Analysis of Cognitive Stress Effects on Reliability of Participatory Sensing*

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Abstract. Thanks to the widespread of smart devices such as smartphones, participatory sensing which is a method of sensing and sharing information about the surrounding environment using the user's own device has been attracting attention. However, there is a problem that the quality of the data relies on the users' attitudes since they do not always give accurate and careful responses to participatory sensing tasks. In this study, we considered that the cause of the occurrence of careless responses in participatory sensing is not only the user's attitude toward the task but also the cognitive stress conditions surrounding the user (e.g., time-limit, ambient noise). In this paper, we investigated whether there is a difference in the ratio of correct answers and response status of a participatory sensing task under stressful conditions and under normal conditions. The results showed that the cognitive stress of noise and walking significantly reduced the ratio of correct answers, while the cognitive stress of walking and time-limit increased and decreased the answering time, respectively. After the experiment, we conducted a subjective evaluation questionnaire on the effects of stress environment conditions on the participatory sensing task. The results showed that the combination of multiple stressful environmental conditions often hindered or affected task responses, especially when the cognitive stress conditions were combined.

Keywords: participatory sensing · crowdsourcing · response reliability · satisficing · cognitive stress

1 Introduction

Smart devices such as smartphones and wearable devices equipped with sensing, computing, and networking capabilities are exploding in popularity. The

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widespread use of such devices has contributed to the realization of *participatory sensing*, a method of sensing and sharing information of surrounding environments using the user's own device [3]. Participatory sensing uses various sensors embedded in devices of ordinary users such as GPS, cameras, microphones, accelerometers, gyroscopes, hence, it has the advantage of eliminating the need to install sensors and enabling data collection from a wide range of locations. However, the amount of data that can be obtained depends on the number of people who contribute to sensing tasks in the target area, and the quality of the data relies on the users' attitudes since the user does not always give accurate and careful responses [1].

One of the risks to data quality in participatory sensing is careless responses. It is often explained in terms of *Satisficing* (minimization of effort), where a person does not pay an appropriate cognitive cost for a given task [8]. The term *satisfice* is a composite of *satisfy* and *suffice*, and refers to a cognitive heuristic in which the finite nature of human cognitive resources leads to a tendency to minimize effort in response to demands, and to determine and pursue procedures that satisfy the minimum necessary to achieve an objective [21]. The attitude of users to given task has been pointed out as one of the factors that cause Satisficing [14]. Gogami *et al.* have revealed the relationship between smartphone screen operation and Satisficing, and built the careless response detection model [7].

In the real world, users usually use smartphones under various conditions that combine obstructive factors (e.g., noise, walking conditions) and their mental factors (e.g., stress, mood). These factors affect smartphone operations, such as inducing a wrong operation [19, 6, 16, 17].

From the above, we considered the cause of a situation that a user gives a careless response is not only due to changes in the attitude and behavior of users, but also obstructive factors surrounding the user (Fig. 1).

The aim of this study is to investigate the effect of obstructive factors on response reliability in participatory sensing. In this paper, we focused on the "cognitive stress" among the obstructive factors, and conducted an experiment to investigate the relationship with response reliability. In the experiment, we give various cognitive stress conditions to participants when they perform a specific participatory sensing task (questions about human flow). To assess the reliability of users' responses, the correctness of the answer was used. In addition, smartphone logs (the embedded sensors data and touch panel operation logs of smartphones) were used to analyze the effects of the cognitive stress condition in users' responses. Based on these data, we analyzed whether there is a difference in the occurrence of careless responses under stressful and normal conditions, and whether the smartphone logs show any difference. The results showed that the cognitive stress of noise and walking significantly reduced the rate of correct answers. The results showed that the cognitive stress of walking and time-limit significantly reduced the answering time.

The organization of this paper is as follows. In Section 2, we outline the existing studies related to the proposed method. Section 3 describes the analytical

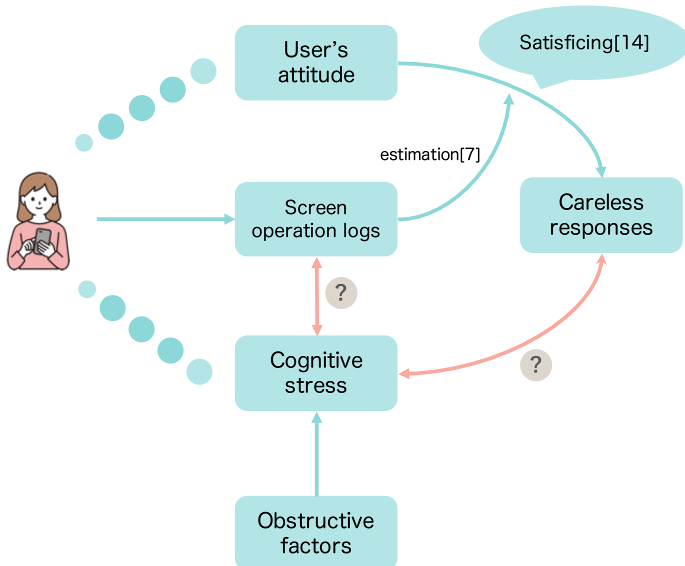

Fig. 1. Focus of this study

framework, Section 4 describes the setup of the survey experiment, Section 5 presents the experimental results and discussion, and Section 7 concludes the paper.

2 Related Work

Careless responses to questions in participatory sensing might make biases in the analysis results of the social surveys. Several studies have pointed out that there are many careless respondents, especially in web surveys. It is suggested that careless responses are caused by the attitude of trying to complete a questionnaire survey with the least effort, called *satisficing*, and there are several studies that have tackled to detect satisficing. The detail of these studies is described in Section 2.1.

In crowdsourcing, it has been shown that monetary incentives do not improve the quality of response results. We describe such a study in Section 2.2, which shows a method to inhibit careless responses in order to improve the quality of response data.

In addition, the influence of obstructive factors such as stress surrounding the user on user behavior is also discussed in Section 2.3, as similar research has been conducted.

Based on these literature surveys, the position of this research is shown in Section 2.4.

2.1 Detection of Careless Responses

Several methods have been proposed for detecting careless responses in questionnaire surveys. Miura *et al.* [14] have evaluated the efficiency and accuracy of the following methods of detecting careless responses: the Attentive Responding Scale (ARS) and the Directed Questions Scale (DQS) [10]. The ARS is the method that detects satisficing by scoring with two subscales: Inconsistency and Infrequency. Inconsistency is a measure of the difference in responses to questions that have similar meanings but different wording. Infrequency is a measure of the difference in the choice which many people will select in common sense and the choice actually selected by the user. The DQS is the method that some questions are inserted to instruct the user to make a choice. If the user does not follow the instruction, he/she is considered to be satisficing. However, the predictive power of the various detection indices is generally not high, and it is stated that it is more important to control the response environment or terminal depending on the survey content (for example, instructing respondents to answer on a PC from home if the survey includes video stimuli). In addition, since these indices are similar to trick questions, they direct suspicion to the respondents. This increases the psychological burden on the respondent and may result in careless responses.

Gogami *et al.* [7] have developed a logger which obtains the screen operation logs on smartphones, and proposed a careless response detection method in online surveys based on features derived from obtained log data. As the example of features, scrolling duration/speed/length, reverse scrolling, the number of option-changing, and text-deleting behavior have been newly employed. The result has shown new features contribute to the improvement of the accuracy of careless response detection in smartphone answer operation logs.

2.2 Suppression of Careless Responses

The crowdsourcing platforms, such as Amazon Mechanical Turk, have received increasing attention due to their ability to collect large data samples quickly and inexpensively [12]. Many studies have focused on how financial incentives in crowdsourcing affect the results of responses, and have shown that higher incentives for the same task increase the number of workers but do not improve the quality of the results [9, 11, 13]. On the other hand, volunteers have been shown to provide more reliable responses than crowdworkers who are given financial incentives, but they also have longer turnaround times and are more likely to not complete the task. Therefore, volunteer crowdsourcing is inappropriate for time-limit tasks [5, 2, 15].

2.3 Effects of Stress on Behavior of People

In the fields of behavioral science and psychology, there have been many studies on the effects of stress in various factors on human daily life. Stress has been identified as a factor that is likely to have an impact during mobile interaction [18].

Sarsenbayeva *et al.* [17] used the Trier Social Stress Test (TSST) to induce stress in participants and investigate the effects of stress on performance in three common mobile interaction tasks: target acquisition, visual search, and text entry. During stress induction, the access time and accuracy of the target in the target acquisition task and the completion time in the visual search task were significantly reduced compared to the baseline.

Davide *et al.* [4] used a non-invasive approach to measure human stress levels by acquiring data from devices (touch operation, touch accuracy, touch intensity, touch duration, user movement, acceleration) and comparing the results during task execution in a stress-free environment The results were compared between a stress-free environment and a stress-affected environment (device vibration, loud and unpleasant sound, unexpected device movement) during task execution. The results showed that stress affected acceleration, maximum and average intensity of touch, user movement and cognitive performance.

In addition, Schildbach *et al.* [20] focused on the background of the increasing number of people who operate cell phones while walking. They showed that walking, which can be an important environmental factor in mobile interaction, has a negative impact on tasks (target acquisition, text reading).

2.4 The position of this study

Conventional research on careless responses has mainly focused on people's attitudes toward a given task, but has not considered the effects of cognitive stress from the outside world (obstructive factors). In participatory sensing, which is the subject of our study, we assume that the accuracy of responses is strongly influenced not only by human attitudes but also by obstructive factors. In this paper, we investigate the effects of obstructive factors on responses in participatory sensing by inducing cognitive stress in the user during the execution of the task.

3 Analytical framework

3.1 Overview

In order to investigate the effects of obstructive factors on responses in participatory sensing, this experiment aims to analyze how the quality of responses and response behavior change when users are subjected to the multiple cognitive stress conditions described below. The following participatory sensing scenarios were used. In this experiment, the user was asked to answer a question about people walking on the road, which could be confirmed visually, while walking on the sidewalk. In the following sections, we describe the details of the analytical framework of the experiment.

3.2 Cognitive stress conditions

In this paper, we set up eight different cognitive stress conditions consisting of combinations of three different stress factors (answering under time-limit, answering in noisy environments, and answering while walking). These stress environment conditions were set to simulate actual situations in participatory sensing, such as answering in a limited time, noisy situations such as crowded urban environments, and situations in which a task is requested while moving. The details are shown below.

Cognitive stress due to time-limit: In general, *time-limit* are known to be stressful in performing any task. In the case of participatory sensing, time-limit is considered to be severe because the user is required to observe and report the ever-changing situation of the city (information about people walking on the road in the scenario assumed in this paper) in a small amount of time, such as waiting at a red light or at a meeting place. Therefore, time-limit is included as the first stress factor.

Cognitive stress due to environmental noise: Environmental noise was perceived negatively by participants, with many commenting that the noise distracted them and negatively impacted their task performance [19]. In participatory sensing, it is assumed that the user is continuously exposed to the hustle and bustle of the city and other unpleasant noises while performing the task. Therefore, noise (in this case, urban noise) is included as the second stress factor.

Cognitive stress due to body movement (walking): Walking negatively affects the performance of tasks (target acquisition, text reading) during interaction with mobile devices [20]. In the participatory sensing scenario that we assume in this paper, the user is on foot, and thus is expected to move and perform the task at the same time. For this reason, we include walking as the third stress factor.

3.3 Investigation metrics

As metrics that can be used in actual participatory sensing, we employ non-invasive data obtained from the device as follows.

Ratio of correct answers: In this experiment, we set a task in which the correct answer is uniquely determined, so the task answer rate is an index directly related to the reliability of the response. In this study, we hypothesized that the ratio of correct answers would change depending on the cognitive stress conditions.

Answering time: Stressed users rush through tasks, and that rushing through tasks results in lower task performance [17]. In this study, we hypothesized that the answering time would change depending on the given stress environment condition.

Table 1. Description of the devices used

Device	Main features
Smartphone (iPhone 11)	iOS 14.2 6.1-inch touchscreen (1792×828px) Accelerometer (100Hz)
Large monitor	42-inch
Speaker (BOSE Companion 20)	30W

Acceleration (user's movement): Using data obtained from the accelerometer built into the device, we analyze how much and how the user moves during the task in participatory sensing, and analyze the effect of stressful environmental conditions on the user's movements. Since a related study [4] has shown that stressed users tend to move more or move suddenly, we hypothesized that the user's movement would change depending on the given stress environment conditions (e.g., variation in acceleration and angular acceleration data).

Screen operation: The screen operation logs (e.g., single tap event, double-tap event, touched location on the screen) of the smartphone during task answering are obtained. We will analyze the influence of stressful environmental conditions on screen operation by obtaining the screen operation logs. In this study, we analyzed the effects of stress conditions on screen operations. In the present study, we hypothesized that there would be a difference in the operation in the application depending on the given stress environment condition.

4 Experiment

4.1 Outline of Experiment

Based on the defined analytical framework, an experiment was conducted with 20 high school and graduate students (age: 15-24 years old, gender: 19 males and 1 female) . This study was approved by the Ethical Review Committee for Research Involving Human Subjects at Nara Institute of Science and Technology (NAIST), and was conducted after getting written consent for experiment participation from the participants (Approval No.: 2020-I-16).

The in-the-wild experiment has the following issues for our study: (1) it was difficult to align the experimental conditions in outdoor environments (the difficulty level of the task can not be controlled), and (2) some of the cognitive stress environmental conditions can not be controlled (e.g., it is not able to remove noise). Therefore, we decided to conduct the experiment by constructing an indoor virtual environment. We used a windowless laboratory (21m^2) in a university as the experimental environment. A large monitor was used to display crowd images of the city, and several speakers were used to play the urban background noise virtually. The details of the equipment used in the experiment are shown in Table 1. For the crowd images used in the experiment, 24 photos

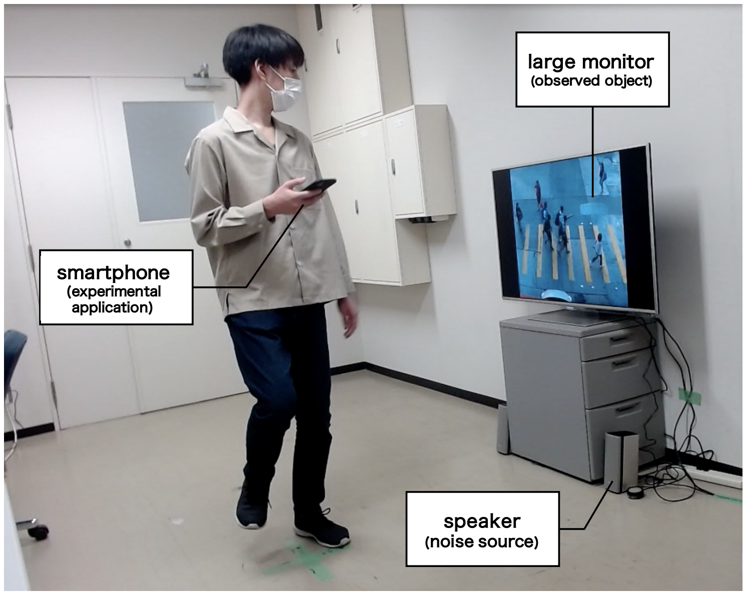

Fig. 2. The experimental environment

were selected from the CityStreet dataset [22]. Fig. 3 shows one of the example photos.

The specific task contents were set as follows according to the setting of the participatory sensing scenario in the analysis framework. These three questions are presented in a random order, and a part of the question text (indicated by "⇔") is also presented randomly.

- How many people are in the photo?
- How many people are walking in the direction of "right" ⇔ "left"?
- How many people are walking "on" ⇔ "out of" the crosswalk ?

the cognitive stress conditions were presented as a set of $2^3 = 8$ patterns as shown in Table 2, which were combinations of the presence and absence of three different stress items (time-limit, noise, and walking) set in the analytical framework. The time-limit was set at 10 seconds per question based on a preliminary survey of the time required to answer the above questions. For walking, we reproduced the actual walking by marching in place in front of the large monitor so that the participants could always see the monitor. In order to avoid order effects, these stress environmental conditions were presented to the participants in a random order.

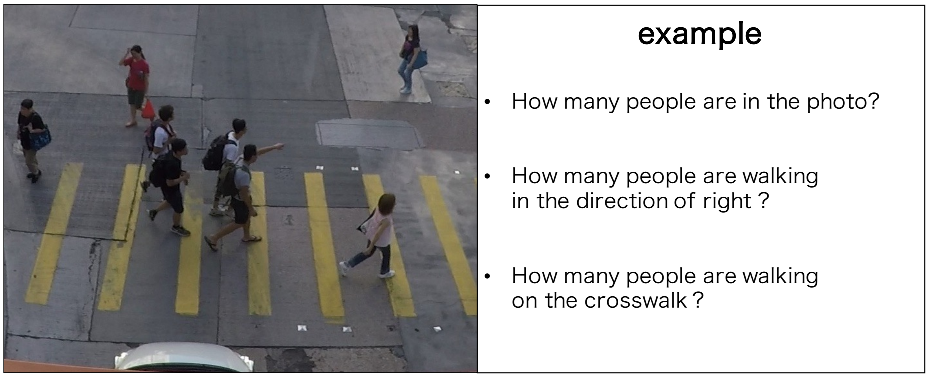

Fig. 3. Examples of crowd images used in the experiment and three questions [22]

Table 2. obstructive factor

Pattern	time-limit	Noise	Walking
Pattern 0	✓	✓	✓
Pattern 1	✓	✓	-
Pattern 2	✓	-	✓
Pattern 3	✓	-	-
Pattern 4	-	✓	✓
Pattern 5	-	✓	-
Pattern 6	-	-	✓
Pattern 7	-	-	-

4.2 Experimental Procedure

The experimental procedure is shown in Fig. 4 and below. The experiment took a total of about 30 minutes per participant, including preceding explanations.

procedure 1) Preceding explanation to participants
After entering the laboratory, the participants will get briefing in advance. After explaining the outline and purpose of the study, the participants are asked to fill out a consent form for participation in the study. Next, we explain the operation of the application to be used in the experiment (hereinafter referred to as the "experimental application"). Next, we explain the operation of the application used in the experiment (hereinafter referred to as the "experimental application"), and have the participants try out the task execution procedure once on the experimental application in order to become familiar with the operation. Finally, the type of stress to be induced is explained to the participants.

procedure 2) Performing the task
Perform the participatory sensing task as instructed by the experimental application. The operation procedure on the experimental application is shown in Fig. 4 and below.

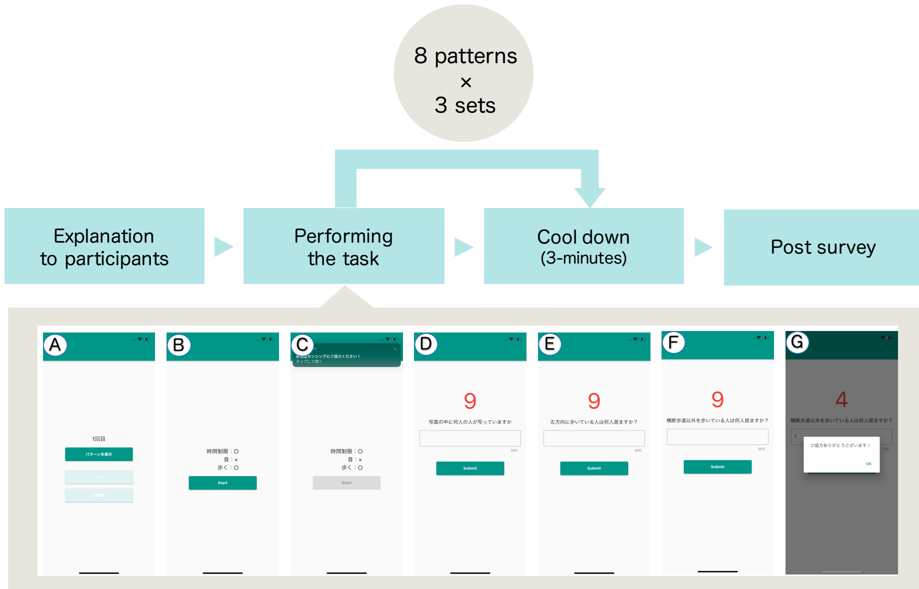

Fig. 4. Interface and operating procedure of the experimental application

(A) Move on to screen (B) by clicking the Pattern Display button. Resetting the order of patterns and setting user IDs, which are for identifying each participant, are also done on this screen.
(B) The cognitive stress conditions for the trial are displayed. After confirming the cognitive stress conditions, the participant press the Start button to start the experiment. Three seconds later, a notification from the experimental application is sent to the user's smartphone.
(C) Tap the notification message to go to screen (D).
(D-F) Task answer screen. When there is a time-limit, the time-limit (time remaining) is displayed as a red number. When the participant clicks the Submit button to submit his/her answer, the screen changed to the next. After answering the three tasks, the dialog shown in screen (G) is displayed.
(G) The Task Completion dialog box is displayed, and the experiment is completed. By clicking the OK button, the screen moves back to (A).

procedure 3) Cool down

In order to prevent the effects of the previous stress conditions, a 3-minute rest period is provided after the completion of procedure 2).

procedure 4) Repeat

Repeat procedure 2) to 3). In this experiment, three sets of eight patterns of the cognitive stress conditions × were used, for a total of 24 trials.

Table 3. ratio of correct answers and answering time for each pattern

	cognitive stress			ratio of correct answers (%)		Answering time (s)	
	Time	Noise	Walking	Avg.	SD	Avg.	SD
Pattern 0	✓	✓	✓	0.667	0.149	17.767	2.575
Pattern 1	✓	✓	-	0.672	0.127	16.450	2.375
Pattern 2	✓	-	✓	0.656	0.101	17.150	2.443
Pattern 3	✓	-	-	0.711	0.122	16.400	2.205
Pattern 4	-	✓	✓	0.617	0.142	18.050	2.249
Pattern 5	-	✓	-	0.667	0.140	17.150	2.775
Pattern 6	-	-	✓	0.706	0.116	17.083	2.205
Pattern 7	-	-	-	0.706	0.136	17.417	2.189

procedure 5) Post survey

After all trials are completed, a post-test questionnaire will be administered to the participants to provide a subjective assessment of the effects of the cognitive stress conditions on the participatory sensing task.

5 Experimental Results

In this Section, we present results on the effects of stress on participatory sensing participants based on their responses and smartphone logs.

5.1 Analysis of Results

In this section, we describe the results of the analysis of the evaluation indices. In this paper, only the results for the ratio of correct answers and the answering time will be discussed.

In order to examine the effects of the three types of stress items, a three-factor analysis of variance is conducted for each evaluation metric. To do so, we first averaged entire 480 data (8 patterns $\times 20$ people $\times 3$ times) along the times, to aggregate them into 160 data (8 patterns $\times 20$ people). A three-factor analysis of variance was then conducted based on the presence or absence of three stress items (noise, walking, and time-limit). The mean values of the ratio of correct answer and answering time for each pattern are shown in Table 3.

The results of the analysis of variance confirmed that noise and walking stress show a main effect (10% significant trend) on the ratio of correct answers. On the other hand, no interaction effect was found. These results indicate that the cognitive stresses of noise and walking cause differences in the ratio of correct answers. In other words, noise and walking stress degrade the ratio of correct answers.

For answering time, we found a main effect for walking (5% significance) and a main effect for time-limit (10% significance trend). In addition, we found an interaction (10% significant trend) of walking $\times$ noise. Therefore, we tested for a simple main effect of walking both with and without noise. We confirm by the results that, in the presence of noise stress, the presence of walking stress produces a significant difference (1% significant) in answering time.

These results indicate that walking and time-limit stresses lead to differences in answering time, i.e., walking and time-limit stresses lead to longer and shorter answering time, respectively. In addition, the results of a simple main effect test for noisy × walking indicate that stress due to walking increases the answering time in the presence of stress due to noise.

We also analyzed the acceleration and screen operation logs in the same way, and found no correlation between any of them.

5.2 Analysis Results by Post-questionnaires (subjective evaluation)

The results of the post-questionnaires answered by the experiment participants are shown in Table 4. The numbers below the column "Choices" indicate the number of respondents for each answer. In addition, the average of all the respondents' answers is shown as "Average Score" (1: no disturbance/effect – 4: great disturbance/effect). The higher the score, the more the cognitive stress conditions interfered with or affected the responses.

As a result, we confirmed high scores of 3.4, 3.0, and 2.9 for Pattern 0 with all stresses, Pattern 1 with time-limit and noise stress, and Pattern 2 with time-limit and walking stress, respectively. In addition, it can be confirmed that the score decreases with the relaxation of the cognitive stress conditions.

For each of the patterns 0 to 7, we asked the question *"Why did you think so?"*. Some of the collected answers are shown below.

- Pattern 0 (time-limit, noise, walking)
  - The noise did not affect me that much. Walking was a hindrance because of the increased eye movement. If the time-limit was shorter, I might have been impatient.
  - I had to pay attention to the time-limit, noise, and walking.
  - I felt a little distracted by the noise. It was a little difficult to count the number of people while walking because my vision was being shaken.
- Pattern 1 (time-limit, noise, no walking)
  - I felt urgent because of the time-limit while my concentration was hampered by the noise.
  - The time-limit made me feel impatient. The noise was not a good feeling.
  - When counting a large number of people, the time-limit made me panic. The noise did not bother me so much.
- Pattern 2 (time-limit, no noise, walking)
  - The eye movement takes a little time, so I thought it would have a slight effect.
  - When I counted a large number of people, I was in a hurry when there was a time-limit. I was not bothered by the walking movements.
  - I feel impatient and the display was hard to see.
- Pattern 3 (time-limit, no noise, no walking)

Table 4. Post-experiment questionnaire results (Did these cognitive stress conditions interfere with or affect your responses?)

	Cognitive stress			Choices				Average Score
	time	noise	walking	Never (1)	Not very often (2)	Some of the time (3)	Most of the time (4)	
Pattern 0	✓	✓	✓	0 (0.0%)	1 (5.0%)	11 (55.0%)	8 (40.0%)	3.4
Pattern 1	✓	✓	-	1 (5.0%)	1 (5.0%)	15 (75.0%)	3 (15.0%)	3.0
Pattern 2	✓	-	✓	0 (0.0%)	4 (20.0%)	14 (70.0%)	2 (10.0%)	2.9
Pattern 3	✓	-	-	3 (15.0%)	8 (40.0%)	8 (40.0%)	1 (5.0%)	2.4
Pattern 4	-	✓	✓	3 (15.0%)	8 (40.0%)	8 (40.0%)	1 (5.0%)	2.4
Pattern 5	-	✓	-	9 (45.0%)	6 (30.0%)	5 (25.0%)	0 (0.0%)	1.8
Pattern 6	-	-	✓	6 (30.0%)	10 (50.0%)	3 (15.0%)	1 (5.0%)	2.0
Pattern 7	-	-	-	20 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.0

  - Since there was no sound and no walking, I was able to answer calmly despite the time-limit.
  - There was relatively enough time to answer the questions, and it did not disturb my concentration on answering.
  - I was not bothered when there were only a few people to count, but when there were many, I panicked.
- Pattern 4 (no time-limit, noise, walking)
  - With noise and walking, I felt like I was using both my body and my brain.
  - Even if there was no time-limit, I might not be able to tell how many people were counted in my head because of the noise.However, walking did not affect me that much.
- Pattern 5 (no time-limit, noise, no walking)
  - It is difficult to know how many people were counted when there is noise.
  - Because there was no time-limit, I could count the number of people calmly. The noise did not bother me much.
- Pattern 6 (no time-limit, no noise, walking)
  - I did not feel rushed because there were no restrictions other than moving.
  - Because there was no time-limit, I could count the number of people calmly. I don't think the inclusion of walking movements had much of an impact.

- Pattern 7 (no time-limit, no noise, no walking)
  - I was able to answer the questions carefully because there was nothing to interrupt me.
  - Since there were no restrictions at all, I felt that it was most relaxing both physically and mentally.

As a whole, the respondents said that it was difficult for them to concentrate on answering when multiple cognitive stress conditions are overlapped. When the number of participants was small, the time-limit did not bother them, but when the number of participants was large, they felt rushed. As for the noise, the participants commented that it was used and affected their answers because they felt that it interfered with their concentration. As for the cognitive stress caused by walking, the participants commented that it did not bother them as much as usual because it was an experimental environment and safety was taken into consideration. In future experiments, we would like to devise ways to provide safe obstacles.

6 Discussion

The results of the experiment and post-questionnaire have suggested the combination of task type and the obstructive factor causes different cognitive stress. In this paper, we have assumed that obstructive factors induce emotional effects such as impatience and restlessness. However, the result has showed these factors cause changes of task difficulty in addition to that. For example, the task of crowd counting during walking requires paying attention than a normal situation, because the user needs to stabilize their gaze. The increase in cognitive costs for performing given tasks might result in careless responses. In future work, we will organize component elements of cognitive stress, and investigate the relationship between obstructive factors and them.

7 Conclusion

This study aimed to investigate the effects of environmental factors on the response reliability of participatory sensing by inducing the cognitive stress conditions in the user during the execution of the participatory sensing task.

In addition, we conducted a subjective evaluation of the effects of the cognitive stress conditions on the participatory sensing task after the experiment, and found that participants felt that the combination of multiple cognitive stress conditions interfered with or affected their task responses.

This experiment revealed that stress affects the ratio of correct answers and answering time even in a safe indoor experimental environment, which suggests that users may feel more stress in actual participatory sensing. In the future, we would like to test this hypothesis by conducting experiments in scenarios similar to real environments.

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