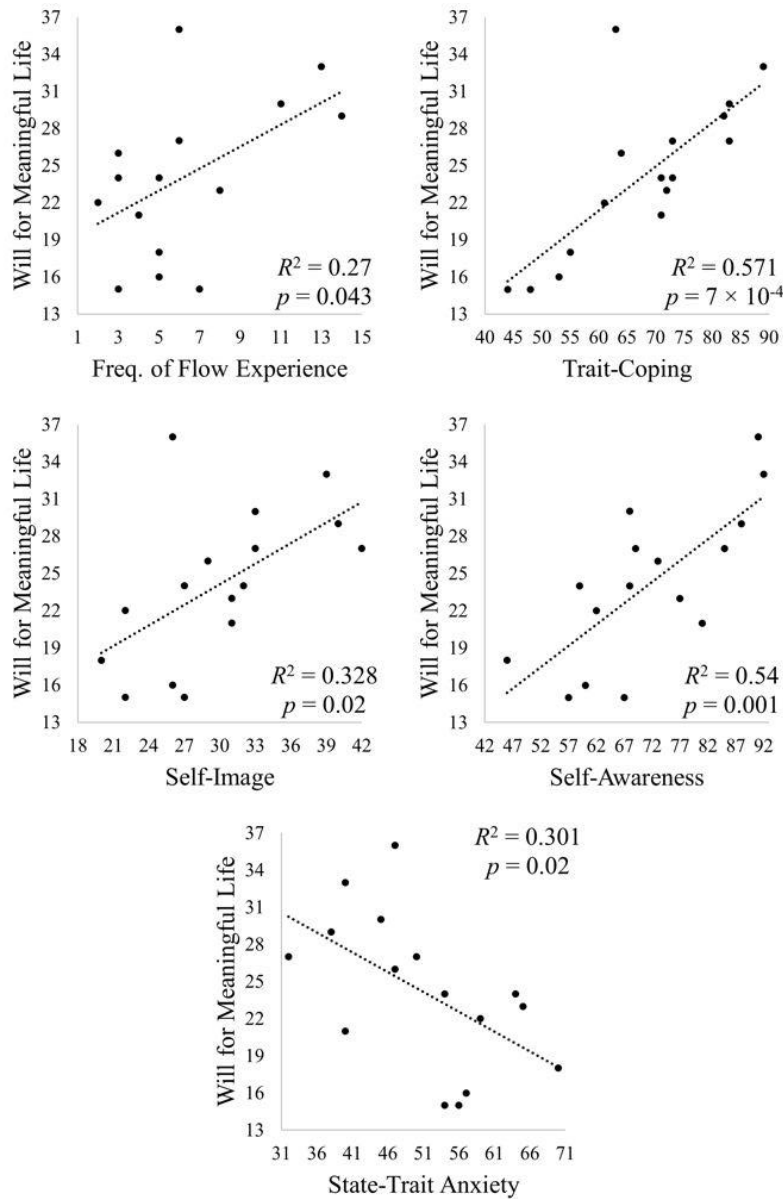
**Figure 4.3** Regression analysis showing the relationship between *Self-Image* and other psychological measures.

**Fig. 4.4** shows the scatter diagrams of *Self-Awareness* and other psychological measures. Positive psychological measures comprising *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, and *Will for Meaningful Life* showed significant positive correlations with *Self-Awareness* ( $p < 0.05$ ), while the only negative psychological measure; *State-Trait-Anxiety*, showed a negative correlation with *Self-Awareness* ( $p < 0.05$ ).



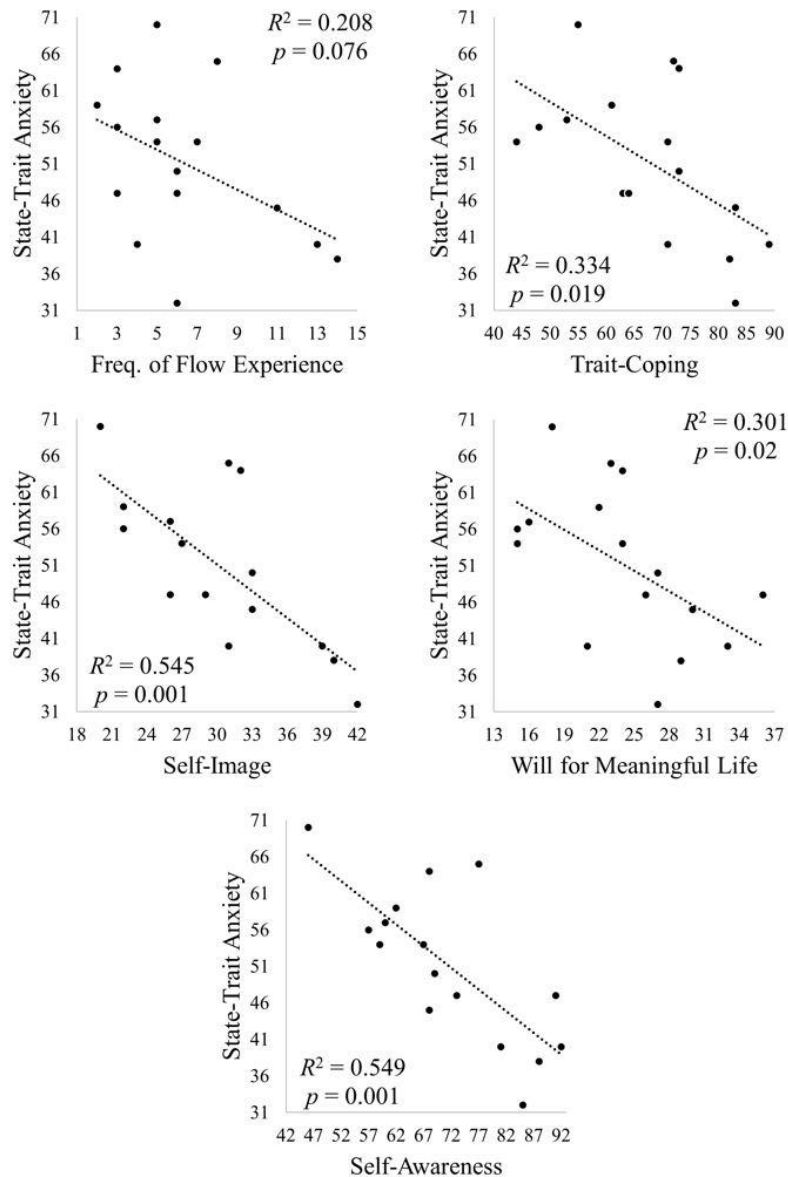
**Figure 4.4** Regression analysis showing the relationship between *Self-Awareness* and other psychological measures.

**Fig. 4.5** shows the scatter diagrams of *Will for Meaningful Life* and other psychological measures. Positive psychological measures comprising *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, and *Self-Awareness* showed significant positive correlations with *Will for Meaningful Life* ( $p < 0.05$ ), while the only negative psychological measure; *State-Trait-Anxiety*, showed a negative correlation with *Will for Meaningful Life* ( $p < 0.05$ ).



**Figure 4.5** Regression analysis showing the relationship between *Will for Meaningful Life* and other psychological measures.

**Fig. 4.6** shows the scatter diagrams of *State-Trait Anxiety* and other psychological measures. Positive psychological measures comprising *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, *Self-Awareness*, and *Will for Meaningful Life* showed negative correlations with *State-Trait Anxiety* ( $0.001 < p < 0.08$ ).

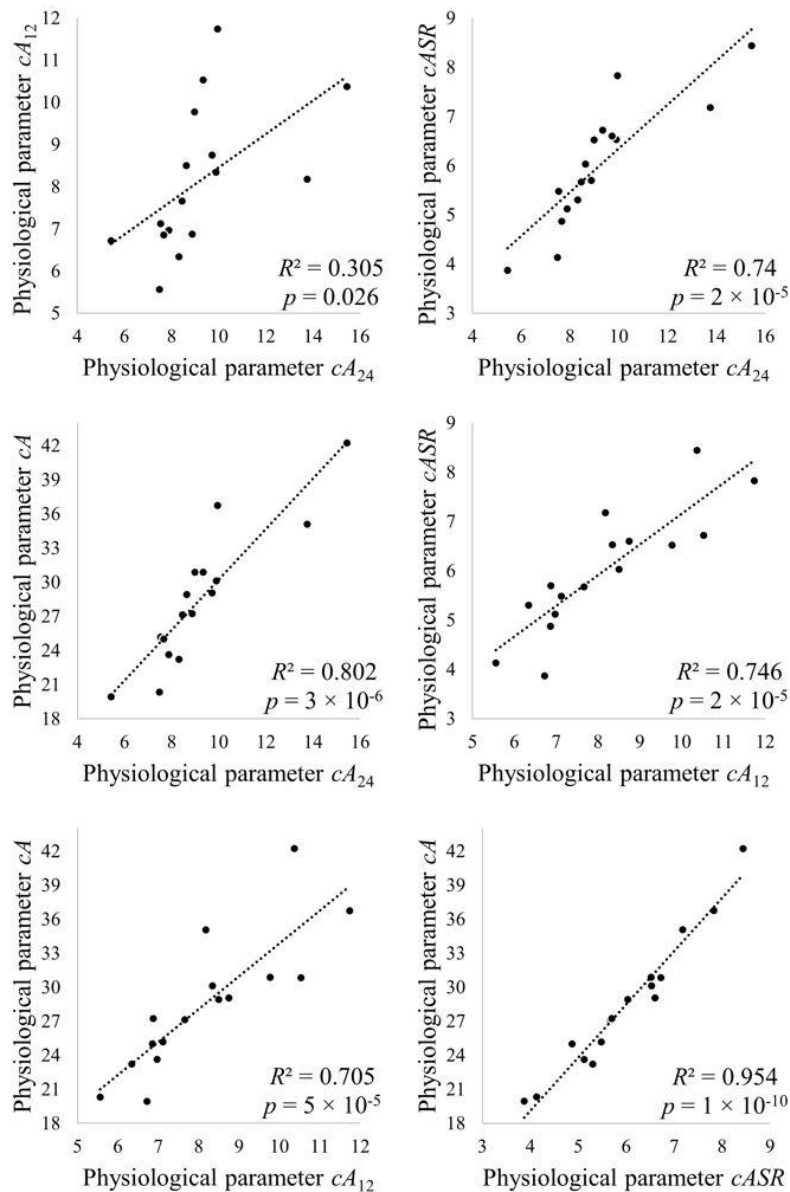


**Figure 4.6** Regression analysis showing the relationship between *State-Trait Anxiety* and other psychological measures.



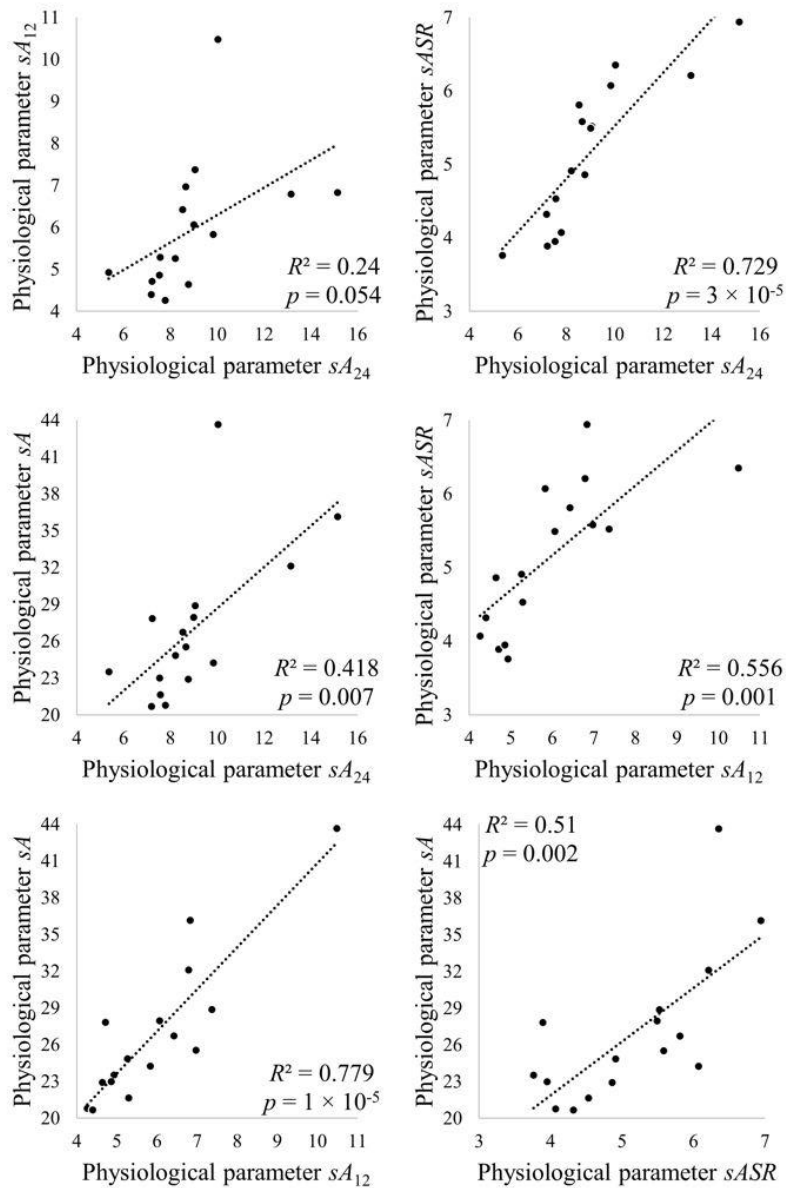
# 4.4 Relationship between physiological parameters

Fig. 4.7 shows the scatter diagrams of cosinor-based physiological parameters of diurnal heart rate rhythm. There are significant correlations among all cosinor-based parameters ( $p < 0.05$ ). The highest correlation result is seen between  $cA$  and  $cASR$ .



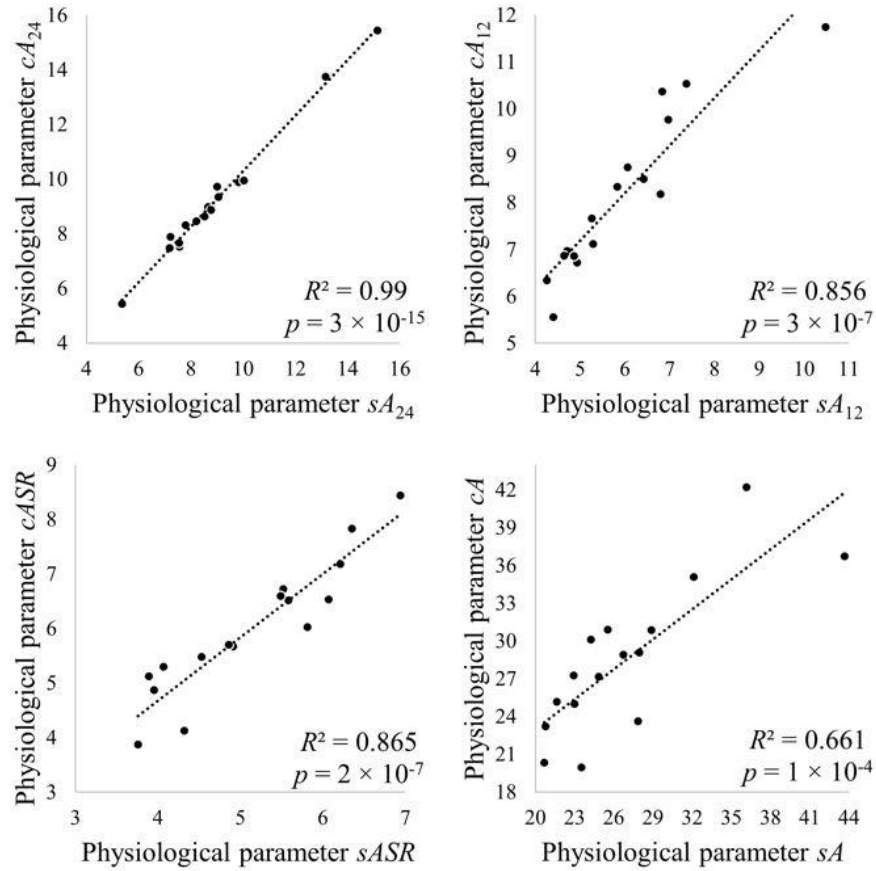
**Figure 4.7** Regression analysis showing the relationship between four double cosinor physiological parameters of diurnal heart rate rhythm.

**Fig. 4.8** shows the scatter diagrams of spline-based physiological parameters of diurnal heart rate rhythm. There are significant correlations among most of the spline-based parameters ( $p < 0.05$ ).  $sA_{24}$  and  $sA_{12}$  showed a trend of significant correlation ( $p < 0.1$ ) The highest correlation result is seen between  $sA$  and  $sA_{12}$ .



**Figure 4.8** Regression analysis showing the relationship between four spline-smoothed physiological parameters of diurnal heart rate rhythm.

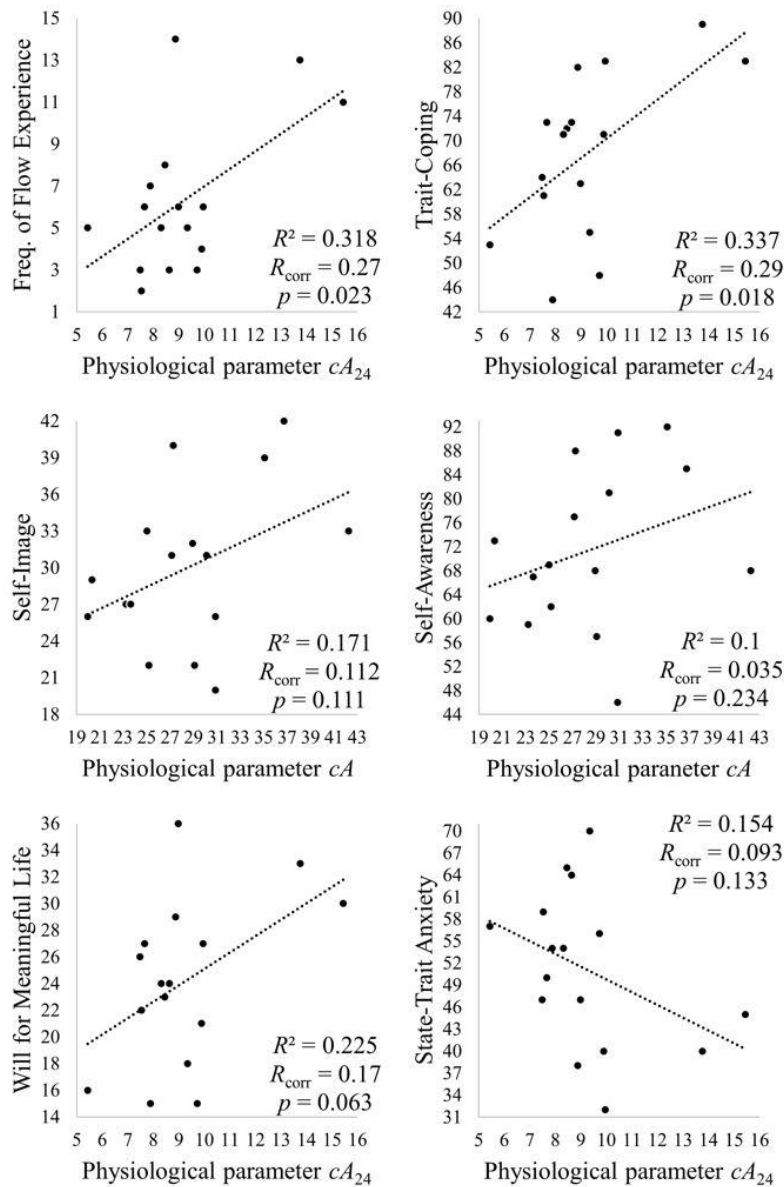
**Figure 4.9** shows the scatter diagrams of cosinor-based and spline-based physiological parameters of diurnal heart rate rhythm. There are significant correlations among all eight parameters ( $p < 0.05$ ).



**Figure 4.9** Regression analysis showing the relationship between four double cosinor and four spline-smoothed physiological parameters of diurnal heart rate rhythm.

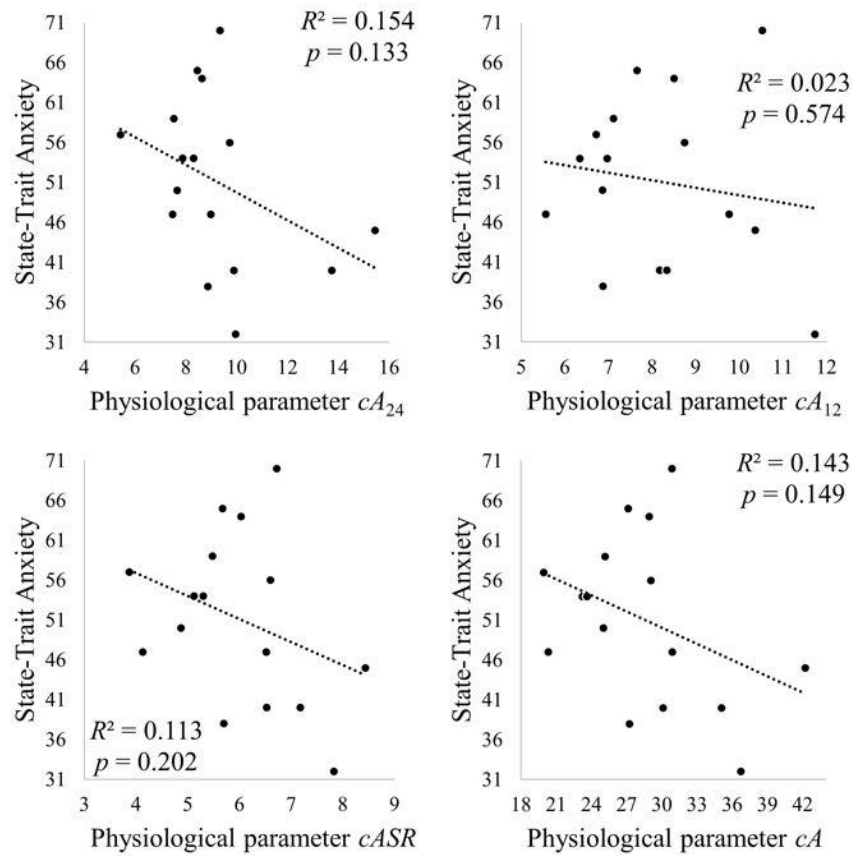
## 4.5 Relationship between psychological measures and physiological parameters

Fig. 4.10 shows the scatter diagrams of psychological measures and cosinor-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, a trend of significant correlation ( $p < 0.1$ ) of *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Image*, *Self-Awareness*, and *State-Trait Anxiety* with single cosinor parameter. In this analysis, *Trait-Coping* shows the highest correlation with  $cA_{24}$ .



**Figure 4.10** Correlation between psychological measures and cosinor physiological parameters. Only the cosinor parameters that give the highest  $R^2$  are selected.

**Fig. 4.11** shows the scatter diagrams of *State-Trait Anxiety* and cosinor-based physiological parameters. The result shows that *State-Trait Anxiety* is not only shows a negative correlation with other psychological measures but also with physiological parameters of diurnal heart rate rhythm in single regression analysis. In addition, there is no correlation of *State-Trait Anxiety* with cosinor parameters ( $p < 0.1$ ).



**Figure 4.11** Correlation between *State-Trait Anxiety* and cosinor physiological parameters.

Fig. 4.12 shows the scatter diagrams of psychological measures and cosinor-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, a trend of significant correlation ( $p < 0.1$ ) of *Self-Image*, *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Awareness*, and *State-Trait Anxiety* with two cosinor parameters. In this analysis, *Trait-Coping* shows the highest correlation with  $cA_{12}$  and  $cA$ .

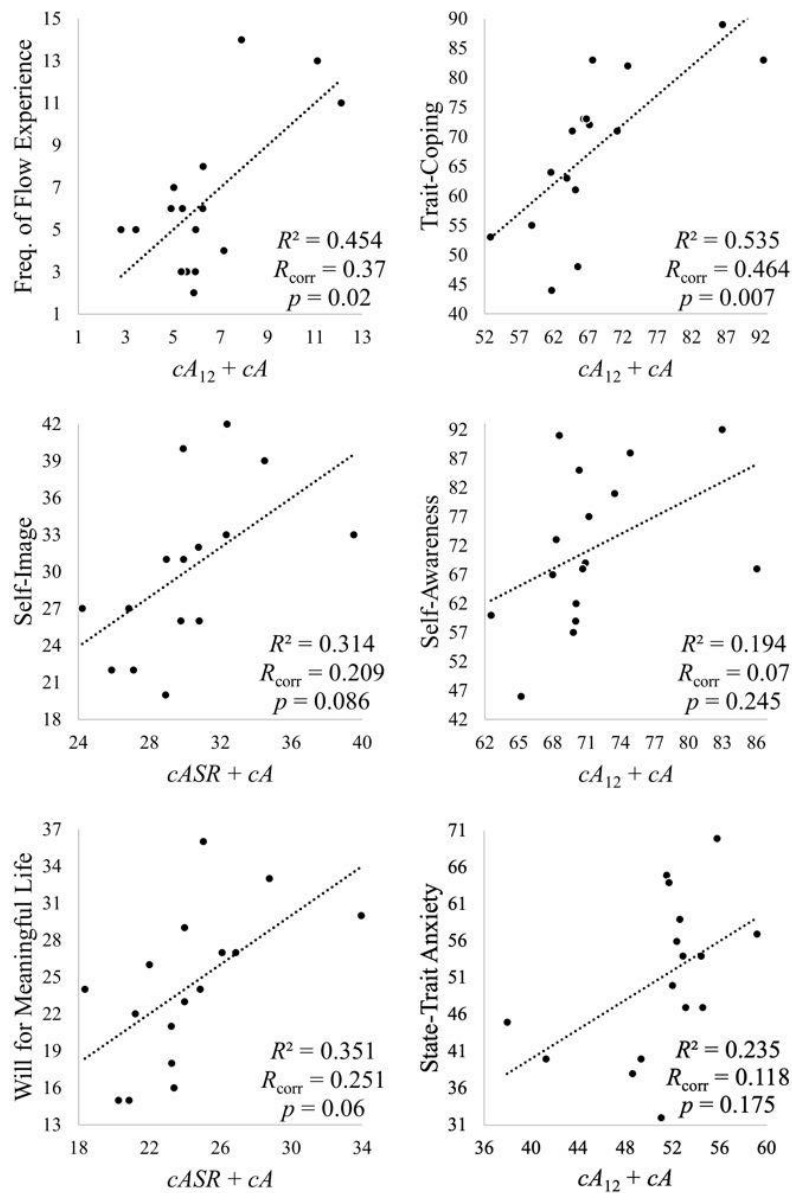
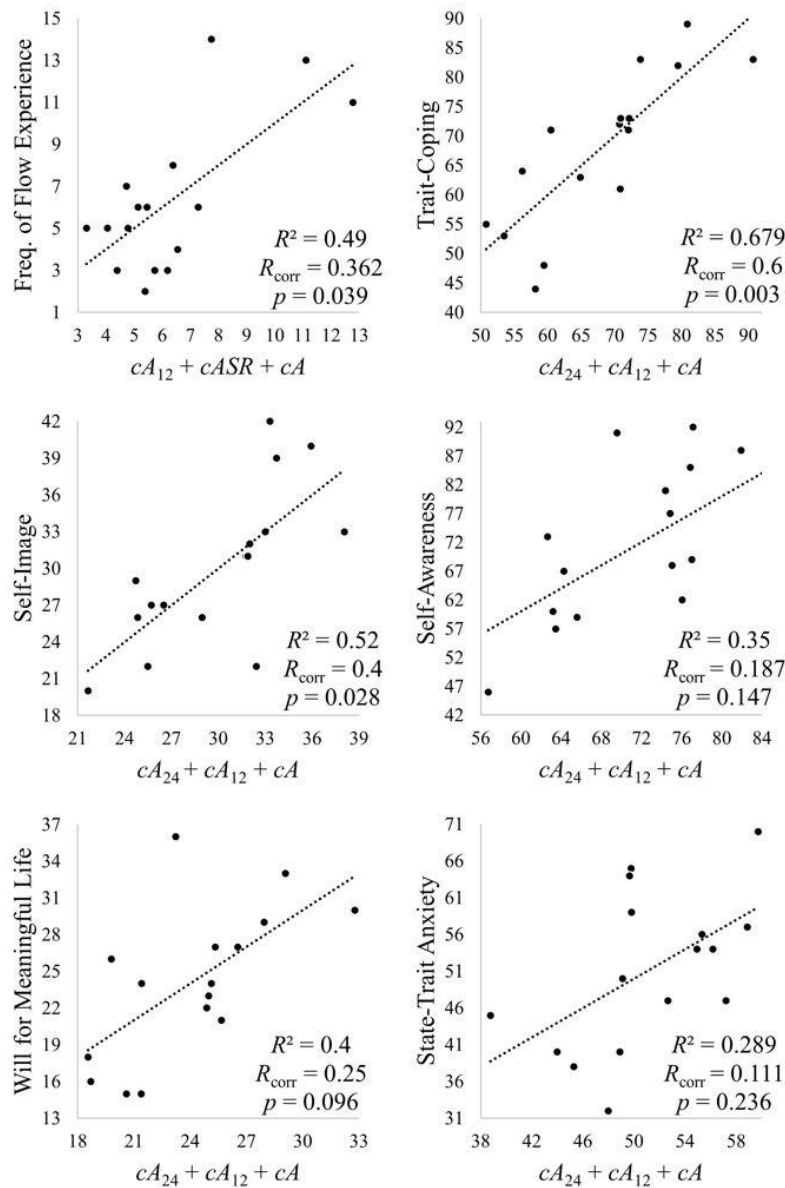


Figure 4.12 Correlation between psychological measures and cosinor physiological parameters. Only the two cosinor parameters that give the highest  $R^2$  are selected.

**Fig. 4.13** shows the scatter diagrams of psychological measures and cosinor-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, a trend of significant correlation ( $p < 0.1$ ) of *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Awareness*, and *State-Trait Anxiety* with three cosinor parameters. In this analysis, *Trait-Coping* shows the highest correlation with  $cA_{24}$ ,  $cA_{12}$  and  $cA$ .



**Figure 4.13** Correlation between psychological measures and cosinor physiological parameters. Only the three cosinor parameters that give the highest  $R^2$  are selected.

Fig. 4.14 shows the scatter diagrams of psychological measures and spline-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Will for Meaningful Life*, a trend of significant correlation ( $p < 0.1$ ) of *Self-Image*, and no correlation ( $p \geq 0.1$ ) of *Self-Awareness*, and *State-Trait Anxiety* with single spline parameter. In this analysis, *Trait-Coping* shows the highest correlation with  $sA_{24}$ .

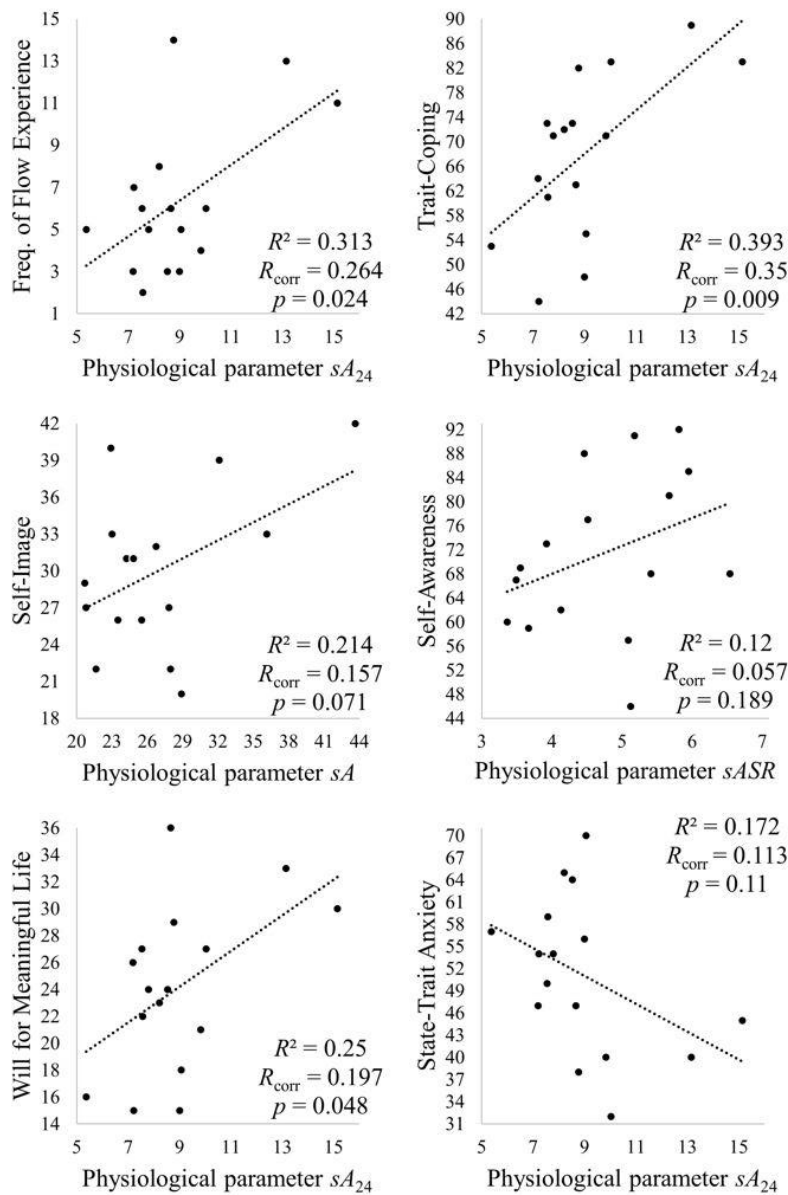
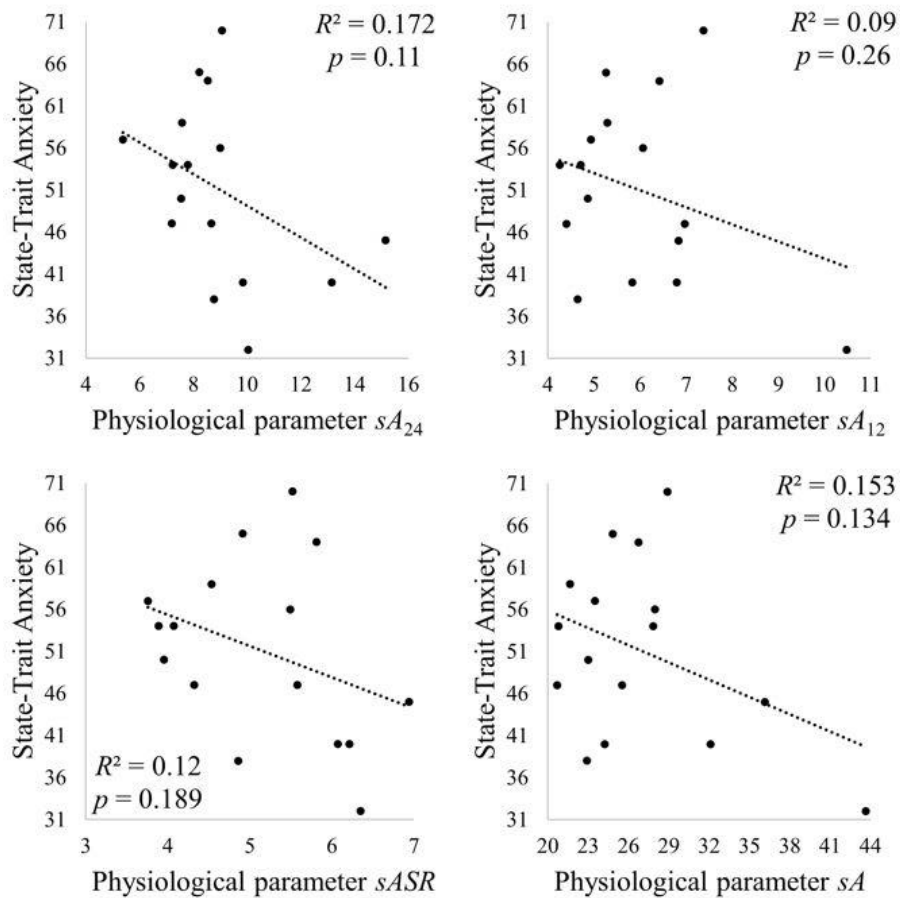


Figure 4.14 Correlation between psychological measures and spline physiological parameters. Only the spline parameters that give the highest  $R^2$  are selected.

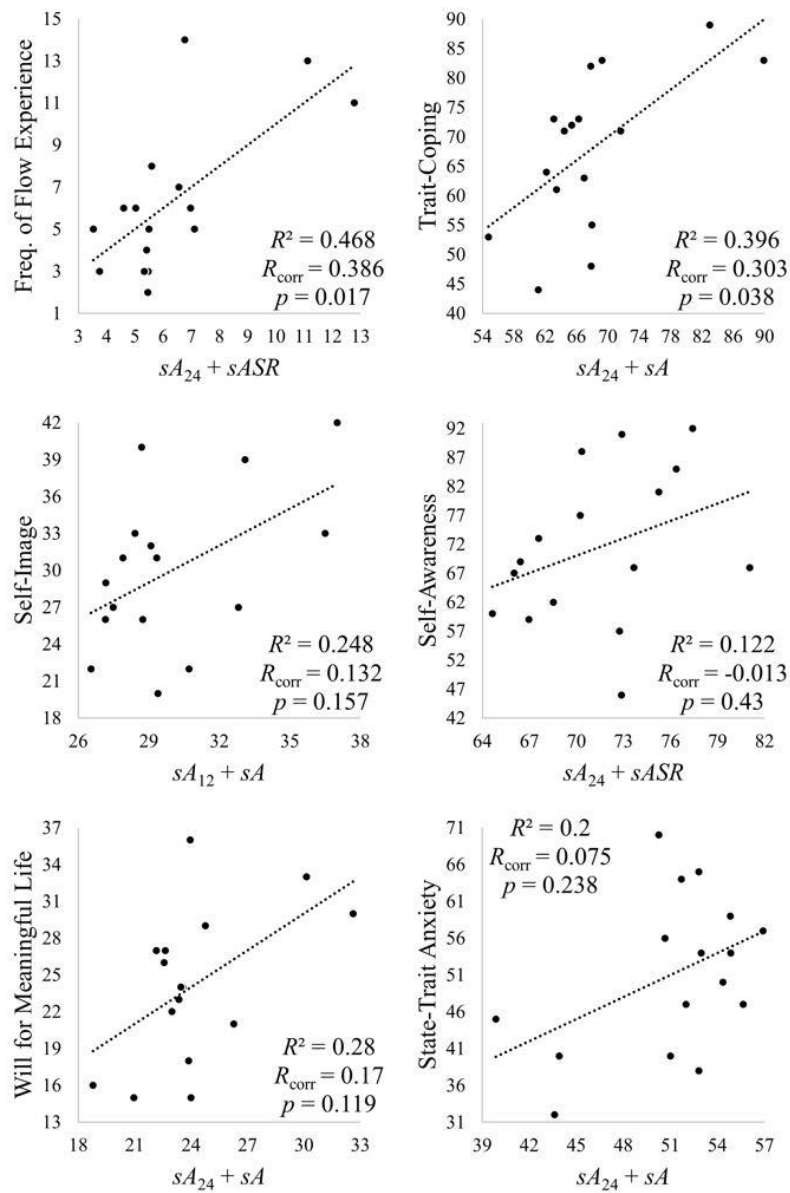


**Fig. 4.15** shows the scatter diagrams of *State-Trait Anxiety* and spline-based physiological parameters. The result shows that *State-Trait Anxiety* is not only shows a negative correlation with other psychological measures but also with physiological parameters of diurnal heart rate rhythm in single regression analysis. In addition, there is no correlation of *State-Trait Anxiety* with cosinor parameters ( $p \geq 0.1$ ).



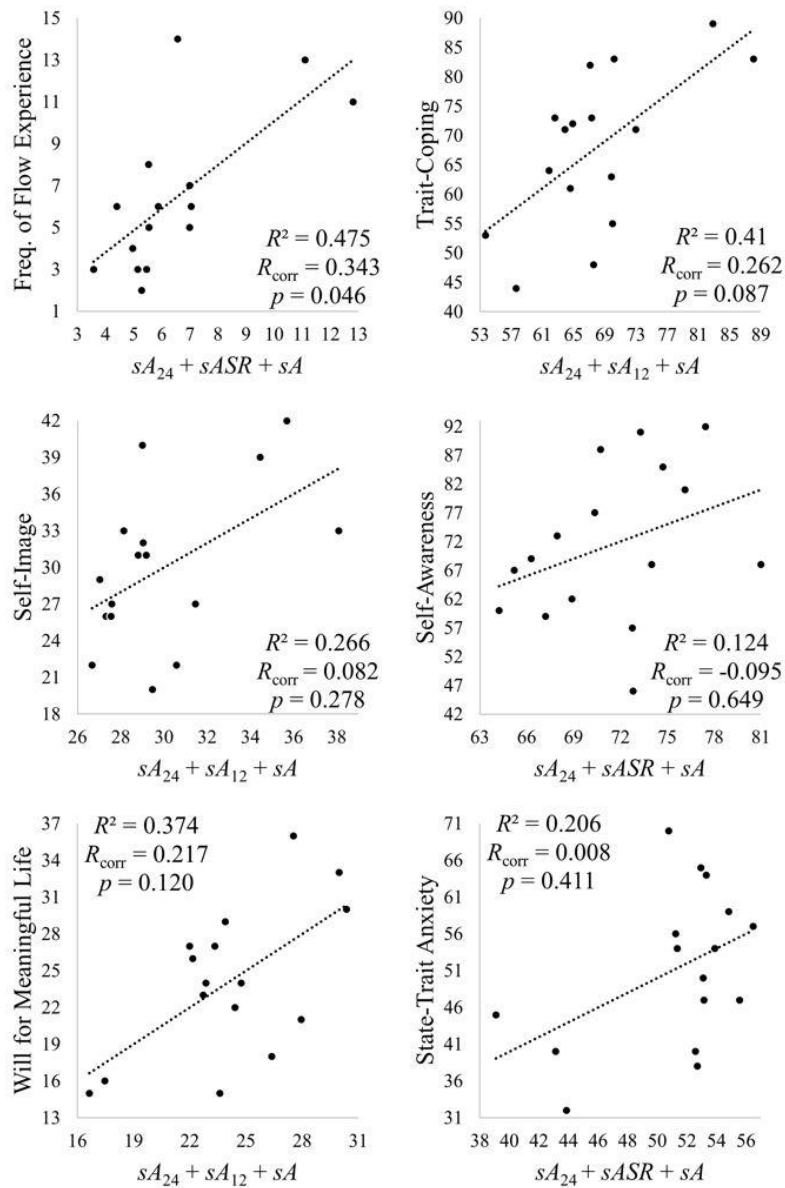
**Figure 4.15** Correlation between *State-Trait Anxiety* and spline physiological parameters.

**Fig. 4.16** shows the scatter diagrams of psychological measures and spline-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, and no correlation ( $p \geq 0.1$ ) of *Self-Image*, *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* with two spline parameters. In this analysis, *Frequency of Flow Experience* shows the highest correlation with  $sA_{24}$  and  $sASR$ .



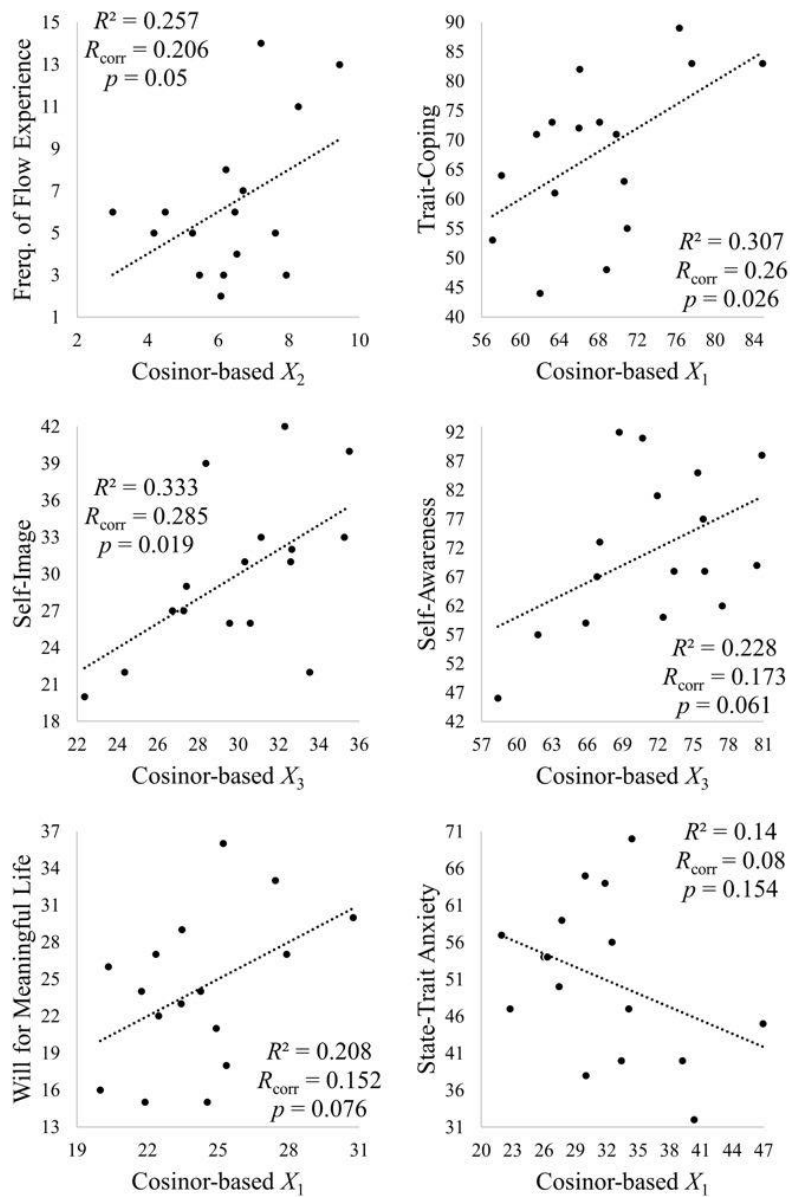
**Fig. 4.16** Correlation between psychological measures and spline physiological parameters. Only the two spline parameters that give the highest  $R^2$  are selected.

**Fig. 4.17** shows the scatter diagrams of psychological measures and spline-based physiological parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, a trend of significant correlation ( $p < 0.1$ ) of *Trait-Coping*, and no correlation ( $p \geq 0.1$ ) of *Self-Image*, *Self-Awareness*, *Will for Meaningful Life*, and *State-Trait Anxiety* with two spline parameters. In this analysis, *Frequency of Flow Experience* shows the highest correlation with  $sA_{24}$ ,  $sASR$ , and  $sA$ .



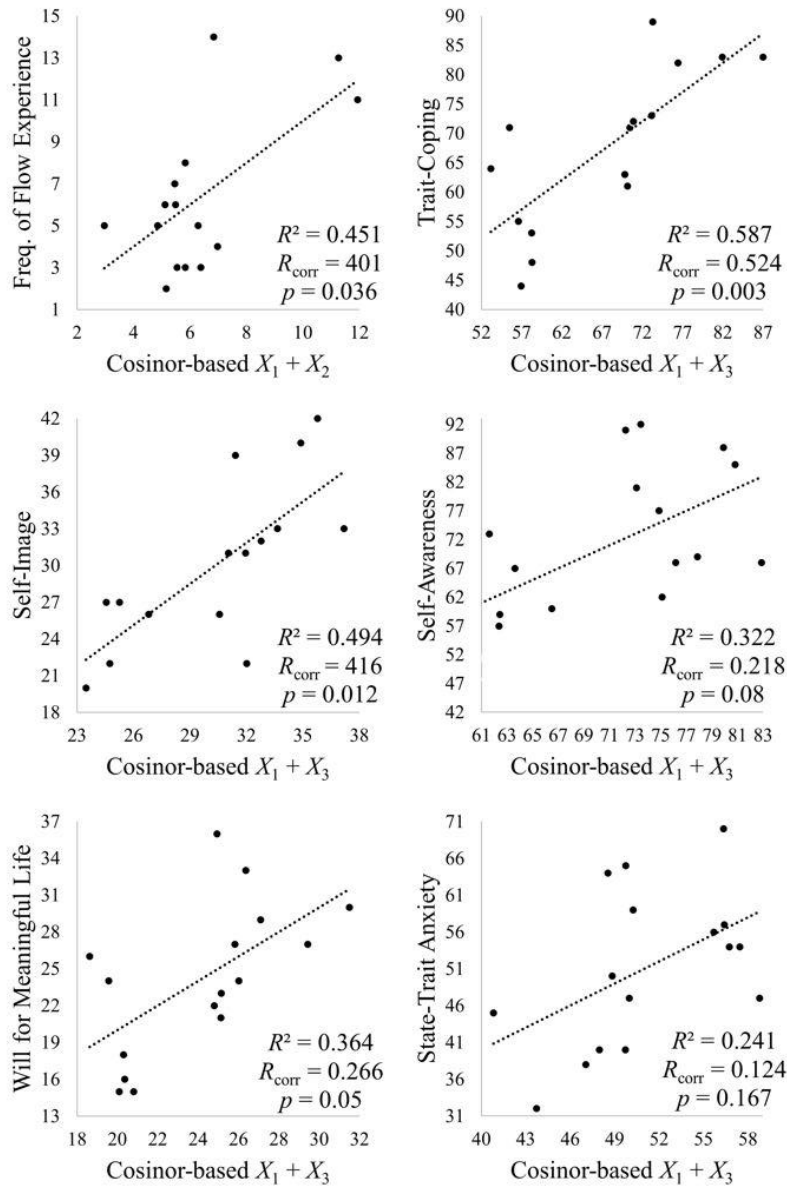
**Figure 4.17** Correlation between psychological measures and spline physiological parameters. Only the three spline parameters that give the highest  $R^2$  are selected.

**Fig. 4.18** shows the results of single PCA component regression for cosinor parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, a trend of significant correlation ( $p < 0.1$ ) of *Self-Awareness*, *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *State-Trait Anxiety* with single cosinor PCA component. In this analysis, *Self-Image* shows the highest correlation with the third principal component that has the elements of  $cA_{12}$  (see **Eq. 4.3**).



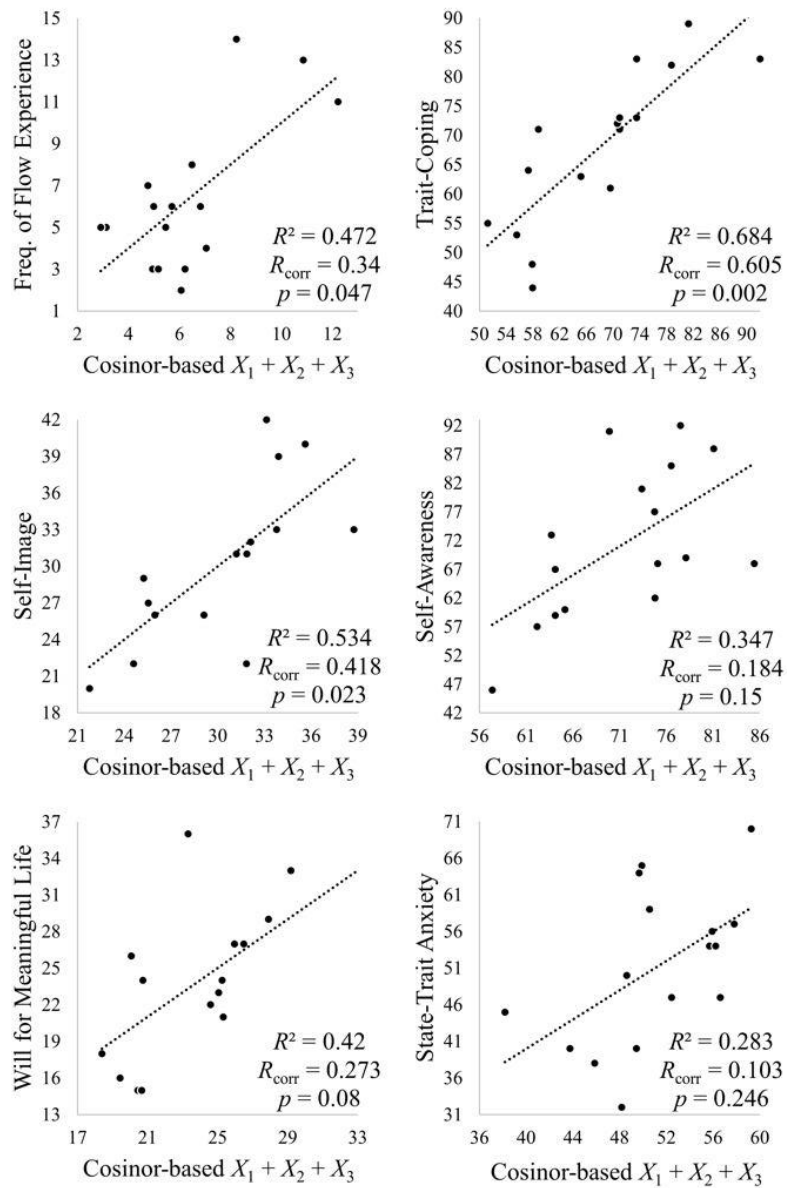
**Figure 4.18** Results of single principal component regression using cosinor-based parameters.

**Fig. 4.19** shows the results of two PCA component regression for cosinor parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, *Will for Meaningful Life*, a trend of significant correlation ( $p < 0.1$ ) of *Self-Awareness*, and no correlation ( $p \geq 0.1$ ) of *State-Trait Anxiety* with two cosinor PCA components. In this analysis, *Trait-Coping* shows the highest correlation with the first and the third principal components that have the elements of  $cA$  and  $cA_{12}$  respectively (see **Eqs. 4.1** and **4.2**).



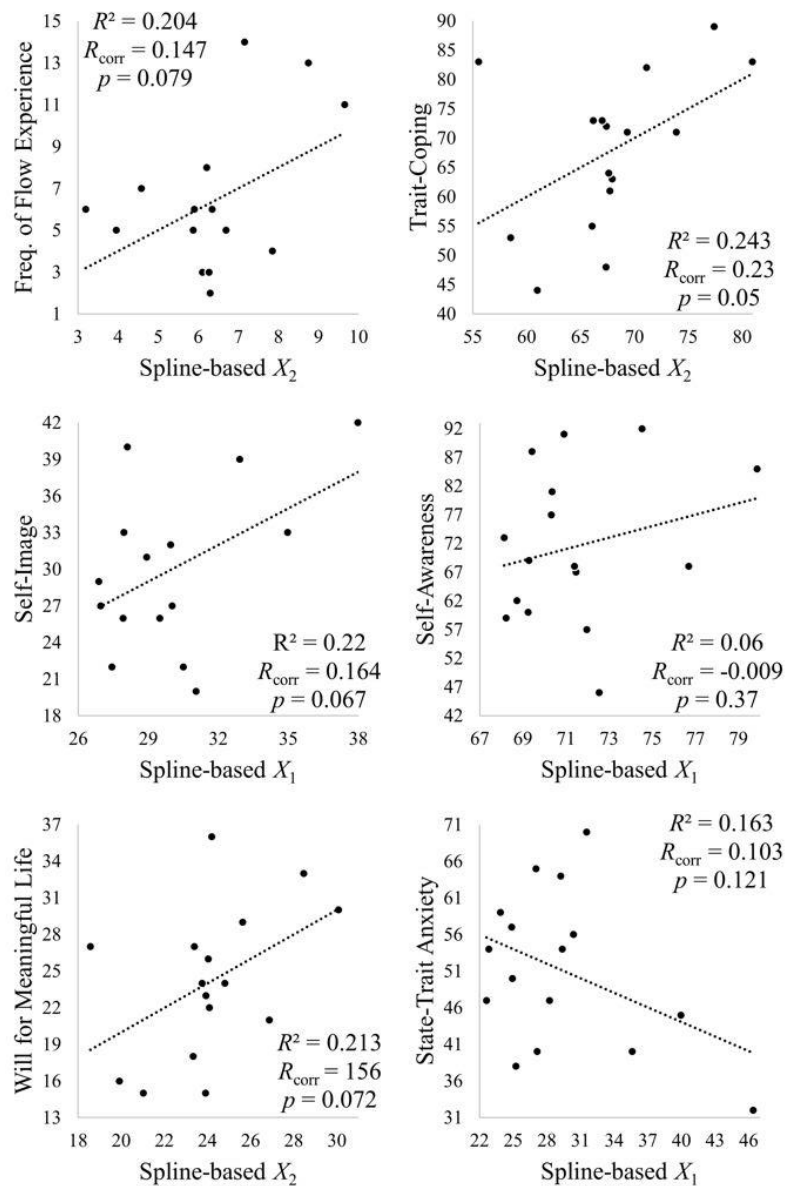
**Figure 4.19** Results of two principal components regression using cosinor-based parameters.

**Fig. 4.20** shows the results of three PCA component regression for cosinor parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, a trend of significant correlation ( $p < 0.1$ ) of *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Awareness* and *State-Trait Anxiety* with three cosinor PCA components. In this analysis, *Trait-Coping* shows the highest correlation with the first, the second, and the third principal components that have the elements of  $cA$ ,  $cA_{24}$ , and  $cA_{12}$  respectively (see **Eqs. 4.1–4.3**).



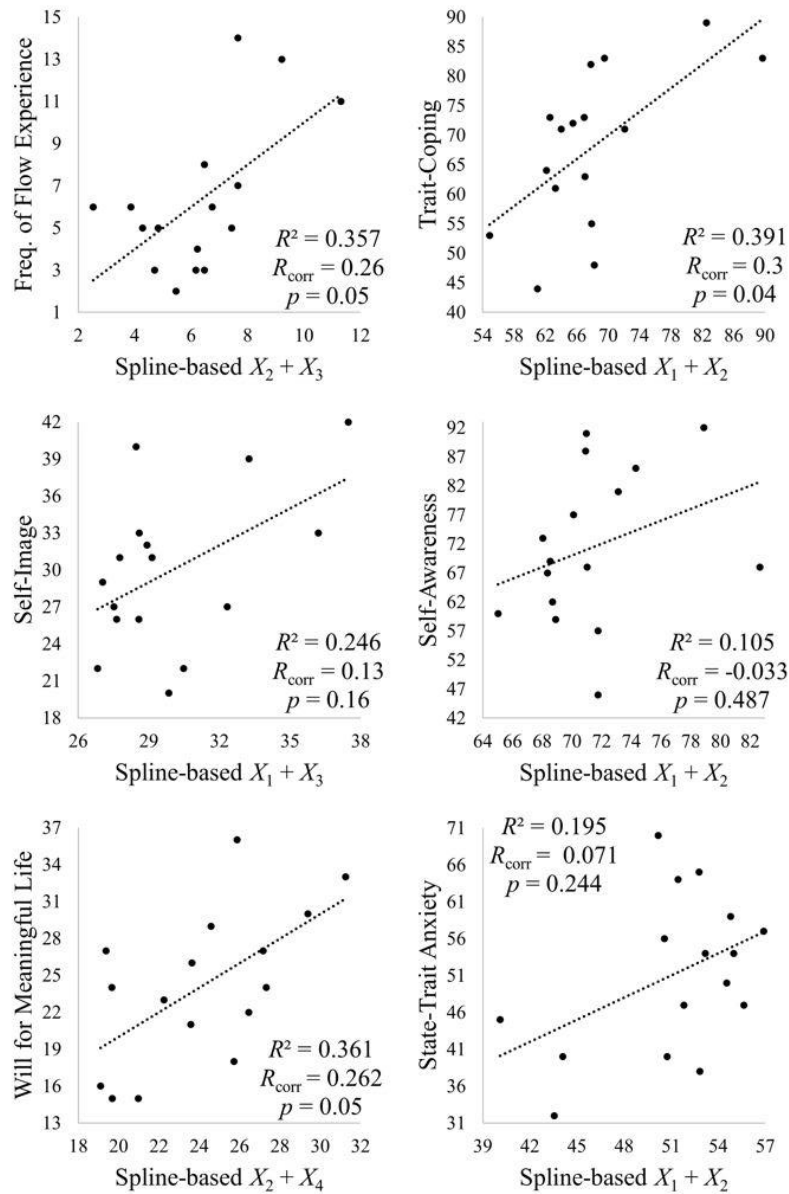
**Figure 4.20** Results of three principal component regression using cosinor-based parameters.

**Fig. 4.21** shows the results of single PCA component regression for spline parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Trait-Coping*, *Self-Image*, a trend of significant correlation ( $p < 0.1$ ) of *Frequency of Flow Experience*, *Self-Image*, *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Awareness*, and *State-Trait Anxiety* with single spline PCA component. In this analysis, *Trait-Coping* shows the highest correlation with the second principal component that has the elements of  $sA_{24}$  (see **Eq. 4.6**).



**Figure 4.21** Results of single principal component regression using spline-based parameters.

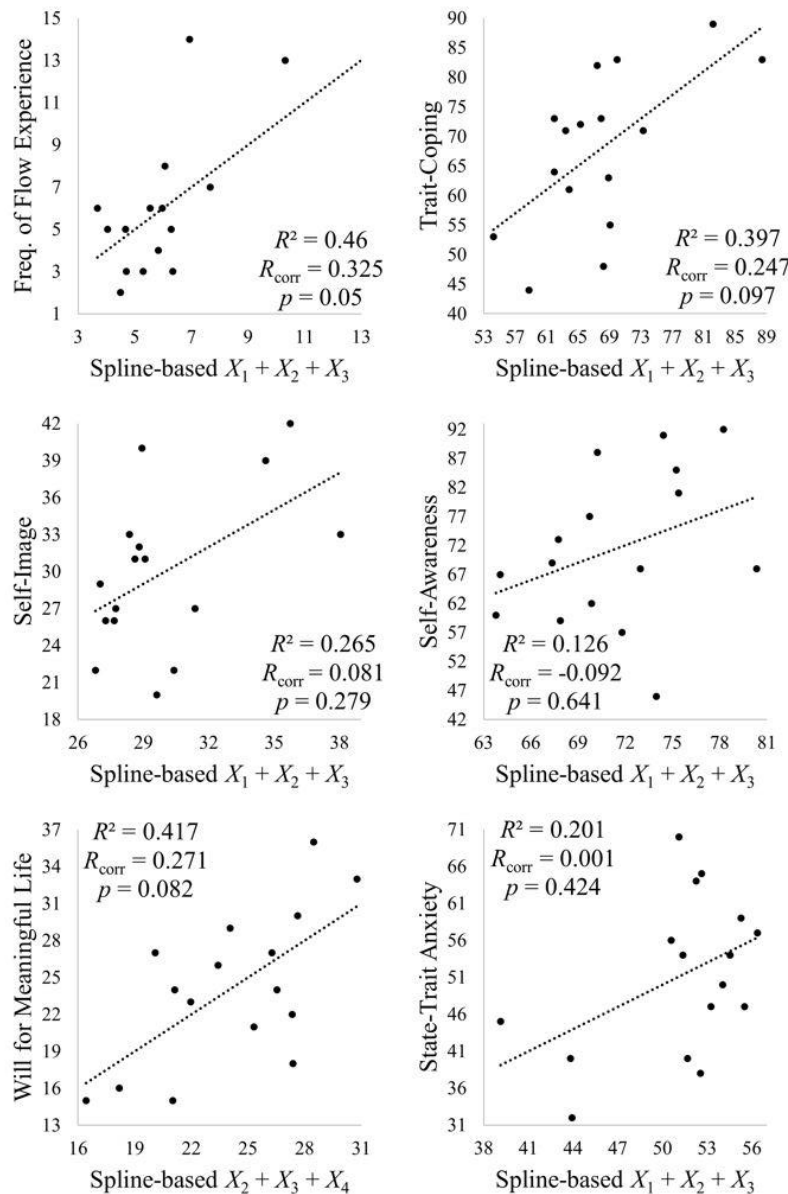
**Fig. 4.22** shows the results of two PCA component regression for spline parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, *Trait-Coping*, *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Image*, *Self-Awareness*, and *State-Trait Anxiety* with two spline PCA components. In this analysis, *Trait-Coping* shows the highest correlation with the first and the second principal components that have the elements of  $sA$  and  $sA_{24}$  respectively (see **Eqs. 4.5** and **4.6**).



**Figure 4.22** Results of two principal component regression using spline-based parameters.

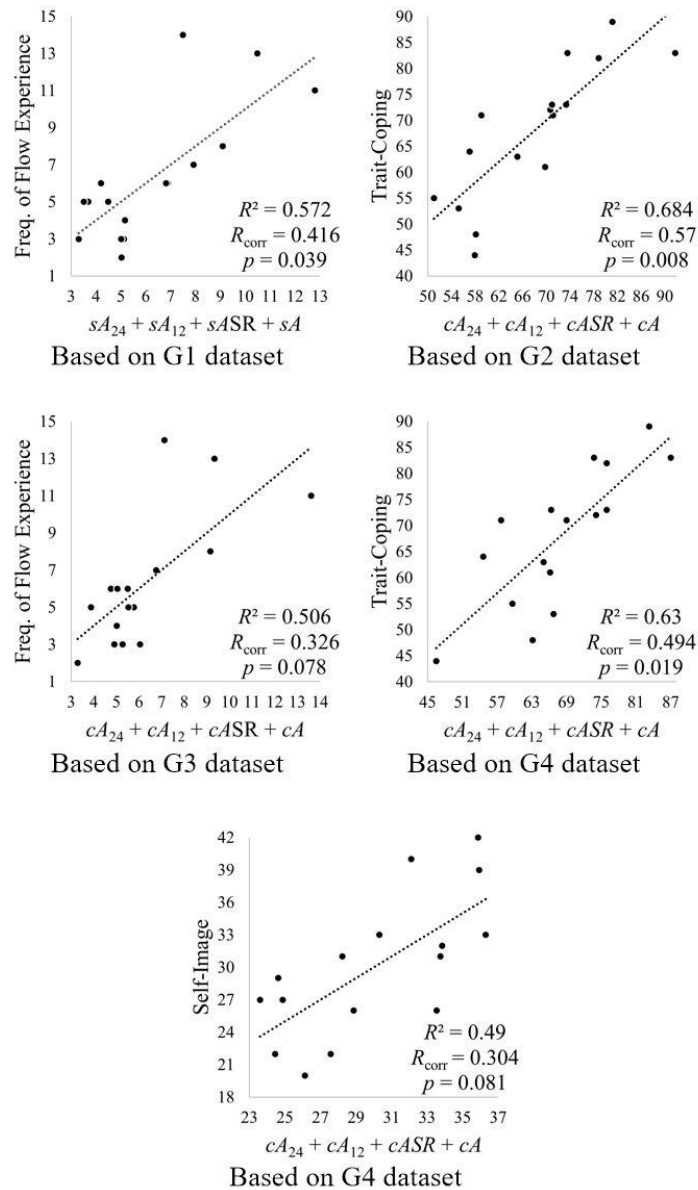


**Fig. 4.23** shows the results of three PCA component regression for spline parameters. The result shows a significant correlation ( $p < 0.05$ ) of *Frequency of Flow Experience*, a trend of significant correlation of *Trait-Coping*, *Will for Meaningful Life*, and no correlation ( $p \geq 0.1$ ) of *Self-Image*, *Self-Awareness*, and *State-Trait Anxiety* with three spline PCA components. In this analysis, *Frequency of Flow Experience* shows the highest correlation with the first, the second, and the third principal components that have the elements of  $sA$  and  $sA_{24}$ , and  $sA_{12}$  respectively (see **Eqs. 4.5–4.7**).



**Figure 4.23** Results of three principal component regression using spline-based parameters.

During multiple regression analysis using all four physiological parameters, the correlation results were either close or slightly larger than the correlation results of multiple regression analysis using three parameters. This indicates that one physiological parameter is probably extra. Only a few datasets gave increased correlation and improved significance level scores. **Fig. 4.24** shows the scatter diagrams of some psychological measures and four physiological parameters. Compared to multiple regression using two or three parameters, the results are better. *Trait-Coping* showed the highest correlation in this analysis.



**Figure 4.24** Correlation between psychological measures and cosinor and spline-based physiological parameters. Only the datasets that give the highest  $R^2$  using all four physiological parameters are selected.

## 4.6 Result summary of all four datasets

**TABLE 4.6** Results of regular single regression analysis using a double cosinor heart rate parameter (The heart rate parameter in the brackets gave the maximum  $R^2$  score).

Double cosinor-based parameters				
Dispositional Psychological measures	max $R^2$			
	G1	G2	G3	G4
Frequency of Flow Experience	0.3* [cA <sub>24</sub> ]	0.318* [cA <sub>24</sub> ]	0.305* [cA <sub>24</sub> ]	0.285* [cA <sub>24</sub> ]
Trait-Coping	0.1† [cA <sub>24</sub> ]	0.337* [cA <sub>24</sub> ]	0.366* [cA <sub>24</sub> ]	0.375* [cA]
Self-Image	0.088† [cA <sub>24</sub> ]	0.171† [cA]	0.156† [cA <sub>24</sub> ]	0.186▲ [cA]
Self-Awareness	0.118† [cA <sub>24</sub> ]	0.1† [cA]	0.058† [cA <sub>24</sub> ]	0.084† [cA]
Will for Meaningful Life	0.163† [cA <sub>24</sub> ]	0.225▲ [cA <sub>24</sub> ]	0.176† [cA <sub>24</sub> ]	0.21▲ [cA]
State-Trait Anxiety	0.133† [cA]	0.154† [cA <sub>24</sub> ]	0.132† [cA]	0.136† [cA]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p > 0.1$ : no correlation).

**TABLE 4.6** notes:

1. In G1 dataset,  $cA_{24}$  was the most dominant physiological parameter.
2. In G2 dataset,  $cA_{24}$  was the most dominant physiological parameter.
3. In G3 dataset,  $cA_{24}$  was the most dominant physiological parameter.
4. In G4 dataset,  $cA$  was the most dominant physiological parameter.
5. In this analysis, weekday G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.7** Results of regular single regression analysis using a spline smoothed heart rate parameter (The heart rate parameter in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.337* [sA <sub>24</sub> ]	0.313* [sA <sub>24</sub> ]	0.303* [sA <sub>24</sub> ]	0.286* [sA <sub>24</sub> ]
Trait-Coping	0.276* [sA <sub>24</sub> ]	0.393* [sA <sub>24</sub> ]	0.367* [sA <sub>24</sub> ]	0.334* [sA <sub>24</sub> ]
Self-Image	0.157† [sA <sub>24</sub> ]	0.214 ▲ [sA]	0.155† [sA <sub>24</sub> ]	0.217 ▲ [sA]
Self-Awareness	0.12† [sA <sub>24</sub> ]	0.123† [sASR]	0.06† [sASR]	0.103† [sASR]
Will for Meaningful Life	0.234† [sA <sub>24</sub> ]	0.25* [sA <sub>24</sub> ]	0.176† [sA <sub>24</sub> ]	0.192 ▲ [sA <sub>24</sub> ]
State-Trait Anxiety	0.163† [sA]	0.172† [sA <sub>24</sub> ]	0.137† [sA]	0.191 ▲ [sA]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p > 0.1$ : no correlation).

**TABLE 4.7** notes:

1. In G1 dataset,  $sA_{24}$  was the most dominant physiological parameter.
2. In G2 dataset,  $sA_{24}$  was the most dominant physiological parameter.
3. In G3 dataset,  $sA_{24}$  was the most dominant physiological parameter.
4. In G4 dataset,  $sA_{24}$  was the most dominant physiological parameter.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.8** Results of regular multiple regression analysis using two double cosinor heart rate parameters (The heart rate parameters in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological</b>	<b>max<math>R^2</math></b>			
<b>measures</b>	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow	0.432*	0.454*	0.453*	0.372*
Experience	[cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cASR]	[cA <sub>12</sub> , cA]
Trait-Coping	0.108†	0.536*	0.37*	0.474*
	[cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> ]	[cA <sub>12</sub> , cA]
Self-Image	0.153†	0.314▲	0.394*	0.39*
	[cA <sub>12</sub> , cA]	[cASR, cA]	[cASR, cA]	[cASR, cA]
Self-Awareness	0.192†	0.194†	0.063†	0.155†
	[cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cASR]	[cASR, cA]
Will for Meaningful Life	0.189†	0.351▲	0.178†	0.252†
	[cASR, cA]	[cASR, cA]	[cA <sub>24</sub> , cA <sub>12</sub> ]	[cA <sub>12</sub> , cA]
State-Trait Anxiety	0.17†	0.235†	0.168†	0.157†
	[cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cA]	[cASR, cA]	[cASR, cA]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and † $p \geq 0.1$ : no correlation).

**TABLE 4.8** notes:

1. Among all datasets, [cA<sub>12</sub>, cA] were the most dominant physiological parameters.
2. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.9** Results of regular multiple regression analysis using two spline smoothed heart rate parameters (The heart rate parameters in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow	0.524*	0.468*	0.434*	0.372*
Experience	[sA <sub>24</sub> , sA <sub>12</sub> ]	[sA <sub>24</sub> , sASR]	[sA <sub>24</sub> , sASR]	[sA <sub>24</sub> , sASR]
Trait-Coping	0.316 ▲	0.396*	0.374*	0.362*
	[sA <sub>24</sub> , sA]	[sA <sub>24</sub> , sA]	[sA <sub>24</sub> , sASR]	[sA <sub>24</sub> , sASR]
Self-Image	0.166 †	0.248 †	0.288 †	0.302 ▲
	[sA <sub>24</sub> , sA <sub>12</sub> ]	[sA <sub>12</sub> , sA]	[sA <sub>12</sub> , sA]	[sA <sub>12</sub> , sA]
Self-Awareness	0.18 †	0.122 †	0.1 †	0.112 †
	[sA <sub>24</sub> , sA <sub>12</sub> ]	[sA <sub>24</sub> , sASR]	[sA <sub>12</sub> , sA]	[sA <sub>24</sub> , sASR]
Will for Meaningful Life	0.3 ▲	0.28 †	0.181 †	0.196 †
	[sA <sub>24</sub> , sASR]	[sA <sub>24</sub> , sA]	[sA <sub>24</sub> , sA]	[sA <sub>24</sub> , sASR]
State-Trait Anxiety	0.187 †	0.2 †	0.188 †	0.267 †
	[sA <sub>12</sub> , sA]	[sA <sub>24</sub> , sA]	[sA <sub>12</sub> , sA]	[sA <sub>12</sub> , sA]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and †  $p \geq 0.1$ : no correlation).

**TABLE 4.9** notes:

1. Among all datasets, [sA<sub>24</sub>, sASR] were the most dominant physiological parameters.
2. In this analysis, G1 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.10** Results of regular multiple regression analysis using three double cosinor heart rate parameters (The heart rate parameters in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological</b>	<b>max<math>R^2</math></b>			
<b>measures</b>	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow	0.433 ▲	0.49*	0.458 ▲	0.488*
Experience	[cA <sub>12</sub> , cASR, cA]	[cA <sub>12</sub> , cASR, cA]	[cA <sub>12</sub> , cASR, cA]	[cA <sub>12</sub> , cASR, cA]
Trait-Coping	0.116†	0.68*	0.388†	0.496*
	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cASR, cA]
Self-Image	0.272†	0.52*	0.275†	0.419 ▲
	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cASR, cA]	[cA <sub>24</sub> , cASR, cA]
Self-Awareness	0.232†	0.35†	0.068†	0.176†
	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cASR, cA]	[cA <sub>24</sub> , cASR, cA]
Will for Meaningful Life	0.192†	0.4 ▲	0.255†	0.257†
	[cA <sub>24</sub> , cASR, cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cASR, cA]
State-Trait Anxiety	0.372†	0.29†	0.171†	0.16†
	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>24</sub> , cA <sub>12</sub> , cA]	[cA <sub>12</sub> , cASR, cA]	[cA <sub>24</sub> , cASR, cA]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p > 0.1$ : no correlation).

**TABLE 4.10** notes:

- Among all datasets, [cA<sub>24</sub>, cA<sub>12</sub>, cA] were the most dominant physiological parameters.
- In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.11** Results of regular multiple regression analysis using three spline smoothed heart rate parameters (The heart rate parameters in the brackets gave the maximum  $R^2$  score).

Dispositional Psychological measures	Spline-based parameters			
	max $R^2$			
	G1	G2	G3	G4
Frequency of Flow Experience	0.571* [sA <sub>24</sub> , sA <sub>12</sub> , sASR]	0.475* [sA <sub>24</sub> , sASR, sA]	0.486* [sA <sub>24</sub> , sA <sub>12</sub> , sASR]	0.404 ▲ [sA <sub>24</sub> , sA <sub>12</sub> , sASR]
Trait-Coping	0.356† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.41 ▲ [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.382† [sA <sub>24</sub> , sA <sub>12</sub> , sASR]	0.362† [sA <sub>24</sub> , sA <sub>12</sub> , sASR]
Self-Image	0.2† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.266† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.326† [sA <sub>12</sub> , sASR, sA]	0.307† [sA <sub>12</sub> , sASR, sA]
Self-Awareness	0.203† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.124† [sA <sub>24</sub> , sASR, sA]	0.174† [sA <sub>12</sub> , sASR, sA]	0.128† [sA <sub>12</sub> , sASR, sA]
Will for Meaningful Life	0.313† [sA <sub>24</sub> , sA <sub>12</sub> , sASR]	0.374† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.181† [sA <sub>24</sub> , sA <sub>12</sub> , sA]	0.206† [sA <sub>24</sub> , sA <sub>12</sub> , sA]
State-Trait Anxiety	0.211† [sA <sub>12</sub> , sASR, sA]	0.206† [sA <sub>24</sub> , sASR, sA]	0.252† [sA <sub>12</sub> , sASR, sA]	0.28† [sA <sub>12</sub> , sASR, sA]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and †  $p > 0.1$ : no correlation).

**TABLE 4.11** notes:

1. Among all datasets, [sA<sub>12</sub>, sASR, sA] were the most dominant physiological parameters.
2. In this analysis, two datasets, G1 and G2, gave good coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores.



**TABLE 4.12** Results of Spearman regression analysis using a double cosinor heart rate parameter (The heart rate parameter in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.585* [cA <sub>24</sub> ]	0.38† [cA <sub>24</sub> ]	0.374† [cA <sub>24</sub> ]	0.362† [cA <sub>24</sub> ]
Trait-Coping	0.274† [cASR]	0.503* [cA <sub>24</sub> ]	0.622* [cA <sub>24</sub> ]	0.542* [cA <sub>24</sub> ]
Self-Image	0.294† [cA <sub>24</sub> ]	0.373† [cA <sub>24</sub> ]	0.455 ▲ [cA <sub>24</sub> ]	0.376† [cA <sub>24</sub> ]
Self-Awareness	0.383† [cA <sub>24</sub> ]	0.384† [cA]	0.368† [cA <sub>24</sub> ]	0.334† [cA <sub>24</sub> ]
Will for Meaningful Life	0.314† [cASR]	0.454 ▲ [cA]	0.37† [cA]	0.416† [cA]
State-Trait Anxiety	-0.420† [cASR]	-0.458 ▲ [cA <sub>24</sub> ]	-0.382† [cASR]	-0.448 ▲ [cA <sub>24</sub> ]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and †  $p > 0.1$ : no correlation).

**TABLE 4.12** notes:

1. In G1 dataset,  $cA_{24}$  and  $cASR$  were the most dominant physiological parameters.
2. In G2 dataset,  $cA_{24}$  was the most dominant physiological parameter.
3. In G3 dataset,  $cA_{24}$  was the most dominant physiological parameter.
4. In G4 dataset,  $cA_{24}$  was the most dominant physiological parameter.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.13** Results of Spearman regression analysis using a spline smoothed heart rate parameter (The heart rate parameter in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.516* [sA <sub>24</sub> ]	0.35† [sA]	0.355† [sA <sub>24</sub> ]	0.297† [sA <sub>24</sub> ]
Trait-Coping	0.425 ▲ [sASR]	0.588* [sASR]	0.62* [sA <sub>24</sub> ]	0.545* [sA <sub>24</sub> ]
Self-Image	0.34† [sA <sub>24</sub> ]	0.397† [sASR]	0.45 ▲ [sA <sub>24</sub> ]	0.381† [sA <sub>24</sub> ]
Self-Awareness	0.465 ▲ [sA <sub>24</sub> ]	0.421† [sASR]	0.36† [sA <sub>24</sub> ]	0.3† [sA <sub>24</sub> ]
Will for Meaningful Life	0.346† [sA <sub>24</sub> ]	0.455 ▲ [sASR]	0.343† [sA <sub>24</sub> ]	0.332† [sA <sub>24</sub> ]
State-Trait Anxiety	-0.447 ▲ [sA <sub>24</sub> ]	-0.436 ▲ [sA <sub>24</sub> ]	-0.353† [sA <sub>24</sub> ]	-0.422† [sA <sub>24</sub> ]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and †  $p > 0.1$ : no correlation).

**TABLE 4.13** notes:

1. In G1 dataset,  $sA_{24}$  was the most dominant physiological parameter.
2. In G2 dataset,  $sA_{24}$  was the most dominant physiological parameter.
3. In G3 dataset,  $sA_{24}$  was the most dominant physiological parameter.
4. In G4 dataset,  $sA_{24}$  was the most dominant physiological parameter.
5. In this analysis, G1 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.14** Results of PCA single regression analysis using a double cosinor principal component (The principal component in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.255* [ $X_2^C$ ]	0.257* [ $X_2^C$ ]	0.231 $\blacktriangle$ [ $X_2^C$ ]	0.18 $\blacktriangle$ [ $X_2^C$ ]
Trait-Coping	0.096 $\dagger$ [ $X_1^C$ ]	0.307* [ $X_1^C$ ]	0.33* [ $X_1^C$ ]	0.363* [ $X_1^C$ ]
Self-Image	0.125 $\dagger$ [ $X_4^C$ ]	0.333* [ $X_3^C$ ]	0.15 $\dagger$ [ $X_1^C$ ]	0.2 $\blacktriangle$ [ $X_4^C$ ]
Self-Awareness	0.086 $\dagger$ [ $X_2^C$ ]	0.228 $\blacktriangle$ [ $X_3^C$ ]	0.046 $\dagger$ [ $X_1^C$ ]	0.098 $\dagger$ [ $X_3^C$ ]
Will for Meaningful Life	0.15 $\dagger$ [ $X_1^C$ ]	0.208 $\blacktriangle$ [ $X_1^C$ ]	0.151 $\dagger$ [ $X_1^C$ ]	0.205 $\blacktriangle$ [ $X_1^C$ ]
State-Trait Anxiety	0.213 $\blacktriangle$ [ $X_4^C$ ]	0.14 $\dagger$ [ $X_1^C$ ]	0.132 $\dagger$ [ $X_1^C$ ]	0.136 $\dagger$ [ $X_1^C$ ]

(\* $p \leq 0.05$ : highly significant correlation,  $\blacktriangle p < 0.1$ : a trend of significant correlation, and  $\dagger p \geq 0.1$ : no correlation).

**TABLE 4.14** notes:

1. In G1 dataset,  $X_1^C$ ,  $X_2^C$ , and  $X_4^C$  were the most dominant principal components.
2. In G2 dataset,  $X_1^C$  was the most dominant principal component.
3. In G3 dataset,  $X_1^C$  was the most dominant principal component.
4. In G4 dataset,  $X_1^C$  was the most dominant principal component.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.15** Results of PCA single regression analysis using a spline smoothed principal component (The principal component in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.31* [ $X_2^S$ ]	0.204 ▲ [ $X_2^S$ ]	0.213 ▲ [ $X_3^S$ ]	0.168 † [ $X_3^S$ ]
Trait-Coping	0.236 ▲ [ $X_2^S$ ]	0.243* [ $X_2^S$ ]	0.23 ▲ [ $X_1^S$ ]	0.216 ▲ [ $X_1^S$ ]
Self-Image	0.114 † [ $X_1^S$ ]	0.22 ▲ [ $X_1^S$ ]	0.167 † [ $X_1^S$ ]	0.214 ▲ [ $X_1^S$ ]
Self-Awareness	0.078 † [ $X_2^S$ ]	0.06 † [ $X_1^S$ ]	0.124 † [ $X_4^S$ ]	0.09 † [ $X_4^S$ ]
Will for Meaningful Life	0.15 † [ $X_2^S$ ]	0.213 ▲ [ $X_2^S$ ]	0.09 † [ $X_1^S$ ]	0.106 † [ $X_2^S$ ]
State-Trait Anxiety	0.17 † [ $X_1^S$ ]	0.163 † [ $X_1^S$ ]	0.157 † [ $X_4^S$ ]	0.191 ▲ [ $X_1^S$ ]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p \geq 0.1$ : no correlation).

**TABLE 4.15** notes:

1. In G1 dataset,  $X_1^S$  was the most dominant principal components.
2. In G2 dataset,  $X_1^S$  and  $X_2^S$  were the most dominant principal components.
3. In G3 dataset,  $X_1^S$  was the most dominant principal component.
4. In G4 dataset,  $X_1^S$  was the most dominant principal component.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**Table 4.16** Results of PCA multiple regression analysis using two double cosinor principal components (The principal components in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.422* [ $X_1^C, X_2^C$ ]	0.451* [ $X_1^C, X_2^C$ ]	0.39* [ $X_1^C, X_2^C$ ]	0.352 ▲ [ $X_1^C, X_2^C$ ]
Trait-Coping	0.103 † [ $X_1^C, X_2^C$ ]	0.587* [ $X_1^C, X_3^C$ ]	0.363 ▲ [ $X_1^C, X_2^C$ ]	0.57* [ $X_1^C, X_3^C$ ]
Self-Image	0.188 † [ $X_1^C, X_4^C$ ]	0.494* [ $X_1^C, X_3^C$ ]	0.254 † [ $X_1^C, X_3^C$ ]	0.377* [ $X_1^C, X_4^C$ ]
Self-Awareness	0.161 † [ $X_1^C, X_2^C$ ]	0.322 ▲ [ $X_1^C, X_3^C$ ]	0.059 † [ $X_1^C, X_2^C$ ]	0.175 † [ $X_1^C, X_3^C$ ]
Will for Meaningful Life	0.17 † [ $X_1^C, X_3^C$ ]	0.364* [ $X_1^C, X_3^C$ ]	0.252 † [ $X_1^C, X_4^C$ ]	0.28 † [ $X_1^C, X_3^C$ ]
State-Trait Anxiety	0.345 ▲ [ $X_1^C, X_4^C$ ]	0.241 † [ $X_1^C, X_3^C$ ]	0.17 † [ $X_1^C, X_3^C$ ]	0.155 † [ $X_1^C, X_4^C$ ]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p \geq 0.1$ : no correlation).

**TABLE 4.16** notes:

1. In G1 dataset, [ $X_1^C, X_2^C$ ] were the most dominant principal components.
2. In G2 dataset, [ $X_1^C, X_3^C$ ] were the most dominant principal components.
3. In G3 dataset, [ $X_1^C, X_2^C$ ] were the most dominant principal components.
4. In G4 dataset, [ $X_1^C, X_3^C$ ] were the most dominant principal components.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.17** Results of PCA multiple regression analysis using two spline smoothed principal components (The principal components in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.483* [ $X_2^S, X_3^S$ ]	0.357* [ $X_2^S, X_3^S$ ]	0.39* [ $X_2^S, X_3^S$ ]	0.28† [ $X_1^S, X_3^S$ ]
Trait-Coping	0.32▲ [ $X_1^S, X_2^S$ ]	0.391* [ $X_1^S, X_2^S$ ]	0.375* [ $X_1^S, X_2^S$ ]	0.351* [ $X_1^S, X_2^S$ ]
Self-Image	0.151† [ $X_1^S, X_2^S$ ]	0.246† [ $X_1^S, X_3^S$ ]	0.273† [ $X_1^S, X_4^S$ ]	0.303▲ [ $X_1^S, X_4^S$ ]
Self-Awareness	0.152† [ $X_2^S, X_3^S$ ]	0.105† [ $X_1^S, X_2^S$ ]	0.162† [ $X_1^S, X_4^S$ ]	0.16† [ $X_1^S, X_4^S$ ]
Will for Meaningful Life	0.271† [ $X_2^S, X_4^S$ ]	0.361* [ $X_2^S, X_4^S$ ]	0.18† [ $X_1^S, X_2^S$ ]	0.2† [ $X_1^S, X_2^S$ ]
State-Trait Anxiety	0.19† [ $X_1^S, X_3^S$ ]	0.195† [ $X_1^S, X_2^S$ ]	0.3▲ [ $X_1^S, X_4^S$ ]	0.295▲ [ $X_1^S, X_4^S$ ]

(\* $p \leq 0.05$ : highly significant correlation, ▲ $p < 0.1$ : a trend of significant correlation, and † $p > 0.1$ : no correlation).

**TABLE 4.17** notes:

1. In G1 dataset, [ $X_1^S, X_2^S$ ] and [ $X_2^S, X_3^S$ ] were the most dominant principal components.
2. In G2 dataset, [ $X_1^S, X_2^S$ ] were the most dominant principal components.
3. In G3 dataset, [ $X_1^S, X_4^S$ ] were the most dominant principal components.
4. In G4 dataset, [ $X_1^S, X_4^S$ ] were the most dominant principal components.
5. In this analysis, two datasets, G2, and G3 gave good coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores.

**TABLE 4.18** Results of PCA multiple regression analysis using three double cosinor principal components (The principal components in the brackets gave the maximum  $R^2$  score).

<b>Double cosinor-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.428 $\blacktriangle$ [ $X_1^C, X_2^C, X_4^C$ ]	0.472* [ $X_1^C, X_2^C, X_3^C$ ]	0.46* [ $X_1^C, X_2^C, X_3^C$ ]	0.47* [ $X_1^C, X_2^C, X_4^C$ ]
Trait-Coping	0.11 $\dagger$ [ $X_1^C, X_2^C, X_4^C$ ]	0.684* [ $X_1^C, X_2^C, X_3^C$ ]	0.38 $\dagger$ [ $X_1^C, X_2^C, X_4^C$ ]	0.601* [ $X_1^C, X_2^C, X_3^C$ ]
Self-Image	0.237 $\dagger$ [ $X_1^C, X_2^C, X_4^C$ ]	0.534* [ $X_1^C, X_2^C, X_3^C$ ]	0.271 $\dagger$ [ $X_1^C, X_3^C, X_4^C$ ]	0.49* [ $X_1^C, X_3^C, X_4^C$ ]
Self-Awareness	0.235 $\dagger$ [ $X_1^C, X_2^C, X_4^C$ ]	0.347 $\dagger$ [ $X_1^C, X_2^C, X_3^C$ ]	0.07 $\dagger$ [ $X_1^C, X_2^C, X_3^C$ ]	0.243 $\dagger$ [ $X_1^C, X_3^C, X_4^C$ ]
Will for Meaningful Life	0.19 $\dagger$ [ $X_1^C, X_3^C, X_4^C$ ]	0.42 $\blacktriangle$ [ $X_1^C, X_2^C, X_3^C$ ]	0.271 $\dagger$ [ $X_1^C, X_2^C, X_4^C$ ]	0.294 $\dagger$ [ $X_1^C, X_2^C, X_3^C$ ]
State-Trait Anxiety	0.374 $\dagger$ [ $X_1^C, X_3^C, X_4^C$ ]	0.283 $\dagger$ [ $X_1^C, X_2^C, X_3^C$ ]	0.168 $\dagger$ [ $X_1^C, X_2^C, X_3^C$ ]	0.155 $\dagger$ [ $X_1^C, X_3^C, X_4^C$ ]

(\* $p \leq 0.05$ : highly significant correlation,  $\blacktriangle p < 0.1$ : a trend of significant correlation, and  $\dagger p > 0.1$ : no correlation).

**TABLE 4.18** notes:

1. In G1 dataset, [ $X_1^C, X_2^C, X_4^C$ ] were the most dominant principal components.
2. In G2 dataset, [ $X_1^C, X_2^C, X_3^C$ ] were the most dominant principal components.
3. In G3 dataset, [ $X_1^C, X_2^C, X_3^C$ ] were the most dominant principal components.
4. In G4 dataset, [ $X_1^C, X_3^C, X_4^C$ ] were the most dominant principal components.
5. In this analysis, G2 dataset generally gave better coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores compared to other datasets.

**TABLE 4.19** Results of PCA multiple regression analysis using three spline smoothed principal components (The principal components in the brackets gave the maximum  $R^2$  score).

<b>Spline-based parameters</b>				
<b>Dispositional Psychological measures</b>	<b>max<math>R^2</math></b>			
	<b>G1</b>	<b>G2</b>	<b>G3</b>	<b>G4</b>
Frequency of Flow Experience	0.554* [ $X_1^S, X_2^S, X_3^S$ ]	0.46 ▲ [ $X_1^S, X_2^S, X_3^S$ ]	0.5* [ $X_1^S, X_2^S, X_3^S$ ]	0.432 ▲ [ $X_1^S, X_2^S, X_3^S$ ]
Trait-Coping	0.366† [ $X_1^S, X_2^S, X_4^S$ ]	0.397 ▲ [ $X_1^S, X_2^S, X_3^S$ ]	0.39 ▲ [ $X_1^S, X_2^S, X_4^S$ ]	0.363† [ $X_1^S, X_2^S, X_4^S$ ]
Self-Image	0.188† [ $X_1^S, X_2^S, X_3^S$ ]	0.265† [ $X_1^S, X_2^S, X_3^S$ ]	0.317† [ $X_1^S, X_3^S, X_4^S$ ]	0.32† [ $X_1^S, X_3^S, X_4^S$ ]
Self-Awareness	0.196† [ $X_1^S, X_2^S, X_3^S$ ]	0.126† [ $X_1^S, X_2^S, X_3^S$ ]	0.184† [ $X_1^S, X_2^S, X_4^S$ ]	0.17† [ $X_1^S, X_3^S, X_4^S$ ]
Will for Meaningful Life	0.361† [ $X_1^S, X_2^S, X_4^S$ ]	0.417 ▲ [ $X_2^S, X_3^S, X_4^S$ ]	0.18† [ $X_1^S, X_2^S, X_4^S$ ]	0.203† [ $X_1^S, X_2^S, X_4^S$ ]
State-Trait Anxiety	0.2 [ $X_1^S, X_2^S, X_3^S$ ]	0.201† [ $X_1^S, X_2^S, X_3^S$ ]	0.302† [ $X_1^S, X_2^S, X_4^S$ ]	0.302† [ $X_1^S, X_3^S, X_4^S$ ]

(\* $p \leq 0.05$ : highly significant correlation, ▲  $p < 0.1$ : a trend of significant correlation, and †  $p > 0.1$ : no correlation).

**TABLE 4.19** notes:

1. In G1 dataset, [ $X_1^S, X_2^S, X_3^S$ ] were the most dominant principal components.
2. In G2 dataset, [ $X_1^S, X_2^S, X_3^S$ ] were the most dominant principal components.
3. In G3 dataset, [ $X_1^S, X_2^S, X_4^S$ ] were the most dominant principal components.
4. In G4, [ $X_1^S, X_3^S, X_4^S$ ] were the most dominant principal components.
5. In this analysis, three datasets, G1, G2, and G4 gave good coefficient of determination ( $R^2$ ) and level of significance ( $p$ ) scores.



# Chapter 5: Discussion

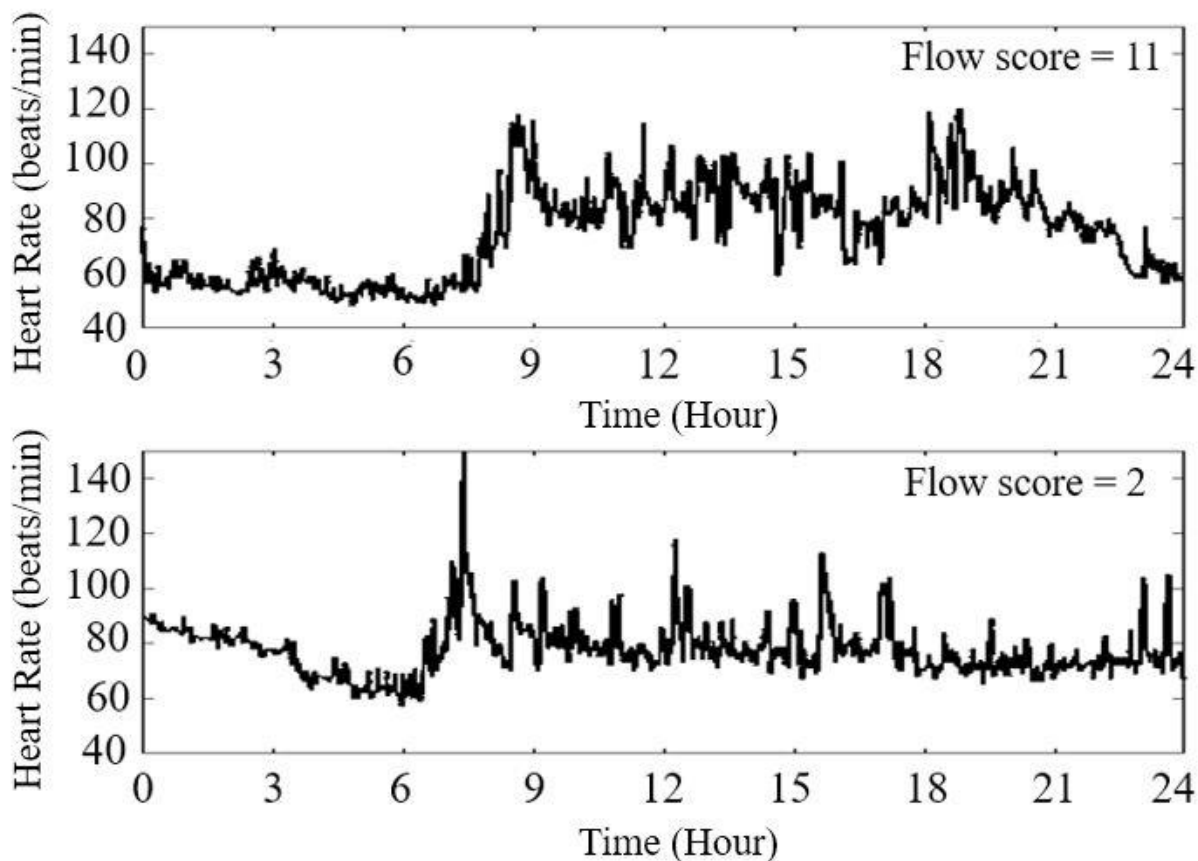
This study intended to show how the association between physiological parameters of heart rate rhythm and various dispositional psychological measures could be useful in mental health assessment. To obtain a general picture of the psychological attributes of 20 Japanese engineers as the participants of this study, we first examined the frequency of *Flow* experiences and five other psychological measures in their daily life activities by employing dispositional questionnaires. Finding physiological correlates with psychological mental states is an emerging field of interest. Previous studies [21–24] have associated *Flow* experience during a certain activity period with short-term physiological data observed during the period of interest. We, however, explored a new research perspective to find long-term physiological parameters associated with dispositional *Flow* and related psychological measures. We chose diurnal heart rate rhythms that reflect the long-term nature of autonomic nervous activities.

The appropriateness of the psychological measures introduced in this research was also extensively examined. In single regression analysis, *Frequency of Flow Experience* and four dispositional positive psychological measures (*Trait-Coping*, *Self-Image*, *Self-Awareness*, and *Will for Meaningful Life*) showed a significant positive correlation with heart rate rhythm parameters ( $p < 0.05$ ). In addition, all positive psychological measures showed a significant positive correlation with each other, and they were negatively correlated with the only negative psychological measure in this study, known as *State-Trait Anxiety*. These results confirm the positive nature of the *Flow* experience and other positive psychological measures, validating the appropriateness of the questionnaires we utilized in this study.

For physiological parameters, double cosinor and spline-based parameter sets were introduced to characterize the heart rate diurnal rhythm. For cosinor rhythm parameters, 24-hour and 12-hour heart rate rhythm amplitudes  $cA_{24}$  and  $cA_{12}$ , and the diurnal heart rate range amplitude  $cA$  are traditional heart rate rhythm parameters. In addition to these, an original cosinor parameter  $cASR$  unique to this research study was introduced, which was defined as the maximum value of the derivative of the double cosinor representation of diurnal heart rate change. This parameter represents the speed of switching from parasympathetic to sympathetic nervous activity and is named the autonomic switching rate. An alternative spline-based parameter set was introduced to capture a more detailed trend pattern of the heart rate diurnal change. The double cosinor and spline-based parameters were divided into two groups and each parameter had a physiological interpretation. The first parameter group included  $*A_{24}$ ,  $*A_{12}$ , and  $*A$  ( $* \in \{c, s\}$ ,  $c$ : cosinor and  $s$ : spline) which reflect the sympathetic and parasympathetic dominant activity spans of different rhythm cycles, and  $*ASR$  was interpreted as the sensitivity of these autonomic activity changes.

The results of the single regression analysis of original parameters showed that  $A_{24}$  gave the best  $R^2$  values for *Frequency of Flow Experience* as well as most of the psychological measures. In summary, these results claim that the higher the *Frequency of Flow Experience* and other positive psychological measures, the higher the amplitude of diurnal heart rate changes. Although the significance levels were not always sufficiently high, the fact that all physiological parameters showed a consistent positive correlation with the five positive psychological measures and a negative correlation with the negative measure of *State-Trait-*

*Anxiety* is supportive of the validity of the claim. Typical examples of the heart rate diurnal changes in participants with high and low *Flow* scores are shown in **Fig. 5.1**.



**Figure 5.1** Typical examples of diurnal heart rate changes in a patient each with of high (a) and low (b) Flow scores.

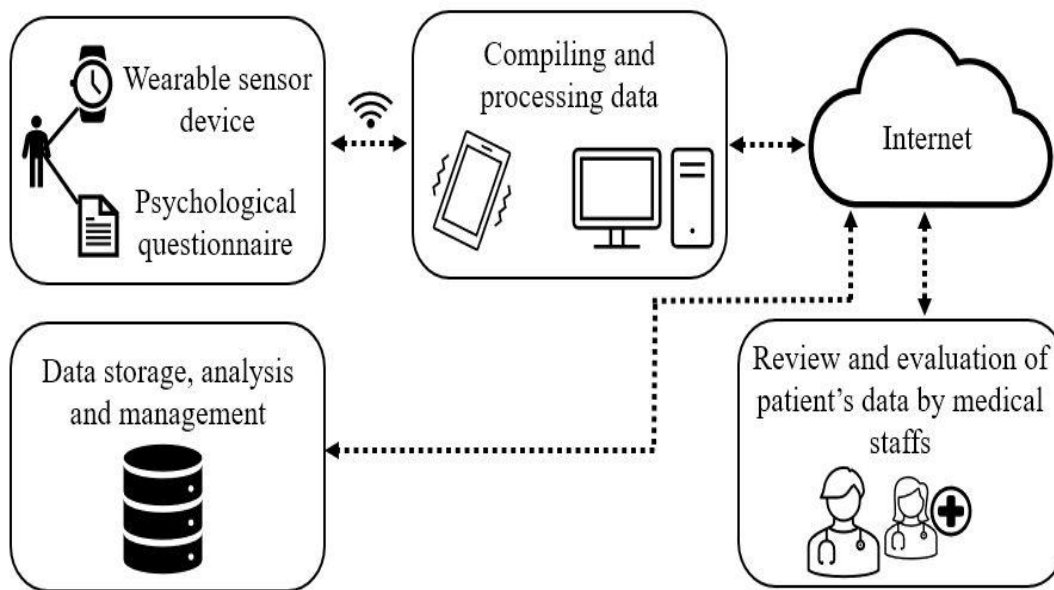
PCA showed that the first principal component reflected the first parameter group especially \*A. The second principal component included the element of the second parameter group \*A<sub>24</sub>. The third and fourth principal components included the elements of \*A<sub>12</sub> and \*ASR, respectively, as the major contributing factors. *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, *Self-Awareness*, and *Will for Meaningful Life* showed the highest  $R^2$  values by the multiple regression analysis of two principal components. In addition, *Frequency of Flow Experience*, *Trait-Coping*, *Self-Image*, and *Will for Meaningful Life* showed

the highest corrected  $R^2$  values by the multiple regression analysis using three principal components. The analysis showed that some psychological measures were correlated well with our physiological parameters of diurnal heart rate rhythm. It also highlighted that the multiple regression analysis of two principal components would be sufficient. The significance of the result is also supported by the claim in previous study that both *Frequency of Flow Experience* and *Trait-Coping*, also known as resilience contribute highly to the healthy mental state of individuals [60]. It may also be worth pointing out that the *Frequency of Flow Experience* depends more on the second component while both *Self-Image* and *Self-Awareness* depend more on the third principal component. Furthermore, *Trait-Coping* and *Will for Meaningful Life* depend more on the first component.

The research outcomes of this research study imply the importance of long-term monitoring of both physiological and psychological indices for daily healthcare assessment. This is mainly because the IoT and the Internet of Medical Things combined with cloud-based services have become popular research topics [61]. Moreover, the importance of wearable technologies has also been extensively recognized as these devices can routinely acquire biomedical signals and transmit them to the cloud system, which can then be used for different purposes such as long-term data storage or detailed data evaluation to provide patients with appropriate treatment services [62].

It is important that individuals maintain a balance between their physical and mental states to achieve full health. Hence, in clinical practice, long-term monitoring of physiological data also attracts attention [63, 64]. A study compared the arrhythmia detection rate of continuous two-week ECG recordings by the US Food and Drug Administration-approved adhesive sensor with conventional Holter recordings [45]. They found that the long-term recordings detected 57% more incident arrhythmia. Continuous glucose monitoring with adhesive sensors is another example of an effective clinical tool [66]. Such long-term recording sensors provide more opportunities for detecting clinical deficiencies. For this very reason, the long-term monitoring of psycho-physiological indices is also essential in the field of healthcare for assessing both physical and mental wellness.

Since the association between different psychological measures evaluating mental wellness and physiological parameters representing diurnal heart rate rhythm was revealed, this finding could envision a ubiquitous healthcare system designed to provide a means for healthcare assessment combining both mental and physical aspects of one’s wellness. In such a system, continuous physiological data are recorded by IoT devices and psychological measures are assessed by a web questionnaire system at appropriate times. Both data are integrated into the cloud data system for further analysis to be fed back to the user. This also allows the professional healthcare providers to assess both the physical and mental wellness of patients. Such a scheme is shown in **Fig. 5.2**.



**Figure 5.2** A scheme for a ubiquitous psychophysiological health assessment system.

Psychological measures and physiological parameters of diurnal heart rate rhythm have strengths and weaknesses in characterizing dispositional psychological characteristics. Psychological measures are designed to evaluate specific psychological characteristics such as *Self-Image* and *Trait-Coping* but the scores are subjective. Meanwhile, heart rate diurnal rhythm parameter values are objective but lack the sensitivity to distinguish the specific nature of psychological characteristics. Hence the integration of psychological measures and physiological parameters will be useful for a more definite characterization of the dispositional psychological state, by complementing each other.

# Chapter 6: Conclusion

In conclusion, this research showed that *Flow* and *Flow*-related positive psychological measures may be associated with heart rate diurnal rhythm parameters. *Resilience* was the psychological measure showing the highest correlation with physiological parameters, according to the original single regression and PCA multiple regression results. Finding other physiological correlates with dispositional psychological measures will be an important forthcoming research direction. Long-term trend analysis of conventional short-term HRV parameters that characterize autonomic nervous activity could be one of the alternative candidates. Developing IoT devices for continuous monitoring of such long-term physiological data could provide important means for realizing an integrated physiological and psychological healthcare monitoring system.

## Conflicts of interest

The author has no conflicts of interest to declare that are relevant to the contents of this dissertation per the guidelines of Niigata University.

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# Publications

1. Omid Jamalipournokandeh, Kazuo Yana, Junichi Hori: Deployment of Physiologic-Heart Rate Indices in Mental Healthcare (メンタルヘルスケアにおける生理的心拍数指標の展開), IEEE-EMBS International Conference on Biomedical and Health Informatics-Body Sensor Networks 2021, 2021年7月27日.
2. Omid Jamalipournokandeh, Kazuo Yana, Junichi Hori: Assessing Mental Health through Physiological Heart Rate Rhythm Indicators (生理的心拍リズム指標によるメンタルヘルスの評価), Biomedical Engineering Symposium 2021, 2021年9月17日.
3. Omid Jamalipournokandeh, Kazuo Yana, Junichi Hori: Association of Physiological Heart Rate Rhythm Parameters with Psychological Indicators (生理的心拍リズムパラメータと心理的指標との関連), The 61st Annual Meeting of the Japanese Society for Medical and Biological Engineering, 2022年6月28日.
4. Omid Jamalipournokandeh, Junichi Hori, Kazuo Yana, Kiyoshi Asakawa: Association of the Heart Rate Rhythm with Flow-Related Dispositional Psychological Indicators (心拍リズムとフロー関連の気質心理指標との関連), Biomedical Engineering Symposium 2022, 2022年9月10日.
5. Omid Jamalipournokandeh, Junichi Hori, Kiyoshi Asakawa, Kazuo Yana: Dispositional Flow and Related Psychological Measures Associated with Heart Rate Diurnal Rhythm (日内心拍変動を用いたフローおよび他の関連する心理的測定), Journal of Advanced Biomedical Engineering, vol. 12, no. 2023, pp. 9–20, 2023.
6. Omid Jamalipournokandeh, Junichi Hori, Kazuo Yana: Principal Component Analysis Applied to Associate Psychological Measures with Diurnal Heart Rate Rhythm (心理学的測定値を日周心拍数リズムと関連付けるために適用される主成分分析), Special Interest Group of JSMBE: Bio-signal Measurements and Interpretations, 2022年12月20日.

# Appendix and supplementary materials

## A. English version of questionnaires

### I: Frequency of Flow Experience

Question A. Have you ever experienced not noticing something (e.g., another person speaking, loud sounds, time passing, hunger or fatigue, promises, or physical discomfort or distress) because you are deeply concentrating, your attention is focused, or you are day-dreaming about what you are doing?

Question B. Have you ever experienced the feeling that you were born with the skills and abilities you have mastered, that everything is going naturally without much effort at all, and you are confident about any new challenges (difficult or challenging activities)?

Question C. Do you do activities that you feel are worth doing? In other words, activities through which benefits can be gained (e.g., financial rewards or technology and capability improvements)? Have you ever had an experience that made you think that you would do such an activity even if no one praised you for it (i.e., doing it for pleasure)?

Question D. Have you ever experienced a unique and unforgettable moment that changed your way of seeing or thinking about life (or yourself) and that made you feel very lucky and grateful for it?

1. Several times per year, 2. Once a month, 3. Several times per month, 4. Once a week, 5. Several times a week, 6. Once a day, and 7. Several times per day. If there is no experience, the score is 0.

II: The Self-Image Scale is a measure of how well you feel you are valued, and it evaluates the degree to which the following 10 questions apply to you on a 5-point scale (1 = not applicable, 2 = slightly not applicable, 3 = cannot say, 4 = somewhat applicable, and 5 = applicable).

1. I am a human being of value, as least as much as others.
2. I have a variety of good qualities.
3. I often think of myself as a loser. (Reversed Item)
4. I can do things as well as others.
5. I don't have much to boast about. (Reversed Item)
6. I am positive about myself.
7. Most of the time, I am satisfied with myself.
8. I want to be able to respect myself more. (Reversed Item)
9. Sometimes I think of myself as a completely useless person. (Reversed Item)
10. In some ways, I think I am a person who is not useful. (Reversed Item)

The intensity of Self-Image will be assessed by the relative value of the total score of 5-point ratings of each item or a total score of 50 points on a full score of 1. However, the reversed item scores should be calculated by reversing the scores (1 to 5 ... 5 to 1).

III: State-Trait Anxiety Scale is a measure of the degree to which anxiety is perceived and uses 4-point self-ratings (1 = not at all, 2 = somewhat so, 3 = almost so, and 4 = quite so) for the following 20 questions.

#### Questions

The sentences describing the state of mind are as follows. For each sentence, gauge the extent of the condition (in your mind) and enclose the corresponding number in a circle. You don't have to think too much about it, but rather try to mark an answer based what best describes your current feelings.

1. It's fun. (Reversed Item)
2. I get tired easily.
3. I feel like crying.
4. I wish I were as happy as other people.
5. I can't make up my mind right away and it's easy to get lost.
6. I feel relaxed. (Reversed Item)
7. I am calm and collected. (Reversed Item)
8. Difficulties can be overwhelming.
9. It really doesn't matter, and worrying does not help.
10. I am happy. (Reversed Item)
11. I tend to make things difficult.
12. I lack confidence.
13. I am relieved. (Reversed Item)
14. I try to avoid troublesome things.
15. I am depressed.
16. I am satisfied. (Reversed Item)
17. I don't worry about the little things.
18. When I am severely disgusted, it is not possible for me to switch moods.
19. Things don't move me. (Reversed Item)
20. I get very nervous and confused when I think about familiar (worrisome) problems.

The intensity of anxious feelings will be assessed by the relative value of the total score or a total score of 80 points. However, the reversed items are summed by reversing the scores (1=4 ... 4=1).

IV: Will for Meaningful Life Scale (motivation) gauges motivation and quantifies how much you feel a sense of purpose of life. The total score (or relative value) of the first nine items is used as the sense of purpose in life (motivation) score. Item 10 gauges the sense of fulfillment in one item.

#### Questions

Please read the following items and answer by choosing from four options the one that applies to you. 1: No; 2: Maybe, 3: Yes, and 4: Very much so.

1. I have hopes for the future.
2. I have great expectations for my life.
3. I am motivated to do things.
4. I have a purpose and have something I want to accomplish.
5. I am thinking of working actively on everything.
6. I am doing something worthwhile right now.
7. I am crazy about doing what I like.
8. I think I am currently living by exercising my abilities to the fullest.
9. I often engage in my hobbies and things I like.
10. My daily life is fulfilling.

V: Self-Awareness is a measure of how well you recognize your potential to perform the necessary actions while doing an activity.

#### Questions

Please answer in terms of the following five options how much the following sentences (1–23) apply to you: 1: I don't think so, 2: I don't think much so, 3: I can't say either, 4: Possibly so, 5: I think so.

1. I am confident that my plan will work.
2. Sometimes it is difficult to get started on doing things that I have to do. (Reversed Item)
3. Even if I don't do the job well at first, I'll continue trying until I can do it.
4. I'm not good at making new friends. (Reversed Item)
5. I am seldom successful even if I set important goals. (Reversed Item)
6. I give up even before I finish something. (Reversed Item)
7. If I see someone I want to meet, I don't wait for the person to come over to me, I go to that person.
8. I avoid encountering difficulties. (Reversed Item)
9. I don't want to do something that looks very confusing. (Reversed Item)
10. Even if I there is someone I want to be friends with, if I think it will be hard, I quit immediately. (Reversed Item)
11. Even when I do something that is not interesting, I persevere until the end.

12. If I want to do something, I start it right away.
13. Even if I decide to start a new thing, I give up as soon as I stumble. (Reversed Item)
14. Even if I don't feel like becoming friends with a person at first, I don't give up immediately and try to become friends.
15. When an unexpected problem occurs, I cannot handle it properly. (Reversed Item)
16. I don't think I'll learn anything new that seems difficult. (Reversed Item)
17. If I fail, I will try harder.
18. In a gathering of people, it is not possible for me to behave well. (Reversed Item)
19. When I try to do something, I get anxious about whether I can do it. (Reversed Item)
20. I don't depend on people.
21. I am good at making friends by myself.
22. I give up immediately. (Reversed Item)
23. I don't think that many of the problems that arise in life can be dealt with. (Reversed Item)

A total score of 23 (or the relative value with the highest score set as 1) is used as the Characteristic Self-efficacy score.

VI: Trait-Coping is a measure of the mental strength to recover quickly when things go wrong.

#### Questions

Please answer the following questions (1 to 21) choosing from the following five options in terms of how much they apply to yourself: 1: not applicable, 2: somewhat applicable, 3: cannot say, 4: somewhat true, and 5: true.

1. I can't stand difficult things. (Reversed Item)
2. I like to try various things.
3. I can control my feelings.
4. I'm sure there's something good in my future.
5. I like new and unusual things.
6. Even if I am upset, I can calm myself down.
7. The prospects of the future seem to be bright.
8. My behavior is likely to be influenced by my mood on that day. (Reversed Item)
9. My interest in things is strong.
10. I always try to stay calm.
11. I want to know many things.
12. I think I am tired of it. (Reversed Item)

13. I have hope for my future.
14. I think that life is worthwhile, even if it is difficult.
15. I think I am a persistent person.
16. I don't like doing things that I can't get used to. (Reversed Item)
17. I have a goal for the future.
18. It's hard to start doing new things. (Reversed Item)
19. I can't change my mood easily. (Reversed Item)
20. I am working toward my goals.
21. Feeling angry makes it impossible for me to restrain myself. (Reversed Item)

Mental coping is measured by the following three subscales and their overall scores: Interpretation degree (1) Novelty seeking: 2, 5, 9, 11, 14, 16, 18. Interpretation degree (2) Emotion adjustment: 1, 3, 6, 8, 10, 12, 15, 19, 21. Interpretation degree (3) Positive future orientation: 4, 7, 13, 17, 20 or higher total score (1) + (2) + (3) as a measure of mental resilience.





B. これまでに習得してきた技術や能力がまるで生まれながらに備わっているかのように感じられ、すべてのことが自然に、まったく努力を必要としない状態で進み、また、どんな新しいチャレンジ（難しく、挑戦的な活動）に対しても自信に満ちあふれた状態になるような、そんな経験をすることがありますか？

(1) ある \_\_\_\_\_ ない \_\_\_\_\_ (どちらかに○をつけてください)

「ある」と答えた方は以下の質問(2)、(3)に答えてください。

「ない」と答えた方はCに進んでください。

(2) どのような活動で最も頻繁にこのような経験をしますか？具体的に書いてください。

( \_\_\_\_\_ )

(3) どのくらいの頻度でこのような経験をしますか？当てはまる番号ひとつに○をつけてください。

1年に数回	.....	1	1週間に数回	.....	5
1か月に1回	.....	2	1日に1回	.....	6
1か月に数回	.....	3	1日に数回	.....	7
1週間に1回	.....	4			

C. あなたは、それをすること自体に価値があると感じられるような活動をすることがありますか？ 言い換えれば、ある活動に対して、それをすることによってもたらされる他の利益（例えば、金銭的報酬が得られる、技術や能力が向上する、他人からほめられる、等）がまったくなかったとしても、それをするだろうと思われるような（つまり、楽しいからそれをするといった）、そんな経験をすることがありますか？

(1) ある \_\_\_\_\_ ない \_\_\_\_\_ (どちらかに○をつけてください)

「ある」と答えた方は以下の質問(2)、(3)に答えてください。

「ない」と答えた方は質問Dに進んでください。

(2) どのような活動で最も頻繁にこのような経験をしますか？具体的に書いてください。

( \_\_\_\_\_ )

(3) どのくらいの頻度でこのような経験をしますか？当てはまる番号ひとつに○をつけてください。

1年に数回	.....	1	1週間に数回	.....	5
1か月に1回	.....	2	1日に1回	.....	6
1か月に数回	.....	3	1日に数回	.....	7
1週間に1回	.....	4			

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D. ある意味で、人生(あるいはあなた自身)に対するあなたの見方や考え方を変えてしまうような、非常にユニーク(特別)で、忘れることのできない瞬間を与えてくれる(そしてそれを、あなたは非常に幸運であり、感謝すべきことであると感じるような)、そんな経験をすることがありますか?

(1) ある \_\_\_\_\_ ない \_\_\_\_\_ (どちらかに○をつけてください)

「ある」と答えた方は以下の質問(2)、(3)に答えてください。

「ない」と答えた方は質問IIに進んでください。

(2) どのような活動で最も頻繁にこのような経験をしますか?具体的に書いてください。

( \_\_\_\_\_ )

(3) どのくらいの頻度でこのような経験をしますか?当てはまる番号ひとつに○をつけてください。

1年に数回	.....	1	1週間に数回	.....	5
1か月に1回	.....	2	1日に1回	.....	6
1か月に数回	.....	3	1日に数回	.....	7
1週間に1回	.....	4			

II. 次の特徴(1~10)が、あなた自身にどの程度あてはまるかを答えてください。他人からどう見られているかではなく、あなたが、あなた自身をどのように思っているかを、ありのままに答えてください。回答は、以下の5つの選択肢を用い、あなたにあてはまると思う番号に○をつけてください。

1 = あてはまらない      2 = ややあてはまらない      3 = どちらともいえない  
4 = ややあてはまる      5 = あてはまる

1. 少なくとも人並みには、価値のある人間である。

あてはまらない ⇐ 1    2    3    4    5 ⇒ あてはまる

2. いろいろな良い素質を持っている。

あてはまらない ⇐ 1    2    3    4    5 ⇒ あてはまる

3. 敗北者だと思ふことがよくある。

あてはまらない ⇐ 1    2    3    4    5 ⇒ あてはまる

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4. 物事を人並みには、うまくやれる。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

5. 自分には、自慢できるところがあまりない。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

6. 自分に対して肯定的である。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

7. 大体において、自分に満足している。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

8. もっと自分自身を尊敬できるようになりたい。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

9. 自分はまったくだめな人間だと思ふことがある。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

10. 何かにつけて、自分は役に立たない人間だと思ふ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

III. 心の状態を表現する文章が下に記述してあります。その各文章について、ふだん、一般に（あなたの心は）どの程度の状態か、該当する番号を○で囲んでください。あまり考える必要はありませんが、現在の気持ちを最もよく表現しているものに反応するように心がけてください。

全くそうでない    いくぶんそうである    ほぼそうである    全くそうである

1

2

3

4

1. たのしい。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

2. 疲れやすい。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

3. 泣き出したくなる。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

4. ほかの人と同じくらい幸せであったらと思う。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

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5. すぐに決心がつかず迷いやすい。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

6. ゆったりした気持ちである。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

7. 平静・沈着で落ち着いている。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

8. 困難なことがかさなると圧倒されてしまう。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

9. 実際にたいしたこともないことが気になってしかたがない。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

10. 幸せである。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

11. 物事を難しく考える傾向がある。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

12. 自信が欠如している。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

13. 安心している。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

14. やっかいなことは避けて通ろうとする。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

15. 憂鬱である。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

16. 満足している。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

17. ささいなことに思いわずらう。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

18. ひどくがっかりしたときには気分転換ができない。

全くそうでない ⇐ 1 2 3 4 ⇒ 全くそうである

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19. 物事に動じないほうである。



V. 次の文章（1～23）が、あなた自身にどの程度あてはまるかを答えてください。回答は、以下の5つの選択肢を用い、あなたにあてはまると思う番号に○をつけてください。

1 = そう思わない      2 = あまりそう思わない      3 = どちらともいえない  
4 = まあそう思う      5 = そう思う

1. 自分が立てた計画はうまくできる自信がある。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

2. しなければならないことがあっても、なかなかとりかからない。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

3. 初めはうまくいかない仕事でも、できるまでやり続ける。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

4. 新しい友達を作るのが苦手だ。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

5. 重要な目標を決めても、めったに成功しない。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

6. 何かを終える前にあきらめてしまう。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

7. 会いたい人を見かけたら、向こうから来るのを待たないでその人の所へ行く。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

8. 困難に出会うのを避ける。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

9. 非常にややこしく見えることには、手を出そうとは思わない。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

10. 友達になりたい人でも、友達になるのが大変ならばすぐにやめてしまう。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

11. 面白くないことをする時でも、それが終わるまでがんばる。

そう思わない    ⇐ 1      2      3      4      5    ⇒    そう思う

(次のページに続く)

12. 何かをしようと思ったら、すぐにとりかかる。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

13. 新しいことをはじめようと決めても、出だしでつまずくとすぐにあきらめてしまう。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

14. 最初は友達になる気がしない人でも、すぐにあきらめないで友達になろうとする。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

15. 思いがけない問題が起こった時、それをうまく処理できない。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

16. 難しそうなことは、新たに学ぼうとは思わない。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

17. 失敗すると一生懸命やろうと思う。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

18. 人の集まりの中では、うまく振る舞えない。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

19. 何かしようとする時、自分にそれができるかどうか不安になる。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

20. 人に頼らない方だ。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

21. 私は自分から友達を作るのがうまい。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

22. すぐにあきらめてしまう。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

23. 人生で起きる問題の多くは処理できるとは思えない。

そう思わない ⇐ 1 2 3 4 5 ⇒ そう思う

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VI. 次の質問項目（1～21）が、あなた自身にどの程度あてはまるかを答えてください。回答は、以下の5つの選択肢を用い、あなたにあてはまると思う番号に○をつけてください。

1 = あてはまらない

2 = どちらかというにあてはまらない

3 = どちらとも

もいえない



4 = どちらかというときあてはまる

5 = あてはまる

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

1. つらい出来事があると耐えられない。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

2. 色々なことにチャレンジすることが好きだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

3. 自分の感情をコントロールできるほうだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

4. 自分の未来にはきっと良いことがあると思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

5. 新しいことや珍しいことが好きだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

6. 動揺しても、自分を落ち着かせることができる。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

7. 将来の見通しは明るいと思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

8. その日の気分によって行動が左右されやすい。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

9. ものごとに対する興味や関心が強いほうだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

10. いつも冷静でいられるようこころがけている。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

11. 私は色々なことを知りたいと思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

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12. あきっぽいほうだと思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

13. 自分の将来に希望を持っている。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

14. 困難があっても、それは人生にとって価値のあるものだと思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

15. ねばり強い人間だと思う。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

16. 慣れないことをするのは好きではない。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

17. 自分には将来の目標がある。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

18. 新しいことをやり始めるのはめんどうだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

19. 気分転換がうまくできないほうだ。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

20. 自分の目標のために努力している。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

21. 怒りを感じるとおさえられなくなる。

あてはまらない ⇐ 1 2 3 4 5 ⇒ あてはまる

ご協力、ありがとうございました。

# C. Application developed by this study

## C.1 Downloading Fitbit data

1. Make sure you are logged out from both sites <https://fitbit.com> and <https://dev.fitbit.com/>



2. Open the Fitbit Downloader program via Python command and enter the log in information (email, client ID, client secret). Then log in.

```
>> python GUI_Fitbit_Downloader.py
```

Welcome to Fitbit Downloader

Login to get your Fitbit data

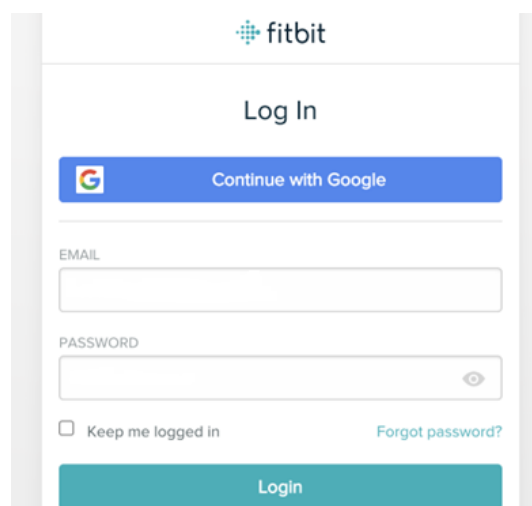
Email

User ID

Secret Key

Remember me?

3. You will be asked to login and approve the permission (only on the first login) at your web browser



The image shows the Fitbit login interface. At the top is the Fitbit logo. Below it is the text "Log In". There is a blue button with the Google logo and the text "Continue with Google". Below that are two input fields: "EMAIL" and "PASSWORD". The "PASSWORD" field has an eye icon to toggle visibility. Below the input fields are two links: "Keep me logged in" (with an unchecked checkbox) and "Forgot password?". At the bottom is a teal button labeled "Login".



Hosei University による [Flow application](#) は、Fitbit アカウントの以下のデータに対する アクセスと書き込み 機能を求めています。

- すべて許可する
  - 場所と GPS
  - 友達 ⓘ
  - 体重 ⓘ
  - アクティビティおよびエクササイズ
  - プロフィール ⓘ
  - Fitbit のデバイスおよび設定
  - 睡眠状態
  - 心拍数
  - 食品および水分の記録 ⓘ

このデータの一部しか許可しない場合には Flow application は想定どおりに機能しない可能性があります。これらのパーミッション [ここ](#) について詳しく知る

拒否

許可

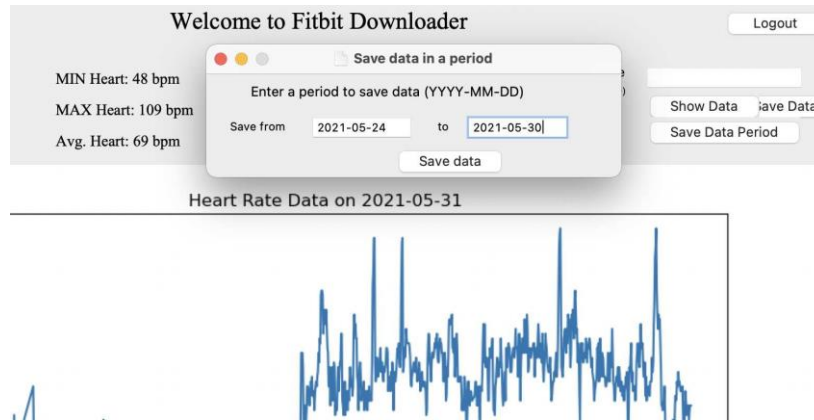
Flow application が共有するデータは、Hosei University の [プライバシーポリシー](#) および [利用規約](#) により規制されます。Fitbit [アカウント設定](#) で、いつでもこの同意を取り消すことができます。

4. If succeed you will see this message

**Get token successfully! You are now authorized to access the Fitbit data!**

**Close this window and get back to Fitbit Downloader to get the data.**

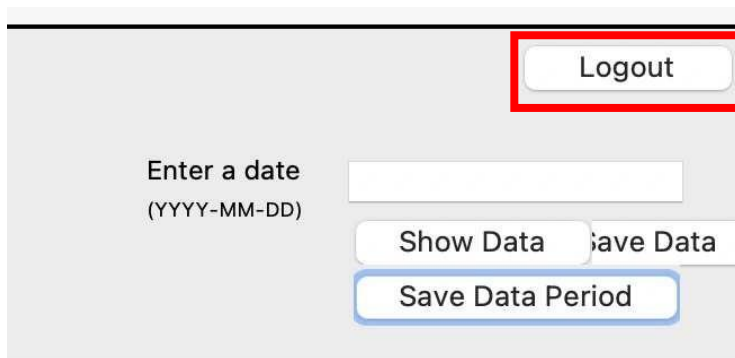
5. Now, just download or show the data of the date you want



You can check the remaining requests at the command prompt

```
[31/May/2021:20:34:13] ENGINE Waiting for child threads to terminate...
Request remaining: 150
Request limit reset in 1534 seconds
Saved data on date 2021-05-24
Saved data on date 2021-05-25
Saved data on date 2021-05-26
Saved data on date 2021-05-27
Saved data on date 2021-05-28
Saved data on date 2021-05-29
Saved data on date 2021-05-30
```

6. To switch and download another account, click the logout button on the Fibit Downloader



## C.2 Guidelines

This is a guideline to get your own Fitbit data via FitbitDownloader tool. The FitbitDownloader tool was written by Python. In this guideline, we assume that you're already sync your Fitbit data with your Phone.

### Requirements

#### 1. Installing Python and related packages

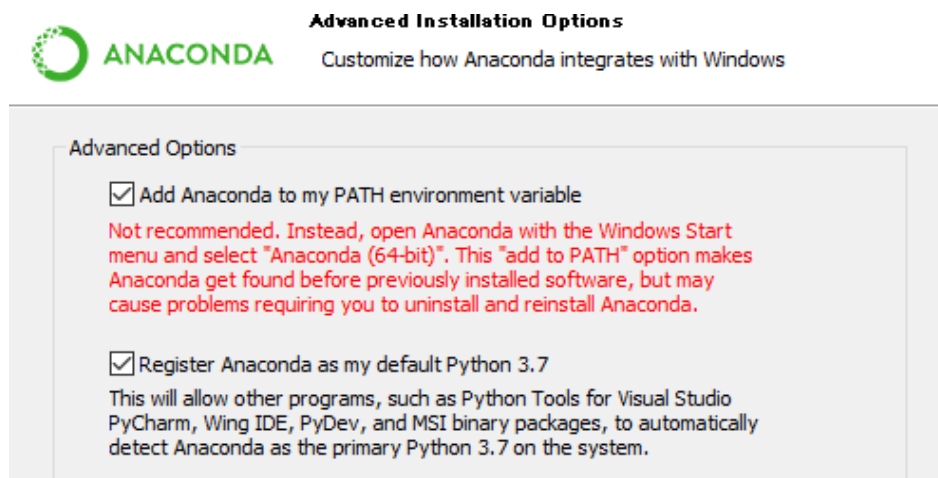
Please download Anaconda 3 with Python 3.8 version. Please select the correct version of your OS. It's recommended to download the T4-bit version. This tutorial is on Windows T4-bit OS.

Link: <https://www.anaconda.com/products/individual>

If you already have Python installed, you DO NOT need to download Anaconda. If you want to use Anaconda, please uninstall Python on your PC before installing Anaconda.

Windows 	MacOS 	Linux 
Python 3.8 64-Bit Graphical Installer (477 MB) 32-Bit Graphical Installer (409 MB)	Python 3.8 64-Bit Graphical Installer (440 MB) 64-Bit Command Line Installer (433 MB)	Python 3.8 64-Bit (x86) Installer (544 MB) 64-Bit (Power8 and Power9) Installer (285 MB) 64-Bit (AWS Graviton2 / ARM64) Installer (413 M) 64-bit (Linux on IBM Z & LinuxONE) Installer (292 M)

For Windows users, please make sure that you select the: **“Add Anaconda to my PATH environment variable”** and **“Register Anaconda as my default Python”** when installing Anaconda (see below)



## 2. After installing Anaconda, install the following packages for Python

### a) **CherryPy** - <http://cherrypy.org/>

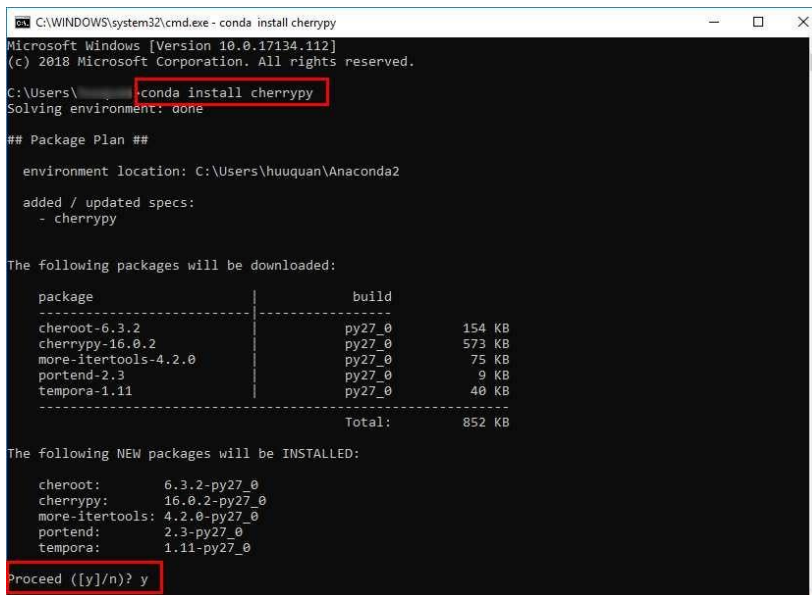
Please run Command Prompt (Windows + R  *cmd*) and enter the following commands.

For conda users:

```
>> conda install cherrypy
```

If you don't have Anaconda, use this

```
>> pip install cherrypy
```



```
C:\WINDOWS\system32\cmd.exe - conda install cherrypy
Microsoft Windows [Version 10.0.17134.112]
(c) 2018 Microsoft Corporation. All rights reserved.

C:\Users\...> conda install cherrypy
Solving environment: done

## Package Plan ##

  environment location: C:\Users\huhuquan\Anaconda2

added / updated specs:
- cherrypy

The following packages will be downloaded:

package | build | size
-----|-----|-----
cheroot-6.3.2 | py27_0 | 154 KB
cherrypy-16.0.2 | py27_0 | 573 KB
more-itertools-4.2.0 | py27_0 | 75 KB
portend-2.3 | py27_0 | 9 KB
tempora-1.11 | py27_0 | 40 KB
-----|-----|-----
Total: | | 852 KB

The following NEW packages will be INSTALLED:

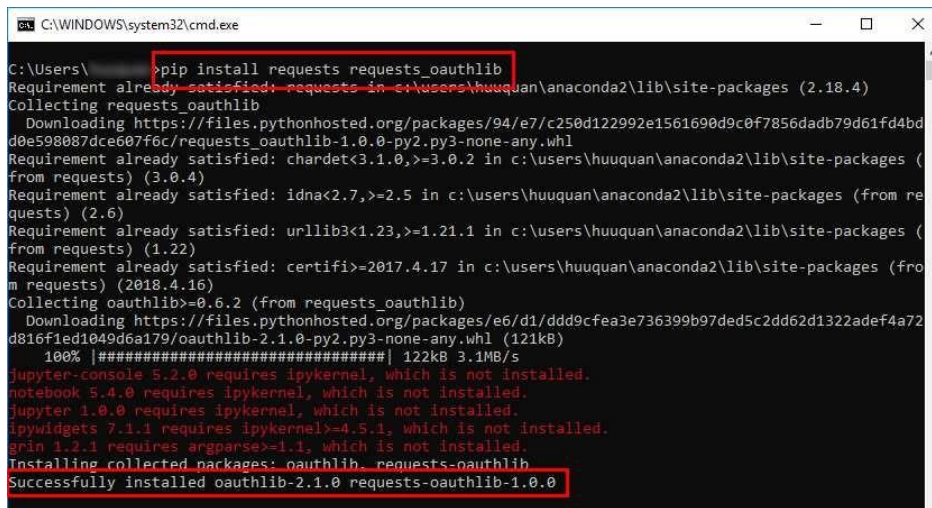
cheroot: 6.3.2-py27_0
cherrypy: 16.0.2-py27_0
more-itertools: 4.2.0-py27_0
portend: 2.3-py27_0
tempora: 1.11-py27_0

Proceed ([y]/n)? y
```

### b) **Requests Oauthlib** - <https://github.com/requests/requests-oauthlib> **Warning:** You must install the *requests\_oauthlib* version **1.0.0**. Using other versions will cause unknown errors.

Enter this command to Command Prompt

```
>> pip install requests requests_oauthlib==1.0.0
```



```
C:\WINDOWS\system32\cmd.exe
C:\Users\> pip install requests requests_oauthlib
Requirement already satisfied: requests in c:\users\hhuquan\anaconda2\lib\site-packages (2.18.4)
Collecting requests_oauthlib
  Downloading https://files.pythonhosted.org/packages/94/e7/c250d122992e1561690d9c0f7856dadb79d61fd4bd
d0e598087dce607f6c/requests_oauthlib-1.0.0-py2.py3-none-any.whl
Requirement already satisfied: chardet<3.1.0,>=3.0.2 in c:\users\hhuquan\anaconda2\lib\site-packages (
from requests) (3.0.4)
Requirement already satisfied: idna<2.7,>=2.5 in c:\users\hhuquan\anaconda2\lib\site-packages (from re
quests) (2.6)
Requirement already satisfied: urllib3<1.23,>=1.21.1 in c:\users\hhuquan\anaconda2\lib\site-packages (
from requests) (1.22)
Requirement already satisfied: certifi>=2017.4.17 in c:\users\hhuquan\anaconda2\lib\site-packages (fro
m requests) (2018.4.16)
Collecting oauthlib>=0.6.2 (from requests_oauthlib)
  Downloading https://files.pythonhosted.org/packages/e6/d1/ddd9cfea3e736399b97ded5c2dd62d1322a72a72
d816f1ed1049d6a179/oauthlib-2.1.0-py2.py3-none-any.whl (121kB)
 100% |#####| 122kB 3.1MB/s
jupyter-console 5.2.0 requires ipykernel, which is not installed.
notebook 5.4.0 requires ipykernel, which is not installed.
jupyter 1.0.0 requires ipykernel, which is not installed.
ipywidgets 7.1.1 requires ipykernel>=4.5.1, which is not installed.
grin 1.2.1 requires argparse>=1.1, which is not installed.
Installing collected packages: oauthlib, requests-oauthlib
Successfully installed oauthlib-2.1.0 requests-oauthlib-1.0.0
```

### 3. Using the FitbitDownloader

To download your Fitbit data, you first login with your registered Fitbit account in: <https://dev.fitbit.com/login>

Next, please click “*Register an app*” or visit this link: <https://dev.fitbit.com/apps/new> to create your new application.



## Register an application

Application Name \*

My Application

Description \*

This is my application for monitoring my health

Application Website \*

http://www.hosei.ac.jp/

Organization \*

Hosei University

Organization Website \*

http://www.hosei.ac.jp/

Terms Of Service Uri \*

http://www.hosei.ac.jp/

Privacy Policy Uri \*

http://www.hosei.ac.jp/

OAuth 2.0 Application Type \*

Server  Client  Personal

Callback URL \*

http://127.0.0.1:8080/

Default Access Type \*

Read & Write  Read-Only

+ Add a subscriber

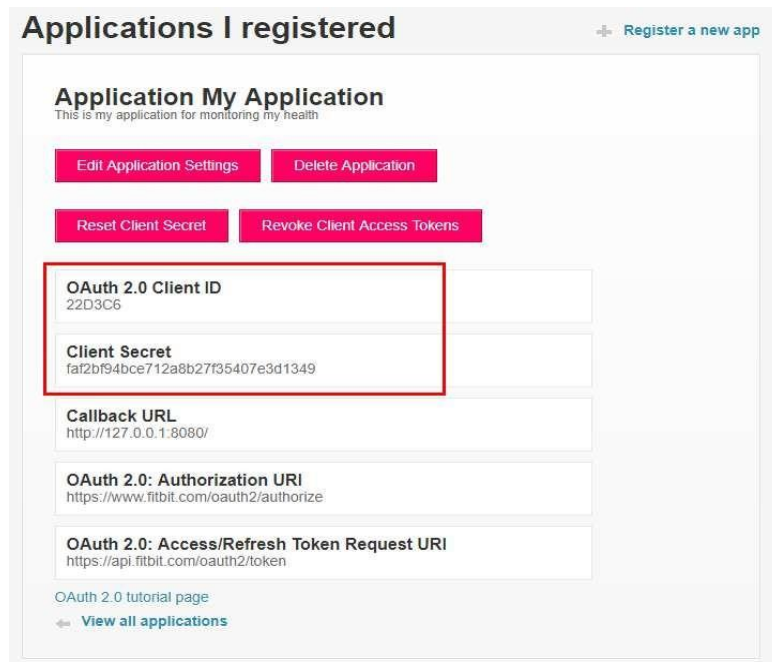
I have read and agree to the [terms of service](#)

Register

Cancel

- **Application name:** Just enter a name for your app
- **Description:** Describing your Fitbit app. For example, “This is my application for....”
- **Application Website:** In this case, please use: <https://www.hosei.ac.jp>
- **Organization:** Enter your organization’s name. Such as: “**Hosei University**”
- **Organization Website, Terms of Service URL, Privacy Policy URL:** In this case, we use: <https://www.hosei.ac.jp>
- **OAuth 2.0 Application Type:** This is the way how you authenticate Fitbit server. In this case, we choose “**Personal**”
- **Callback URL:** Fitbit server uses port 8080 to connect with their clients. So, please enter: <http://127.0.0.1:8080/> as a callback URL. **Warning: DO NOT USE https**
- **Default Access Type:** Since our modified Fitbit API uses “Read & Write” as an access type, please choose “**Read & Write**” in **Default Access Type** option.

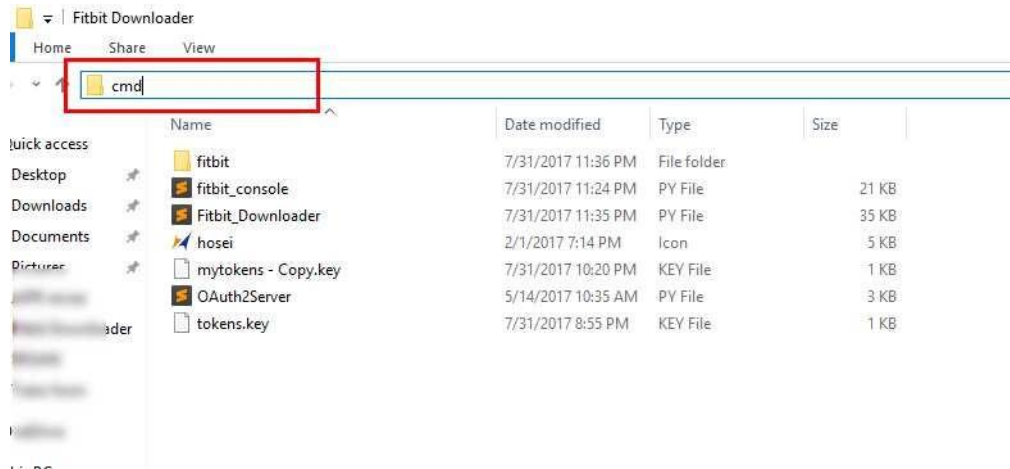
Click “**Register**” to finish registration. After that, your app info will be shown in Fitbit website.



Two important pieces of information are OAuth 2.0 Client ID and Client Secret. You can see there are 2 new pieces of information: **OAuth 2.0 Client ID** and **Client Secret**. This information helps you to access your Fitbit data via the API.

#### 4. Login to the FitbitDownloader

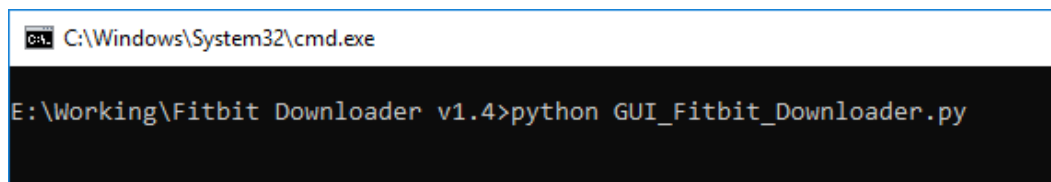
Before logging in, you must synchronize your data with your phone. Once you got the **OAuth 2.0 Client ID** and **Client Secret**, click the path of FitbitDownloader folder and type “cmd” to open Command Prompt



Type this command and hit Enter:

```
>> python GUI_Fitbit_Downloader.py
```

in command line and hit Enter.



Enter the command to open FitbitDownloader.

You need to enter the information for the following panel:

### Welcome to Fitbit Downloader

Login to get your Fitbit data

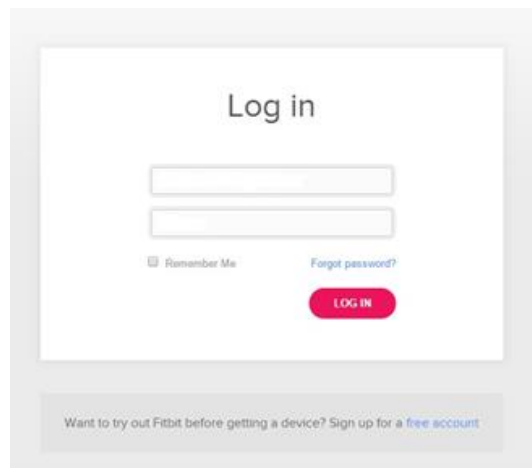
Email

User ID

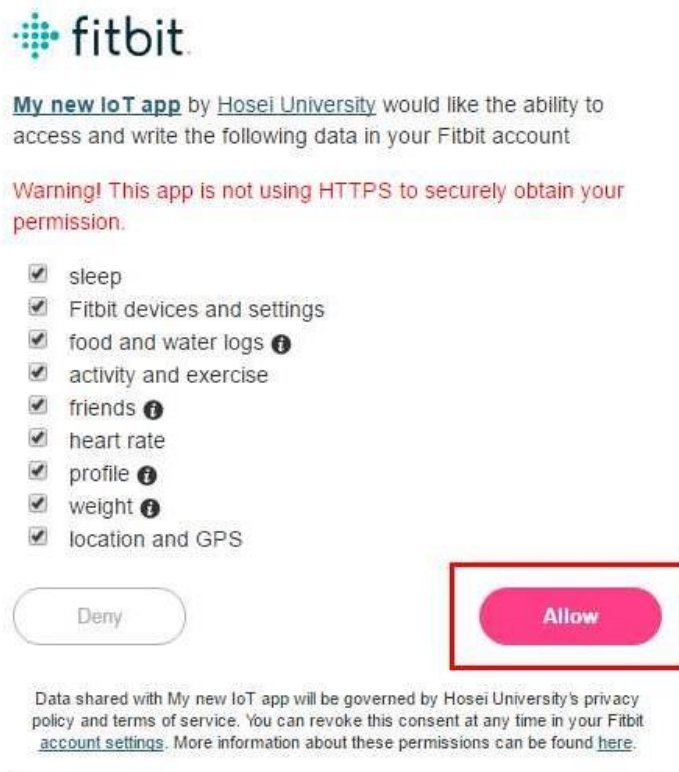
Secret Key

Remember me?

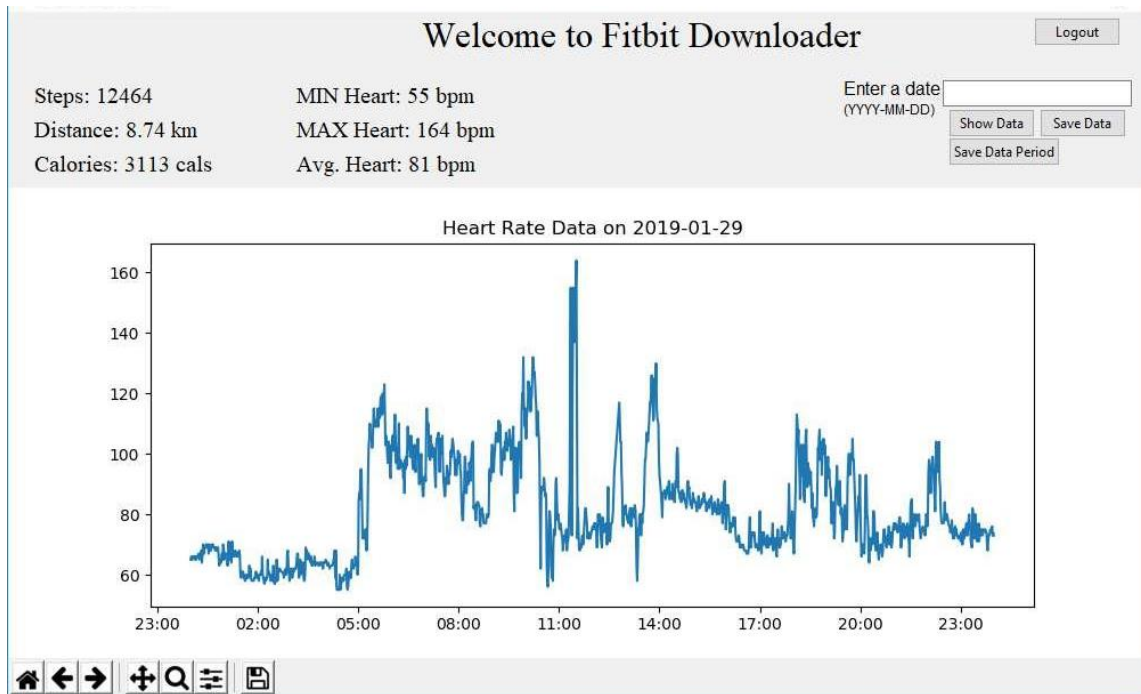
If this is your first time to log in, a message said “*Your token has been expired, please login to continue*” will be shown with a Fitbit login website after you click OK button. You need to login your account again via that website.



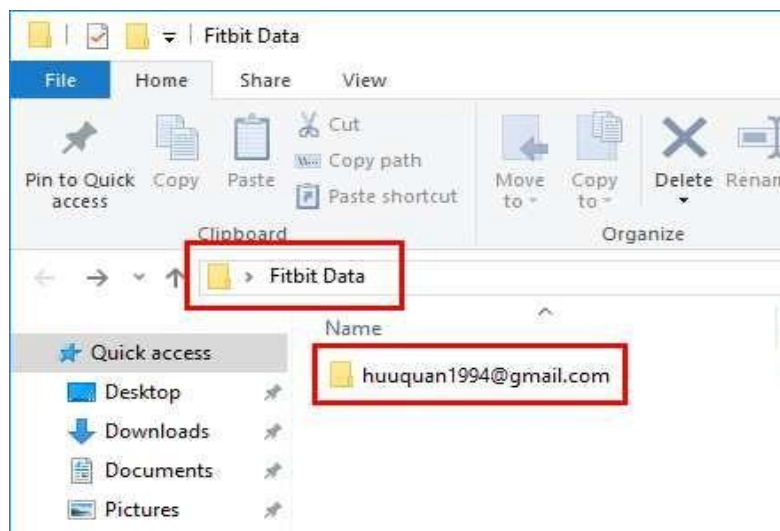
After logging in, click Allow button and you will see the result message: “**Get token successfully! You are now authorized to access the Fitbit data! Close this window and get back to FitbitDownloader to get the data.**”. When you see this, you’ve finished connecting between the API and your Fitbit data. The following allows the application to access your data.



Back to the FitbitDownloader, you will see a graph of your heart rate data in the current day.



Also, when you check your desktop, you will see a new folder called “**Fitbit Data**” with your email address. Your Fitbit data is stored in that folder when you download it.



## 5. Main functions of the FitbitDownloader

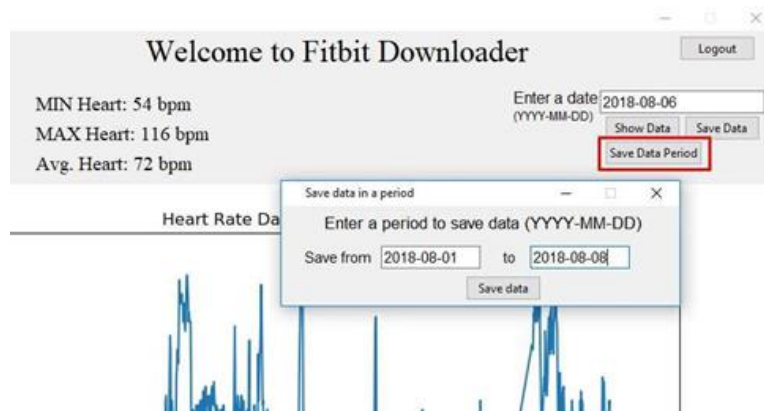
The FitbitDownloader has several main functions. Show data of a day, save data from a day, and save data from a period (maximum 30 days), track your remaining requests (beta). All the above functions

require you to enter a day string first. The day string will follow this format: “yyyy-mm-dd”, for example: “2019-01-29”.

- **Show Data:** This button will show your data in a specific day. That information to be shown are the graph of heart rate, distance, calories, walking steps.
- **Save Data:** This button will help you get your Fitbit data into the folder in your desktop. The data to be saved are Calories, Distances, Heart Rate, Sleep, Steps in the CSV format.

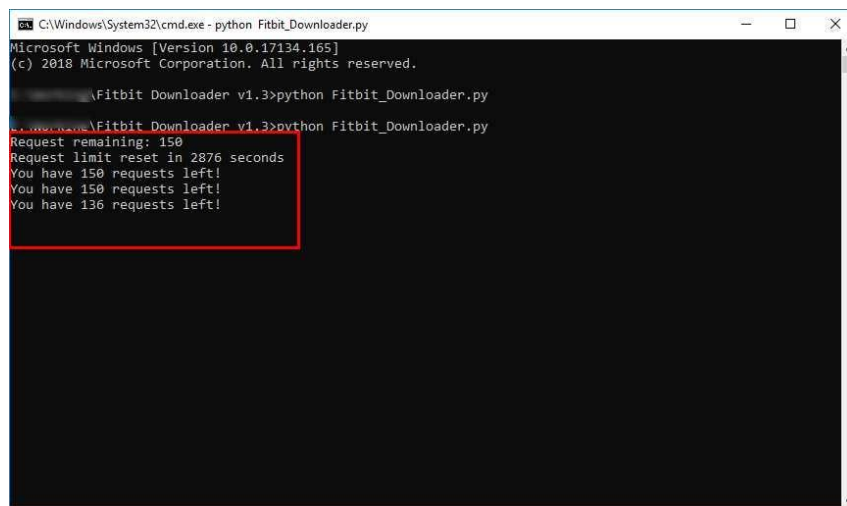
Name	Date modified
Calories_1Min_2019-01-29	1/29/2019 11:58 PM
CaloriesSummary_2019-01-29	1/29/2019 11:58 PM
Distances_1Min_2019-01-29	1/29/2019 11:58 PM
DistancesSummary_2019-01-29	1/29/2019 11:58 PM
HeartRate_1Min_2019-01-29	1/29/2019 11:58 PM
HeartRate_1Sec_2019-01-29	1/29/2019 11:58 PM
SleepLogs_2019-01-29	1/31/2019 6:32 PM
SleepSummary_2019-01-29	1/31/2019 6:32 PM
Steps_1Min_2019-01-29	1/29/2019 11:58 PM
StepsSummary_2019-01-29	1/29/2019 11:58 PM

- **Save Data Period:** Download your data in a custom period with the “Save Data Period” button. You only can enter a period within **30**. For example, saving data from **2018-06-20** to **2018-08-20** is **not** allowed since it has so many days. All the tracking logs can be viewed in the *Command Prompt*



```
Request remaining: 150
Request limit reset in 1984 seconds
You have 150 requests left!
You have 150 requests left!
Saved data on date 2018-08-01
Saved data on date 2018-08-02
Saved data on date 2018-08-03
Saved data on date 2018-08-04
Saved data on date 2018-08-05
Saved data on date 2018-08-06
Saved data on date 2018-08-07
Saved data on date 2018-08-08
You have 111 requests left!
```

- **Tracking your remaining requests (beta):** You can make 150 API requests (download or show your Fitbit data) per hour. The remaining requests can be seen while running the program via the Command Prompt. Request limit reset in 2,87T seconds means your requests will be reset to 150 after 2,87T seconds. If you exceed over 150 requests, a “*TooManyRequest*” exception will show up and let you know how long you will be able to access your data again.



```
C:\Windows\System32\cmd.exe - python Fitbit_Downloader.py
Microsoft Windows [Version 10.0.17134.165]
(c) 2018 Microsoft Corporation. All rights reserved.

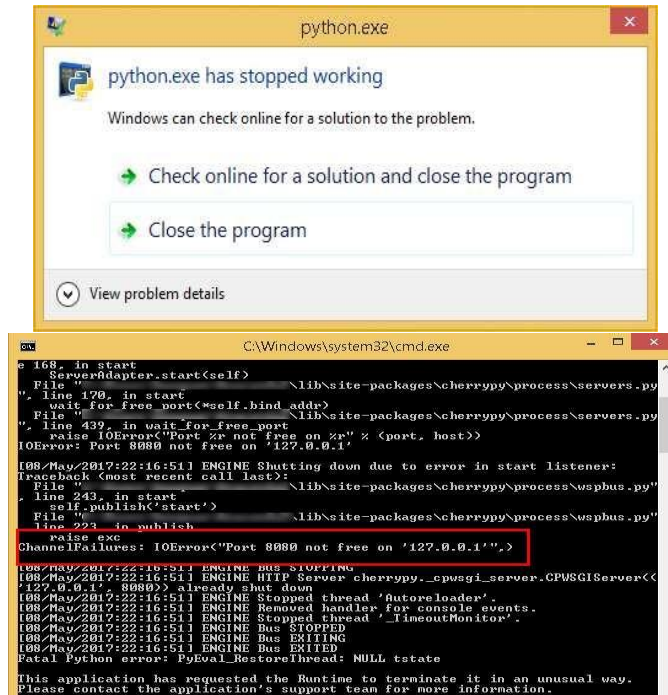
C:\Users\user>python Fitbit_Downloader.py
Fitbit Downloader v1.3>python Fitbit_Downloader.py
Request remaining: 150
Request limit reset in 2876 seconds
You have 150 requests left!
You have 150 requests left!
You have 136 requests left!
```



This example, you need to wait approximately 40 minutes until the next login.

## 6. Troubleshooting

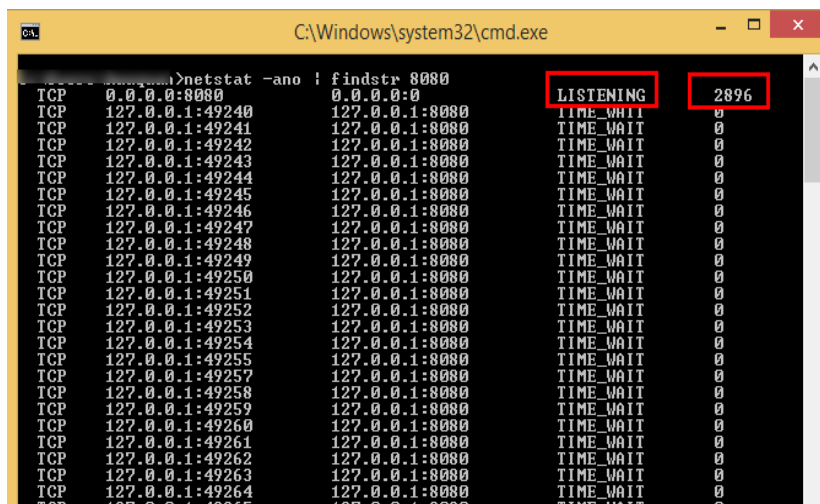
Make sure the port 8080 is free on your PC. You will see this error: “**Python.exe has stopped working**” or “**Port 8080 not free on ‘127.0.0.1’**” if the port 8080 is being used by another applications.



This means you can't use port 8080 to get data from Fitbit server. You only can access Fitbit data via port 8080, if it's not free, the FitbitDownloader will stop working. To check if some programs are using port 8080 in your PC, open Command Prompt and enter this command:

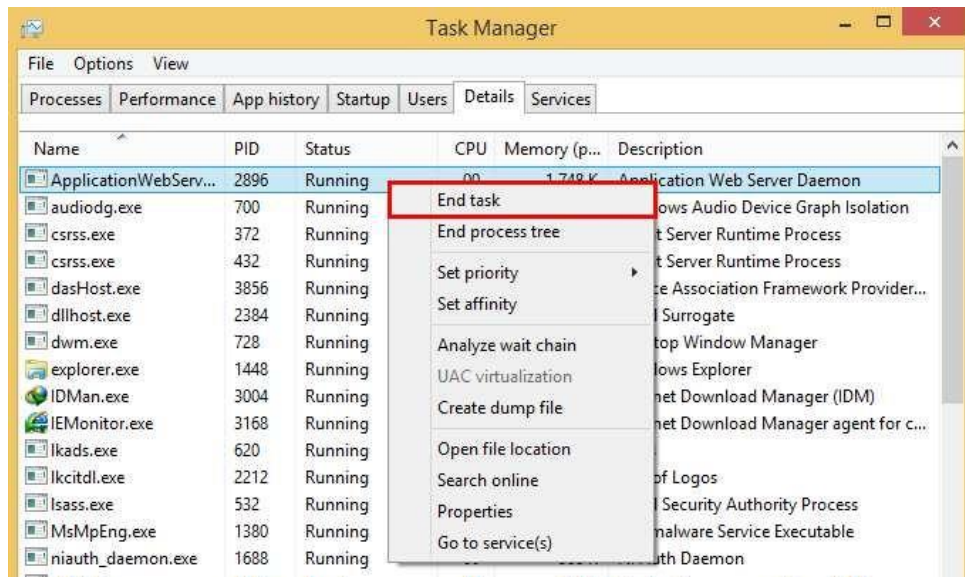
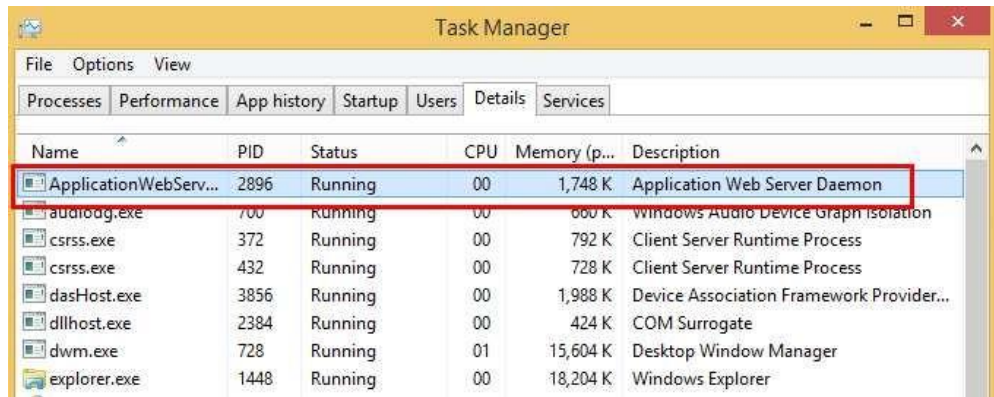
```
>> netstat -ano | findstr 8080
```

This command will search all process that are using (Listening) the port 8080 in your PC.





We only care about the process that listed with “LISTENING” status. In this example, that process has ID is **2896**. Next step, open Task Manager and go to tab “**Details**”. Look at PID column, you will find one process has the ID of **2896**. Right-click on that and click “**End task**”, the problem will be resolved.



## D. Codes

### D.1 Python code for “Console\_Fitbit\_Data\_Downloader

```
# Author:      Omid Jamalipournokandeh
# Email:      f191503c@mail.cc.niigata-u.ac.jp
import fitbit
import OAuth2Server
import os
import re
import datetime
import json
import time

today = datetime.datetime.now().strftime("%Y-%m-%d")
EMAIL_REGEX = re.compile(r"^[^@]+@[^@]+\.[^@]+$")
# From this line is the remake version of Fitbit API
# This new class aims to simplify your steps to downloading your Fitbit data
class fitbitDownloader(object):
    def __init__(self):
        self.save_path = ""
        self.USER_ID = ""
        self.CLIENT_SECRET = ""
        try:
            with open('console_tokens.key') as f:
                self.tokens = f.readlines()
                f.close()
            if(self.tokens != []):
                self.CURR_EMAIL = str(self.tokens[0][0:len(self.tokens[0])-1])
                self.USER_ID = str(self.tokens[1][0:len(self.tokens[1])-1])
                self.CLIENT_SECRET = str(self.tokens[2][0:len(self.tokens[2])-1])
                self.ACCESS_TOKEN = str(self.tokens[3][0:len(self.tokens[3])-1])
                self.REFRESH_TOKEN = str(self.tokens[4])
                self.save_path = "~\\Desktop\\" + "Fitbit Data\\" + self.CURR_EMAIL
            else:
                self.CURR_EMAIL = ""
                self.ACCESS_TOKEN = ""
```

```

        self.REFRESH_TOKEN = "
except:
    f = open('console_tokens.key', 'w')
    f.close()
    self.CURR_EMAIL = "
    self.ACCESS_TOKEN = "
    self.REFRESH_TOKEN = "
# Show the current logging in account info
def show_info(self):
    print("Your are currently working with this Fitbit account:")
    print("EMAIL:\t" + self.CURR_EMAIL)
    print("USER ID:\t" + self.USER_ID)
    print("If you want to switch your account, please call 'gather_tokens' function with
another email!")
# Re-login when your token is expried
def re_login(self):
    print("Your token has been expired, please login again to continue!")
    server = OAuth2Server.OAuth2Server(self.USER_ID, self.CLIENT_SECRET)
    server.browser_authorize()
    self.ACCESS_TOKEN = server.oauth.token['access_token']
    self.REFRESH_TOKEN = server.oauth.token['refresh_token']
    f = open("console_tokens.key", "w")
    f.write(self.CURR_EMAIL + "\n")
    f.write(self.USER_ID + "\n")
    f.write(self.CLIENT_SECRET + "\n")
    f.write(self.ACCESS_TOKEN + "\n")
    f.write(self.REFRESH_TOKEN)
    f.close()
    print("Get token successfully!\nPlease try to get your data again!")
# When you reach the limited request (150 requests/hour), you will be no longer get the data.
# Therefore, you have to wait for an hour. This function will calculate the remaining time to
download your data again
def cal_remain_time(self, exc):
    reset_time = exc.retry_after_secs
    reset_time = reset_time/60.0

```

```

        print("Opps!", "Too many requests!\nPlease try again after {0:.0f}
minutes!".format(reset_time))
    # Show how many request that you can send to server and how many time they will be reset
    def show_request_remaining(self):
        print("Request remaining: %d" % self.auth2_client.rate_limit_remaining)
        print("Request limit reset in {0:.0f} seconds".format(self.auth2_client.rate_limit_reset
- time.time()))
    # This gather_tokens function will help you get access tokens from Fitbit API
    def gather_tokens(self, email, userID, clientSecret):
        if(EMAIL_REGEX.match(email) != None):
            self.USER_ID = str(userID)
            self.CLIENT_SECRET = str(clientSecret)
            try:
                # Check entered email if it's different from your previous email
                if(self.CURR_EMAIL != email):
                    print("We found that your entered email is different from your
current emai!")
                    print("Do you want to continue login with this email? if YES,
you must login again!")
                    flag = raw_input("Y/N ?: ")
                    print(flag)
                    if(flag == "Y" or flag == "y"):
                        raise fitbit.exceptions.HTTPUnauthorized()
                    else:
                        print("Please try to get tokens again!")
                        return "Failed to get tokens of " + email
                self.auth2_client = fitbit.Fitbit(self.USER_ID, self.CLIENT_SECRET,
oauth2=True, access_token=self.ACCESS_TOKEN,
refresh_token=self.REFRESH_TOKEN)
                self.save_path = "~\\Desktop\\" + "Fitbit Data\\" + self.CURR_EMAIL
                if not os.path.exists(os.path.expanduser(self.save_path)):
                    os.makedirs(os.path.expanduser(self.save_path))
                fitbit_stats = self.auth2_client.intraday_time_series('activities/heart',
today, detail_level='1min')
                print("Login Succeed!")

```

```

except (fitbit.exceptions.HTTPUnauthorized, TypeError):
    print("Oops! Your token has been expired, please login to continue!")
    server = OAuth2Server.OAuth2Server(self.USER_ID,
self.CLIENT_SECRET)
    server.browser_authorize()
    self.ACCESS_TOKEN = server.oauth.token['access_token']
    self.REFRESH_TOKEN = server.oauth.token['refresh_token']
    self.CURR_EMAIL = email
    self.save_path = "~\\Desktop\\" + "Fitbit Data\\" + self.CURR_EMAIL
    f = open("console_tokens.key", "w")
    f.write(self.CURR_EMAIL + "\n")
    f.write(self.USER_ID + "\n")
    f.write(self.CLIENT_SECRET + "\n")
    f.write(self.ACCESS_TOKEN + "\n")
    f.write(self.REFRESH_TOKEN)
    f.close()
    print("Get token successfully!\nNow you can get your data!")
except fitbit.exceptions.HTTPTooManyRequests as exc:
    self.cal_remain_time(exc)
except IndexError:
    print("Oops! We can't get your data!\nPlease sync your data and login
again!")
else:
    print("Error! Please enter an valid email!")

# Save heart rate data
# Detail_time must be in ['1sec', '1min', '15min', '5min']
def save_heart_detail(self, date, detail_time):
    self.show_info()
    if not detail_time in ['1sec', '1min', '5min', '15min']:
        raise ValueError("Period must be either '1sec', '1min', '5min', or '15min'")
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/heart', date,
detail_level=detail_time)
        stats = fitbit_stats['activities-heart-intraday']['dataset']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):

```

```

os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

csv_file = open(os.path.join(os.path.expanduser(self.save_path), date,
                             "HeartRate_"+detail_time+"_%s.csv" %
str(date)), 'w')

for var in range(0, len(stats)):
    csv_file.write(stats[var]['time'])
    csv_file.write(',')
    csv_file.write(str(stats[var]['value']))
    csv_file.write("\n")

csv_file.close()

print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))

except (fitbit.exceptions.HTTPUnauthorized):
    self.re_login()

except fitbit.exceptions.HTTPTooManyRequests as exc:
    self.cal_remain_time(exc)

# Save calories in different detail of time level (1sec, 1min, ect.)
def save_calories_detail(self, date, detail_time):
    self.show_info()
    if not detail_time in ['1sec', '1min', '5min', '15min']:
        raise ValueError("Period must be either '1sec', '1min', '5min', or '15min'")
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/calories', date,
detail_level=detail_time)

stats = fitbit_stats['activities-calories-intraday']['dataset']
if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
    os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

csv_file = open(os.path.join(os.path.expanduser(self.save_path), date,
                             "Calories_"+detail_time+"_%s.csv" %
str(date)), 'w')

for var in range(0, len(stats)):
    csv_file.write(str(stats[var]['mets']))
    csv_file.write(',')

```

```

        csv_file.write(stats[var]['time'])
        csv_file.write(',')
        csv_file.write(str(stats[var]['value']))
        csv_file.write("\n")
    csv_file.close()
    print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
# Save calories summary
def save_calories_summary(self, date):
    self.show_info()
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/calories', date)
        stats = fitbit_stats['activities-calories']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))
        csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"CaloriesSummary_%s.csv" % str(date)), 'w')
        csv_file.write(stats[0]['dateTime'])
        csv_file.write(',')
        csv_file.write(str(stats[0]['value']))
        csv_file.close()
        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
# Save the walking steps in different detail of time level (1sec, 1min, ect.)
def save_steps_detail(self, date, detail_time):
    self.show_info()
    try:

```

```

        fitbit_stats = self.auth2_client.intraday_time_series('activities/steps', date,
detail_level=detail_time)
        stats = fitbit_stats['activities-steps-intraday']['dataset']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

        csv_file = open(os.path.join(os.path.expanduser(self.save_path), date,
                                "Steps_"+detail_time+"_%s.csv" % str(date)),
'w')

        for var in range(0, len(stats)):
            csv_file.write(stats[var]['time'])
            csv_file.write(',')
            csv_file.write(str(stats[var]['value']))
            csv_file.write("\n")

        csv_file.close()
        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
        except (fitbit.exceptions.HTTPUnauthorized):
            self.re_login()
        except fitbit.exceptions.HTTPTooManyRequests as exc:
            self.cal_remain_time(exc)

# Save the summary of walking steps
def save_steps_summary(self, date):
    self.show_info()
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/steps', date)
        stats = fitbit_stats['activities-steps']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

        csv_file =
open(os.path.join(os.path.expanduser(self.save_path),date,"StepsSummary_%s.csv" % str(date)), 'w')
        csv_file.write(stats[0]['dateTime'])
        csv_file.write(',')
        csv_file.write(str(stats[0]['value']))
        csv_file.close()

```



```

        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)

# Save sleep data (Sleep summary)
def save_sleep_summary(self, date):
    self.show_info()
    try:
        date_sleep = datetime.datetime.strptime(date, '%Y-%m-%d')
        fitbit_stats = self.auth2_client.get_sleep(date_sleep)
        stats = fitbit_stats['sleep']

        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

        csv_file =
open(os.path.join(os.path.expanduser(self.save_path),date,"SleepLogs_%s.csv" % date), 'w')
        for var in range(0, len(stats)):
            sleep_type = stats[var]['type']
            csv_file.write('type' + "," + str(stats[var]['type']))
            csv_file.write("\n")
            csv_file.write('isMainSleep' + "," + str(stats[var]['isMainSleep']))
            csv_file.write("\n")
            csv_file.write('startTime' + "," + stats[var]['startTime'])
            csv_file.write("\n")
            csv_file.write('timeInBed' + "," + str(stats[var]['timeInBed']))
            csv_file.write("\n")
            csv_file.write("Summary each level:\n")
            sleep_levels = stats[var]['levels']
            # There are two types of sleep: stages and classic
            if(sleep_type=="stages"):
                csv_file.write('deep' + "," +
str(sleep_levels['summary']['deep']['minutes']))

```

```

        csv_file.write("\n")
        csv_file.write('light' + "," +
str(sleep_levels['summary']['light']['minutes']))
        csv_file.write("\n")
        csv_file.write('rem' + "," +
str(sleep_levels['summary']['rem']['minutes']))
        csv_file.write("\n")
        csv_file.write('wake' + "," +
str(sleep_levels['summary']['wake']['minutes']))
        csv_file.write("\n\n")
    else: # The classic type of sleep
        csv_file.write('asleep' + "," +
str(sleep_levels['summary']['asleep']['minutes']))
        csv_file.write("\n")
        csv_file.write('awake' + "," +
str(sleep_levels['summary']['awake']['minutes']))
        csv_file.write("\n")
        csv_file.write('restless' + "," +
str(sleep_levels['summary']['restless']['minutes']))
        csv_file.write("\n\n")
    # Get the data for each stage
    csv_file.write("Detailed data:\n")
    for i in range(len(sleep_levels['data'])):
        dt_dateTime = sleep_levels['data'][i]['dateTime']
        dt_level = sleep_levels['data'][i]['level']
        dt_seconds = str(sleep_levels['data'][i]['seconds'])
        csv_file.write(dt_level+ ',' + dt_dateTime + "," + dt_seconds)
        csv_file.write("\n")
    csv_file.write("\n")
    csv_file.close()
    # Sleep summary
    stats = fitbit_stats['summary']
    csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"SleepSummary_%s.csv" % date), 'w')
    csv_file.write('totalTimeInBed' + "," + str(stats['totalTimeInBed']))
    csv_file.write("\n")

```

```

        csv_file.write('totalMinutesAsleep' + "," + str(stats['totalMinutesAsleep']))
        csv_file.write('\n')
        csv_file.write('totalSleepRecords' + "," + str(stats['totalSleepRecords']))
        csv_file.write('\n')
        csv_file.close()
        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
    except ValueError:
        print("Error! Please enter a vaild date!")
# Save distance in different detail of time level (1sec, 1min, ect.)
def save_distance_detail(self, date, detail_time):
    self.show_info()
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/distance', date,
detail_level=detail_time)
        stats = fitbit_stats['activities-distance-intraday']['dataset']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))
        csv_file = open(os.path.join(os.path.expanduser(self.save_path), date,
                                "Distance_"+detail_time+"_%s.csv" %
str(date)), 'w')
        for var in range(0, len(stats)):
            csv_file.write(stats[var]['time'])
            csv_file.write(',')
            csv_file.write(str(stats[var]['value']))
            csv_file.write("\n")
        csv_file.close()
        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()

```

```

        except fitbit.exceptions.HTTPTooManyRequests as exc:
            self.cal_remain_time(exc)
# Save the distance summary
def save_distance_summary(self, date):
    self.show_info()
    try:
        fitbit_stats = self.auth2_client.intraday_time_series('activities/distance', date)
        stats = fitbit_stats['activities-distance']
        if not os.path.exists(os.path.join(os.path.expanduser(self.save_path), date)):
            os.makedirs(os.path.join(os.path.expanduser(self.save_path),
date))

        csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"DistancesSummary_%s.csv" % str(date)), 'w')
        mile = float(stats[0]['value'])
        km = mile*1.60934
        csv_file.write(stats[0]['dateTime'])
        csv_file.write(',')
        csv_file.write(str(km))
        csv_file.close()
        print("Your Fitbit data has been stored in: " +
os.path.join(os.path.expanduser(self.save_path), date))
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
# Test the customized saving function
def save_daily_activity(self, date, filename=""):
    try:
        fitbit_stats = self.auth2_client.get_daily_activity(date)
        with open(filename + '.json', 'w') as f:
            json.dump(fitbit_stats, f)
    except (fitbit.exceptions.HTTPUnauthorized):
        self.re_login()
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)

```

## D.2 Python code for “GUI\_Fitbit\_Downloader”

```
# Fitbit Downloader v1.4
# Author:      Omid Jamalipournokandeh
# Email:      f191503c@mail.cc.niigata-u.ac.jp
'''
This source code is for personal use only.
The code is still simple and insecure in some perspective. Please keep your personal data safe!
'''

import numpy as np
import datetime
import matplotlib
matplotlib.use("TkAgg")
from matplotlib import style
import matplotlib.dates as md
import dateutil
from matplotlib.backends.backend_tkagg import FigureCanvasTkAgg
from matplotlib.figure import Figure
import fitbit
import OAuth2Server
import os
import re
import time
import sys

##### USING FITBIT DOWNLOADER WITH PYTHON 3.X #####
if sys.version_info[0] == 3:
    from tkinter import messagebox as tkMessageBox
    import tkinter as tk
    from tkinter import Toplevel
    import tkinter.ttk as ttk
    from matplotlib.backends.backend_tkagg import NavigationToolbar2Tk as
NavigationToolbar2TkAgg
## For Python 2.x
elif sys.version_info[0] == 2:
    import tkMessageBox
    import Tkinter as tk
```

```

from Tkinter import Toplevel
import ttk
from matplotlib.backends.backend_tkagg import NavigationToolbar2TkAgg
else: raise Exception("Unknown Python version! Please check again!")
EMAIL_REGEX = re.compile(r"^[^@]+@[^@]+\.[^@]+$") # For checking the entered email
# Declaring the fonts use for the GUI
LARGE_FONT=("Times New Roman", 32)
TITLE_FONT=("Times New Roman", 23)
MEDIUM_FONT = ("Times New Roman", 20)
SMALL_FONT = ("Times New Roman", 15)
today = datetime.datetime.now().strftime("%Y-%m-%d")
# Main class
class FitbitApp(tk.Tk):
    def __init__(self, *args, **kwargs):
        tk.Tk.__init__(self, *args, **kwargs)
        tk.Tk.iconbitmap(self, "hosei.ico")
        tk.Tk.wm_title(self, "Fitbit Downloader 1.4")
        self.container = tk.Frame(self)
        self.container.pack(side="top", fill="both", expand= True)
        self.container.grid_rowconfigure(0, weight=1)
        self.container.grid_columnconfigure(0, weight=1)

        self.frames = {}
        for F in (StartPage, Summary):
            frame = F(self.container, self)
            frame.grid(row=0,column=0,sticky="nsew")
            self.frames[F] = frame

        self.show_frame(StartPage)
    def show_frame(self, cont):
        frame = self.frames[cont]
        frame.tkraise()

# Frame for Start Page
class StartPage(tk.Frame):

```

```

def __init__(self, parent, controller):
    tk.Frame.__init__(self, parent)
    self.save_path = ""
    # load UserID and ScretKey. If None, create a new one
    try:
        with open('gui_tokens.key') as f:
            self.tokens = f.readlines()
            f.close()
        if(self.tokens != []):
            self.CURR_EMAIL = str(self.tokens[0][0:len(self.tokens[0])-1])
            self.CLIENT_ID = str(self.tokens[1][0:len(self.tokens[1])-1])
            self.CLIENT_SECRET = str(self.tokens[2][0:len(self.tokens[2])-1])
            self.ACCESS_TOKEN = str(self.tokens[3][0:len(self.tokens[3])-1])
            self.REFRESH_TOKEN = str(self.tokens[4])
        else:
            self.CURR_EMAIL = 'None'
            self.CLIENT_ID = 'None'
            self.CLIENT_SECRET = 'None'
            self.ACCESS_TOKEN = 'None'
            self.REFRESH_TOKEN = 'None'
    except:
        f = open('gui_tokens.key', 'w')
        f.close()
        self.CURR_EMAIL = 'None'
        self.CLIENT_ID = 'None'
        self.CLIENT_SECRET = 'None'
        self.ACCESS_TOKEN = 'None'
        self.REFRESH_TOKEN = 'None'

    self.wel_Label=tk.Label(self, text="Welcome to Fitbit Downloader",
font=LARGE_FONT)
    self.wel_Label.place(x=270, y=60)
    self.login_Label=tk.Label(self, text="Login to get your Fitbit data",
font=MEDIUM_FONT)
    self.login_Label.place(x=400, y=160)

```

```

# Create button style
s = ttk.Style()
s.configure('my.TButton', font=('Times New Roman', 20))

self.btnLogin = ttk.Button(self, text="Login", command = lambda:
self.click_login(controller), style='my.TButton')
self.btnLogin.place(x=450, y=450)
# Create label
self.email_Label = ttk.Label(self, text="Email", font="TimesNewRoman 14")
self.id_Label = ttk.Label(self, text="User ID", font="TimesNewRoman 14")
self.SKey_Label = ttk.Label(self, text="Scret Key", font="TimesNewRoman 14")
self.email_Label.place(x=350, y=250)
self.id_Label.place(x=350, y= 300)
self.SKey_Label.place(x=350, y= 350)
# Create Entry
self.en_Email = ttk.Entry(self, font="TimesNewRoman 14")
self.en_Email.place(x=460, y=250)
if(self.CURR_EMAIL!='None'):
    self.en_Email.insert(0, self.CURR_EMAIL)
self.en_ID = ttk.Entry(self, font="TimesNewRoman 14")
self.en_ID.place(x=460, y=300)
if(self.CLIENT_ID!='None'):
    self.en_ID.insert(0, self.CLIENT_ID)
self.en_Key = ttk.Entry(self, font="TimesNewRoman 14")
self.en_Key.place(x=460, y=350)
if(self.CLIENT_SECRET!='None'):
    self.en_Key.insert(0, self.CLIENT_SECRET)
self.check_var = tk.BooleanVar(value=True)
self.remember_usr = ttk.Checkbutton(self, text="Remember
me?",variable=self.check_var)
self.remember_usr.place(x=640, y=460)
# Customize to work with Ctrl+A, Tab key
self.en_ID.bind("<Control-Key-a>", self.select_all_ID)
self.en_ID.bind("<Tab>", self.tab_ID)
self.en_ID.bind("<Control-Key-A>", self.select_all_ID)

```



```

self.en_Key.bind("<Control-Key-a>", self.select_all_Key)
self.en_Key.bind("<Control-Key-A>", self.select_all_Key)
self.en_Key.bind("<Tab>", self.tab_Key)
self.en_Email.bind("<Control-Key-a>", self.select_all_Email)
self.en_Email.bind("<Control-Key-A>", self.select_all_Email)
self.en_Email.bind("<Tab>", self.tab_Email)
self.btnLogin.bind("<Tab>", self.tab_Login)

# Binding for button and entry
def tab_Email(self, event):
    self.en_ID.focus()
    return 'break'
def tab_ID(self, event):
    self.en_Key.focus()
    return 'break'
def tab_Key(self, event):
    self.btnLogin.focus()
    return 'break'
def tab_Login(self, event):
    self.en_Email.focus()
    return 'break'
def select_all_ID(self, event):
    self.en_ID.select_range(0, tk.END)
    return 'break'
def select_all_Key(self, event):
    self.en_Key.select_range(0, tk.END)
    return 'break'
def select_all_Email(self, event):
    self.en_Email.select_range(0, tk.END)
    return 'break'

# Action for the Login button
def click_login(self, controller):
    if(tkMessageBox.askokcancel("Verify", "Make sure that you've synchronized your
data!")):
        self.gather_token(controller)

# When you reach the limited request (150 requests/hour), you will be no longer get the data.

```

# Therefore, you have to wait for an hour. This function will calculate the remaining time to download your data again

```
def cal_remain_time(self, exc):
    reset_time = exc.retry_after_secs
    reset_time = reset_time/60.0
    tkMessageBox.showerror("Opps!", "Too many requests!\nPlease try again after
{0:.0f} minutes!".format(reset_time))
```

```
def login(self, controller):
    if(self.EMAIL != self.CURR_EMAIL):
        raise fitbit.exceptions.HTTPUnauthorized()
    self.auth2_client = fitbit.Fitbit(self.CLIENT_ID, self.CLIENT_SECRET,
oauth2=True, access_token=self.ACCESS_TOKEN,

refresh_token=self.REFRESH_TOKEN)
    self.save_path = "~\\Desktop\\" + "Fitbit Data\\" + self.EMAIL
    if not os.path.exists(os.path.expanduser(self.save_path)):
        os.makedirs(os.path.expanduser(self.save_path))
    fitbit_stats = self.auth2_client.intraday_time_series('activities/heart', today,
detail_level='1min')
    controller.frames[Summary].HEART_DATA = fitbit_stats['activities-heart-
intraday']['dataset']
    controller.frames[Summary].DATE = str(today)
    # Load steps
    fitbit_stats = self.auth2_client.intraday_time_series('activities/steps', today,
detail_level='1min')
    controller.frames[Summary].STEPS = str(fitbit_stats['activities-steps'][0]['value'])

    #Load distance
    fitbit_stats = self.auth2_client.intraday_time_series('activities/distance', today,
detail_level='1min')
    distance = round(float(fitbit_stats['activities-distance'][0]['value'])*1.60934,2)
    controller.frames[Summary].DISTANCE = str(distance)
    #Load calories
    fitbit_stats = self.auth2_client.intraday_time_series('activities/calories', today,
detail_level='1min')
```

```

controller.frames[Summary].CAL = str(fitbit_stats['activities-calories'][0]['value'])

tkMessageBox.showinfo("Login Succeed!", "Let's access your data!")
print("Request remaining: %d" % self.auth2_client.rate_limit_remaining)
print("Request limit reset in {0:.0f} seconds".format(self.auth2_client.rate_limit_reset
- time.time()))
if(self.check_var.get()==False):
    f = open("gui_tokens.key","w")
    f.close()
controller.frames[Summary].USER = self.EMAIL
controller.frames[Summary].load_data()
controller.show_frame(Summary)
# Gathering token and login with the loaded information
def gather_token(self, controller):
    self.EMAIL = self.en_Email.get()
    if(EMAIL_REGEX.match(self.EMAIL) != None):
        self.CLIENT_ID = self.en_ID.get()
        self.CLIENT_SECRET = self.en_Key.get()
        try:
            self.login(controller)
        except (fitbit.exceptions.HTTPUnauthorized, TypeError):
            tkMessageBox.showinfo("Oops!", "Something went wrong with your
tokens, please login to retrieve them!")
            server = OAuth2Server.OAuth2Server(self.CLIENT_ID,
self.CLIENT_SECRET)
            server.browser_authorize()
            self.ACCESS_TOKEN = server.oauth.token['access_token']
            self.REFRESH_TOKEN = server.oauth.token['refresh_token']
            self.CURR_EMAIL = self.EMAIL
            if(self.check_var.get()==True):
                f = open("gui_tokens.key","w")
                f.write(self.CURR_EMAIL + "\n")
                f.write(self.CLIENT_ID + "\n")
                f.write(self.CLIENT_SECRET + "\n")
                f.write(self.ACCESS_TOKEN + "\n")
                f.write(self.REFRESH_TOKEN)

```

```

        f.close()
        tkMessageBox.showinfo("Congratulation!", "Get token successfully!")
        self.login(controller)
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
    except IndexError:
        tkMessageBox.showerror("Oops!", "We can't get your data!\nPlease
sync your data and login again!")
        return 'break'
    else:
        tkMessageBox.showerror("Oops!", "Please enter a valid email address!")

def save_heart(self, auth, date):
    fitbit_stats = auth.intraday_time_series('activities/heart', date, detail_level='1min')
    stats = fitbit_stats['activities-heart-intraday']['dataset']
    csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"HeartRate_1Min_%s.csv" % str(date)), 'w')
    for var in range(0, len(stats)):
        csv_file.write(stats[var]['time'])
        csv_file.write(',')
        csv_file.write(str(stats[var]['value']))
        csv_file.write("\n")
    csv_file.close()
    fitbit_stats = auth.intraday_time_series('activities/heart', date, detail_level='1sec')
    stats = fitbit_stats['activities-heart-intraday']['dataset']
    csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"HeartRate_1Sec_%s.csv" % str(date)), 'w')
    for var in range(0, len(stats)):
        csv_file.write(stats[var]['time'])
        csv_file.write(',')
        csv_file.write(str(stats[var]['value']))
        csv_file.write("\n")
    csv_file.close()

def save_calories(self, auth, date):
    fitbit_stats = auth.intraday_time_series('activities/calories', date, detail_level='1min')
    stats = fitbit_stats['activities-calories-intraday']['dataset']

```

```

        csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"Calories_1Min_%s.csv" % str(date)), 'w')
        for var in range(0, len(stats)):
            csv_file.write(str(stats[var]['mets']))
            csv_file.write(',')
            csv_file.write(stats[var]['time'])
            csv_file.write(',')
            csv_file.write(str(stats[var]['value']))
            csv_file.write("\n")
        csv_file.close()
        stats = fitbit_stats['activities-calories']
        csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"CaloriesSummary_%s.csv" % str(date)), 'w')
        csv_file.write(stats[0]['dateTime'])
        csv_file.write(',')
        csv_file.write(str(stats[0]['value']))
        csv_file.close()
    def save_steps(self, auth, date):
        fitbit_stats = auth.intraday_time_series('activities/steps', date, detail_level='1min')
        stats = fitbit_stats['activities-steps-intraday']['dataset']
        csv_file =
open(os.path.join(os.path.expanduser(self.save_path),date,"Steps_1Min_%s.csv" % str(date)), 'w')
        times = []
        values = []
        for var in range(0, len(stats)):
            csv_file.write(stats[var]['time'])
            csv_file.write(',')
            csv_file.write(str(stats[var]['value']))
            csv_file.write("\n")
        csv_file.close()
        # Save steps summary
        stats = fitbit_stats['activities-steps']
        csv_file =
open(os.path.join(os.path.expanduser(self.save_path),date,"StepsSummary_%s.csv" % str(date)), 'w')
        csv_file.write(stats[0]['dateTime'])
        csv_file.write(',')

```

```

        csv_file.write(str(stats[0]['value']))
    csv_file.close()
def save_sleep(self, auth, date):
    fitbit_stats = auth.get_sleep(date)
    stats = fitbit_stats['sleep']
    save_date = date.strftime("%Y-%m-%d")
    csv_file =
open(os.path.join(os.path.expanduser(self.save_path),save_date,"SleepLogs_%s.csv" % save_date),
'w')

    for var in range(0, len(stats)):
        sleep_type = stats[var]['type']
        csv_file.write('type' + "," + str(stats[var]['type']))
        csv_file.write("\n")
        csv_file.write('isMainSleep' + "," + str(stats[var]['isMainSleep']))
        csv_file.write("\n")
        csv_file.write('startTime' + "," + str(stats[var]['startTime']))
        csv_file.write("\n")
        csv_file.write('timeInBed' + "," + str(stats[var]['timeInBed']))
        csv_file.write("\n")
        csv_file.write("Summary each level:\n")
        sleep_levels = stats[var]['levels']
        # There are two types of sleep: stages and classic
        if(sleep_type=="stages"):
            csv_file.write('deep' + "," +
str(sleep_levels['summary']['deep']['minutes']))
            csv_file.write("\n")
            csv_file.write('light' + "," +
str(sleep_levels['summary']['light']['minutes']))
            csv_file.write("\n")
            csv_file.write('rem' + "," +
str(sleep_levels['summary']['rem']['minutes']))
            csv_file.write("\n")
            csv_file.write('wake' + "," +
str(sleep_levels['summary']['wake']['minutes']))
            csv_file.write("\n\n")
        else: # The classic type of sleep

```

```

        csv_file.write('asleep' + "," +
str(sleep_levels['summary']['asleep']['minutes']))
        csv_file.write("\n")
        csv_file.write('awake' + "," +
str(sleep_levels['summary']['awake']['minutes']))
        csv_file.write("\n")
        csv_file.write('restless' + "," +
str(sleep_levels['summary']['restless']['minutes']))
        csv_file.write("\n\n")

# Get the data for each stage
csv_file.write("Detailed data:\n")
for i in range(len(sleep_levels['data'])):
    dt_dateTime = sleep_levels['data'][i]['dateTime']
    dt_level = sleep_levels['data'][i]['level']
    dt_seconds = str(sleep_levels['data'][i]['seconds'])
    csv_file.write(dt_level+ ',' + dt_dateTime + "," + dt_seconds)
    csv_file.write("\n")
    csv_file.write("\n")
csv_file.close()
# Sleep summary
stats = fitbit_stats['summary']
csv_file = open(os.path.join(os.path.expanduser(self.save_path),
save_date,"SleepSummary_%s.csv" % save_date), 'w')
csv_file.write('totalTimeInBed' + "," + str(stats['totalTimeInBed']))
csv_file.write("\n")
csv_file.write('totalMinutesAsleep' + "," + str(stats['totalMinutesAsleep']))
csv_file.write("\n")
csv_file.write('totalSleepRecords' + "," + str(stats['totalSleepRecords']))
csv_file.write("\n")
csv_file.close()

def save_distance(self, auth, date):
    fitbit_stats = auth.intraday_time_series('activities/distance', date, detail_level='1min')
    stats = fitbit_stats['activities-distance-intraday']['dataset']
    csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"Distances_1Min_%s.csv" % str(date)), 'w')

```

```

for var in range(0, len(stats)):
    csv_file.write(stats[var]['time'])
    csv_file.write(',')
    csv_file.write(str(stats[var]['value']))
    csv_file.write("\n")
csv_file.close()

stats = fitbit_stats['activities-distance']
csv_file = open(os.path.join(os.path.expanduser(self.save_path),
date,"DistancesSummary_%s.csv" % str(date)), 'w')
mile = float(stats[0]['value'])
km = mile*1.60934
csv_file.write(stats[0]['dateTime'])
csv_file.write(',')
csv_file.write(str(km))
csv_file.close()

def save_data(self, controller, date):
    self.save_path = "~\\Desktop\\" + "Fitbit Data\\" + self.EMAIL
    if not os.path.exists(os.path.join(os.path.expanduser(self.save_path),date)):
        os.makedirs(os.path.join(os.path.expanduser(self.save_path),date))
    self.save_heart(self.auth2_client, date)
    self.save_calories(self.auth2_client, date)
    self.save_steps(self.auth2_client, date)
    self.save_distance(self.auth2_client, date)
    date_sleep = datetime.datetime.strptime(date, '%Y-%m-%d')
    self.save_sleep(self.auth2_client, date_sleep)
def loadDataForSum(self, auth, controller, date):
    fitbit_stats = auth.intraday_time_series('activities/heart', date, detail_level='1min')
    controller.frames[Summary].HEART_DATA = fitbit_stats['activities-heart-
intraday']['dataset']
    fitbit_stats = auth.intraday_time_series('activities/steps', date, detail_level='1min')
    controller.frames[Summary].STEPS = str(fitbit_stats['activities-steps'][0]['value'])
    #Load distance
    fitbit_stats = auth.intraday_time_series('activities/distance', date, detail_level='1min')

```



```

distance = round(float(fitbit_stats['activities-distance'][0]['value'])*1.60934,2)
controller.frames[Summary].DISTANCE = str(distance)
#Load calories
fitbit_stats = auth.intraday_time_series('activities/calories', date, detail_level='1min')
controller.frames[Summary].CAL = str(fitbit_stats['activities-calories'][0]['value'])
# Summary for one date data
class Summary(tk.Frame):
    def __init__(self, parent, controller):
        tk.Frame.__init__(self,parent)
        self.panel = tk.Canvas(self, height=150)
        self.panel.pack(side=tk.TOP, fill=tk.BOTH, expand = True)
        self.labelTitle = tk.Label(self.panel, font=TITLE_FONT)
        self.labelTitle.place(x=360)
        self.USER = ""
        self.HEART_DATA = []
        self.DATE = ""
        self.CURR_DATE = ""
        self.CLIENT_ID = controller.frames[StartPage].CLIENT_ID
        self.CLIENT_SECRET = controller.frames[StartPage].CLIENT_SECRET
        self.ACCESS_TOKEN = controller.frames[StartPage].ACCESS_TOKEN
        self.REFRESH_TOKEN = controller.frames[StartPage].REFRESH_TOKEN
        # Button logout
        self.btnLogout = ttk.Button(self.panel, text="Logout", command=lambda:
self.log_out(controller))
        self.btnLogout.place(x=900, y=5)
        # Button save today
        self.btnSaveData = ttk.Button(self.panel, text="Save Data", command=lambda:
self.save_data_date(controller))
        self.btnSaveData.place(x=905, y= 85)
        # Button show data
        self.btnShowData = ttk.Button(self.panel, text="Show Data", command=lambda:
self.show_data(controller))
        self.btnShowData.place(x=825, y= 85)
        # Button save data from...
        self.btnSaveDataPeriod = ttk.Button(self.panel, text="Save Data Period",
command=lambda: self.btnClick_save_period(controller))

```

```

self.btnSaveDataPeriod.place(x=825, y= 110)
# Label steps
self.labelStep = tk.Label(self.panel, font=SMALL_FONT)
self.labelStep.place(x=20, y=60)
self.labelDistance = tk.Label(self.panel, font=SMALL_FONT)
self.labelDistance.place(x=20, y=90)
self.labelCalo = tk.Label(self.panel, font=SMALL_FONT)
self.labelCalo.place(x=20, y=120)
self.labelMinHeart = tk.Label(self.panel, font=SMALL_FONT)
self.labelMinHeart.place(x=250, y=60)
self.labelMaxHeart = tk.Label(self.panel, font=SMALL_FONT)
self.labelMaxHeart.place(x=250, y=90)
self.labelAvgHeart = tk.Label(self.panel, font=SMALL_FONT)
self.labelAvgHeart.place(x=250, y=120)
self.labelDay = tk.Label(self.panel, text="Enter a date", font="TimesNewRoman 12")
self.labelDay.place(x=730, y=55)
self.labelday = tk.Label(self.panel, text="(YYYY-MM-DD)",
font="TimesNewRoman 9")
self.labelday.place(x=730, y=75)
# Entry day
self.en_Day = ttk.Entry(self.panel, font="TimesNewRoman 11")
self.en_Day.place(x=820, y=60)
self.en_Day.bind("<Control-Key-a>", self.select_all)
self.en_Day.bind("<Control-Key-A>", self.select_all)
# Show personal data
self.STEPS = "
self.DISTANCE = "
self.MIN_HEART = "
self.MAX_HEART = "
self.AVG_HEART = "
self.CAL = "
# Figure to show heart rate data
self.xfmt = md.DateFormatter('%H:%M')
self.fig = Figure()
self.a = self.fig.add_subplot(111)

```

```

self.canvas = FigureCanvasTkAgg(self.fig, self)
self.toolbar = NavigationToolbar2TkAgg(self.canvas, self)
def select_all(self, event):
    self.en_Day.select_range(0, tk.END)
    return 'break'
def log_out(self, controller):
    if (tkMessageBox.askyesno('Verify', 'Are you sure you want to logout?')):
        controller.show_frame(StartPage)
def show_request_status(self, controller):
    print("You have %d requests left!" %
controller.frames[StartPage].auth2_client.rate_limit_remaining)
def btnClick_save_period(self, controller):
    width = 400
    height = 100
    self.win = Toplevel()
    self.win.title('Save data in a period')
    self.win.iconbitmap("hosei.ico")
    self.win.geometry('%dx%d+650+220' % (width, height))
    self.win.resizable(0,0)
    self.win.grab_set()
    labelDay_from = tk.Label(self.win, text="Enter a period to save data (YYYY-MM-
DD)", font="TimesNewRoman 13")
    labelDay_from.place(x=40, y=5)
    labelDay_from = tk.Label(self.win, text="Save from", font="TimesNewRoman 11")
    labelDay_from.place(x=20, y=40)
    labelDay_to = tk.Label(self.win, text="to", font="TimesNewRoman 11")
    labelDay_to.place(x=220, y=40)
    self.en_Day_from = ttk.Entry(self.win, font="TimesNewRoman 11")
    self.en_Day_from.place(x=100, y=40, width=100)
    self.en_Day_to = ttk.Entry(self.win, font="TimesNewRoman 11")
    self.en_Day_to.place(x=250, y=40, width=100)
    btnSaveData = ttk.Button(self.win, text="Save data", command=lambda:
self.btnClick_start_save_period(controller))
    btnSaveData.place(x=185, y=70)
def btnClick_start_save_period(self, controller):
    try:

```

```

        tday = datetime.datetime.now()
        date_from = datetime.datetime.strptime(self.en_Day_from.get(),
'%Y-%m-%d')

        date_to = datetime.datetime.strptime(self.en_Day_to.get(), '%Y-%m-%d')
        if(date_from > date_to or date_to > tday):
            raise ValueError()
        if((date_to - date_from).days > 30):
            raise IndexError
        self.date_from = date_from
        self.date_to = date_to
        self.win.destroy()
        self.save_data_period(controller)
    except (ValueError):
        tkMessageBox.showerror("Opps!", "Something went wrong! please check the
date again.")
    except (IndexError):
        tkMessageBox.showerror("Limited saving date!", "The period must be less
than 30 days!")
    def save_data_date(self, controller):
        try:
            tday = datetime.datetime.now()
            date = datetime.datetime.strptime(self.en_Day.get(), '%Y-%m-%d')
            if(date > tday):
                raise IndexError()
            dat = date.strftime("%Y-%m-%d")
            if
os.path.exists(os.path.join(os.path.expanduser(controller.frames[StartPage].save_path),dat)):
                if tkMessageBox.askyesno("Verify", "This data already exists. Do you
want to overwrite?"):
                    self.auth2_client = controller.frames[StartPage].auth2_client
                    date = date.strftime("%Y-%m-%d")
                    self.DATE = date
                    controller.frames[StartPage].save_data(controller, date)
                    print("Saved data on date {}".format(date))
                    tkMessageBox.showinfo("Information", "Saved your data
successfully in\n")

```

```

+
os.path.expanduser(controller.frames[StartPage].save_path) + "\\\" + self.DATE)
    else:
        self.auth2_client = controller.frames[StartPage].auth2_client
        fitbit_stats = self.auth2_client.intraday_time_series('activities/heart',
date, detail_level='1min')
        HEART_DATA = fitbit_stats['activities-heart-intraday']['dataset']
        if (len(HEART_DATA)==0):
            if tkMessageBox.askyesno("Opps", "No data was synced on
this date! Continue to save?"):
                date = date.strftime("%Y-%m-%d")
                self.DATE = date
                controller.frames[StartPage].save_data(controller, date)
                print("Saved data on date {}".format(date))
                tkMessageBox.showinfo("Information", "Saved your
data successfully in\n"

```

```

+
os.path.expanduser(controller.frames[StartPage].save_path) + "\\\" + self.DATE)
    else:
        date = date.strftime("%Y-%m-%d")
        self.DATE = date
        controller.frames[StartPage].save_data(controller, date)
        print("Saved data on date {}".format(date))
        tkMessageBox.showinfo("Information", "Saved your data
successfully in\n"

```

```

+
os.path.expanduser(controller.frames[StartPage].save_path) + "\\\" + self.DATE)
    self.show_request_status(controller)
    except (ValueError):
        tkMessageBox.showerror("Opps!", "Something went wrong with your input
date, please check again.")
    except (fitbit.exceptions.HTTPUnauthorized):
        tkMessageBox.showinfo("Opps!", "Your token has been expired, please
logout and login again!")
    except (IndexError):
        tkMessageBox.showerror("Opps!", "Please sync your data first or check your
date again!")

```

```

except fitbit.exceptions.HTTPTooManyRequests as exc:
    self.cal_remain_time(exc)

def show_data(self, controller):
    try:
        tday = datetime.datetime.now()
        date = datetime.datetime.strptime(self.en_Day.get(), '%Y-%m-%d')
        if(date > tday):
            raise IndexError()
        if (self.CURR_DATE == date):
            pass
        else:
            self.auth2_client = controller.frames[StartPage].auth2_client
            fitbit_stats = self.auth2_client.intraday_time_series('activities/heart',
date, detail_level='1min')
            HEART_DATA = fitbit_stats['activities-heart-intraday']['dataset']
            self.CURR_DATE = date
            if (len(HEART_DATA)==0):
                raise IndexError()
            date = date.strftime("%Y-%m-%d")
            self.DATE = date
            controller.frames[StartPage].loadDataForSum(self.auth2_client,
controller, date)
            self.load_data()
            self.show_request_status(controller)

    except (ValueError):
        tkMessageBox.showerror("Oops!", "Something went wrong with your input
date, please check again.")
    except (IndexError):
        print("You have %d requests left!" % self.auth2_client.rate_limit_remaining)
        tkMessageBox.showerror("Oops!", "No data was synced on this date! Please
check your date again!")
    except (fitbit.exceptions.HTTPUnauthorized):
        tkMessageBox.showinfo("Oops!", "Your token has been expired, please
logout and login again!")

```

```

except fitbit.exceptions.HTTPTooManyRequests as exc:
    self.cal_remain_time(exc)
def check_folder(self, controller):
    dateFrom = self.date_from
    while(dateFrom <= self.date_to):
        date = dateFrom.strftime("%Y-%m-%d")
        if
os.path.exists(os.path.join(os.path.expanduser(controller.frames[StartPage].save_path),date)):
            return True
        dateFrom = dateFrom + datetime.timedelta(days=1)
    return False

def save_data_period(self, controller):
    try:
        if self.check_folder(controller):
            if tkMessageBox.askyesno("Verify", "Some of your data already
exists. Do you want to overwrite?"):
                self.auth2_client = controller.frames[StartPage].auth2_client
                tkMessageBox.showinfo("Information", "Saving your data
from " +
                    self.date_from.strftime("%Y-%m-%d") + " to " +
self.date_to.strftime("%Y-%m-%d") +
                    " will take some moments. Please wait...")
                dateFrom = self.date_from
                while(dateFrom <= self.date_to):
                    date = dateFrom.strftime("%Y-%m-%d")
                    self.DATE = date
                    controller.frames[StartPage].save_data(controller, date)
                    dateFrom = dateFrom + datetime.timedelta(days=1)
                    print("Saved data on date {}".format(date))
                tkMessageBox.showinfo("Information", "Saved your data
successfully in\n"
                    +
os.path.expanduser(controller.frames[StartPage].save_path))
            else:
                self.auth2_client = controller.frames[StartPage].auth2_client

```

```

        dateFrom = self.date_from
        while(dateFrom <= self.date_to):
            date = dateFrom.strftime("%Y-%m-%d")
            if not
os.path.exists(os.path.join(os.path.expanduser(controller.frames[StartPage].save_path),date)):
                self.DATE = date

        controller.frames[StartPage].save_data(controller, date)
            print("Saved data on date {}".format(date))
            dateFrom = dateFrom + datetime.timedelta(days=1)

            tkMessageBox.showinfo("Information", "Saved your data
successfully in\n"
                                +
os.path.expanduser(controller.frames[StartPage].save_path))
        else:
            self.auth2_client = controller.frames[StartPage].auth2_client
            if tkMessageBox.askyesno("Continue?", "Saving your data from " +
                self.date_from.strftime("%Y-%m-%d") + " to " +
self.date_to.strftime("%Y-%m-%d") +
                " will take some moments. Do you want to continue?"):
                dateFrom = self.date_from
                while(dateFrom <= self.date_to):
                    date = dateFrom.strftime("%Y-%m-%d")
                    self.DATE = date
                    controller.frames[StartPage].save_data(controller, date)
                    print("Saved data on date {}".format(date))
                    dateFrom = dateFrom + datetime.timedelta(days=1)

                tkMessageBox.showinfo("Information", "Saved your data
successfully in\n"
                                    +
os.path.expanduser(controller.frames[StartPage].save_path))
                    self.show_request_status(controller)

        except (ValueError):

```



```

        tkMessageBox.showerror("Oops!", "Something went wrong with your input
date, please check again.")
    except (fitbit.exceptions.HTTPUnauthorized):
        tkMessageBox.showinfo("Oops!", "Your token has been expired, please
logout and login again!")
    except fitbit.exceptions.HTTPTooManyRequests as exc:
        self.cal_remain_time(exc)
def load_data(self):
    # Load hear rate data from CSV file
    self.labelTitle['text'] = "Welcome to Fitbit Downloader"
    try:
        self.a.clear()
        self.fig.clear()
        self.a = self.fig.add_subplot(111)
        self.a.xaxis.set_major_formatter(self.xfmt)
        self.a.set_title("Heart Rate Data on " + self.DATE)
        timestamps = [x['time'] for x in self.HEART_DATA]
        times = [dateutil.parser.parse(s) for s in timestamps]
        heart_rate = [x['value'] for x in self.HEART_DATA]
        self.a.plot(times, heart_rate)
        self.canvas.draw()
        self.canvas.get_tk_widget().pack(side=tk.TOP, fill=tk.BOTH, expand = True)
        self.toolbar.update()
        self.canvas._tkcanvas.pack(side=tk.TOP, fill=tk.BOTH, expand = True)
        self.labelStep['text'] = "Steps: " + self.STEPS
        self.labelDistance['text'] = "Distance: " + self.DISTANCE + " km"
        self.labelCalo['text'] = "Calories: " + self.CAL + " cals"
        new_heart_rate = [int(x) for x in heart_rate]
        self.MIN_HEART = str(min(new_heart_rate))
        self.MAX_HEART = str(max(new_heart_rate))
        self.AVG_HEART =
str(int(round(float(sum(new_heart_rate))/len(new_heart_rate))))

        self.labelMinHeart['text'] = "MIN Heart: " + self.MIN_HEART + " bpm"
        self.labelMaxHeart['text'] = "MAX Heart: " + self.MAX_HEART + " bpm"
        self.labelAvgHeart['text'] = "Avg. Heart: " + self.AVG_HEART + " bpm"

```

```

        except (TypeError, ValueError) as e:
            tkMessageBox.showinfo("Oops!", "Can't retrieve your data. Make sure that
you've synced your data before!")
def on_closing():
    if tkMessageBox.askyesno("Quit", "Do you really want to quit?"):
        app.destroy()
app = FitbitApp()
w = 1000
h = 600
ws = app.winfo_screenwidth() # width of the screen
hs = app.winfo_screenheight() # height of the screen
x = (ws/2) - (w/2)
y = (hs/2) - (h/2)
app.geometry('%dx%d+%d+%d' % (w, h, x, y))
app.protocol("WM_DELETE_WINDOW", on_closing)
app.resizable(width=False, height=False)
app.mainloop()

```

## D.3 MATLAB code for calculating cosinor elements double cosinor method

```
function[a0,a1,b1,a2,b2,M,A1,A2,fai1,fai2,tmax1,tmax2,errval,z]=cosinorcalc02r2(t,y,N)
omega=pi/12;omegat=omega*t;omegat2=2*omegat;
f0=1/24;
C1=cos(2*pi*f0*t);S1=sin(2*pi*f0*t);
C2=cos(4*pi*f0*t);S2=sin(4*pi*f0*t);
R=zeros(5,5);
R(1,:)=[N sum(C1) sum(S1) sum(C2) sum(S2)];
R(2,:)=[R(1,2) C1'*C1 S1'*C1 C2'*C1 S2'*C1];
R(3,:)=[R(1,3) R(2,3) S1'*S1 C2'*S1 S2'*S1];
R(4,:)=[R(1,4) R(2,4) R(3,4) C2'*C2 S2'*C2];
R(5,:)=[R(1,5) R(2,5) R(3,5) R(4,5) S2'*S2];
p1=sum(y);
p2=y'*C1;
p3=y'*S1;
p4=y'*C2;
p5=y'*S2;
p=[p1 p2 p3 p4 p5]';
w=inv(R)*p;
a0=w(1);a1=w(2);b1=w(3);a2=w(4);b2=w(5);
a3=w(4);a4=w(5);
% M: Masor( value about which oscillation occurs)
M=a0;
% A:Amplitude( half the difference between the highest and lowest values)
A=sqrt(a1^2+b1^2);
A1=sqrt(a1^2+b1^2);
% fai: Acrophase(timing of high point, in degrees)
fai=atan2(b1,a1);
fai1=fai;
tmax1=fai1*12/pi;
if(tmax1<0) tmax1=tmax1+24;
end
A2=sqrt(a2^2+b2^2);
% fai: Acrophase(timing of high point, in degrees)
fai=atan2(b2,a2);
fai2=fai;
tmax2=fai2*12/pi/2;
if(tmax2<0) tmax2=tmax2+12;
end
% z=M+A*cos(omegat+fai);
% z=M+a1*C1+b1*S1+a2*C2+b2*S2;
```

```
z=M+A1*cos(2*pi*f0*t-fai1)+A2*cos(4*pi*f0*t-fai2);  
errval=((z-y)*(z-y))/N;
```

## D.4 MATLAB code for heart rate analysis and extracting double cosinor elements

```
clear
close all
clc
CurrentDirectory=pwd;
%% Input subject number
subject=input('Input subject number(1-20):');
cd(num2str(subject));
%% Input a filename that you will analyze
data1=input('Input the date of a filename that will be analyzed(ex.2017-07-17):','s');
data2='_HRminData.csv';
data1=horzcat(data1,data2);
% data1='2017-07-17_HRminData.csv';
%% Divide the data of the contents(Year,Month,Day,Hour,Minute,Second,HR)
fid=fopen(data1,'r');
data=textscan(fid,'%s');
N=length(data{1});
year=zeros(1,N-1);month=zeros(1,N-1);day=zeros(1,N-1);
hour=zeros(1,N-1);minute=zeros(1,N-1);
sec=zeros(1,N-1);hrorg=zeros(1,N-1);
for n=2:N
    c=strsplit(data{1}{n},{',','/',':',' ','.'});
    year(n-1)=str2num(char(c(1,3)));
    month(n-1)=str2num(char(c(1,4)));
    day(n-1)=str2num(char(c(1,5)));
    hour(n-1)=str2num(char(c(1,6)));
    minute(n-1)=str2num(char(c(1,7)));
    sec(n-1)=str2num(char(c(1,8)));
    hrorg(n-1)=str2num(char(c(1,9)));
end
hr_data=hrorg; % HR data
%% To aquire time when HR happned
time=zeros(1,N-1);
for k=1:length(hour)
    time(k)=hour(k)+minute(k)/60+sec(k)/3600;
end
%% plot original data
figure(1)
plot(time,hr_data,'b','linewidth',1.3)
xlim([min(time) max(time)])
ylim([40 160])
```

```

set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
time1=0:1/60:24-1/60;
    hr_data1=zeros(1,1440);
    for n=1:length(hrorg)
        ntime=hour(n)*60+minute(n)+1;
        hr_data1(ntime)=hrorg(n);
    end
figure(2)
plot(time1,hr_data1,'b','linewidth',1.3)
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Cosinor method applies to HR data
y=hr_data';
zihr=zeros(1,length(y));
cd(CurrentDirectory)
[a0,a1,b1,a2,b2,Mihr,A1ihr,A2ihr,fai1ihr,fai2ihr,...
    tmax1ihr,tmax2ihr,errvlihr,zihr]=cosinorcalc02r2(time',y,length(y));
f0=1/24;
c_single = Mihr+A1ihr*cos(2*pi*f0*time-fai1ihr);
c_double = Mihr+A2ihr*cos(4*pi*f0*time-fai2ihr);
t=time1;
y1a=a0*ones(1,1440);
y2a=Mihr+A1ihr*cos(2*pi*t/24-fai1ihr);
y3a=Mihr+A2ihr*cos(2*pi*t/12-fai2ihr);
y4a=Mihr+A1ihr*cos(2*pi*t/24-fai1ihr)+A2ihr*cos(2*pi*t/12-fai2ihr);
%% plot cosinor (blue:HR data, green: cosinor(24 hours circle), mazenata(pink):cosinor(24 hours
circle), red: green + mazenata, black: average HR )
figure(3)
plot(time1,hr_data1,'b','linewidth',1.0)
hold on
plot(time1,y2a,'g','LineWidth',2.0)
plot(time1,y3a,'m','LineWidth',2.0)
plot(time1,y4a,'r','LineWidth',2.5)
plot(time1,y1a,'k','linewidth',1.5)
hold off
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')

```

```

ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
cd(num2str(subject))
%% Cosinor parameter
residual=y-zahr;
sigma=std(residual);
t1=fai1ahr*24/2/pi;
t2=fai2ahr*12/2/pi;
%% Phase parameter(blue solid line: cosinor(24 hours circle), blue short dashes line: cosinor(12
hours circle), red solid line: blue solid line + blue short dashes line, black: average HR )
figure(4)
hold on
plot(time1,y2a,'b','LineWidth',2.0)
plot(time1,y3a,'b--','LineWidth',2.0)
plot(time1,y4a,'r','LineWidth',2.5)
plot(time1,y1a,'k','linewidth',1.5)
hold off
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% To show cosinor parameter
sprintf(' mean: %.2f(bpm) \n a1: %.2f (bpm) t1: %.2f (hours) \n a2: %.2f (bpm) t2: %.2f (hours)\n
residual SD %.2f (bpm)')...
    ,a0, A1ahr,fai1ahr*24/2/pi, A2ahr,fai2ahr*12/2/pi,sigma )
cd(CurrentDirectory)

```

## D.5 MATLAB code for spline fitting

```
x=csvread('spline_fitting.csv');
x=x'; % to make x be a row vector
% set the Unit Time be "Min"
t=0:1439;T=1440;
a0=trapz(x)/T;
C24=cos(2*pi*t/T);S24=sin(2*pi*t/T);
C12=cos(2*pi*t/(T/2));S12=sin(2*pi*t/(T/2));
CosAmp24=trapz(x.*C24)*2/T;
SinAmp24=trapz(x.*S24)*2/T;
CosAmp12=trapz(x.*C12)*2/T;
SinAmp12=trapz(x.*S12)*2/T;
y=a0+CosAmp24*C24+SinAmp24*S24+CosAmp12*C12+ SinAmp12*S12;
% x(blue)=original, y(red)=Fourier Series
figure(1)
plot(t./60,x,'linewidth',1);hold on;plot(t./60,y,'linewidth',1)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate (bpm)','FontSize',20,'FontName','Times New Roman')
xlim([0 24])
a24spline=sqrt(CosAmp24^2+SinAmp24^2)
a12spline=sqrt(CosAmp12^2+SinAmp12^2)
error=sqrt(((y-x)*(y-x))/1440)/var(x)
figure(2)
plot(t./60,y-x,'linewidth',1)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Error Series','FontSize',20,'FontName','Times New Roman')
xlim([0 24])
```



## D.6 MATLAB code for cosinor-based and spline-based parameters extraction

```
clear
close all
clc
CurrentDirectory=pwd;
%% Input subject number
subject=input('Input subject number(1-20):');
cd(num2str(subject));
%% Input a filename that you will analyze
data1=input('Input the date of a filename that will be analyzed(ex.2017-07-17):','s');
data2='_HRminData.csv';
data1=horzcat(data1,data2);
% data1='2017-07-17_HRminData.csv';
%% Divide the data of the contents(Year,Month,Day,Hour,Minute,Second,HR)
fid=fopen(data1,'r');
data=textscan(fid,'%s');
N=length(data{1});
year=zeros(1,N-1);month=zeros(1,N-1);day=zeros(1,N-1);
hour=zeros(1,N-1);minute=zeros(1,N-1);
sec=zeros(1,N-1);hrorg=zeros(1,N-1);
for n=2:N
    c=strsplit(data{1}{n},{' ','/',':','.'});
    year(n-1)=str2num(char(c(1,3)));
    month(n-1)=str2num(char(c(1,4)));
    day(n-1)=str2num(char(c(1,5)));
    hour(n-1)=str2num(char(c(1,6)));
    minute(n-1)=str2num(char(c(1,7)));
    sec(n-1)=str2num(char(c(1,8)));
    hrorg(n-1)=str2num(char(c(1,9)));
end
hr_data=hrorg; % HR data
%% To aquire time when HR happned
time=zeros(1,N-1);
for k=1:length(hour)
    time(k)=hour(k)+minute(k)/60+sec(k)/3600;
end
%% plot original data
figure(1)
plot(time,hr_data,'b','linewidth',1.3)
xlim([min(time) max(time)])
ylim([40 160])
```

```

set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Zero Interpolation
time1=0:1/60:24-1/60;
hr_data1=zeros(1,1440);
for n=1:length(hrorg)
    ntime=hour(n)*60+minute(n)+1;
    hr_data1(ntime)=hrorg(n);
end
figure(2)
plot(time1,hr_data1,'b','linewidth',1.3)
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Cosinor Methos is applied
y=hr_data';
zihr=zeros(1,length(y));
cd(CurrentDirectory)
[a0,a1,b1,a2,b2,Mihr,A1ihr,A2ihr,fai1ihr,fai2ihr,...
    tmax1ihr,tmax2ihr,errvlihr,zihr]=cosinorcalc02r2(time',y,length(y));
f0=1/24;
c_single = Mihr+A1ihr*cos(2*pi*f0*time-fai1ihr);%% 24 hour rhythm cosinor
c_double = Mihr+A2ihr*cos(4*pi*f0*time-fai2ihr);%% 12 hour rhythm cosinor
d_double= Mihr+A1ihr*cos(2*pi*f0*time-fai1ihr)+A2ihr*cos(4*pi*f0*time-fai2ihr);
t=time1;
y1a=a0*ones(1,1440);
y2a=Mihr+A1ihr*cos(2*pi*t/24-fai1ihr);
y3a=Mihr+A2ihr*cos(2*pi*t/12-fai2ihr);
y4a=Mihr+A1ihr*cos(2*pi*t/24-fai1ihr)+A2ihr*cos(2*pi*t/12-fai2ihr);
%% original cosinor
figure(3)
plot(time,hr_data,'k','linewidth',0.5)
hold on
plot(time,c_single,'k--','LineWidth',1.0)% 24 hour rhythm
plot(time,c_double,'k-','LineWidth',1.0)% 12 hour rhythm
plot(time,d_double,'k','LineWidth',2.0)% 24 hour rhythm +12 hour rhythm
hold off
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')

```

```

ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Interpolation cosinor
figure(4)
plot(time1,hr_data1,'k-','linewidth',1.0)
hold on
plot(time1,y4a,'k','LineWidth',4.5)% 24 hour rhythm +12 hour rhythm
hold off
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Cosinor ASR
t1=fai1ihr*24/2/pi;
t2=fai2ihr*12/2/pi;
t_c=0:1/60:24-1/60;
M=Mih;
hr=M+A1ihr*cos(2*pi/24*(t-t1))+A2ihr*cos(2*pi/12*(t-t2));
CA=max(y4a)-min(y4a);
hrd=diff(hr);
hrd=[hrd(1) hrd];
hrd=hrd*60;
[ASR1,ASR_p]=max(hrd);
figure(5)
plot(t_c,hrd,'k','linewidth',2.0)
hold on
scatter(t_c(ASR_p),ASR1,100,'k','o','filled')
hold off
% hold on
% plot(t_c,M-hr,'k-','linewidth',1.0)
% hold off
xlim([0 24])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
%% Spline method applies to HR data
%*****You have to chane P value
below*****
p=0.002;
%*****
*****

shr=csaps(time',hrorg',p,time');
shr2=csaps(time',hrorg',p,time1');
dshr=fndir(spline(time,shr),1));

```

```

figure(6)
plot(time1,hr_data1,'b','linewidth',1.0)
hold on
plot(time1,shr2,'r','linewidth',2.0)
hold off
xlim([0 24])
ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel('Heart Rate(beat/min)','FontSize',20,'FontName','Times New Roman')
splineamp=max(shr2)-min(shr2);
%% Spline ASR
[max1,maxp1]=max(dshr(1:720));
[max2,maxp2]=max(dshr(721:1440));
if(max1>max2)
    maxd=max1;
    maxi=maxp1;
else
    maxd=max2;
    maxi=maxp2+720;
end
label=strcat('ASRS',num2str(p));
figure(7)
plot(time1,shr2-mean(shr2),'b','linewidth',1.0)
hold on
plot(time1,dshr,'r','linewidth',2.0)
plot([maxi/60,maxi/60], [min(shr)-mean(shr),max(dshr)],'k','linewidth',1.3)
hold off
xlim([0 24])
ylim([-inf inf])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')
ylabel(label,'FontSize',20,'FontName','Times New Roman')
figure(8)
% plot(time1,hr_data1,'b','linewidth',0.2)
hold on
plot(time1,shr2,'r','linewidth',2.0)
plot(time1,y4a,'k--','LineWidth',2.5)%
24ŽžŠŌŽžŠŌŽžŠŌ, ÌfRfTfCf“, Æ12ŽžŠŌŽžŠŌ, ÌfRfTfCf“, Ì?‡?–”g
hold off
xlim([0 24])
% ylim([40 160])
set(gca,'FontSize',20,'FontName','Times New Roman')
xlabel('Time (Hour)','FontSize',20,'FontName','Times New Roman')

```

```

ylabel('Heart Rate(bpm)', 'FontSize', 20, 'FontName', 'Times New Roman')
%% Spline A24 and A12

x=shr2;
x=x';
t=0:1439;T=1440;
a0=trapz(x)/T;
C24=cos(2*pi*t/T);S24=sin(2*pi*t/T);
C12=cos(2*pi*t/(T/2));S12=sin(2*pi*t/(T/2));
CosAmp24=trapz(x.*C24)*2/T;
SinAmp24=trapz(x.*S24)*2/T;
CosAmp12=trapz(x.*C12)*2/T;
SinAmp12=trapz(x.*S12)*2/T;
y=a0+CosAmp24*C24+SinAmp24*S24+CosAmp12*C12+ SinAmp12*S12;
% x(blue)=original, y(red)=Fourier Series
figure(9)
plot(t./60,x,'b','linewidth',1);hold on;plot(t./60,y,'r','linewidth',1)% blue: spline, red: Fourier series
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel('Time (Hour)', 'FontSize', 20, 'FontName', 'Times New Roman')
ylabel('Heart Rate (bpm)', 'FontSize', 20, 'FontName', 'Times New Roman')
xlim([0 24])
a24spline=sqrt(CosAmp24^2+SinAmp24^2);
a12spline=sqrt(CosAmp12^2+SinAmp12^2);
error=sqrt(((y-x)*(y-x)/1440)/var(x));
figure(10)
plot(t./60,y-x,'linewidth',1)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel('Time (Hour)', 'FontSize', 20, 'FontName', 'Times New Roman')
ylabel('Error Series', 'FontSize', 20, 'FontName', 'Times New Roman')
xlim([0 24])
%% To Show Data
fprintf('*****Amplitude
Below*****\n');
fprintf('Spline Amplitude(p value %s):%.2f\n',num2str(p),splineamp);
fprintf('Cosinor Amplitude:%.2f\n',CA)
fprintf('*****Switching Rate
Below*****\n');
fprintf('ASR(Spline p value=%s):%.2f\n',num2str(p),maxd);
fprintf('ASR(cosinor):%.2f\n',ASR1)
fprintf('*****A24 and A12*****\n');
fprintf('A24(Spline p value=%s):%.2f,A12(Spline p
value=%s):%.2f\n',num2str(p),a24spline,num2str(p),a12spline);
fprintf('A24(cosinor):%.2f,A12(cosinor):%.2f\n',A1ihr,A2ihr)
cd(CurrentDirectory)

```

## D.7 MATLAB code for single regression analysis

```
clear
clc
close all
x=xlsread('memo_mean_median_cosinor_parameters.xlsx');
CA24=x(:,2);
MEDCA24=x(:,3);
CA12=x(:,4);
MEDCA12=x(:,5);
CASR=x(:,6);
MEDCASR=x(:,7);
CAMP=x(:,8);
MEDCAMP=x(:,9);
FF=x(:,10); %% physiological Index - Flow Frequency
%% Exclude data with FF zero
zero_index=find(FF>0);
CA24=CA24(zero_index);
MEDCA24=MEDCA24(zero_index);
CA12=CA12(zero_index);
MEDCA12=MEDCA12(zero_index);
CASR=CASR(zero_index);
MEDCASR=MEDCASR(zero_index);
CAMP=CAMP(zero_index);
MEDCAMP=MEDCAMP(zero_index);
FF=FF(zero_index);
Label='Flow Frequency';
Label1=strcat('Flow Frequency Prediction by');
%% FF prediction by CA24
X=[ones(size(FF)) CA24];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*CA24;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(1)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA-24'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA-24\n');
fprintf('Regression Formula: %.3f+%.3f*cA-24\n',b(1),b(2))
```

```

% fprintf('Approximate Line:%.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2:%.4f, P value:%.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
*****\n')
%% FF prediction by MEDCA24
X=[ones(size(FF)) MEDCA24];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*MEDCA24;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(2)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA-24*'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA-24\n');
fprintf('Regression Formula:%.3f+%.3f*cA-24\n',b(1),b(2))
% fprintf('Approximate Line:%.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2:%.4f, P value:%.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
*****\n')
%% FF prediction by CA12
X=[ones(size(FF)) CA12];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*CA12;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(3)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA-12'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA-12\n');
fprintf('Regression Formula:%.3f+%.3f*cA-12\n',b(1),b(2))
% fprintf('Approximate Line:%.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2:%.4f, P value:%.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
*****\n')

```

```

%% FF prediction by MEDCA12
X=[ones(size(FF)) MEDCA12];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*MEDCA12;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(4)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA-12*'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA-12*\n');
fprintf('Regression Formula: %.3f+%.3f*cA-12*\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%.3f*\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% FF prediction by CASR
X=[ones(size(FF)) CASR];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*CASR;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(5)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cASR'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' '), 'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cASR\n');
fprintf('Regression Formula: %.3f+%.3f*cASR\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%.3f*\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% FF prediction by MEDCASR
X=[ones(size(FF)) MEDCASR];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*MEDCASR;

```



```

p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(6)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cASR*'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cASR*\n');
fprintf('Regression Formula: %.3f+%.3f*cASR*\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% FF prediction by CAMP
X=[ones(size(FF)) CAMP];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*CAMP;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(7)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA*\n');
fprintf('Regression Formula: %.3f+%.3f*cA*\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% FF prediction by MEDCAMP
X=[ones(size(FF)) MEDCAMP];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*MEDCAMP;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(8)
scatter(f1,FF,80,'k','o')

```

```

hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' cA*'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by cA*\n');
fprintf('Regression Formula: %.3f+%.3f*cA*\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')

```

## D.8 MATLAB Code for multiple regression analysis

```
clear
clc
close all
x=xlsread('only_cosinor_param');
A24=x(:,2);
A12=x(:,3);
CASR1=x(:,4);
FF=x(:,5); %% Flow Frequency (physiological Index)
%% Exclude data with FF zero
zero_index=find(FF>0);
A24=A24(zero_index);
A12=A12(zero_index);
CASR1=CASR1(zero_index);
FF=FF(zero_index);
Label='Flow Frequency';
Label1=strcat(Label,' prediction by');
%% FF prediction by A24
X=[ones(size(A24)) A24];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*A24;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(1)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' A24'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by A24\n');
fprintf('Regression Formula:%.3f+%.3f*A24\n',b(1),b(2))
% fprintf('Approximate Line:%.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2:%.4f, P value:%.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% FF prediction by A12
X=[ones(size(A12)) A12];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*A12;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
```

```

figure(2)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' A12'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('FF prediction by A12\n');
fprintf('Regression Formula: %.3f+%.3f*A12\n',b(1),b(2))
% fprintf('Approximate Line: %.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% Multiple Regression with A24 and CASR1
X=[ones(size(A24)) A24 CASR1];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*A24+b(3).*CASR1;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(3)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)
set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' A24 and CASR1'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('Multiple Regression with A24 and CASR1\n');
fprintf('Regression Formula: %.3f+%.3f*A24+%.3f*CASR1\n',b(1),b(2),b(3))
% fprintf('Approximate Line: %.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2: %.4f, P value: %.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')
%% Multiple Regression with A12 and CASR1
X=[ones(size(A12)) A12 CASR1];
[b,bint,r,rint,state]=regress(FF,X);
f1=b(1)+b(2).*A12+b(3).*CASR1;
p=polyfit(f1,FF,1);
pre=p(1).*f1+p(2);
figure(4)
scatter(f1,FF,80,'k','o')
hold on
plot(f1,pre,'k','linewidth',1.3)

```

```

set(gca,'FontSize',16,'FontName','Times New Roman')
xlabel(strcat(Label1,' A12 and CASR1'),'FontSize',16,'FontName','Times New Roman')
ylabel(strcat(Label,' Index'),'FontSize',16,'FontName','Times New Roman')
[R, P,RL,RP]=corrcoef(f1,FF);
fprintf('Multiple Regression with A12 and CASR1\n');
fprintf('Regression Formula:%.3f+%.3f*A12+%.3f*CASR1\n',b(1),b(2),b(3))
% fprintf('Approximate Line:%.3f*Pre+%f\n',p(1),p(2))
fprintf('R^2:%.4f, P value:%.4f\n',R(1,2)^2,P(1,2))
fprintf('*****\n')

```