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Analysis and Visualization of Relationship between Stress and Care Activities toward Reduction in Caregiver Workload†

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In Japan, the demand for nursing homes is increasing owing to the rapid aging of the population, and the shortage of caregivers has become a serious problem. This problem has been recognized as a social issue because it increases the workload per caregiver. In response, we have been developing a platform that can easily collect data on nursing care activities to reduce the workload on the basis of the idea that the mental state (i.e., stress) of caregivers, which changes during care activities, might markedly affect their work efficiency. The objective of this study was to obtain new knowledge for reducing the workload of caregivers by visualizing and analyzing their stress. Specifically, we asked caregivers to wear the device, from which we obtained the objective stress indicators of R–R interval (RRI) and low frequency (LF)/high frequency (HF) ratio. We also obtained subjective stress indicators from questionnaires administered before the start of the experiment, before work, during breaks, and after work. To confirm that the stress level of caregivers depends on their care activity, work shift, and workday, we conducted an empirical experiment in an actual nursing home. We distributed devices and applications to five caregivers, obtained measurement data for a total of 28 days, and analyzed and visualized the changes in psychological states related to care activities, work shift, and workdays. As a result, we were able to collect data on the psychological state for 5 to 15 days per caregiver. Furthermore, the analysis of the data showed that, even though objective stress indicators and subjective evaluations did not necessarily coincide, stress tended to increase with specific care activities, work shift, and workdays. In addition, the subjective and objective stress indicators may change depending on the personality of the caregivers themselves.

1. Introduction

The aging of the population is a major policy issue in Japan. As of October 2020, 28.8% of the population were aged 65 and above, the highest level among developed countries, as reported by the Cabinet Office.(2) Under these circumstances, the demand for nursing homes has been increasing in recent years, in which the presence of caregivers is essential. On the other hand, if

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the population continues to age, the supply of long-term care services may not be able to keep up with the shortage of workers. According to a survey released by the Ministry of Health, Labour, and Welfare in 2015, there will be a shortage of approximately 377000 nursing care workers by 2025. The shortage of caregivers is expected to sharply increase the workload per caregiver, which is a serious problem in nursing homes, impacting on their safety and quality. Therefore, to reduce the workload of caregivers, services are required to make caregiving tasks more efficient.

We have been attempting to solve the above problems with information and communication technology (ICT)[3,4] We consider that changes in caregivers' mental state (i.e., stress) might have a significant impact on their workload. Therefore, this study focuses on changes in stress caused by caregiving work with the aim of improving caregiving work efficiency. If such changes in stress can be estimated, they could be applied to an objective review of the caregivers themselves, a review of care work plans, and the promotion of activities to refresh caregivers.

Many methods have been proposed to measure stress, such as using questionnaires.[5,6] However, these methods place a high burden on respondents owing to the large number of questions. Thus, it is desirable to be able to analyze and estimate data from biological indicators. Studies on estimating stress utilizing biological data have been conducted in many situations, such as in offices and daily life.[7,8] Although these studies can estimate stress on a daily basis, they do not focus on specific activities. Also, these methods based on biological indicators do not focus on the level of stress that the participants felt on each task.

In this paper, we focus on caregiver stress and aim to obtain new knowledge to reduce the workload of caregivers by visualizing and analyzing changes in their stress indicators related to care activities. As a first step, we conducted a measurement experiment using a heart-rate sensor and questionnaires on caregivers at a nursing home in order to confirm the relationship between care activity and stress among caregivers.[1] The results of the analysis showed that stress tended to increase with specific care activities, confirming several relationships between care activities and stress. In addition, from the interview at the nursing home, we received an opinion that changes in stress may be caused by differences in work shift (day shift, night shift, and so on), in the number of patients cared for, and in the personalities of the individual caregivers. On the basis of this opinion, we reviewed the data measurement method and aimed to obtain further findings on changes in care activities and stress states. To accomplish this, we conducted an experiment for 28 days with five caregivers wearing a heart-rate sensor in cooperation with Senior Villa Jure Hashimoto, a residential fee-based nursing home in Hashimoto, Wakayama, Japan. Caregivers are asked to wear a heart-rate sensor, which measured objective stress indicators such as R–R interval (RRI) and low frequency (LF)/high frequency (HF) ratio. In addition, questionnaires were administered before the start of the experiment, before work, during breaks, and after work to measure the caregivers' subjective stress indicators. The analysis of the collected data showed that, even though objective stress indicators and subjective stress indicators did not necessarily coincide, stress tended to increase with specific care activities, work shift, and workdays. Also, we found that the subjective and objective stress indicators may change depending on the personality of the caregivers themselves.

The rest of this paper is organized as follows. The existing work related to our research is provided in Sect. 2. Section 3 explains objective and subjective stress indicators to measure biological data associated with stress. Section 4 describes a system for measuring caregivers' stress at work by collecting biological indicators. Section 5 describes the experiment conducted in an actual nursing home. Finally, Sect. 6 concludes this paper.

2. Related Work

In this section, we introduce existing studies on stress estimation using questionnaires and devices, and then describe some related studies conducted in the nursing care field. Finally, we clarify the position of our study with respect to the existing studies.

2.1 Stress estimation by questionnaire

Since questionnaires can easily collect and quantitatively evaluate individual stress, various questionnaires have been developed in Japan and abroad in recent years. These questionnaires encourage the confirmation and self-control of one's own stress. The Ministry of Health, Labour, and Welfare developed the Brief Occupational Stress Questionnaire in an attempt to prevent mental disorders among workers. This questionnaire can be used to regularly assess stress conditions to reinforce the primary prevention of mental health problems among workers. Stress has also been suggested to cause a decline in the quality of life (QoL). The World Health Organization (WHO) has developed questionnaires such as WHOQOL-100[(5)] and SF-36[(6)] to quantitatively assess QoL. However, these questionnaires have a very large number of questions (54 questions for the Brief Occupational Stress Questionnaire, 100 questions for WHOQOL-100, and 36 questions for SF-36), and if the questionnaire is administered every day, the respondents will be overburdened. Also, these questionnaires are conducted sporadically, meaning that changes in stress conditions cannot be captured in a timely manner.

2.2 Stress estimation by devices

With the improvement of sensing and analysis technologies, studies have been conducted in various situations and environments to estimate and analyze stress by collecting biometric information using devices. Fukuda *et al.*[(7)] constructed a machine learning model to predict three levels of mood (depression, positivity, and anxiety) obtained from the Depression and Anxiety Mood Scale (DAMS) questionnaire at the time of waking for office workers in a company using sleep data acquired from a wearable device. Garcia-Ceja *et al.*[(8)] classified subjects' stress into three levels using accelerometer data from smartphones and the Oldenburg Burnout Inventory,[(9)] which was conducted three times a day. The sensors in these studies were in the subjects' smartphones and also in wearable devices and fitness trackers, and their range of applications is expanding.

Heart-rate variability, another type of biometric information, can be measured non-invasively with small sensors and wearable devices, and is used to analyze mental stress. Matsui *et al.*[(10)]

visualized differences in stress by collecting psychological indicators related to activities of daily living (ADLs) to understand the QoL of residents during daily life in their homes. Cinaz *et al.*[11] classified mental workload levels in an office scenario by modeling heart-rate data from mobile electrocardiogram (ECG) loggers and by subjective assessment using the NASA-TLX workload index. Muaremi *et al.*[12] built a machine learning model to estimate daily and long-term stress for individuals using voice, physical activity, and communication data acquired from smartphones during the day and heart-rate variability acquired from a chest-belt heart-rate sensor during nighttime sleep. Adler *et al.*[13] built a system to find indicators of stress resilience (adaptability to stress) using step count, sleep, heart rate, and ecological momentary assessments collected from wearable devices. They also proposed a method of predicting future stress resilience from the collected data. Thus, relating heart-rate variability to daily activity may lead to the identification of stressful behaviors.

Some studies have also analyzed the relationship between personality and stress by incorporating indicators related to individual personality.[14,15] For instance, Kallio *et al.*[15] assessed employee stress and productivity from environmental data from schools and offices using machine learning, and evaluated the relationship with personality traits using the Big Five personality traits. The results revealed that people with extroverted personalities are more likely to be stressed by poor environments and are more sensitive to environmental factors when stressed.

2.3 Research in nursing care field

With the improvement of ICT and devices, there has been much research in recent years on utilizing these technologies in the nursing care field. In particular, the creation of nursing care records is considered to be the most time-consuming task in nursing care work.[16,17] For this reason, much effort is being made to reduce the burden of nursing care record creation. Morita *et al.*[3] proposed a semi-automatic system for estimating the location of elderly people on the basis of the received signal strength index (RSSI) emitted from a BLE beacon and creating a record of caregiving activities by arranging the location data in time series. Wada *et al.*[4] developed a mobile memo system that can easily record detailed items (e.g., diet and excretion status) associated with caregiving behavior, in addition to time-series information on caregiving behavior. Inoue *et al.*[18] developed an application system that simultaneously collects sensor data from smartphones owned by caregivers and caregiver behavior labels recorded by caregivers. The system is expected to automatically generate nursing care records through behavior recognition and significantly shorten the time required to create nursing care records.

Studies have also been conducted on monitoring elderly people. Postawka and Rudy[19] developed a system that recognizes posture and behavior based on skeletal coordinates obtained from Kinect, and identifies dangerous activity. Abdulbaqi *et al.*[20] developed a system that wirelessly measures biometric information, such as the body temperature and pulse rate of a patient, and sends an SMS to the patient when any parameter reaches a value of concern.

2.4 Position of our study

Most of the studies on stress estimation mentioned in Sects. 2.1–2.3 focus mainly on the workplace and daily life. Although using the methods in these studies, stress can be estimated at specific times, they have not yet been able to estimate stress according to the activity, which is the objective of this study. In this paper, we propose a method that enables us to collect data related to stress from caregivers working in an actual nursing home using a heart-rate sensor and to visualize and analyze in detail changes in stress during caregivers' work and the relationship between care activity and stress. The method used in this study may be applied to an objective review of the caregivers themselves, a review of care work plans, and the promotion of strategies to reduce the stress of caregivers. Thus, in Sect. 3, we first describe methods of measuring biological indicators associated with stress used in our study. Then, in Sect. 4, we describe a system for measuring caregivers' stress at work by collecting biological indicators.

3. Methods of Measuring Biological Indicators Associated with Stress

In this section, we describe methods of measuring biological indicators associated with stress. Specifically, we explain the objective and subjective stress indicators used to measure the mental state of caregivers during care activity.

3.1 Objective stress indicators

We first describe the objective stress indicators used in our study. Heart-rate variability is a typical biological indicator for measuring objective stress. It is calculated from the periodically fluctuating heartbeat interval, and various methods of analyzing heart-rate variability exist, focusing on the time and frequency domains. The RRI calculated by time-domain analysis represents the interval of the R wave, the characteristic wave of the heartbeat. The standard deviation of N–N intervals (SDNN), calculated from the standard deviation of the RRI, is an index of parasympathetic activity, and a higher value indicates a more relaxed state. As shown in Fig. 1, the Lorenz plot,[21] which plots the RRI on a 2D orthogonal graph and represents fluctuations in heart rate, is also used as an indicator for estimating stress. Here, the RRI at a point is plotted on the *x*-axis and the RRI one beat later on the *y*-axis, and all the plotted points are projected onto axes corresponding to the $y = x$ and $y = -x$ axes. After plotting, the standard

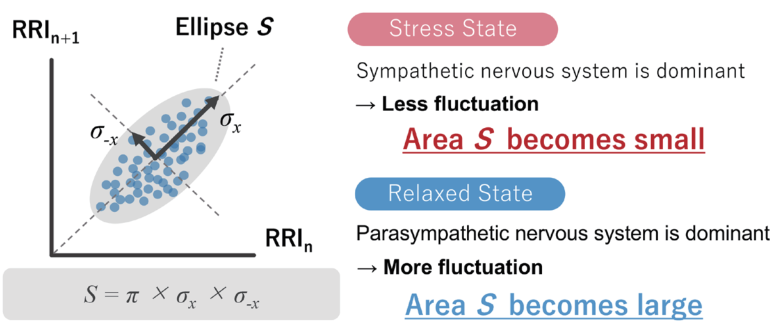


Fig. 1. (Color online) Lorenz plot.

deviation of the distance from the origin on the $y = x$ axis is defined as σ_x and that on the $y = -x$ axis is defined as σ_{-x}. The distribution of the Lorenz plot is taken as an ellipse whose area S is given by

$$S = \pi \times \sigma_x \times \sigma_{-x}. \tag{1}$$

S represents the fluctuation of the heartbeat and indicates whether the parasympathetic nervous system is dominant. S tends to be small during stress and large during relaxation. This indicator is also used in various situations to estimate stress.

The LF/HF ratio, calculated from the frequency conversion of heart-rate variability into a power spectrum, is also used to determine the state of stress. The frequency-converted heart-rate variability is divided into an LF component representing the low frequency range (0.04 to 0.15 Hz) and an HF component representing the high frequency range (0.15 to 0.40 Hz). The LF/HF ratio is the power ratio of the LF and HF components. During relaxation, the parasympathetic nervous system is activated, and both the LF and HF components increase, but during stress, the LF component increases, while the HF component decreases. Therefore, the LF/HF ratio is higher during stress than during relaxation and can therefore be used to determine the stress state.

3.2 Subjective stress indicators

Next, we describe the subjective stress indicators used in our study. Some questionnaires are used to assess subjective human stress. This section describes the questionnaires utilized to measure workers' stress state and mental workload.

Depression and Anxiety Mood Scale (DAMS)[22]

DAMS is a questionnaire designed to measure three types of mood: positive, depressed, and anxious. The respondents are asked to choose, on a seven-point scale, the degree to which they fit the nine adjectives: pleasant, happy, lively, anxious, worried, anxious, downcast, gloomy, and dislikeable.

Utrecht Work Engagement Scale (UWES)[23]

UWES is a survey instrument based on the concept of "work engagement" proposed by Schaufeli and Salanova. There are three versions: 17-item, nine-item (shortened), and three-item (ultrashortened) versions.

Recovery Experience Questionnaire (REQ)[24]

REQ is a questionnaire about behaviors to restore the psychological state that deteriorates in a stressful environment to its original level. Respondents are asked to answer questions about how they spend their time after the end of the workday. REQ was found to be positively correlated with work engagement.

NASA-TLX[25]

The NASA Task Load Index (NASA-TLX) is used to analyze the factors of mental load during work and consists of six evaluation items: 1) mental demand, 2) physical demand, 3) temporal demand, 4) own performance, 5) effort, and 6) frustration.

On the basis of these four questionnaires, we developed the questionnaire on work used in our study. The detailed contents of our questionnaire are described in Sect. 5.3.

4. System for Collecting Objective Stress of Caregivers

In this section, we describe a system developed for estimating caregivers' stress at work by collecting biological indicators related to stress to achieve the research objective described in Sect. 2.

4.1 System architecture

Figure 2 shows the system configuration. The system collects data using the heart-rate sensor and records care activity labels by a smartphone application. In this system, a device that can measure heart-rate variability is worn to collect objective stress indicators and estimate stress. A Union Tool Co. WHS-3 chest-mounted heart-rate sensor was chosen because it is easy to wear and does not interfere with caregivers' work activities. This sensor calculates RRI, LF, and HF from heart-rate data collected at a sampling period of 1 ms and can store the data in a Bluetooth device such as an iPod touch.

4.2 How to record labels for care activities

In this section, we explain how labels are recorded for care activities. To accurately record the care activity of caregivers, a care activity recording application for a mobile device is used to record the care activity time during work. In order not to disturb the caregiving work, the application can be operated by simply pressing the icon of the target care activity to record the start/end time. Figure 3 shows an example of an application screen. We implemented the application on the iPod touch, which is easy to carry around during work, after consulting with caregivers. The application displays the participant's ID, the care activity currently being performed, and a button representing each care activity. When the button of the care activity is tapped, the button turns yellow and switches to the care activity during work. Otherwise, the button remains white to indicate that no activity is in progress. With the implemented application, the caregiver simply presses the button for the next care activity to be performed,

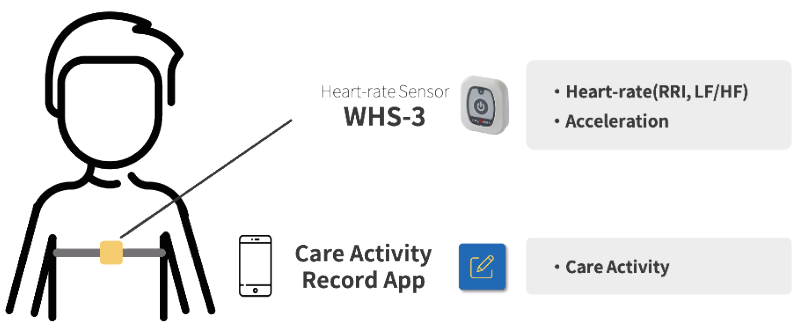


Fig. 2. (Color online) System configuration.

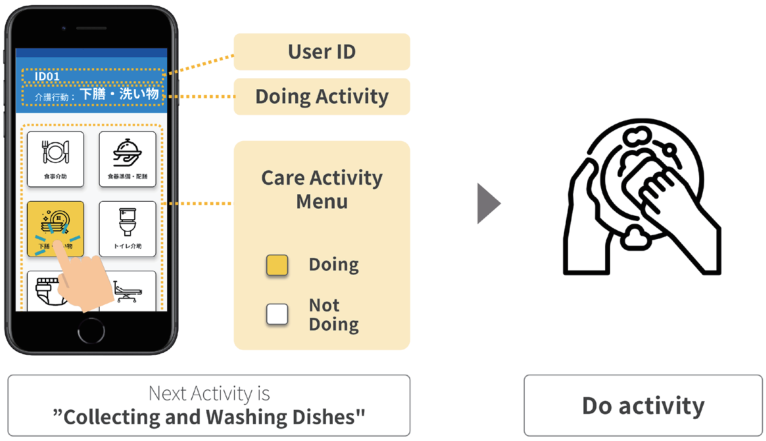


Fig. 3. (Color online) Care activity label recording application.

and the application can be easily used without the need for complicated operations. Also, this application can be used to generate time-series data for care activity labels. Because caregivers generally cannot perform more than one type of care activity at the same time, our application does not currently support multilabeling.

4.3 Stress measurement by care activity

The collected stress data and activity labels are used to output the stress value for each care activity. Figure 4 shows the method used to output the stress value for each care activity. The RRI and LF/HF ratio are calculated from the heart rate sensor and used as the caregiver's biological data at that time. From the stress data and care activity labels, the stress value for each time period when the care activity was being performed is extracted. After that, the average stress value is calculated to output the stress value for each care activity.

5. Experiments

In this section, we describe our experiment conducted in an actual nursing home. We first explain the experimental objective and outline. Then, we describe care activities targeted in this experiment and the questionnaire used in our experiment. Finally, we describe the experimental results.

5.1 Objective and outline

To confirm that the proposed system can record stress during work and that caregivers' stress values change depending on their care activity, work shift, and workday, we carried out the experiment at a nursing home after obtaining approval from the Ethics Review Committee of Nara Institute of Science and Technology (Approval Number: 2018-I-31-2). As shown in Fig. 5, this experiment was conducted on five caregivers at Senior Villa Jure Hashimoto, a residential

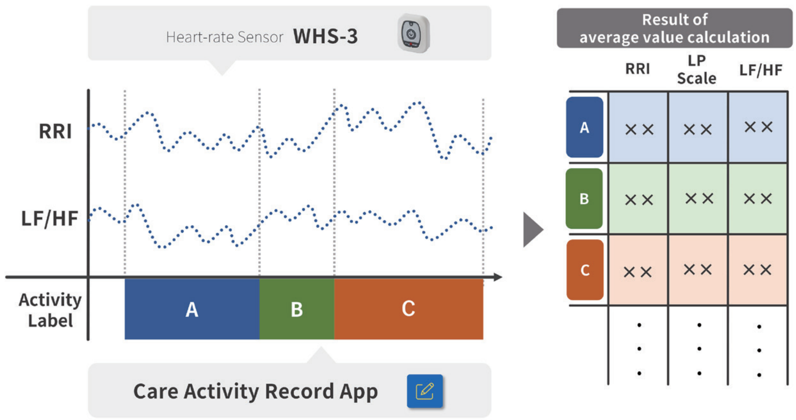


Fig. 4. (Color online) Method used to output stress value.

Fig. 5. (Color online) Experiment environment (Senior Villa Jure Hashimoto).

fee-based nursing home in Hashimoto, Wakayama, Japan. The experiment was conducted from June 28, 2021 to July 8, 2021 and from July 19, 2021 to August 4, 2021, with a total of 28 days of data collection. Caregivers were asked to wear a WHS-3 heart-rate sensor on their chests before work and to perform their usual duties. In addition, to measure subjective stress, they were asked to answer a questionnaire three times a day: before the start of work, during a break, and after work.

5.2 Target care activities

Table 1 shows the 14 care activities considered in this experiment and their definitions, where the activities were selected after consultation with the nursing home administrator. In addition to these activities, "Rest" and "Other" buttons were added to the caregiving record application, allowing users to select from a total of 16 types of activity.

Table 1
Target care activities.

Activity	Definition
Meal Assistance	Supporting the elderly in eating
Meal Preparation and Serving	Preparation before meals
Dismantling and Washing Dishes	Clean up after meals
Toilet Assistance	Assist elderly people when they defecate
Changing Diapers	Change diapers of the elderly
Bed Assistance	Raise the elderly out of bed or put them to bed
Bathing Assistance	Assist the elderly to take a bath
Movement Assistance	Assist the elderly with transferring from one place to another
Bed Sheet Changing	Changing bed sheets
Cleaning	Cleaning the nursing home
Laundering	Washing clothes
Dementia Support	Dealing with the elderly with dementia
Drug Management	Manage medications taken by the elderly
Writing Care Record	Create a care record of the elderly

5.3 Questionnaires

To collect caregivers' subjective stress, the questionnaire was conducted three times a day: before the start of work, during a break, and after work. In a preliminary questionnaire administered before the start of the experiment, caregivers were asked about their gender and years of experience as a caregiver to ascertain their abilities and experience. Furthermore, to determine whether the personality of the caregivers affects their stress, we used the Big Five questionnaire to assess personality. This questionnaire consists of 60 questions that classify the personality of individuals into five traits: neuroticism, extroversion, openness, cooperativeness, and sincerity, each with 12 questions. All items were answered on a 7-point scale from 0 to 6.

Table 2 shows the content of the questionnaire administered three times a day during the workday, where caregivers were asked to respond by considering their mood and motivation at that time. All items were answered on a 7-point scale from 0 to 6. The work questionnaire was based on DAMS, UWES, REQ, and NASA-TLX described in Sect. 3.2 and is shown in Table 3. In this questionnaire, we categorized the nine adjectives of the DAMS into three moods, i.e., positive, depressed, and anxious. The three adjectives belonging to each mood were answered on a 7-point scale from 0 to 6, and then the final rating was made by summing those numbers. Also, the UWES scores were evaluated by rating each of the three questions on a scale of 0 to 6 and then summing those numbers. Similarly, the REQ was evaluated by answering each of the four questions designed within each item (Psychological detachment, Relaxation, Mastery, and Control) on a 7-point scale from 0 to 6 and then summing those numbers. The NASA-TLX was evaluated on a 7-point scale from 0 to 6 for each question.

The DAMS and UWES are answered three times a day, the REQ is answered before work because it relates to how the participants spent their time after their previous shift, and the NASA-TLX is answered after work because it evaluates the entire workday. In the questionnaire administered after the work, the caregivers also responded to the stress by care activity to evaluate the degree of stress they felt for each care activity they engaged in during the day's work.

Table 2
Workday questionnaire content.

Question Item	Number of Questions	Before Work	During Break	After Work
DAMS	9	○	○	○
UWES	3	○	○	○
REQ	16	○		
NASA-TLX	6			○
Stress Assessment by Care Activity	14			○

Table 3
Work questionnaire used in the experiment.

Item	Description
Positive Mood (Vigorous: 0–6, Happy: 0–6, Enjoy: 0–6) Depressed Mood (Gloomy: 0–6, Disagreeable: 0–6, Dull: 0–6) Anxious Mood (Worried: 0–6, Anxious: 0–6, Afraid: 0–6)	DAMS: Understanding the mood
Energy at work, psychological resilience: Do you feel energized when you are working? (0–6) Enthusiasm for work: Do you feel enthusiastic about your work? (0–6) Focus and immersion in the work: Feeling overwhelmed by work? (0–6)	UWES: Understanding work motivation
Forget about work (0–6) Don't think about work at all (0–6) Keep your distance from work (0–6) Take a break from the burdens of work (0–6)	REQ: Psychological detachment
Relax and unwind (0–6) Do something relaxing (0–6) Spend time to relax (0–6) Spend time on leisure time (0–6)	REQ: Relaxation
Learn something new (0–6) Find something intellectually challenging (0–6) Try something challenging (0–6) Do something that expands your horizons (0–6)	REQ: Mastery
I think I can decide for myself what to do (0–6) I decide my own schedule (0–6) I decide how I spend my time (0–6) I can get things done the way I want them done (0–6)	REQ: Control
Mental Demand: How much mental and perceptual activity was required (0–6) Physical Demand: How much physical activity was required (0–6) Temporal Demand: How much time pressure you felt on the progress of the task, the speed of progress, and the timing of the task (0–6) Performance: How well do you think you are doing in setting up the task to accomplish your goal? (0–6) Effort: How hard did you work on the required tasks? (0–6) Frustration: How frustrated, stressed, satisfied, or relaxed did you feel while doing the task? (0–6)	NASA-TLX: Identification of workload factors

All items are answered on a 7-point scale from 0 to 6.

Caregivers in the experimental facility have the following four types of shift work (early, regular, night, and on-duty), so the type of shift work for the day is selected in the pre-work questionnaire.

- Early: 7:00–16:00
- Regular: 8:30–17:30
- Night: 16:30–9:00 (of which 5:30–7:00 is for resting)
- On-duty: 17:30–9:00 (of which 21:30–5:30 is for resting)

5.4 Results

5.4.1 Summary of data

Table 4 shows the attributes of the five participants (one male and four female) obtained from the preliminary questionnaire conducted before the start of the experiment. Three participants had more than 10 years of experience in nursing care work, indicating that a relatively large number of participants had been in the field for a long time. Figure 6 shows the personality characteristics of the participants obtained from the Big Five questionnaire. “Neuroticism” and “openness” differed greatly among the participants, whereas there was no significant difference in “cooperativeness”. Because caregivers have many opportunities to interact with residents and with other caregivers, the ability to care for and empathize with others is an important characteristic, and the results showed little difference among caregivers.

Table 4
Participant attributes.

Participant ID	Gender	Age	Years of experience in nursing care work
ID_01	Female	50’s	More than 10 years, less than 15 years
ID_02	Male	30’s	More than 5 years, less than 10 years
ID_03	Female	30’s	More than 10 years, less than 15 years
ID_04	Female	50’s	Less than 3 years
ID_05	Female	50’s	More than 10 years, less than 15 years

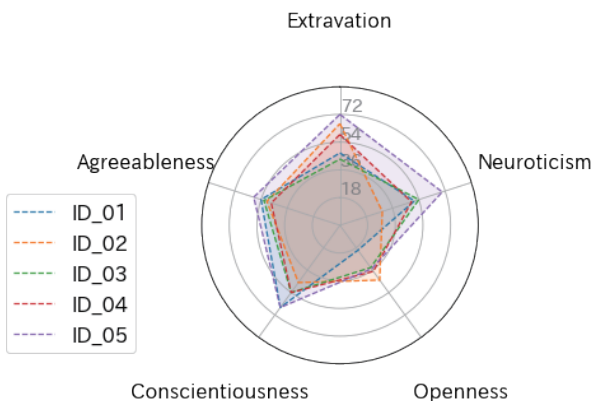


Fig. 6. (Color online) Personality characteristics of participants.

Although the biological indicators, questionnaires, and care activity data were collected for a total of 28 days, there were cases in which the devices were faulty or inadequately attached, and data were not collected in some cases. Similarly, in the questionnaire, there were many cases in which the participants forgot to answer the questionnaire when they were busy with their work because they needed to answer it while performing their usual duties. Table 5 shows the final number of data collected. In the questionnaire, the number of responses was the highest before work and lowest after work. In some cases, the answers to the questionnaire were always constant, and in other cases, the number of recorded care activity labels was small and the participants forgot to record them.

The following are the results of the questionnaire responses of the five caregivers. Figure 7 shows the average stress assessed for each care activity. The average stress was relatively high for dementia support, bathing assistance, bed assistance, and drug management, which require detailed confirmation, and low for housework, such as bed sheet changing, cleaning, and laundry, which do not require contact with elderly people. When we focused on care activities related to bed care, we found that the average stress was higher for bed assistance than for bed sheet changing. This is because bed assistance requires more physical strength than bed sheet changing, as bed assistance involves supporting the elderly so that they do not fall over, according to a staff member at the facility who was interviewed after the experiment. In addition, when we focused on care activities related to eating, the results showed that the meal

Table 5
Number of data obtained in experiment.

Collected Data		Total acquisition days
WHS-3		57
Questionnaire	Before Work	74
	During Break	65
	After Work	56
Care Activity		63

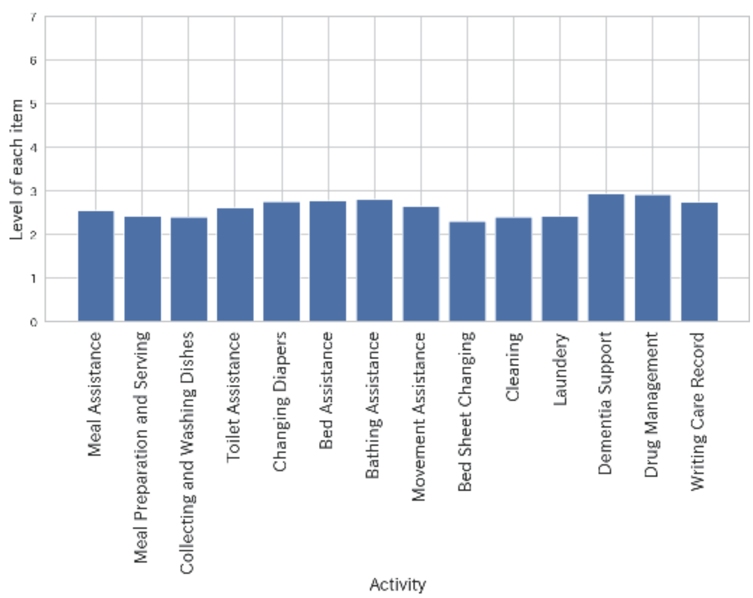


Fig. 7. (Color online) Average stress assessment by care activity (all participants).

assistance was more stressful than meal preparation and serving and collecting and washing dishes because the meal assistance was performed while paying attention to the elderly person. This clearly shows that there is a difference in stress even among activities related to the same domain.

Figure 8 shows the average of the DAMS results by item, work shift, and response timing. The positive mood index tended to be lower than the depression and negative mood indexes. In terms of work shift, night shift workers had lower positive moods than those working during the day, such as early shift workers and regular shift workers. Conversely, the people doing the regular shift tended to have relatively low depression and negative mood scores, and a high positive mood score. Regarding the timing of the response, the positive mood score increased with the passage of work hours. Figure 9 shows the mean UWES results by work shift and response timing. Although there is no significant change with the timing of the response, the

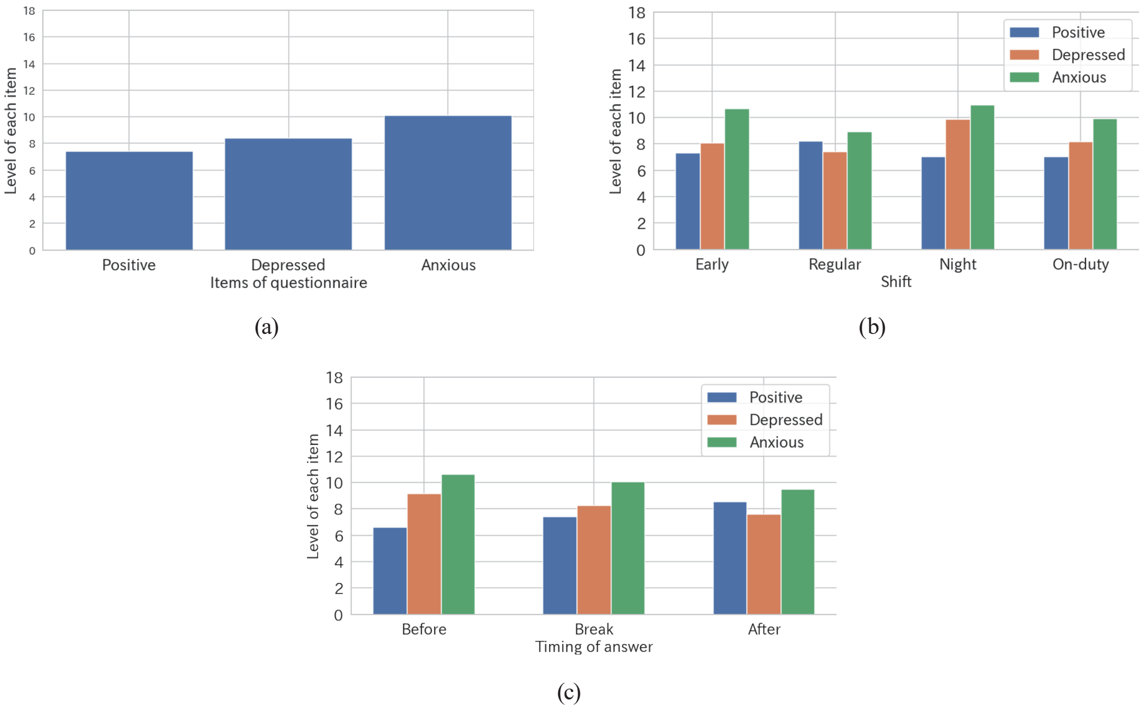


Fig. 8. (Color online) Average of DAMS results (all participants). (a) Item, (b) work shift, and (c) response timing.

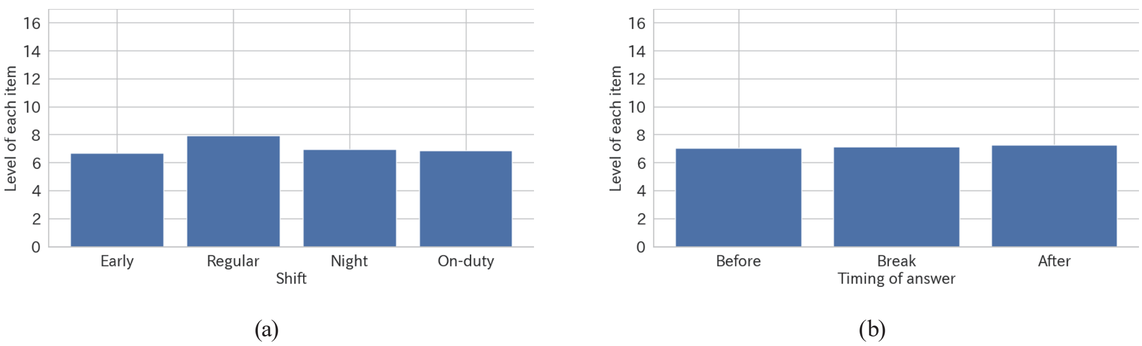
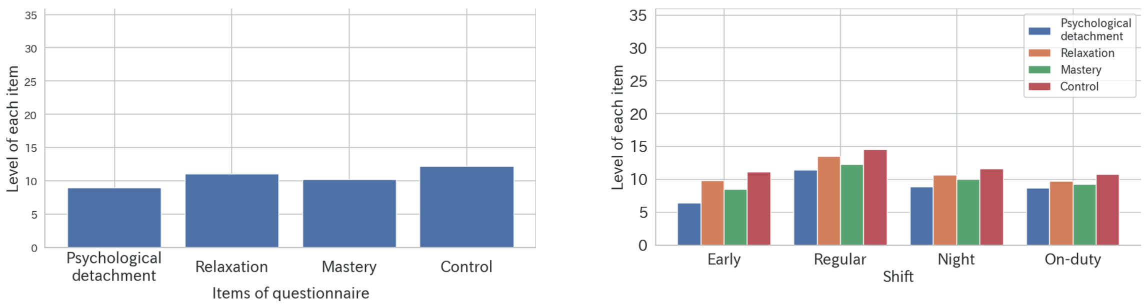


Fig. 9. (Color online) Average of UWES results (all participants). (a) Work shift and (b) responding timing.

average UWES result is higher for regular work than for other types of work. Figure 10 shows the mean REQ values by item and work shift. The "Psychological distance" score is lower than the other scores, suggesting that the respondents do not sufficiently switch off from their jobs when they are not at work. Figure 11 shows the mean values for each of the NASA-TLX items and for each type of work. The work accomplishment level was generally low. While mental demand and physical demand were high for daytime work, such as early arrival and regular work, time pressure and dissatisfaction were high for late-night work, such as night shift and on-duty shift.

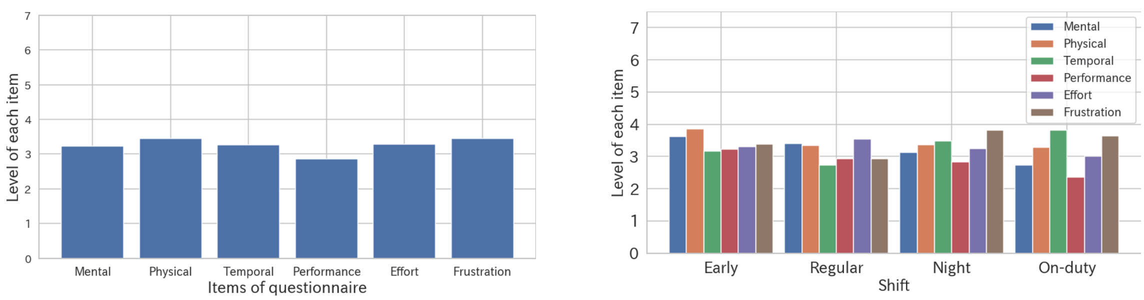
Section 5.4.2 and the subsequent sections present the results of the analysis of WHS-3 data obtained from the device. In this study, five participants attached WHS-3 and collected data, but owing to device malfunctions and insufficient attachment, three participants did not have sufficient data for analysis. Therefore, we focused on the two participants for whom sufficient data could be obtained to see if the individual objective indicators were consistent with the subjective indicators.

Table 6 shows the total implementation time for each care activity. The total implementation time was calculated from the time-series data of the nursing care activity labels recorded by our application. ID_01 had a longer time for collecting and washing dishes and for changing diapers, while ID_02 had a longer time for writing care records and changing diapers. Figure 12 shows



(a) (b)

Fig. 10. (Color online) Average of REQ results (all participants). (a) Item and (b) work shift.

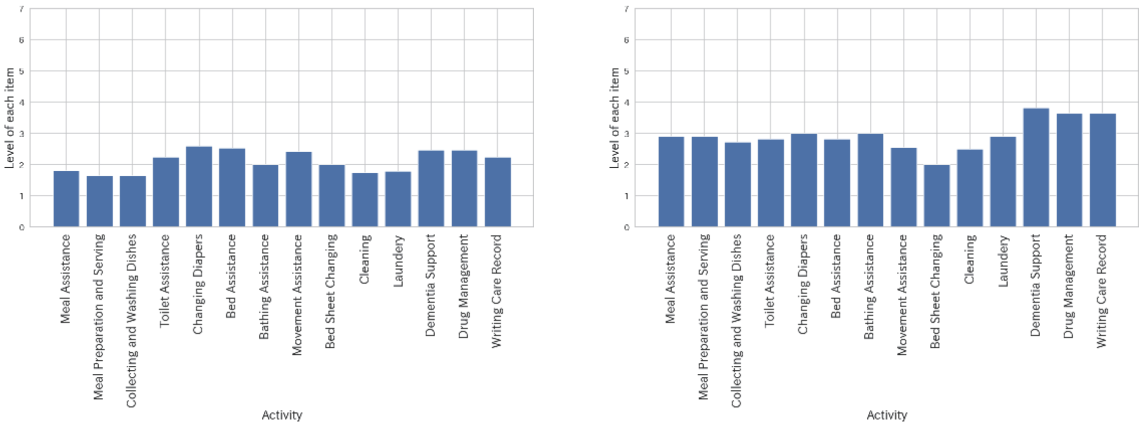


(a) (b)

Fig. 11. (Color online) Average of NASA-TLX results (all participants). (a) Item and (b) work shift.

Table 6
Implementation time for each care activity (min) (ID_01, ID_02).

Activity	ID_01	ID_02
Meal Assistance	43.5	258.6
Meal Preparation and Serving	468.3	522.3
Dismantling and Washing Dishes	630.7	246.9
Toilet Assistance	83.8	61.3
Changing Diapers	523.3	582.9
Bed Assistance	0.0	267.6
Bathing Assistance	11.4	10.6
Movement Assistance	326.6	217.7
Bed Sheet Changing	60.0	0.0
Cleaning	231.5	0.0
Laundering	194.7	319.7
Dementia Support	1.8	114.9
Drug Management	185.3	390.4
Writing Care Record	98.8	937.2



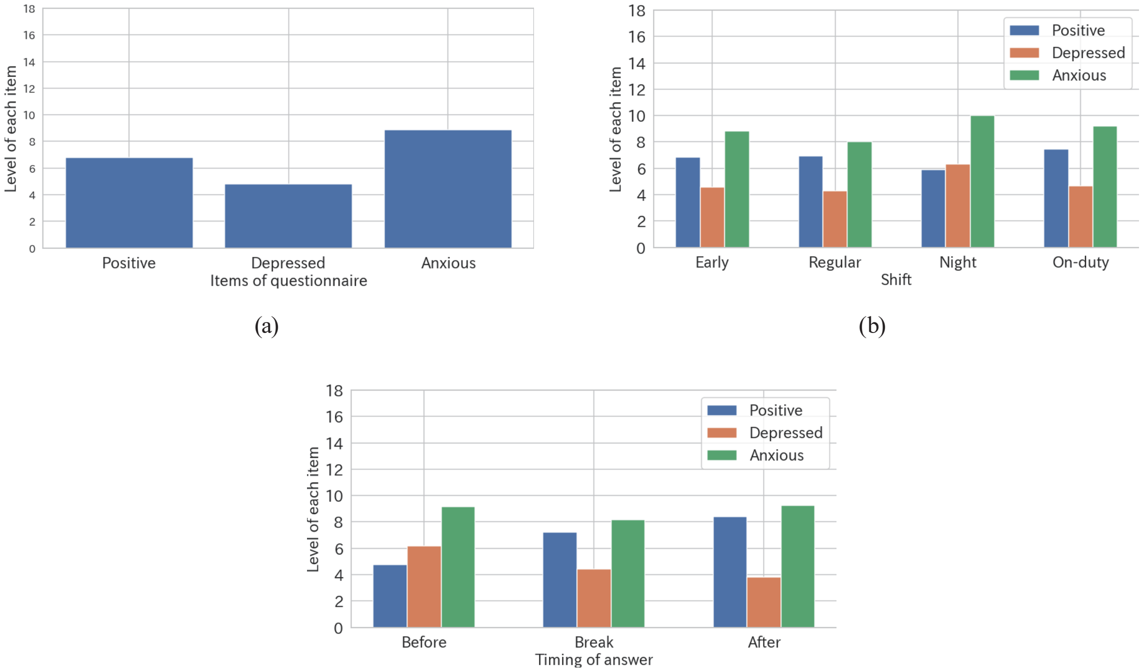
(a) (b)

Fig. 12. (Color online) Average stress assessment by care activity (ID_01, ID_02). (a) ID_01 and (b) ID_02.

the average stress assessment by care activity. Dementia support was high for both caregivers, while diaper changing and bed assistance were the most common activities for ID_01, and drug management and writing care records were the most common activities for ID_02, both of which were individual tasks.

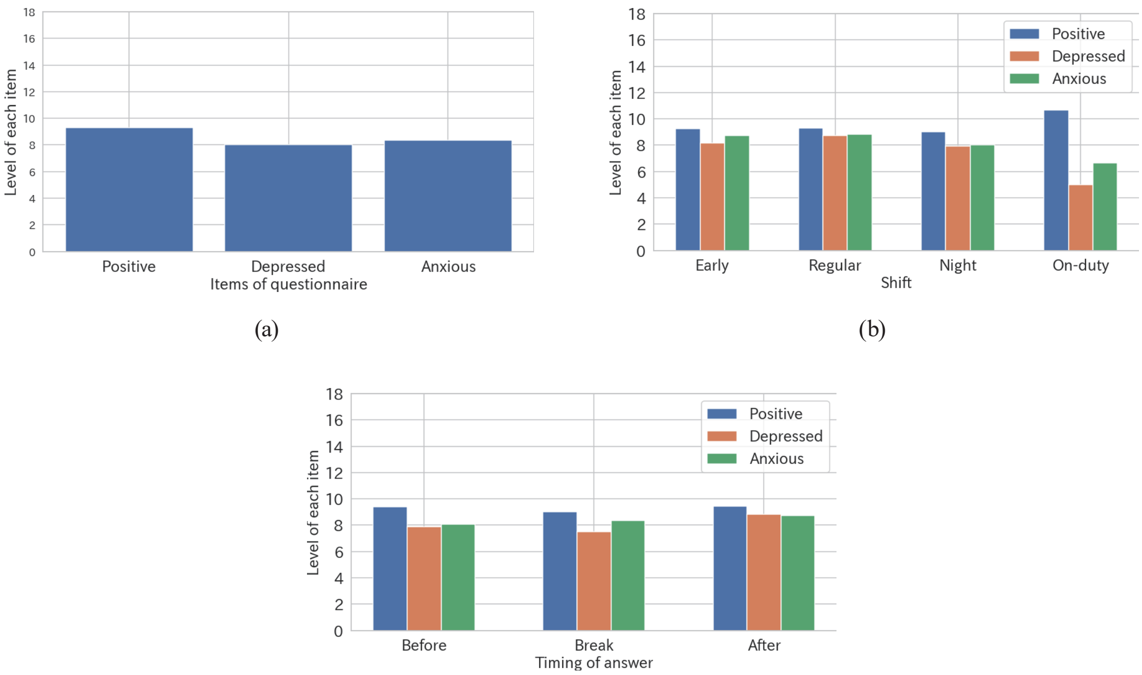
Figures 13 and 14 show the mean values of the DAMS by item, work shift, and timing of the response for ID_01 and ID_02, respectively, indicating that the depressed mood score was lower than the other mood scores for ID_01, but increased during night shift. The depression and negative mood scores was highest before work and decreased after work. On the other hand, the positive mood score was slightly higher than the other mood scores for ID_02, and the difference between the depression and negative mood scores was especially large during on-duty work shift. The positive mood score was consistently higher than the other mood scores, with depression and negative mood scores decreasing during breaks.

Figures 15 and 16 show the mean values of work engagement by work shift and response timing for ID_01 and ID_02, respectively. Although there was no significant change in UWES



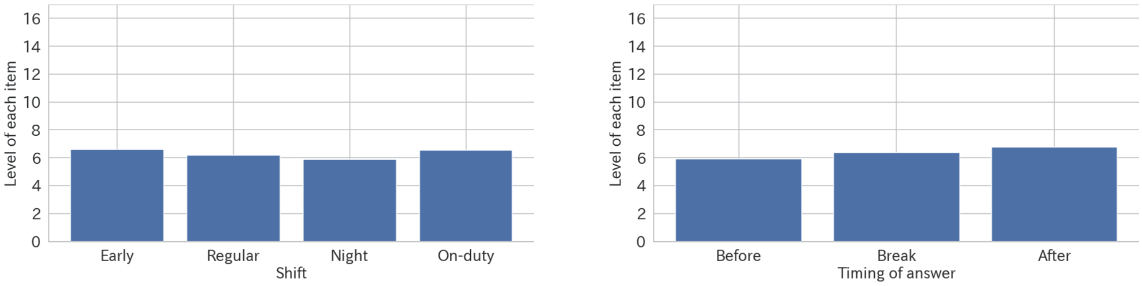
(a) (b) (c)

Fig. 13. (Color online) Average of DAMS results (ID_01). (a) Item, (b) work shift, and (c) responding timing.



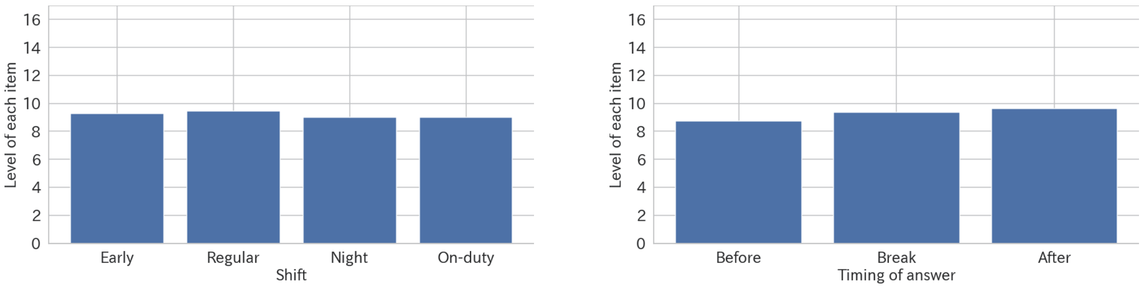
(a) (b) (c)

Fig. 14. (Color online) Average of DAMS results (ID_02). (a) Item, (b) work shift, and (c) responding timing.



(a) (b)

Fig. 15. (Color online) Average of UWES results (ID_01). (a) Work shift and (b) responding timing.



(a) (b)

Fig. 16. (Color online) Average of UWES results (ID_02). (a) Work shift and (b) responding timing.

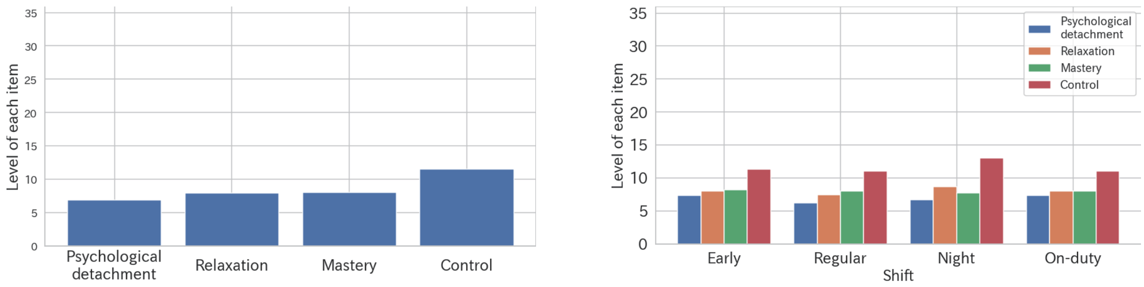
score with the timing of the response, it was found that the scores for night shift work were slightly lower for both ID_01 and ID_02.

Figures 17 and 18 show the average REQ results by item and work shift for ID_01 and ID_02, respectively. Scores tended to be high for control and low for psychological distance for both ID_01 and ID_02, and the score for relaxation was also high for ID_02. For ID_02, there was a large difference between night shift work and on-duty shift work for psychological distance, indicating that there is a difference in how the workers spend their time before the start of the workday, since the rest time during work hours is also significantly different for the same late night shift.

Figures 19 and 20 show the average NASA-TLX results by item and work shift for ID_01 and ID_02, respectively. These effects may have contributed to the increases in depression and negative mood scores in the DAMS and the decrease in UWES score. For ID_02, there were no significant differences among the items. In terms of work shift, time pressure was higher for the night shift and on-duty work shift. The same tendency was observed for ID_01, suggesting that the smaller number of caregivers during late-night work increases the time burden.

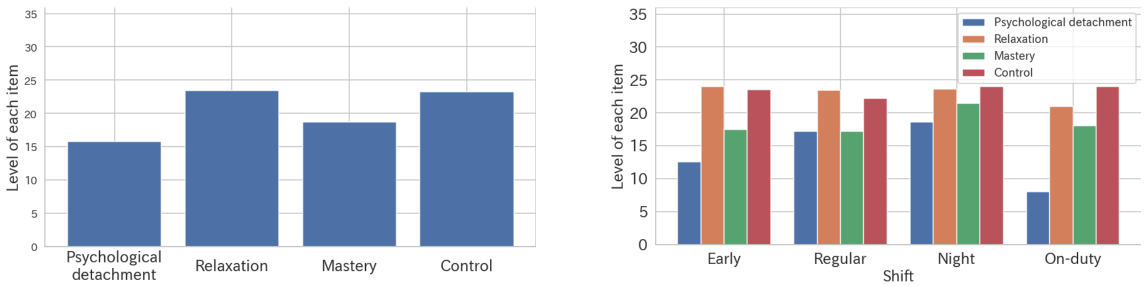
5.4.2 Analysis results by care activity

In this section, we analyze the care activities on the basis of the stress indicator data measured from the WHS-3 device. Care activities that were not recorded in the caregiving record



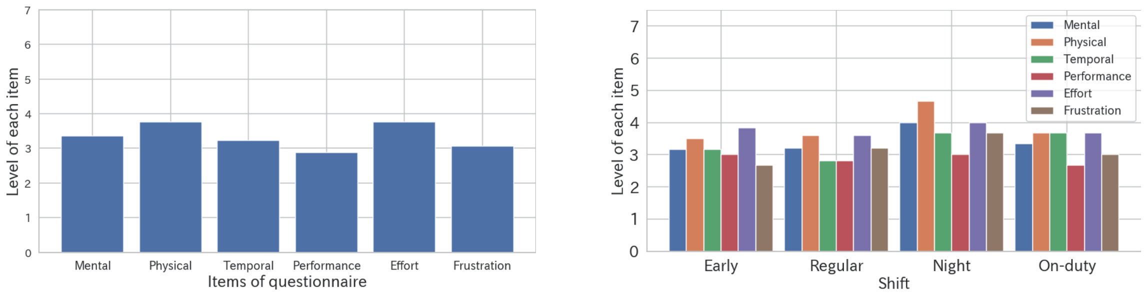
(a) (b)

Fig. 17. (Color online) Average of REQ results (ID_01). (a) Item and (b) work shift.



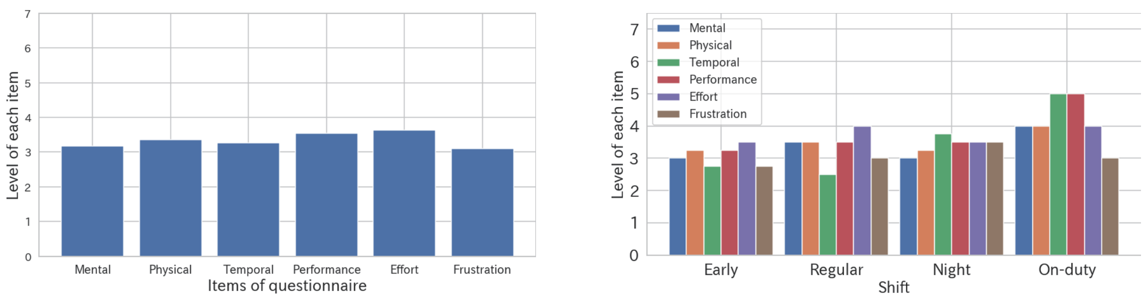
(a) (b)

Fig. 18. (Color online) Average of REQ results (ID_02). (a) Item and (b) work shift.



(a) (b)

Fig. 19. (Color online) Average of NASA-TLX results (ID_01). (a) Item and (b) work shift.

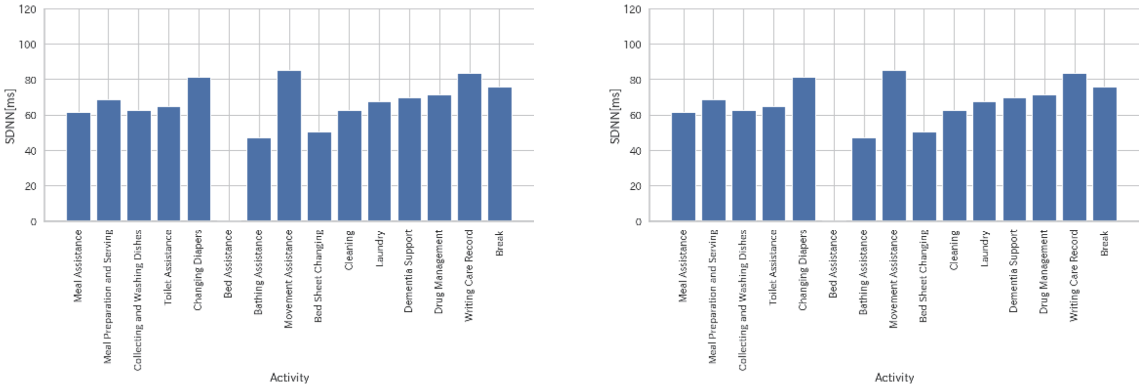


(a) (b)

Fig. 20. (Color online) Average of NASA-TLX results (ID_02). (a) Item and (b) work shift.

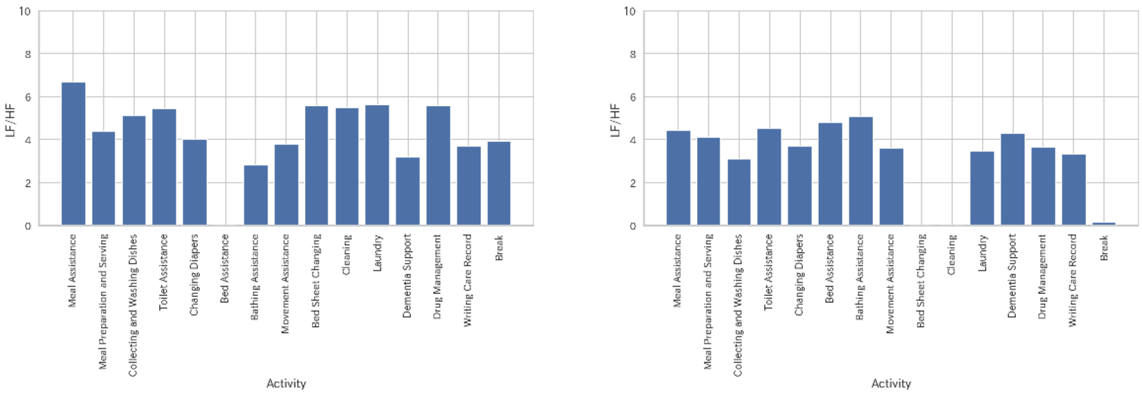
application were considered to have not been performed during the experimental period, and their results were set to 0. As for the Lorenz plot, since the outliers were widely distributed, the area was calculated by using the interquartile range (IQR) of the RRI.

Figures 21–23 respectively show the SDNN, LF/HF ratio, and Lorenz plot area for each participant by care activity. For ID_01, the SDNN is low, the Lorenz plot area is small and the



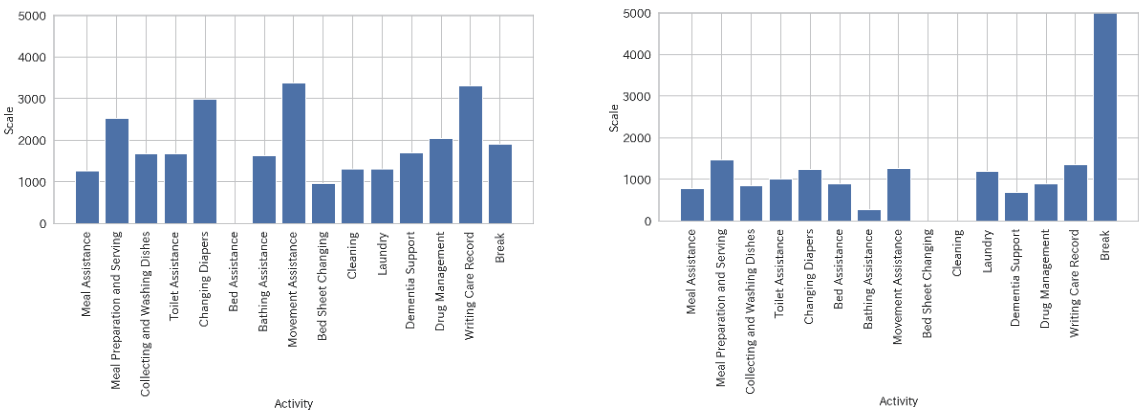
(a) (b)

Fig. 21. (Color online) SDNN by care activity. (a) ID_01 and (b) ID_02.



(a) (b)

Fig. 22. (Color online) LF_HF ratio by care activity. (a) ID_01 and (b) ID_02.



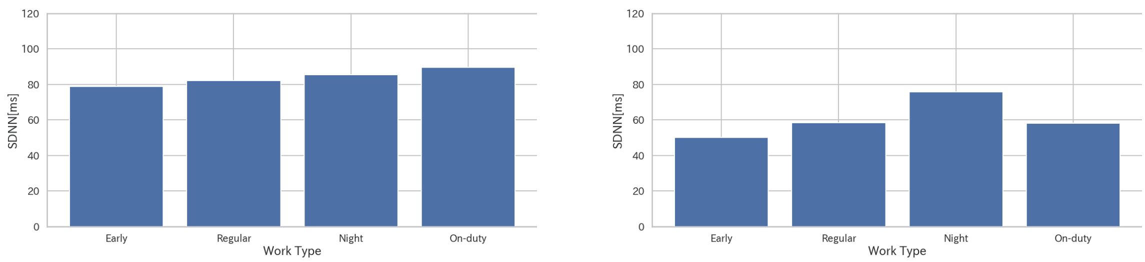
(a) (b)

Fig. 23. (Color online) Lorentz plot area by care activity. (a) ID_01 and (b) ID_02.

LF/HF ratio is high for bed sheet changing. For ID_02, the SDNN is low, the Lorenz plot area is small, and the LF/HF ratio is high for bathing assistance. Since the SDNN and Lorenz plot area respectively tend to be low and small during periods of stress and high and large during periods of relaxation, and the LF/HF ratio tends to be high during periods of stress and low during periods of relaxation, the above-mentioned activities may be relatively stressful. On the other hand, the opposite tendency (high SDNN and large Lorenz plot area and low LF/HF ratio) was observed for movement assistance for ID_01 and for writing care records for ID_02, suggesting that these activities are not particularly stressful. In addition, for ID_02, the tendency to be in a relaxed state during rest was pronounced, whereas this tendency was not observed for ID_01.

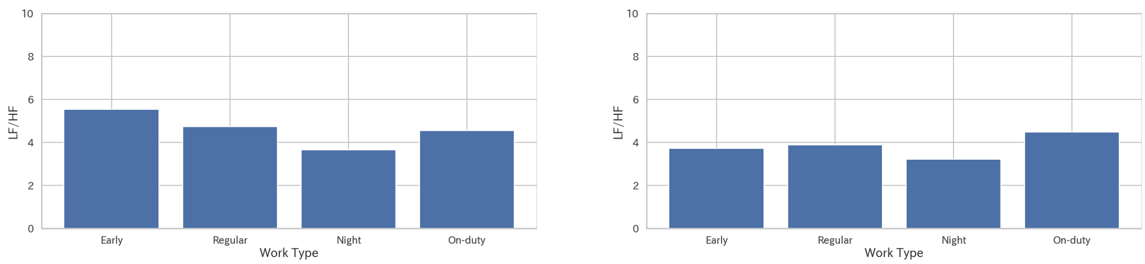
5.4.3 Analysis results by work shift

Figures 24–26 respectively show the SDNN, LF/HF ratio, and Lorenz plot area by work shift for each participant. Participant ID_01 was more likely to feel stress during daytime work such as in the early shift and regular shift, while for ID_02, the SDNN and Lorenz plot area respectively tended to be lower and smaller and the LF/HF ratio tended to be higher for the early shift and on-duty shift. On the other hand, the opposite trend was observed for both types of night shift, suggesting that the mental burden was small.



(a) (b)

Fig. 24. (Color online) SDNN by work shift. (a) ID_01 and (b) ID_02.



(a) (b)

Fig. 25. (Color online) LF/HF ratio by work shift. (a) ID_01 and (b) ID_02.

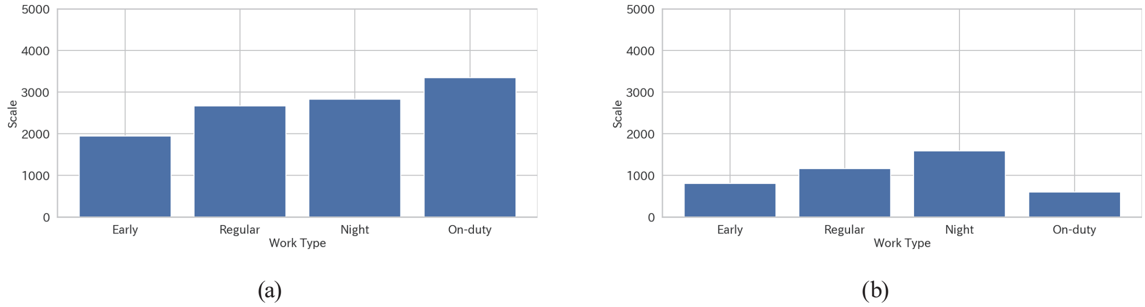


Fig. 26. (Color online) Lorentz plot area by work shift. (a) ID_01 and (b) ID_02.

5.4.4 Analysis results by work day

Figures 27–29 respectively show the SDNN, LF/HF ratio, and Lorenz plot area by workday for each participant. For ID_01, the LF/HF ratio was high and the Lorenz plot area was small on July 2, 6, and 7, suggesting the possibility of stress. For ID_02, the same tendency was observed on July 4, 26, and 28, suggesting that ID_02 experienced stress. The work shift on the above days was either early shift or regular shift, and the work was performed during the daytime. Therefore, it is considered that the mental burden of daytime work fluctuates greatly depending on the day.

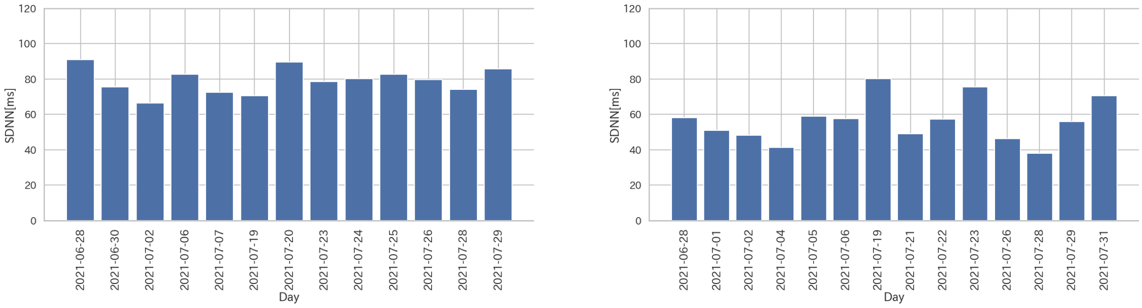
5.5 Discussion

5.5.1 Relationship between personality and stress indicators

In the previous section, we analyzed two caregivers. In Fig. 6, we focus on their personality traits. ID_01 tended to be high in conscientiousness and low in openness. People with high conscientiousness tend to be more self-controlled and focused but cautious.[26] ID_01 had a higher value for the REQ item of control (being able to decide what to do in one's leisure time) than for the other REQ items. Moreover, the value for the NASA-TAX item of effort (how hard people work on tasks) was higher for ID_01. On the other hand, ID_02 tended to have high values for extraversion and openness and low values for neuroticism. People with high extraversion tend to be cheerful and positive and those with low neuroticism tend to have low anxiety and depression. The positive mood score in the DAMS was higher than the depression or negative mood score for ID_02. These characteristics may have affected the results of the DAMS. In addition, the fact that both participants felt little mental stress when they took a break may also have affected their personality traits. The above results suggest that the subjective and objective stress indicators vary depending on the personality.

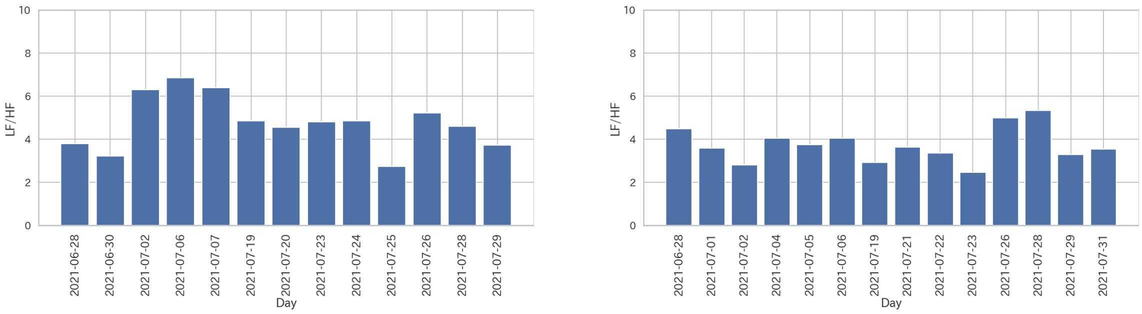
5.5.2 Comparison of subjective and objective stress indicators

The results of the analysis of objective stress indicators by care activity showed that ID_01 may have experienced stress during bed sheet changing and ID_02 may have experienced stress



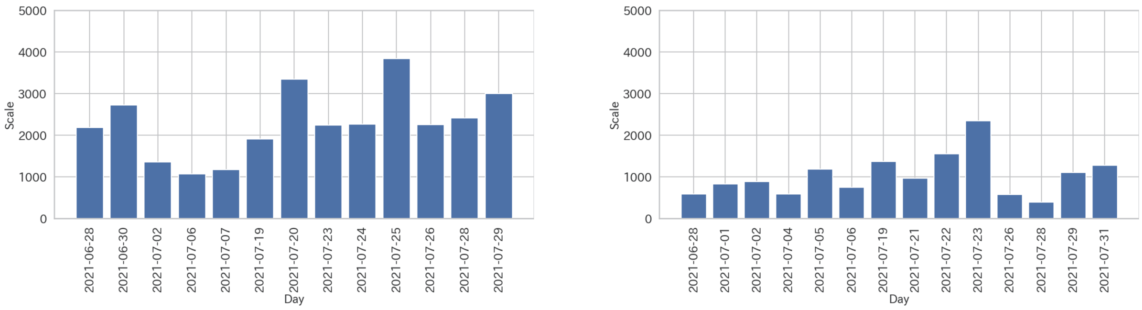
(a) (b)

Fig. 27. (Color online) SDNN by workday. (a) ID_01 and (b) ID_02.



(a) (b)

Fig. 28. (Color online) LF_HF ratio by workday. (a) ID_01 and (b) ID_02.



(a) (b)

Fig. 29. (Color online) Lorentz plot area by workday. (a) ID_01 and (b) ID_02.

during bathing assistance. However, these results did not clearly appear to be mentally stressful tasks in the subjective stress evaluation results. Conversely, the objective stress indicators did not indicate that the caregivers experienced stress even when they indicated care activities that were relatively stressful in the questionnaire. The results of the analysis of the objective stress indicators by work shift showed that ID_01 may have experienced stress in the early shift and regular shift, while ID_02 may have experienced stress in the early shift and on-duty shift. The results of DAMS and UWES did not change significantly for these types of work. This indicates that care activities and work shift that tend to be stressful on the basis of objective stress indicators do not necessarily coincide with the results of subjective stress indicators. This may be due to the inaccurate recording of care activity labels and the effects of external environmental factors. Therefore, while subjective stress can be used as a guideline for estimating objective stress related to care activities, it is not an absolute measure. One of the factors affecting the results is the movement of the caregiver. The WHS-3 heart-rate sensor used in this study is also equipped with an acceleration sensor. The acceleration data showed no significant changes in the care activity or work shift. In the future, we plan to analyze the effects of human movement and heart-rate variability on the basis of step count data and other data from wearable devices such as Fitbit.

5.5.3 Stress caused by recording activity and answering a questionnaire

We think that the application we implemented for recording care activity is highly convenient, as mentioned in Sect. 4.2. However, when the care activity to be performed is short, the caregiver needs to switch to the next care activity immediately, which causes cases where the caregiver forgets to input the next activity. When such cases occur frequently, we think that it may be stressful for the caregiver to operate the application to record the care activity. Thus, we will plan to consider addressing this problem by combining the care activity record platform using BLE beacons, which have been used in previous studies, with our application implemented in this study. By utilizing the care activity record platform, we can reduce the need to manually record care activity records, which will help prevent recording errors and reduce stress. Also, in the questionnaire, some participants forgot to answer on several occasions. This is thought to be due to the fact that the participants were so busy and stressed out that they did not have time to answer the questionnaires. In this case, data could not be obtained at times of high stress compared to those at times of low stress, and the data obtained could be biased. For this reason, we think that appropriate notification of questionnaire responses even during busy times and questionnaire design that allows simple responses are necessary; for example, we will plan to consider incorporating a questionnaire function into our application used to record the care activity implemented in this study.

6. Conclusions

In this paper, we focused on the psychological state of caregivers and aimed to obtain new knowledge to reduce their workload. To this end, we conducted a data collection experiment for a total of 28 days at a nursing home to investigate whether caregivers' psychological states are affected by their care activity, work style, workday, and personality. In the experiment, objective stress indicators, such as RRI and LF/HF ratio, obtained from the device and subjective stress indicators obtained from questionnaires were measured. Although some caregivers did not wear the device sufficiently or forgot to answer the questionnaire, we were able to collect data on the biological state of each caregiver for approximately 5 to 15 days. Furthermore, we analyzed and visualized objective and subjective stress indicators from the biological data of the two participants with the largest amount of data. As a result, although the objective indicators and subjective assessments did not necessarily coincide, we found that stress tended to increase for some specific care activities, work shifts, and workdays. It was also suggested that differences in the personalities of the caregivers themselves led to differences in the subjective and objective stress indicators.

To conduct a more general evaluation in the future, measurement experiments using a larger number of participants over a longer period at multiple nursing care facilities are needed. Also, there were some cases of nonresponse due to the large number of items in the questionnaire. Therefore, to increase the amount of data in the future, it is important to review the questionnaire and the targeted caregiving activities. Regarding devices for collecting stress indicator data, heart-rate sensors have the disadvantages of being time-consuming to wear and of being physically uncomfortable. Thus, we intend to examine whether it is possible to measure changes in mental and physical states using only wearable devices that are relatively easy to wear. Furthermore, we need to investigate the degree of data loss due to participants' mistakes, such as forgetting to push a button or answer the questionnaire, to improve our study. Finally, we plan to increase the amount of data through multiple collection experiments, construct a stress estimation model using these data as feature values, and clarify the relationship between the care activity and stress in more detail.

Acknowledgments

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