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Fundamental Deliberation on Exploring Mental Health through Social Interaction Pattern

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***Abstract*—In order to clarify the relationship between human social interaction and mental health, we measured face-to-face communication pattern for a few months and conducted a questionnaire on mental health in two organizations in real world. Face-to-face interaction data were measured using wearable sensing system in two organizations in Japan. We extracted some feature values from those two kind data and investigated correlation between them. In this study, we reconsidered social network centrality which means the connection strength between people. We classified the group size of simultaneous interaction and duration of interaction. As results, we found that these factors affected the correlation coefficients between face-to-face interaction and degree of stress.**

***Index Terms*—Data mining, Social interaction, Mental health, Social network analysis, Face-to-face interaction.**

I. Introduction

Deterioration of mental health is a quite serious problem. Depressive disorder could cause financial problem and suicide. In the previous researches of social psychology, the relationships between social relationship and mental health have been investigated [1]. For example, it was revealed that office layout arrangement encourages communication between employees and improves their work satisfaction [2]. Social interaction was indicated to be important to mental health.

Recent developments in wearable sensing technologies have enabled us to investigate characteristics of human behavior such as face-to-face interaction and speech activity in daily situation [3]. Olguin *et al.* measured human behavior and attempted to predict job satisfaction of employee using the data of human daily behavior [4]. To reveal the relationship between human behavior and psychological state has potential to help building better organization.

Behavioral-data-oriented approaches to individual mental health have been reported. Nakamura *et al.* found the relationship between temporal characteristics of human behavior and mental illness [5], [6]. Their findings suggest that depressed patients tend to remain in their physically resting state more than healthy people.

In some studies, the positive correlations between total amount of face-to-face interaction and positive mood were indicated [8]. However, what elements of face-to-face interaction improve individual psychological states? For example, the effect of interaction with one partner on mental health could be different from that of interaction with several people. In addition, the duration of each interaction between people could affect the relationship between social interaction and individual mental health. Microscopic structure of face-to-face interaction had not been in consideration in previous studies although we also revealed the relationship between mental health and social interaction measured in real world [7].

The purpose of this research was to investigate the relationships between social interaction and mental health. Especially, we focused on the microscopic, spatio-temporal structure of face-to-face interaction. We used two sets of social interaction data measured in Japanese organizations. Our data are unique in that they were records of face-to-face interaction, measured by using a wearable sensing device for over one month.

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TABLE I
THE ORGANIZATIONS WHERE THE MEASURES WERE CONDUCTED. THE NUMBER IN PARENTHESES IS THE NUMBER OF ELDERLY USERS IN ORG. B.

	Number of participants	Number of valid answers	Number of valid days	Category of organization
Org. A	136	57	34 days	Consulting firm
Org. B	50 (36)	49 (35)	27 days	Care home for the elderly

II. METHODS

A. Data

To investigate the characteristic of social interaction in real world, we analyzed two sets of face-to-face interaction data provided by the World Signal Center, Hitachi, Ltd., Japan. The first set of data was measured in a Japanese consulting firm (Org. A). In Org. A, 136 members participated in the measurement. The second was a Japanese care facility for the elderly(Org. B). In Org. B, 50 members participated in the measurement. The members in Org. B were separated into two different groups: staff and elderly users. All members participated were asked to answer the questionnaire on their mental health. The data were collected anonymously and analyzed. The summary of organization is shown in Table I.

B. Social interaction

1) Measurement method: In order to measure face-to-face interaction behavior of participants, we used the Business Microscope, which was a wearable sensing device developed by the Central Research Laboratory, Hitachi, Ltd [3]. The device could detect physical proximity between people. The device was equipped with an infrared sensor, and its shape was similar to a name tag as shown in Fig. 1. Every participant wore the sensor around the chest while they stayed in their organization. The infrared sensor could detect face-to-face contact between participants if they were within 2 m of one another. The sensor only sensed the other within a 120° circular area in front of the participants. The time resolution of the device was equal to 1 minute.

2) Analysis method: We analyzed face-to-face interaction data mainly from two different perspectives. First, we calculated network centrality of individual from face-to-face interaction data, aiming to reveal individual characteristics in the social network. This perspective focused on temporally macroscopic tendency of individual because the data were summed up for the whole period. Second, we proposed the new extended network centralities for further investigation. This perspective focuses on relatively microscopic structure of social interaction between individuals.

a) Network centralities: Network centrality determines the relative importance of a node within a social network. Nozawa *et al.* applied network centralities for social interaction analysis [9]. In the same manner as the previous study, we regarded the amount of social interaction between participants as connection weight in the social network. For instance, if the total face-to-face contact time between the participant and j was 100 (min), the connection weight between i and j was regarded 100, denoted as f_{ij}. Mathematical definition of f_{ij} is shown in equation (1). $a_{ij}(t)$ denotes whether i and j met at time t. $a_{ij}(t)$ took value of zero or one. Then, $a_{ij}(t)$ was summed up for all the period of the experiment.

$$f_{ij} = \sum_t a_{ij}(t) \tag{1}$$

However, these values were not available as a weighted edge because the sensor-wearing time were dependent on the participants. To overcome individual difference, a normalized

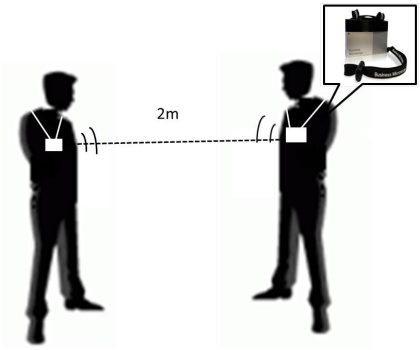


Fig. 1. Device used in the measurement of social interaction. The Business Microscope equipped an infrared sensor and detected face-to-face contact between participants only if they were within 2 m and facing each other.

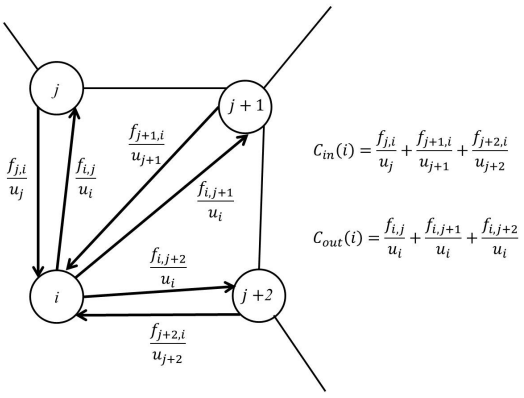


Fig. 2. This is an example of the calculation of social interaction feature values. C_{in} means how often the person i has been required to contact from other people. C_{out} means how much of one's time the person has dedicated to social relationship.

TABLE II
EXAMPLES AND SUBSCALE FOR STRESS CHECK LIST SCALE (SCL) AND QUALITY OF LIFE SCALE (QOL). EACH SUBSCALE HAS FIVE QUESTIONS. EXPRESSIONS OF EACH QUESTION WAS SLIGHTLY CHANGED.

Psychological Scale		Subscale	An Example of Statements
Stress Check List (SCL)	Psychological Stress	Obsession	Obsessed with things
		Inattention	Worried about carelessness
	Social Stress	Interpersonal Avoidance	Feeling worried about meeting someone
		Interpersonal Nervousness	Feeling nervous to meet someone
	Physical Stress	Tired Feeling	Feeling tired
		Sleep Disorder	Trouble falling asleep
Quality of Life (QOL)		Life Satisfaction	Satisfied with your life
		Motivational Life	Having dream for your future

matrix G was adopted as an adjacency matrix for analysis.

$$G = [g_{ij}] = \left[\left(\frac{f_{ij}}{u_i}\right)\right] \tag{2}$$

This matrix G was obtained by dividing each row of $F = [f_{ij}]$ with u_i, where u_i represents the total sensor-wearing time of participant i. In other words, u_i is the total time that the participant i stayed in the organization.

We calculated in-degree centrality C_{in} and out-degree centrality C_{out} using G. These centralities characterize the quality of each participant in the social network [9]. In-degree centrality C_{in} was calculated using the equation (3).

$$C_{in}(i;G) = \sum_j g_{ji} = \sum_j \frac{f_{ji}}{u_j} \tag{3}$$

C_{in} means how often the person has been required to contact from other people. Out-degree centrality C_{out} was calculated using the equation (4).

$$C_{out}(i;G) = \sum_j g_{ij} = \frac{1}{u_i}\sum_j f_{ij} \tag{4}$$

C_{out} means how much of one's time the person has dedicated to social relationship. An example of calculation of C_{in} and C_{out} is shown in Fig. 2.

b) Extended network centrality: For further investigation, we proposed the new classification of network centralities. We classified network centrality from two viewpoints. First, we proposed a classification of social interaction by the number of people gathering at the same time. Especially in social interaction in real society, people often spend their time as groups. We focused on this phenomenon. F_n is a classified adjacency matrix calculated using the equation (5), where n represents the number of people gathering at the same time.

$$F_n = [f_{ij,n}] \tag{5}$$

If there is an interaction with the number of people n, then edges are added cumulatively in F_n. That is, F_n was the network of face-to-face interaction with n participants. G_n was obtained by dividing each row of F_n with u_i. $C_{in,n}$ was a extended network centrality calculated using the equation (6)

$$C_{in,n}(i;G_n) = \sum_j g_{ji,n} \tag{6}$$

$C_{out,n}$ was calculated in the same way as the equation (4) using G_n instead of G.

The second was classification by the duration of face-to-face communication. F_t is a classified adjacency matrix calculated using the equation (7), where *t* represents the duration of face-to-face interaction.

$$F_t = [f_{ij,t}] \tag{7}$$

If there is an continued interaction for *t* minutes, then edges are added cumulatively in F_t. That is, F_t was the network of face-to-face interaction for t minutes duration. G_t was obtained by dividing each row of F_t with u_i. $C_{in,t}$ is a extended network centrality calculated using the equation (8)

$$C_{in,t}(i;G_t) = \sum_j g_{ji,t} \tag{8}$$

$C_{out,t}$ was calculated in the same way as the equation (4) using G_t instead of G.

C. Mental health

1) Participants and measurement periods: A questionnaire to measure mental health was conducted in each organization. In Org. A, 57 valid responses were obtained from 136 participants. In Org. B, 49 valid responses were obtained from 50 participants.

2) Measurement method: In this research, the Mental Health Pattern (MHP) scale developed by Hashimoto *et al.* was adopted for the contents of questionnaire [10], [11]. The MHP scale contains degree of stress and degree of life satisfaction. The Stress Checklist (SCL) scale and Quality of Life (QOL) scale were used to measure. The SCL scale has six subscales. QOL scale has two subscales. Examples of statements are shown in Table II. We used five questions with each subscale. For each question, the participant selected from four options: *strongly agree*, *agree*, *disagree* and *strongly disagree*. The answers were scored from four points (strongly agree) to one point (strongly disagree). The answers of questionnaires were summed up with each scale.

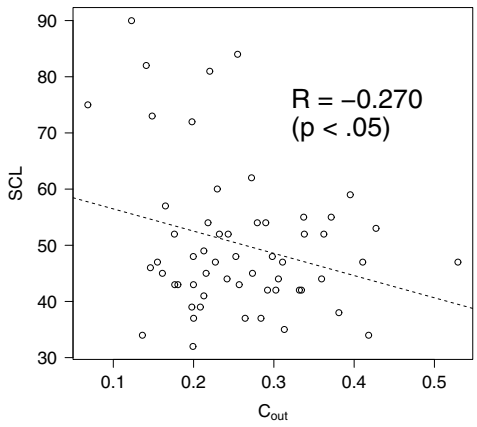
III. RESULTS

A. Network centralities

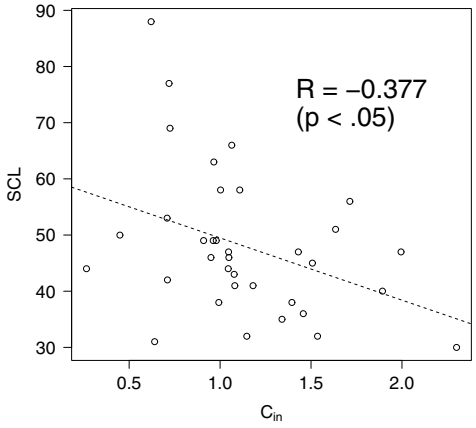
We found statistically significant correlations between network centralities and individual mental health. Significant negative correlation between C_{out} and SCL was observed in Org. A ($p < .05$). This result suggest that people who dedicated their time to interaction tend to have less stress. A significant negative correlation between C_{in} and SCL was observed in the cluster of elderly users in Org. B ($p < .05$). This result suggests that people who received relatively much time for interaction from other people tends to have less stress. Diagrams describing the relationship between social interaction and degree of stress are shown in Fig. 3. Fig. 3(a) shows the results of C_{out} and SCL in Org. A. The x-axis is C_{out} and the y-axis is SCL. Fig. 3(b) shows the results of C_{in} and SCL of elderly people in Org. B. The x-axis is C_{in} and the y-axis is SCL.

B. Extended network centrality

Correlation coefficients between $C_{out,n}$ and SCL of Org. A are shown in Fig. 4(a). The x-axis represents $C_{out,n}$ changing with n. The y-axis represents correlation coefficients between $C_{out,n}$ and SCL. There is a peak at $C_{out,3}$. Correlation

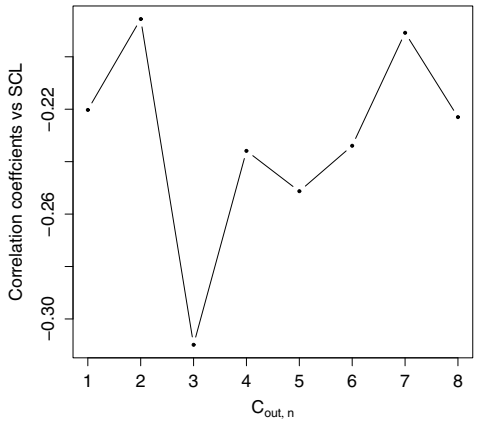


(a) Scatter diagram of C_{out} and SCL (N= 57, in Org. A).

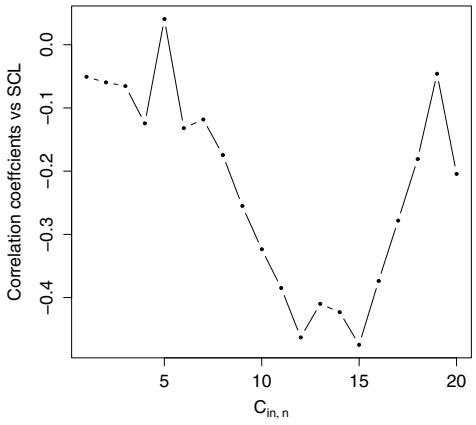


(b) Scatter diagram of C_{in} and SCL (N=35, elderly users in Org. B)

Fig. 3. Scatter diagrams between characteristics of social interaction and degree of stress.

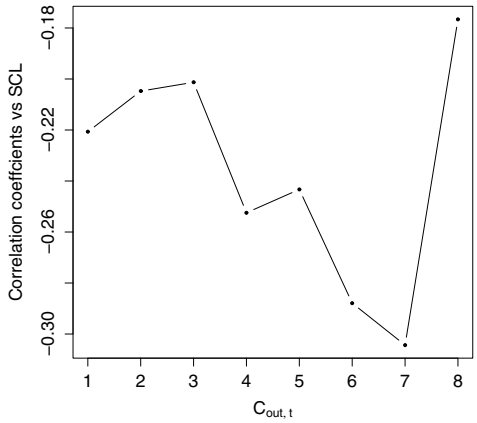


(a) Correlation coefficients $C_{out,n}$ vs SCL (N=57, Org. A). A peak of correlation at $C_{out,3}$ was observed.

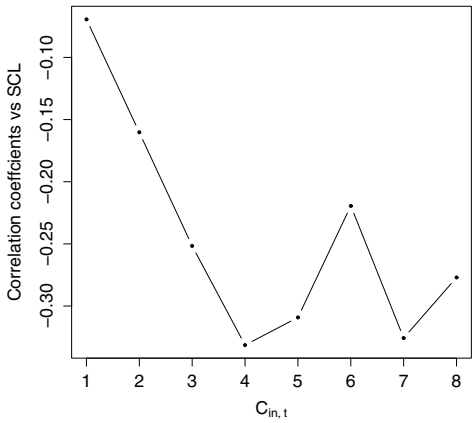


(b) Correlation coefficients $C_{in,n}$ vs SCL (N=49, Org. B). Peaks of correlation at $C_{in,12}$ and $C_{in,15}$ were observed.

Fig. 4. Variation of correlation coefficients showing the relationship between the number of simultaneous interaction and degree of stress.



(a) Correlation coefficients $C_{out,t}$ vs SCL (N=57, Org. A). A peak of correlation at $C_{out,7}$ was observed.



(b) Correlation coefficients $C_{in,t}$ vs SCL (N=49, Org. B). Peaks of correlation at $C_{in,4}$ $C_{in,7}$ were observed.

Fig. 5. Variation of correlation coefficients showing the relationship between the duration of interaction and degree of stress.

coefficients between $C_{in,n}$ and SCL of Org. B are shown in Fig. 4(b). The x-axis represents $C_{in,n}$ changing with n. The y-axis represents correlation coefficients between $C_{in,n}$ and SCL. The shifting pattern of correlation showed concave upward. There is also rough peak around $C_{in,12}$. It should be noted that each organization had different peak relating to mental health.

Correlation coefficients between $C_{out,t}$ and SCL of Org. A are shown in Fig. 5(a). The x-axis represents $C_{out,t}$ changing with t. The y-axis represents correlation coefficients between $C_{out,t}$ and SCL. There is a peak at $C_{out,7}$. Correlation coefficients between $C_{in,t}$ and SCL of Org. B are shown in Fig. 5(b). The x-axis represents $C_{in,t}$ changing with t. The y-axis represents correlation coefficients between $C_{in,t}$ and SCL. The shifting pattern of correlation showed concave upward. There are also peaks at $C_{in,4}$ and $C_{in,7}$.

In addition, we observed an interesting relationship between extended network centralities and QOL although we had to omit the diagram of QOL for want of space. Although the correlation coefficient was not statistically significant, extended network centrality, consisting of a unit of interaction duration for six minutes was the most positively correlated to QOL.

IV. DISCUSSION

First, the results showed that the total amount of social interaction was correlated to individual mental health. Network centralities C_{out} and C_{in} showed significant negative correlation to SCL in both organizations. The amount of face-to-face interaction was indicated to relate to mental health. The results were consistent in both organizations. Second, for further investigation, we proposed to extend network centrality. Extended network centralities, consisting of a unit of simultaneous interaction with several people were the most negatively correlated to SCL. We observed the peak of correlation at three members in Org. A and at twelve members in Org. B. Also, extended network centralities, consisting of a unit of duration of interaction for several minutes were the most negatively correlated to SCL. We observed the peak of correlation in the duration of interaction for seven minutes in both organizations. It is interesting that every organization had a peak in correlation between mental health and the total amount of a certain unit of social interaction. These results suggest that the group size of interaction and duration of interaction affect the individual mental health.

In previous studies of social psychology, the relationships between social relationship and individual mental health have been investigated. The measurement of social relationship was mainly based on self-reports. Development of wearable sensing technologies in recent years enabled us to capture the exact time of interaction and the evolution of conversation partner in the real world. Using these technologies, we attempted to clarify the relationship between objectively measured face-to-face interaction and mental health. As results, we actually found the significant correlation between them [7]. These results suggested that the social relationship mentioned in previous studies relates to the total amount of objectively measured face-to-face interaction.

In the previous studies, the structure of face-to-face interaction had not been in consideration. For example, Moturu *et al.* revealed that the social cohesion is related to individual mood [8]. However, the temporally microscopic structure of face-to-face interaction was not considered in their research. The

new extended network centrality indicated the importance to consider the duration of interaction and number of people gathering at the same time. Findings in this research could be applied for revealing the mechanism of characteristics of human. In the previous studies of social psychology revealed that an open space layout encouraged communication between employees and improved their work satisfaction [2]. For example, to consider the duration of interaction and number of members of interaction, it could be revealed what kind of communication contributes the improvement of the employees' satisfaction.

Here, we describe the application and the limitation of the findings in this research. We assume that findings in this research could be applied for evaluating a team or an organization. For example, we might be able to evaluate individual mental health through objectively measured social interaction. However, we still have problems to apply findings in this research. We did not consider individual characteristics such as sex, age, and employment position. We should also consider that the data were all collected in Japanese organizations. Deeper and large investigations must be done in the future work.

V. CONCLUSION

In order to explore the relationship between objectively measured social interaction and individual mental health, we conducted a correlation analysis between the amount of social interaction and mental health. Significant negative correlations between the amount of social interaction and stress degree were observed. This result implies that people who interact with others relatively tended to have less stress.

We reconsidered the social network centrality which means the social connection among people. We proposed the new extend network centralities in order to classify the meeting situation. We found that extended network centralities consisting of a unit of simultaneous interaction with certain number of people were the most negatively correlated to degree of stress in each organization. Also, we found that extended network centralities consisting of a unit of duration of interaction for seven minutes were the most negatively correlated to degree of stress. The group size and duration of interaction were indicated to be related to individual mental health.

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