Individual Differences in Office Comfort: What Affects Comfort Varies by Person

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Abstract. In the present research, we investigated the factors that affect comfort in the office and individual differences therein. Aside from meta-analysis research, factors that affect comfort were investigated individually (such as thermal factors, lighting, air pollutants, and so on), and the relative importance or relationship between them has not been investigated directly. We conducted a two-week survey in a corporate office and gathered 2075 responses from occupants. For data collection, we applied a method that combined experience sampling method with the evaluation grid method, which allowed us to gather a lot of data in daily situations. The results revealed that subjective comfort was evoked by various factors such as thermal factors, light, sound, inside, and so on. Subjective comfort did not show a significant correlation with the objective thermal comfort index (predicted mean vote; PMV), and subjective productivity was correlated with subjective comfort but not with objective comfort. These results indicate the importance of subjective factors in addition to objective factors. In addition, the 147 occupants were divided into three clusters (inside cluster, balanced cluster, and thermal cluster), each of which had different characteristics indicating the individual differences in components of comfort. In the present research, we succeeded in the reproduction of our previous research, which was conducted in a different season, emphasizing the validity of the present results.

Keywords: Office environment · Comfort · Wellness · Productivity · Individual differences

1 Introduction

In artificial environments, such as offices, houses, and classrooms, people interact with the environment by various means to make it comfortable, such as by turning the air conditioner up/down, wearing other clothes, or opening windows in the room. These activities are induced by the environment and in turn change some aspects of the environment. For example, on a cold morning, office workers will turn on the heater as soon as they arrive at the office. Maybe in the afternoon, the heated up air will make them open the window to ventilate.

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Even when some people feel comfortable in an environment, others may feel uncomfortable for some reason, which results in different reactions across people. Some people might feel that a place is cold, whereas others feel it to be neutral. Some may prefer environments with more noise than others. These individual differences make it difficult to realize a comfortable environment for all people and indicate that different components of comfort exist for each person.

Especially in the office environment, where occupants spend a large part of the day, comfort is an important factor. The importance of office comfort can be seen in WELL certificate [1], which was founded to facilitate comfortable buildings. In addition, comfort is closely related to the productivity of the occupants. Otherwise (or at least if the companies do not recognize it), they will not spend a lot of money to satisfy their employees.

To realize a comfortable environment for each person, it is important (1) to investigate the components of the comfort and (2) to reveal the individual differences in this. In the present study, we investigated the components of comfort in an office and examined individual differences by combining the experience sampling method [2] with the evaluation grid method [3]. We also discuss the relationship between comfort and office productivity. This study is a reproduction of our previous study conducted in November 2018 with 23 participants [4]. The purposes of the reproduction were (1) to test the seasonal effects on comfort and make the results more valid and (2) to investigate the characteristics of individual differences with a larger sample size.

2 Related Studies

2.1 The Effect of Environment on Its Occupants

Many studies about the relationship between an environment and its occupants were conducted according to models in which the physical factors of the environment (independent variable) affected the mental states of the people within it (dependent variable). Among the various environmental factors that affect indoor comfort, the most significant one is the thermal factor (e.g., [5]). Thermal factors affect not only comfort but also motivation and productivity [6]. Another study focused on the physiological aspects of thermal comfort. Low- and high-frequency ratios of heart rate variability may be used to predict thermal comfort [7]. This kind of approach is especially useful with wearable devices [8].

An objective index that measures thermal comfort is predicted mean vote (PMV) [9]. PMV is a scale that predicts the psychological evaluation of the thermal state in an environment, and it is used worldwide [10]. The PMV is calculated using thermal parameters (air temperature, mean radiant temperature, relative air velocity, and vapor pressure in the ambient air) and human parameters (activity level and thermal resistance of clothing), and it is represented on a scale from −3 (cold) to 3 (hot) via 0 (neutral). The PMV corresponds to the predicted percentage of dissatisfied (PPD) [11]. When the PMV is 0, 5% of the people in the environment are dissatisfied with it. When the PMV is 0.5 or −0.5, and 3 or −3, 10% and 80% people are dissatisfied with the environment, respectively.

As well as the thermal factors, various factors affect comfort. These factors include visual factors, sound factors, and indoor air quality. Visual factors usually refer to light. Lighting affects not only psychological health and productivity [12] but also other environmental factors such as perceived temperature and air quality [13]. In addition to the lighting, environmental features perceived through vision affect occupants. For example, ceiling height and wall color change occupants' way of thinking [14] and mood [15].

The environment's effect on occupants varies among people. Sex is one factor that causes individual differences [16, 17]. The "neutral" temperature for a Japanese male is 24.3 °C, whereas the neutral temperature for a Japanese female is 25.2 °C [17]. This difference between males and females in thermal preference was also found in another study [18]. Race can also cause individual differences. A previous study found that the neutral temperature for a non-Japanese male was 22.1 °C. Psychological characteristics can cause individual differences in task performance. A positive mood induced by wall color improved task performance more in participants whose performances were better than average [15].

Even if an environment is consistent, the environmental effects on the people there may change chronically. Being in the same environment for a certain period of time can change how one perceives the environment. One study revealed that taking a rest after bathing decreased the arousal score of participants over time [19]. Another study revealed that although indoor air quality affected the people inside, those who stayed in the environment longer became insensitive to it [20].

3 Components in the Office and Individual Differences in Them: Examination Using the Combination of Experience Sampling Method and Evaluation Grid Method

3.1 Method

Participants. We asked 208 office workers to participate in the study. Among them, 178 (155 males and 23 females) agreed to participate. Their average age was 40.9 (ranging from 24 to 66). All office workers had been working in a common room (2,704 m^2) and participated in the study there. They each had their own desks in the room.

Tasks. In this study, we asked the participants to provide their sequential staying time at their desk, their subjective comfort and the factors that affected it, and their subjective productivity.

The participants reported their sequential staying time by choosing one of the following options: 1: shorter than 5 min, 2: from 5 to 10 min, 3: from 10 to 30 min, or 4: longer than 30 min.

They then responded about their subjective comfort. First, they rated how comfortable their indoor environment was on a scale from 1 (very uncomfortable) to 7 (very comfortable) (subjective comfort). Afterward, they reported up to three factors that affected their subjective comfort (comfort-evoking factors). They also rated how pleasant/unpleasant and how activated/deactivated the factors were in general; this question was asked based on Russell's core affect model [21]. In addition, they rated what kind of factors affected their subjective comfort. These questions were asked with the idea of the evaluation grid method [3]. In the original evaluation grid method, the data are collected through interviews. First, the interviewer asks the interviewee (the participant) to compare items and select which one is better. Then, the interviewer asks the interviewee, "Why is this one better?" and extracts an abstract value judgement. The interviewer also asks the interviewee, "What is needed for the item to be xxx?" and extracts objective understandings for the items. These responses are summarized and represented as a construct system. In the present study, we simplified these procedures to implement it on the Web and gather multiple responses.

The participants also rated their subjective productivity. They were asked to respond to the question, "How would you rate your present work efficiency if your maximum work efficiency in the most proper environment corresponds to 100?"

Procedure. The experiment was conducted during the ten weekdays from April 10, 2019, to April 23, 2019. Over these days, we sent e-mails to the participants five times a day (at 10:00, 11:45, 13:30, 15:15, and 17:00) and asked for a response to the questionnaire in Google Forms. Specifically, we asked participants to respond to the questionnaire at least three times each time. All e-mails were received in the office by the participants, and participants responded to the questionnaire there. During the study, we measured the PMV in the office using HD32.3 (Delta OHM). The present study was conducted according to Kwansei Gakuin University regulations for behavioral research with human participants.

3.2 Results

Basic Data

Response Rate. The number of valid responses gathered in the present study was 2075. The number of responses on each day and at each time is provided in Tables 1 and 2. Many of the responses were given in the earlier part of the study. Regarding response time, many of the responses were given just after the e-mail that asked for the response.

PMV, Comfort and Productivity. Tables 1 and 2 show the participants' PMV, comfort, and productivity changes in this study. PMV was relatively stable, between 0 and 0.5, indicating a stable and comfortable temperature in the office. Comfort and productivity were also stable throughout the study. Although there is a V-shaped decrease and increase from 8:00 to 10:00, the responses were quite few (less than 0.5% of all responses).

Table 1. Daily changes in the indices (numbers in the round bracket indicate *SE*s)

Day	Number of responses	Average comfort	Average productivity	Average PMV
April 10th	400	4.25 (0.06)	71.46 (0.79)	0.40 (0.01)
April 11th	370	4.44 (0.07)	71.39 (0.87)	0.40 (0.01)
April 12th	290	4.35 (0.07)	72.75 (0.93)	0.41 (0.01)
April 15th	269	4.22 (0.07)	68.38 (0.99)	0.45 (0.01)
April 16th	221	4.50 (0.08)	70.71 (1.02)	0.29 (0.02)
April 17th	150	4.45 (0.10)	71.89 (1.28)	0.38 (0.02)
April 18th	127	4.49 (0.10)	71.78 (1.44)	0.38 (0.02)
April 19th	59	4.61 (0.18)	71.07 (2.39)	0.43 (0.03)
April 22nd	114	4.36 (0.13)	70.79 (1.66)	0.33 (0.02)
April 23rd	75	4.44 (0.13)	70.33 (1.84)	0.39 (0.02)

Table 2. Hourly changes in the indices (numbers in the round bracket indicate *SE*s)

Time	Number of responses	Average comfort	Average productivity	Average PMV
08:00	1	5.00 (0.00)	80.00 (0.00)	0.49 (0.00)
09:00	9	3.56 (0.59)	54.22 (11.52)	0.46 (0.05)
10:00	390	4.43 (0.06)	72.03 (0.84)	0.39 (0.01)
11:00	302	4.50 (0.07)	73.91 (0.87)	0.41 (0.01)
12:00	224	4.54 (0.08)	71.42 (1.05)	0.42 (0.01)
13:00	254	4.29 (0.08)	69.11 (1.16)	0.43 (0.01)
14:00	144	4.24 (0.10)	69.80 (1.29)	0.38 (0.02)
15:00	320	4.15 (0.07)	70.28 (0.84)	0.37 (0.01)
16:00	74	4.41 (0.15)	70.78 (1.82)	0.33 (0.03)
17:00	357	4.41 (0.06)	70.72 (0.81)	0.35 (0.01)

Subjective Comfort and Factors That Affect it. Figure 1 represents the evaluation structure of the 11 participants who were selected from the beginning of participants' ID numbers. We used only part of the data because all data are beyond the limitations of the processing capability of the software that we used in the analysis [22]. As in the previous study that we conducted in November 2018, factors that relate to thermal aspects, sound, light, and indoor environment were extracted. Factors that were not extracted in the previous study include wet clothing, work, and pollen. These factors might have been extracted as a result of weather and seasonal changes.

Figure 2 represents the characteristics of the factors that affect comfort. The factors in Fig. 2 are the ones that were listed by the participants more than 20 times (words that seem to represent close meaning were not categorized into one item, and similar words appear in Fig. 2, e.g., silent, tranquility, and silent around). The most frequent factor that affects comfort is "moderate temperature," followed by "silent," "brightness," "noise," "fatigue," and "sleepiness." These factors include not only physical factors (thermal, sound, and light) but also mental factors of the occupants. In addition, the

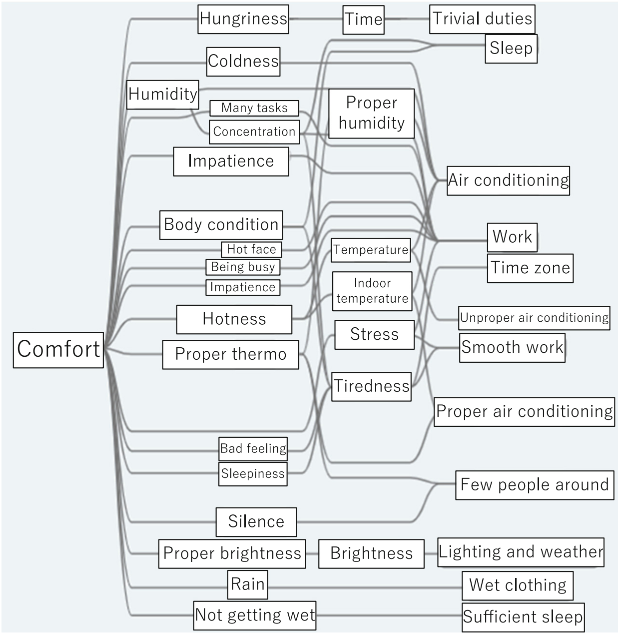

Fig. 1. Evaluation structure on office comfort

valence (pleasant/unpleasant) and arousal (activated/deactivated) varied across factors, indicating the complex effects of the occupants' comfort.

Classification of the Participants. Then, to consider the individual differences among occupants, we conducted cluster analysis based on their responses.

Classification Method. First, we classified the participants' comfort-evoking factors into six categories: thermal factors (52.4% of all responses, e.g., hot, moderate temperature…), sound factors (15.8%, e.g., noisy, silent…), light factors (4.0%, dazzling, dim), inside factors (19.6%, e.g., hungry, sleepy, concentration, body condition, emotion…), work factors (1.8%, e.g., deadline, progress of work…), and other factors (6.4%, e.g., few people around, someone is coughing…). These categories were derived from our previous data and the present data. The classification was conducted by two dependent raters, who were unaware of the purpose of the study. The kappa coefficient was 0.85, indicating almost perfect agreement [23]. When the evaluations by the two raters were different, a third rater evaluated the response.

We conducted clustering analysis based on the relative frequency of the comfort-evoking factors with Ward method. We analyzed data from 147 participants, who had responded to the questionnaire more than four times. We applied three factors, based on the number of each cluster and cluster stability. The demographic features of each

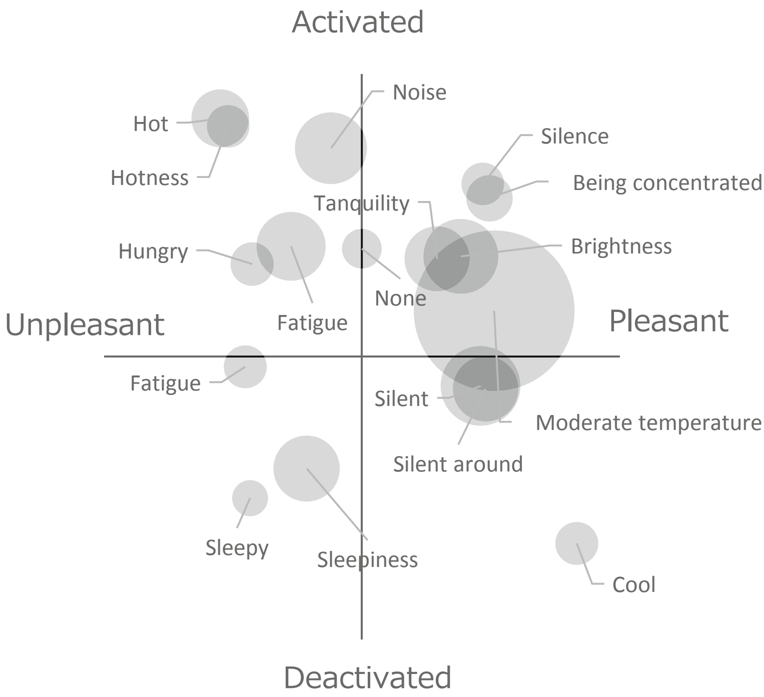

Fig. 2. Circumplex of the factors that affect office comfort (The size of the circle indicates the times of the response of the item)

cluster are represented in Table 3, and the average relative frequency is represented in Fig. 3. A one-way ANOVA of occupants' comfort, productivity, and PMV was conducted. Cluster 1 showed lower comfort and productivity than clusters 2 and 3 (*F*s (2,144) = 9.53, 8.07, η_p^2s = .12, .10, *t*s(144) = 3.67, 3.90, 3.26, 3.67), whereas there was no significant difference in PMV between clusters.

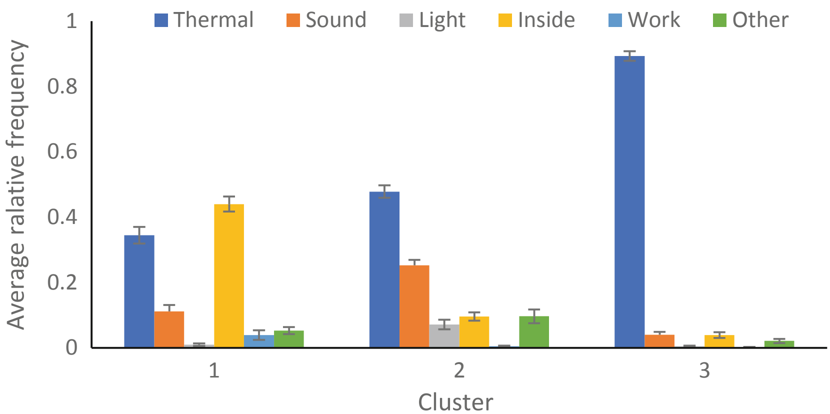

Fig. 3. Average relative frequency of each factor

Table 3. Correlations between comfort, productivity, and PMV in each cluster

Cluster	*n*	Correlation		
		Comfort and productivity	Productivity and PMV	PMV and comfort
Overall	2075	0.54***	0.05	0.04
1	626	0.59***	−0.10*	−0.05
2	824	0.41***	0.17**	0.05
3	564	0.52***	0.06	0.07

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Table 4. Demographic data of each cluster

Cluster	Age	*n*	Sex		
			Male	Female	Unknown
1	37.3	47	40	5	2
2	42.6	61	49	11	1
3	42.9	39	34	3	2

Characteristics of the Clusters. Cluster 1 is distinguished from other clusters by the high relative frequency of the inside factor. Therefore, we named cluster 1 the "inside cluster." Cluster 2 was distinguished by the fact that those in cluster 2 provided relatively different comfort-evoking factors. Therefore, we named cluster 2 the "balanced cluster." Cluster 3 was distinguished by the high relative frequency of thermal factors (nearly 90%). Therefore, we named cluster 3 the "thermal cluster."

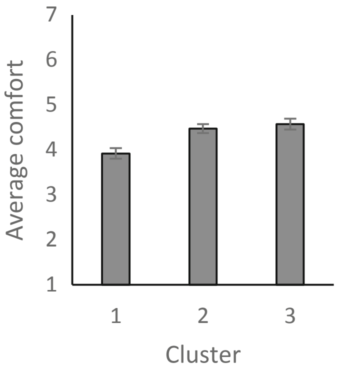

Fig. 4. Average comfort in each cluster (bars indicate *SE*s)

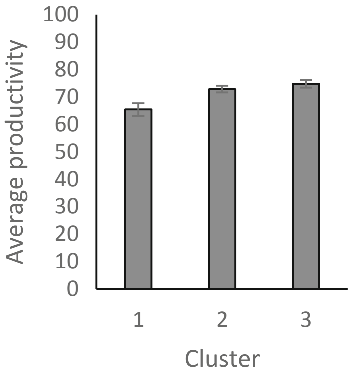

Fig. 5. Average productivity in each cluster (bars indicate *SE*s)

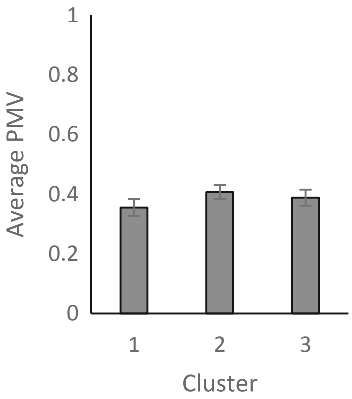

Fig. 6. Average PMV in each cluster (bars indicate *SE*s)

The clusters also differed in the evaluation of the environment. The inside cluster showed lower subjective comfort and subjective productivity, whereas the average PMV did not show significant differences between clusters (Fig. 4, 5 and 6).

To investigate the relationships between objective thermal comfort (PMV), subjective comfort, and subjective productivity, we conducted correlation analysis between these variables. In all clusters, PMV showed no significant correlation with subjective comfort and subjective productivity, whereas subjective comfort showed a strong positive correlation with subjective productivity (Table 4).

4 Conclusions

4.1 Summary of the Results

In the present study, we succeeded in reproducing the previous study we conducted in November 2018 [4].

First, we extracted almost the same comfort-evoking factors. In the present study, we extracted thermal factors, sound factors, light factors, inside factors, work factors, and other factors. In the previous study, we extracted thermal factors (71.4% of all responses), humidity factors (4.5%), light factors (0.9%), sound factors (7.6%), smell factors (0.6%), inside factors (14.4%), and other factors (2.0%) (in the previous study, responses were categorized, allowing duplex classification, and the sum of all factors exceeded 100%). The majority of the responses were classified as common factors (thermal, light, sound, and inside), indicating strong and persistent effects of these factors. This also supports the validity of the method of the present study, a combination of the evaluation grid method and the experience sampling method.

Second, we extracted the same clusters of occupants (inside, balanced, and thermal) as we did in the previous research. This emphasizes the existence of individual differences in office comfort and the validity of our classification. It also suggests that the clusters are independent from the seasonal effect, indicating the robustness of the clusters. All participants in the present study were office workers, and those of the previous one were university students (n = 9) and office workers (n = 14). This also indicates the relative independence of the clusters from their jobs.

In addition to that, participants in each cluster differed in their levels of subjective comfort and subjective productivity in spite of the common thermal environment suggested by the similar level of PMV (Fig. 4, 5, 6). People in the inside cluster showed lower subjective comfort and subjective productivity under similar physical conditions. This might be due to the differences in the characteristics of the people in each cluster.

Throughout the present research, we relied on the subjective responses of the occupants. As a previous study revealed [24], at least in some aspects, subjective responses are better indicators than objective ones. This was true in the present research. The subjective comfort correlated with the subjective productivity, whereas there was no significant correlation between objective index (PMV) and subjective comfort and subjective productivity. This might be due to the fact that the present research was conducted in a daily setting, in which various kinds of factors affect comfort. This was advantageous in the present research, the aim of which was to reveal the components of office comfort.

4.2 Novelty of the Present Research

The novelty of the present research is revealing the inside factors and their effect, as well as the development of the indoor comfort investigation method, which combines the evaluation grid method and experience sampling method.

The existence and effect of inside factors has been overlooked in previous research. For example, a literature review divided comfort into four subtypes: thermal, visual, acoustic, and respiratory [25], all of which focused on the physical aspects of the environment. In addition to these factors, inside factors were extracted. The inside factors were the second largest type that affect comfort and have a significant effect on office comfort, and they are important for inside and balanced clusters.

One might think that inside factors are not environment ones but to occupants' ones. However, as we stated in the introduction, indoor comfort is realized through the interaction between the outer environment and occupants. Therefore, inside factors should be focused to realize a comfortable environment. The more important thing is that occupants recognize that inside factors affect office comfort, indicating that variation of the levels of inside factors would change the levels of comfort in the environment.

The other novelty of the present research is the development of the comfort measurement method combining the evaluation grid method with the experience sampling method. This method allowed us to conduct a detailed investigation of the comfort in the office, not in the experiment room. The experiment room, which is quite different from daily life environments in multiple aspects, is where a detailed investigation of comfort was conducted. Although this let us examine the causal relationship between an environment and people there, the experiment room and manipulation themselves could have changed how people experienced comfort there, thus hindering expanding the findings to daily situations. This method also allowed us to extract factors that vary in category (Fig. 3) and characteristics (Fig. 2). Using the present method, we could infer what and how environmental factors affect comfort. This was also due to the feature of the present method that let us gather multiple data in a daily environment.

4.3 Future Direction

Future researches have to tackle two things: applying objective indices and providing various occupants with the proper environment.

The present methods rely on subjective responses: how much they feel comfort and productivity, and what kind of factors they attribute to the comfort. In a future study, more objective indices are needed (e.g., physiological variables). These indices would let us shed light on aspects that subjective responses cannot reveal (e.g., minimal comfort changes under sensory threshold and high-resolution sequential changes).

Providing a proper environment for each occupant is another task to tackle. As previous studies point out, the proper thermal conditions differ across people. In addition to the quantitative individual differences, qualitative differences, which the present research revealed, need to be focused on. To realize a proper environment for every person, it will be necessary to manipulate proper variables with personalized environmental controls.

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