Emotional responses to virtual reality-based 3D spaces: focusing on ECG Response to single-person housing according to different plan configurations

Jeeyeon Myung & Hanjong Jun

Published online: 08 Jun 2020.

Submit your article to this journal ↗

Article views: 1172

View related articles ↗

View Crossmark data ↗

Citing articles: 1 View citing articles ↗

Taylor & Francis
Taylor & Francis Group

ARCHITECTURAL PLANNING AND DESIGN

🔓 OPEN ACCESS | Check for updates

Emotional responses to virtual reality-based 3D spaces: focusing on ECG Response to single-person housing according to different plan configurations

Jeeyeon Myung and Hanjong Jun

Department of Architecture, Hanyang University, Seoul, Korea

ABSTRACT
The purpose of this study was to use Virtual Reality(VR) and electrocardiograms (ECGs) to analyse differences in autonomic nervous responses affected by the plan configuration. Four different plan configurations of single-person households were chosen based on a prior study and built using VR. An ECG was then recorded within each plan type and the average low-frequency/high-frequency (LF/HF) power ratio was calculated to measure the stress level in each space, and the results revealed significant differences among plan type($p < 0.05$). These results provide compelling evidence that a plan configuration may affect the quality of space for single-person households and also suggest that choice of plan configuration appears to be effective in counteracting the stress that may exacerbate psychological disorders among single-person households.

1. Introduction

1.1. Background and purpose of study

An increase in the number of single-person households is a global trend expected to accelerate because of changes in social paradigms and the effects of aging. This increase resulted from changes in household structures associated with the trend of main consumers, to increasingly move from multi-person households to single-person households, creating increased interest in the associated economic effects of single-person, or "solo", households.

Japan (32.4%) and South Korea (23.9%) have been found to have high ratios of single-person households. Recently, China has also exhibited a trend of rapid increases in the number of single-person households that are expected to exceed 100 million by 2015 (OECD 2013). Consequently, single-person households have been established as a basic major factor underlying significant socioeconomic changes in Asia, reflected by the emergence of new products and related services targeting the needs of single-person households.

In contrast to most other households, single-person households are often associated with living in a very small space such as a studio (Seo 2017). In fact, a survey found that 81% of single-person households live in small houses of area less than 3.3 square meters, and that resulting poor living conditions, second only to the lonely deaths of the elderly, represent one of the most serious social problems related to the increase in single-person households (Lim and Lee 2018).

Accordingly, a variety of studies conducted in the South Korean architectural field have been aimed at solving the problem of single-person households (Lee and Yoo 2017; Choi 2004; Park, Lee, and Choi 2005). While these studies are meaningful in that they analysed various problems related to single-person housing and suggested ways for living more efficiently. However, studies deriving objective conclusions about the effects of single-person housing on the psychophysiological responses of residents through systematic experimental evaluation are very rare.

Since studies on the actual effects of single-person housing on the physiology of prospective residents seem necessary, this study assumed situations in which spatial impressions vary with plan configurations, and, using ECGs, measured users' physiological responses to different single-person housing configurations. The ultimate goal of this study was to investigate the effects of single-person housing configurations on human bodies.

1.2. Study methods and procedures

This study measured the physiological changes in users related to their single-person household housing configurations in the following three steps shown in Figure 1.

First, research hypotheses appropriate to the background were established and the purpose of the study and the direction of experiments was sought with theoretical considerations and analysis of previous studies. Second, subjects were first selected for the experiments, after which the subjects' plan configurations (Plan B, G, J, and H) were selected and fabricated in a VR environment. Third, the resultant ECG data measured in a virtual reality-based three-dimensional

---

CONTACT Hanjong Jun ✉ hanjong@hanyang.ac.kr 🖳 Department of Architecture, Hanyang University, 407, Architectural Design Computing Centre (ADCC), Science and Technology Building, 222, Wangsimni-ro, Seongdong-gu, Seoul, Republic of Korea

Figure 1. Procedure of an experiment.

space were analysed using the LabChart program and the IBM SPSS Statistics program. The resulting data were used to analyse the responses of human bodies related to plan configurations on the single-person household.

2. Literature review

2.1. Environmental psychology and physiological responses

We spend most of our lifetime in built environments that represent environmental structures built by human hands and located between humans and the natural environment. The built environments were found to influence both intended and unintended human behaviours. Therefore, although behavioural considerations such as the degree of coincidence between a design and a user's needs are important, the effect of the relevant space on a user's feelings and body is most important of all. Environmental psychology is the field in which interrelationships among behaviours, artificial environments, and natural environments are studied.

There are many researchers in the field of environmental psychology, and they use a variety of methods, including behavioural changes, subjective assessments, and physiological responses to assess the effects of architecture on users. The physiological response measurement method is often used to record subject's stress according to environmental conditions (Fisher, Bell, and Baum 2001). In fact, when an environment is assessed, the body's response is also determined. This body reaction is very useful in that it helps the one to cope with the state since space can be interpreted as threatening or harmful sometimes.

According to a study conducted by Selye (1956), because environmental stresses increase adrenal gland secretions during the alert response phase and reduce responsiveness during the resistance and exhaustion phases, some responses to environmental stresses are indistinguishable from those that occur when pathogens directly attack body tissues. Other studies have also confirmed that catecholamine-

epinephrine and norepinephrine are activated under stress (Konzett 1975; Schachter and Singer 1962). When catecholamine and adrenal glands are increased, it changes physiological signals such as heart rate, and affects cognitive and emotional functions, resulting in mood and behaviour changes (Fisher, Bell, and Baum 2001).

As such, environmental variables directly affect a user's body and in most cases, it has been found to be manifested as increased arousal level when they are under stress (Aiello, Epstein, and Karlin 1975). There has been extensive research using ECG to measure the stress levels (Kim and Choi 2008). Such measurements used ratio of LF/HF in the variability of R-R intervals (heart rate variability, or HRV) spectral components. The higher the LF/HF value indicates the more stressed the subject is, while the lower the LF/HF value indicates the less stressed the subject is (Shisuke and Minbo 1991; Park, Ahn, and Moon 2010). This means that the higher the LF/HF value, the greater the stress associated with space. On the other hand, a lower LF/HF value is associated with a more relaxing and comfortable space.

ECG based physiological measurement is objective and accurate than the self-reporting method in which research results can be biased or obscured by researchers. Therefore, in this study, the effect of single-person housing on the user will be measured in terms of the ECG-related LF/HF ratio.

2.2. Environmental perception and architectural plans

While conventional perspectives on perception usually discuss how sensory mechanisms detect a single aspect of an object in the environment, environmental perception is more concerned with a holistic and comprehensive process (Ittelson 1970, 1978). In other words, the environment is experienced through the whole environment, not just in individual scenes. In this respect, architectural plans that consider all combinations can be said to have broader effects than others.

Architectural plans are used as central tools to use in making forms by determining central concepts, intentions, and spatial structures during the early design process (Corbusier 1974). Such architectural plans determine both exterior and interior spaces of a building and can configure additional structural spaces through furniture arrangements. Indeed, each of the many different aspects of building environments such as lighting, color, furniture arrangements, and atmosphere, can affect feelings or behaviour, but it has been found that in most cases they collectively affect feelings or behaviour. That is, although the color of a room may affect feelings, a lighting and color combination is more likely to affect feelings more than either one individually.

Recently, Myung, Ji, and Jun (2019) took note of this aspect and proved that a user's biological responses can vary with plan configurations. Taking notice of the fact that the plans of studios, representative South Korean single-person residence type, could be categorized according to bathroom and kitchen locations, the only compartment components (Lee 1994; Lee et al. 1999; Han and Yoon 2011). The relevant study presented 10 plan types through a case study and demonstrated that central and autonomic nervous system responses differed with respect to plan type. This was the first study used ECGs to investigate the effect of plan configurations of studios, identified as stress-related environments, but it had limitations in spatial simulation because it used videos to provide experimental stimuli. Therefore, based on the results of previous studies, this study planned to select four representative plan types and construct them in VR before conducting experiments.

2. 3. Virtual reality for environmental experiments

Although real environments per se are the best laboratories, they sometimes make the interpretation of experimental results difficult because they can contain many extraneous variables. In this respect, virtual reality would seem to be a good alternative to real environments because virtual environments enable manipulation of variables of interest while keeping design elements constant. This characteristic of virtual reality helps to reduce experimental noise produced by numerous extraneous variables often found in real environments (Heydarian et al. 2015). Most importantly, virtual reality enables an experimenter to immerse subjects in space while providing the possibility of controlling various parameters.

Sanchez and Slater (2005) defined the concept of "existence and immersion" and compared subjects' behaviours, perceptions, and presence both in real office spaces and office spaces designed in immersive virtual environments. They reported that subjects' behaviours were similar in both real environments and immersive virtual reality, with the subjects feeling a strong presence in both (Heydarian et al. 2015). Kieferle and Wossner (2001) also reported a presence in virtual environments, and Morie et al. (2005) also found that participants who experienced virtual environments exhibited behaviours and responses similar to those occurring in the real environments. It was also proven that, through preliminary experience in virtual environments, an experimenter can usefully analyse a user's responses under new perceptual conditions (Bergamoasco, Bardy, and Gopher 2012).

Thus, since virtual reality has sometimes been found to offer a better alternative to real environments than other media with respect to the performance of spaces, this study used virtual reality to analyse the effects of plan configurations on the single-person household.

2. 4. Limitations of previous studies and potential contributions of the proposed approach

Through the overview, some facts were revealed.

First, there is evidence that many studies have been conducted regarding the effects of environments on users. Further, recording physiological data such as ECG is proven to be a good method because such data accurately measures users' responses.

Second, environmental perception is determined not just by a single environmental variable, but by a more general set of environmental variables. In this respect, architectural plans developed while considering all combinations can be said to have a greater effect than others.

Third, virtual reality has proven to be a good alternative for conducting environmental experiments.

Studies suggest that it is important to conduct experiments for measuring physiological user response related to architectural plan configurations rather than to just a single environmental variable, for determining the actual effects of a particular three-dimensional space on users and that ECG and VR can effectively be used to conduct such experiments.

Since a better understanding of users' emotional responses to architectural space may improve building design and enable users to better utilize buildings. Therefore, the empirical data on human responses in the three-dimensional space of single-person housing to be presented in this study are expected to serve as a successful key capable of application in a broader range of fields.

3. Experimental method and procedure

3. 1. Fabrication of 3D visual stimuli according to plan configurations

The aim of this research is to provide empirical evidence for the changes in human bodies caused by different plan configurations of single-person housing. We devised an experimental design comparing four types of single-person housing as design environments based on Lee's theory (Lee 1994).

Lee (1994) established that the design of the one-room type unit plan in Korea varies depending on the location of the bathroom and kitchen which are the only compartment component of the house. According to his theory, the one-room type can be subdivided in to "Long/short length entrance types", "Adjacent/Separated type", "Vertical/horizontal type", and "BK/KB type". More recently, Lee et al. (1999) also showed that the one-room unit can be categorized in similar subcategories using the location of the bathroom and Kitchen.

Other studies also used the location of the bathroom and kitchen to categorize a one-room type unit plan (Lee and Oh 1995; Han and Yoon 2011). However, since most studies were conducted over 10 years ago, we conducted sampling and analyzing sites to decide the stimuli of one-room types based on Lee's theory mentioned earlier in our previous study (Myung, Kim, and Jun 2019; Myung, Ji, and Jun, 2019).

The sites were the H-university station, which is located in the Seoul of Korea and was frequently suggested as a good place to find one-room. A total of 43 cases was randomly collected and then analysed based on the categories. A total of ten typed spaces were subsequently converted to videos for the experiment using ECG.

According to the result of the previous study, it was found that there were significant differences in the former group (B, G, J) while there was no difference in the latter group (I, E, H, F). The result of the previous study revealed that there were statistical differences among plan B, G, and J while there was no difference in the latter group (I, E, H, F). Thus, we selected all three plan types (B, G, and J) for our experiment. Plan H was chosen additionally from the latter group for the following reasons.

Although the result of the previous study revealed that there was no difference in the plan I, E, H, and F, we thought it is better to include at least one of them as the baseline for this study to enable us to observe the changes caused by the plan configuration change. Further, although no significant difference was found for the plan H in physiological data (LF/HF ratio), there was a significant difference in psychological data (subjective evaluation). We thought plan H has a higher possibility of being different compare to the other. By including plan H, we checked whether the change in the human body caused by the plan configuration is a general tendency.

This research is a series of research followed after. Our previous studies (Myung, Kim, and Jun 2018; Myung, Ji, and Jun 2018) were meaningful in that it was the first study that investigated the effects of plan configurations using physiological data (EEG and ECG). However, it had limitations with respect to the spatial simulation in that it used, i.e. video stimuli. Therefore, we selected four types of plans (B, G, J, and H), that had representatively exhibited differences based on the result of the previous studies and fabricated it using VR technology.

The Unreal Engine 4,[1] which have been suggested as the limelight in fields of architecture, design, and manufacturing because of its real-time workflow and superior visualization functions. The VR stimuli were presented through Alienware M51 notebook[2] and Oculus Lift[3] equipment. The stimuli for the ECG experiments were shown in Table 1. The K, B, ▲, ●, and □ each stands for Kitchen(K), Bathroom(B), Enterance(▲), Startpoint(●) and Endpoint(□). By applying experimental design comparing four types of single-person housing as design environments based on Lee's theory, we are able to highlight the expected changes in human bodies while using actual plan configuration.

3. 2. Heart rate variability (HRV) signal detection

The scope of this paper is set for "Korean single-person household". And it was found that the most important issue for a single-person household in Korea is related to stress (Lee 2017). For that reason, ECG was selected to measure the stress levels.

ECG, an indicator of autonomic nervous balance, defines stress in terms of the LF/HF ratio which is a components of the R-R interval variability (HRV) spectrum. The LF/HF ratio has been found to be a very useful indicator because it enables the evaluation of autonomic nerve activities divided into sympathetic and parasympathetic nervous systems (Hayano 1988). Since LF/HF ratio can simply measures humans responses in a non-invasive autonomic way, many other studies using LF/HF ratio have also been reported (Kim and Choi 2008; Noh and Jeong 2010; Cho et al. 2018).

In this study, MP30 equipment from Biopac System was used to measure LF/HF to determine differences in stress levels associated with different plan configurations. The sampling rate was set to 1000 Hz and LF and HF bands were set to 0.04 ~ 0.15 and 0.15 ~ 0.4. The LabChart program was used to separate the HRV spectrum from the signal waves.
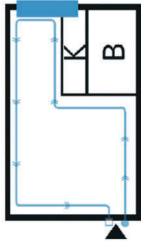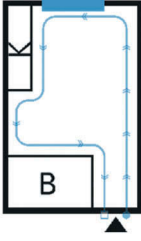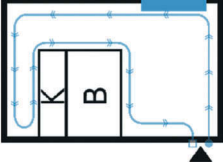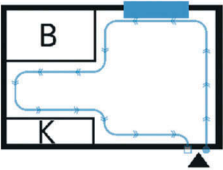
Based on the unipolar limb lead method, ECGs electrodes are connected to the right hand, left hand, and left foot to record the ECG wave patterns. Since the ECG wave patterns recorded with unipolar limb leads were small in size, 1.5 times amplified ECG wave patterns aVR, aVL, and aVF were used.

---

[1]The Unreal Engine was chosen to build VR stimuli: first, it is an integrated game engine that provides overall game development environments. Second, it has been used in dozens of video game development worldwide based on its outstanding design visualization and technical skills. Third, from 1994 to present, it has been used by many users for a long time by including continuous updates, various technical support, and excellent development tools. Therefore, it would be easier to build realistic VR space for this study in a relatively short time based on its excellent technology.

[2]Alienware M51 was used to present stimuli since the visual reality of the constructed VR stimuli is heavily dependent on the graphics performance of the computer. Therefore, among the most powerful gaming notebook line from Alienware which is a subsidiary of the US computer hardware Dell, the latest version of the Alienware M51 released in 2019 was chosen for this study because it offers excellent graphics upgrade possibilities.

[3]Oculus Rift, which is one of the virtual reality head-mounted displays has a wide field of view with a resolution of 1080 × 1200 on both the right and left sides. Since it also includes a function to track rotations and positions, when the participant turns their head while they are experiencing VR, the experimenter can also view the relevant VR scene on the computer screen. Therefore, it was deemed appropriate for this study.

Table 1. Types of the proposed stimuli according to the One-room plan.

Type	Plan	VR	Configuration independent variable
B			1) Short length entrance 2) Adjacent 3) Horizontal 4) BK
G			1) Short length entrance 2) Separate 3) Vertical 4) BK
H			1) Long length entrance 2) Adjacent 3) Horizontal 4) BK
J			1) Long length entrance 2) Separate 3) Vertical 4) KB

*K = Kitchen, B = Bathroom, ▲ = Entrance, ● = Start point, □ = End Point.

3. 3. Experimental methods and procedures

The comparison of four typed plan configuration was intended to emphasize the impact of plan configuration on the human body. Thus, the use of four typed different plan configuration is the major variable in this study, while the remaining variables are set in order to facilitate the experiments without influencing the results.

Thus, this experiment was carried out using a controlled experimental methodology. Since bio-signal within the different plan configuration is difficult to measure in real-life due to the sensitivity of bio-signal, all sessions were conducted under laboratory conditions.

Table 2. Environment of the laboratory.

Place	Temperature	Humidity
Shield Room	22 ± 1.5°	35 ~ 39%

Experiments were conducted in a Shield Room to block noise and external electromagnetic waves that might affect the results. As shown in Table 2, within for the laboratory environment, an internal temperature of 22 ± 1.5 °C and a humidity level of 33-39% were constantly maintained and white walls were installed on three sides of the subject's desk to minimize effects of the surrounding environment.

Since the lighting environment (such as angle, intensity, uniformity, contrast, etc.) plays a very
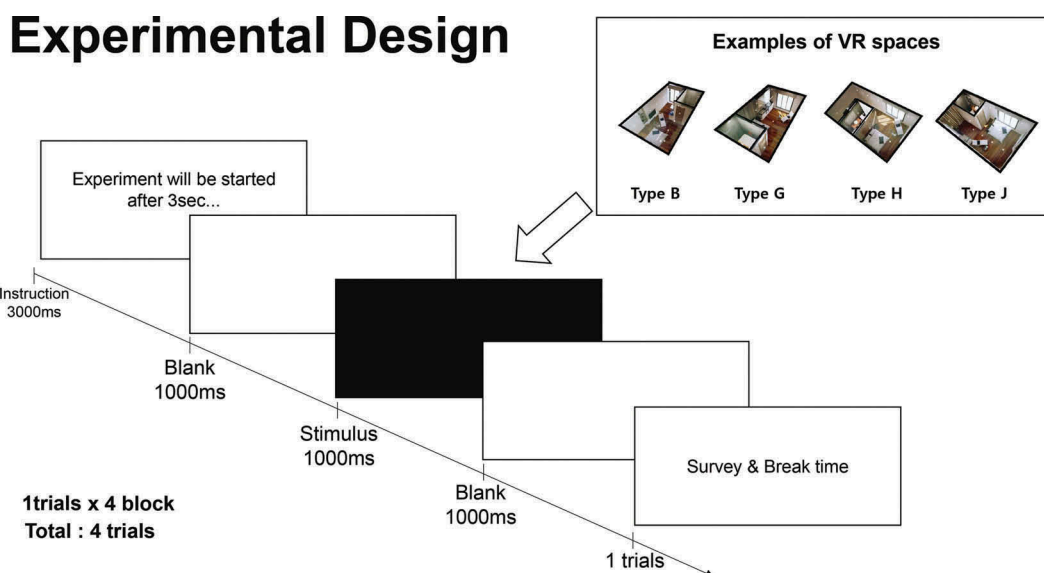
Experimental Design

Figure 2. Procedure of an experiment (Myung and Jun 2019).

important role in spatial perception, the same lighting system was used for all plan types to avoid additional variables other than plan configuration change. For the same reason, the number of the lighting system was also controlled as the same in each functional area within the room (e.g. Bathroom, Kitchen, Bedroom and living room).

For the same reason, we took care to invent a path setting which was realistic and appropriate for single person housing to avoid any extra variable that might influence the results. Thus participants were asked to follow along the wall rather than chaotically move around the place.

A preliminary experiment was conducted with males (n = 2) and females (n = 2) on 3 May 2019. The main experiment was conducted with males (n = 30) and females (n = 30) between May 4 and 17(experiment last for 14 days). A total of 60 college students participated in the main experiment, and the mean age of the subjects was 22 ± 1.8 years. The subjects were randomly sampled through recruitment announcements and a prescribed monetary compensation ($10) was provided to each of the subjects based on research ethics.

The subjects were limited to those with no history of heart disease, diabetes, hypertension, or hypotension due to abnormalities of the autonomic nervous system. In addition, female subjects were selected from among those not experiencing their menstrual periods. All subjects were prohibited for 24 hours before the experiment from drinking, smoking, taking drugs, or caffeine intake that might have affected their central and autonomic nervous systems, and they were advised to get adequate sleep on the day before the experiment.

As shown in Figure 2, before the experiment started, the subjects were induced to achieve psychological stability in the unfamiliar experimental environment, and the VR stimuli stimulating the studio plan configurations as well as the overall experimental procedure were explained in advance. After conducting an orientation related to the experiment, measurement electrodes were attached.

When all preparations had been completed, an initial stable ECG was measured for 1 minute in the absence of an external stimulus. Thereafter, an ECG was measured for 1 minute while the subject wore the Oculus equipment and experienced VR stimuli consistent with the plan configurations. Then, during rest time, the subjects completed a questionnaire related to the plan configurations. This process was identically repeated for the four VR stimuli.

3.4. Analysis method

3. 4. 1. Analysis of physiological signals

The data of six subjects who had experienced movement-related noises and four subjects who had exhibited VR motion sickness was removed. Thus, data from 50 subjects (25 males and 25 females), were used for the analysis. The extracted data were statistically processed using IBM SPSS Statistics 21 to verify whether there was any significant human-response differences-related to the plan configurations. RM-ANOVA was used to assess differences in stress levels between the plan types (floor plans B, G, J, and H). Post hoc analysis was conducted using pairwise comparison tests (LSD) assuming that $p < 0.05$ indicated significant differences.

3. 4. 2. Analysis of subjective assessment

Recently it is highly suggested to conduct a questionnaire survey along with the biometric data-based quantitative evaluation in the field of Ergonomics. Ergonomics is a discipline that quantifies human emotions and applied it to the product or environmental design. In the earlier

period of Ergonomics, the subjective evaluation method (psychological data) and the objective evaluation method (physiological data) were applied differently. Recently, however, studies conduct both subjective and objective methods have become mainstream (Min 2010).

Further, our experimental data contained a large number of data elements of fewer participants. Thus we analysed the experimental data in both qualitative (psychological: normalized rank method) and quantitative (physiological: LF/HF ratio) ways in order to obtain various interpretations of the results.

Based on the theoretical book of 「Applied Ergonomics」 which explains how to apply ergonomics in the research, this study used the normalized rank method to measure changes in emotions according to the plan configurations (Min 2008).[4]

Figure 3 is the original questionnaire for normalized rank method. Equation 1 and Equation 2 was used to calculate the variance ($S2$) and t-value (t_0) based on the normalized rank method. The variance ($S2$) value was used to find out which plan types differed significantly and it was assumed that there was a significant difference if t < t_0 (t_0 = 1.729) is true.[56]

$$s^2 = 1 / \sum (k_e l)^2 \times \left(\sum \{ (k_e l)^2 \times (k_e l)^2 \} \right) - R^2 .. \quad (1)$$

$$t_0 = Rx - Ry / Root \sum (fkl)(s^2 x + s^2 y) \\ \times Root \sum (fkl) \{ \sum (fkl) - 1 \} \quad (2)$$

4. Study results and discussion

The overall purpose of this study was to measure users' responses related to plan configurations. Physiological data were measured, and questionnaire surveys were conducted. The participating subjects were 60 male (n = 30) and female (n = 30) college students, and 83% of the questionnaire responses were collected and statistically processed to test the hypotheses. The null hypotheses were presented in the following form.

- Ho 1: There will be no significant difference related to plan configuration in subjective evaluation by studio type.
- Ho 2: There will be no significant difference related to planar configuration in physiological data by studio type.

4. 1. Results of qualitative comparative analysis of plan configurations

4. 1. 1. Comfort

A normalized ranking method that ranked the most pleasant plan type as 1 and the most unpleasant plan type as 4 was implemented for all participants. Variance ($S2$) values were used to determine whether plan configurations resulted in significant differences in studio comfort evaluation. As a result, the null hypothesis was rejected (t < t_0 = 1.664), indicating that the plan configurations do affect studio comfort.

Consequently, the plan configurations can be listed according to the degree to which they "felt comfortable" in the order shown in Figure 4. The experiment clearly showed that the plan configuration that "felt the most comfortable" was plan G, a short length entrance[7] - separated[8] -vertical[9] -BK[10] type and the plan

---

[4]This document introduces the subjective evaluation method as a method for quantifying and evaluating the extremely vague sensibility that an individual feels subjectively. According to the book, the result from the subjective evaluation is different from those obtained by simple surveys. And there are four ways to apply subjective evaluation: size estimation(ME), normalization ranking, one-to-one comparison, and semantic differentiation (SD). Although, there are various analysis methods including simple questionnaire analysis methods such as RM-ANOVA, but we chose the subjective evaluation method based on the theoretical book. More specifically, a normalized rank method was used to measure emotional changes according to the plan configuration for the following reasons.

Since the aim of this research is to investigate the effect of plan configuration on humans using ECG, we thought it is better to use the 'symbol type' rather than 'analytic type'. (And the normalized ranking method is one of the 'symbol type') According to the book, the subjective evaluation method is further divided into 'analytic type' and 'symbol type' according to the characteristics of the analysis method. The 'analytic type: the size estimation(ME)' is used to quantify the physical strength of stimuli regardless of the emotional pattern caused by the stimuli. On the other hand, the focus of 'symbolic type: normalization ranking method, one-to-one comparison method, and semantic differential method (SD)' is to check the congruency of the stimulus for the scale (reference) set by research.

Thus, we thought 'symbol type' suited better for the research purposes of this manuscript, since the aim of this research is to investigate the effect of plan configuration on humans using ECG(the scale). Further, the normalized ranking places a lower compulsory burden on the subject and involves less computation for analysis than other methods. For that reason, it can be easily conducted, so it was used in many studies. Since the reliability of this method was proved in many studies. Moreover, the normalized ranking method provides more than a simple ranking comparison. It not only compares each stimulus by ranking but also quantifies the difference between the stimuli and analyzes the result statistically. Since it is more objective to use the quantitative and statistical method, we chose the normalized raking method.

[5]The significance level check (t_0) expression uses the variance (S^2) value and Rx −Ry. Here, Rx denotes a scale value of stimulus x, and Ry denotes a scale value of stimulus y. Through this, it can be mentioned that there is a significant difference between the two stimuli in the significance level if the final (t_0) value is larger than the t value. However, if the (t_0) value is smaller than the t value, it can be said that no significant difference is observed between the stimuli at the significance level and there is no statistical difference between the stimuli.

[6]In the variance (S^2) equation, Kel means the deviation rate. The deviation rate Kel is for indicating how far the value of the percentile value in each stimulus is from the average value Kel of the whole percentile value, and can be obtained using a normal distribution table. In the normal distribution table, select the second decimal place of the value as the row and the third decimal place as the column. The value at that intersection is Kel. Next, R in the expression means a scale value. The scale value R represents the degree of agreement with the evaluation criteria of each stimulus. By using this value, each stimulus can be arranged on one scale. In other words, the order of magnitude of this scale value meets the criteria of the one investigated in this experiment.

[7]Long / short length entrance types: According to the length of the entrance side of the studio, in cases where the length of the entrance side is longer than the length of the side perpendicular to the foregoing, the studio is called long side type and in the opposite case, the studio is called short side type.

[8]Adjacent / Separated Type: According to the relationship between the bathroom (B) and the kitchen (K), in cases where the B and K are adjacent, the studio is called an adjacent type, and in opposite cases, the studio is called a separated type.
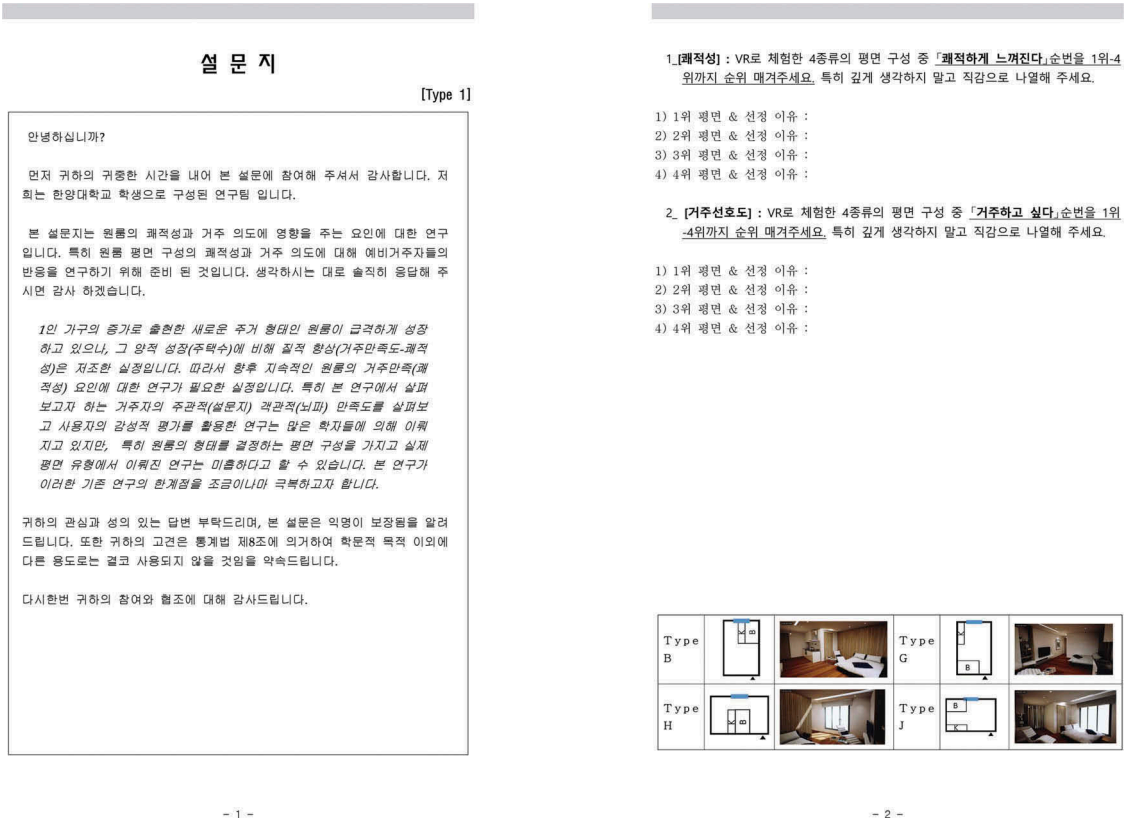
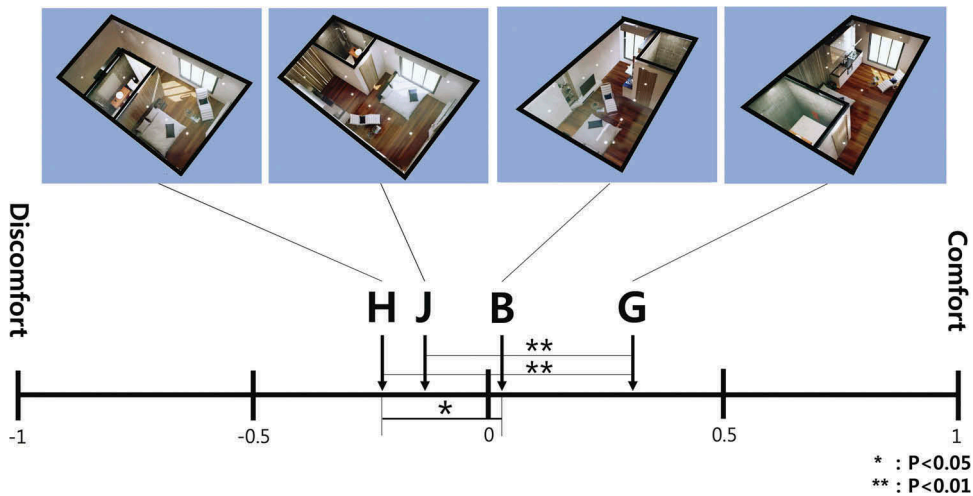**Figure 3.** The original questionnaire for normalized rank method.

Figure 4. Comparison of four typed floor plan configuration of one-room and post-hoc test according to the question 「Feeling comfortable」.

configuration that "felt the most uncomfortable" was plan H, long length entrance-adjacent-horizontal-BK type.

The variance(S2) value was used to find out which plan types differed significantly and it was assumed that there was a significant difference if $t < t_0$ ($t_0 = 1.664$). Consequently, plan H and B exhibited difference at a 95% significance level ($p < 0.05$), and the probability of differences between plan G & J and plan G & H were shown to be 99% ($P < 0.01$). Therefore, plan G was different from plan J and plan H, and at the same time, there was a significant difference between plans H and B.

---

[9]Vertical / horizontal type: According to the locations of the bathroom (B) and the kitchen (K), in cases where the B and K are located vertically, the studio is called a vertical type, and in cases where the B and K are located horizontally, the studio is called a horizontal type.

[10]BK / KB type: According to the order of the bathroom (B) and the kitchen (K) seen after entry, the studio is called a BK type (bathroom → kitchen) or KB type (kitchen → bathroom).
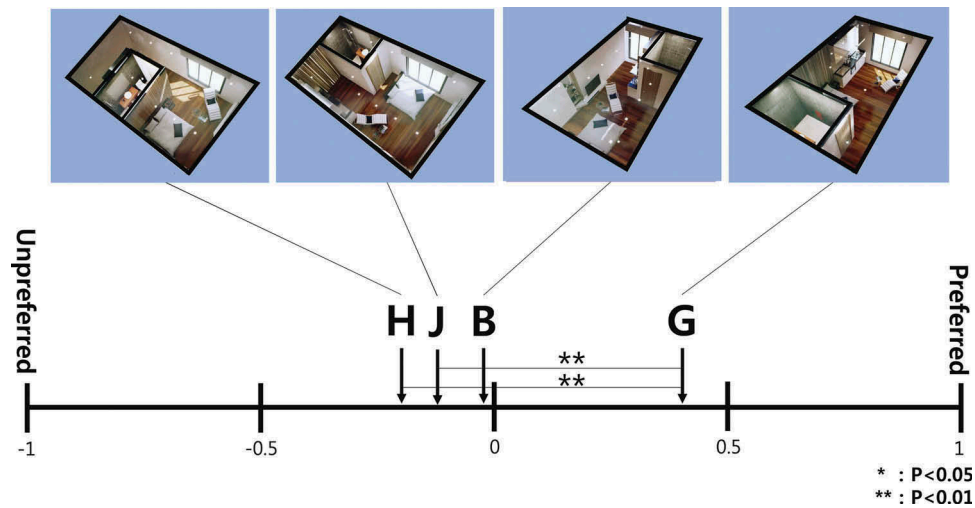
Figure 5. Comparison of four typed floor plan configuration of one-room and post-hoc test according to the question 「Wanting to stay」.

4. 1. 2. Residence preference

Although there were differences in the intentions of the questions, based on the results of the analysis of preferences conducted additionally, the plan configurations can be listed in the order shown in Figure 5 according to the degree to which they are "preferred for living." Consequently, the plan configuration that was "preferred the most for living" was also plan G, which is a short length entrance-separated-vertical-BK type. On the contrary, the plan configuration that was "preferred the least for living" was also plan H, which is a long length entrance-adjacent-horizontal-BK type, identically to comfort.

Variance (S2) values were used to determine which plan types exhibited significant differences, assuming that the differences should be fsignificant if $t < t_0$ ∴ (t_0 = 1.664) is true. Consequently, plan G was different from plans H and B at a significance level of 95% ($p < 0.05$), i.e. plan G is different from plan J and plan B.

Based on these results, although there were slight degrees of difference, it can be said that the comfort and preference related to plan configuration were similar, and that, among plan configurations used as stimuli in the main experiment, plan G, a short length entrance-separated-vertical-BK type, coincided with the original concept.

4. 2. Results of quantitative analysis of plan configurations

4.2.1. Analysis of Significance Differences between All Plan Types

RM-ANOVA was used to determine the validity of differences related to plan configuration in physiological data by studio type, and as a result, the null hypotheses were rejected, indicating that plan configuration does affect the activity of the sympathetic nervous system ($p < 0.05$).

As can be seen in Figure 6, plan J (long length entrance-separated-vertical-KB type) producing the lowest LF/HF value was identified as the most relaxed and comfortable space. On the contrary, plan B (short length entrance-adjacent-horizontal-BK type) had the highest LF/HF value, indicating that it was a space associated with the greatest tension.

A post-hoc analysis (LSD) was performed to determine plan types for which significant differences appeared, and it was assumed that P -values smaller than 0.05, reflected a significant difference.

Post-hoc analysis revealed significant differences between plans J and B ($p = 0.007$) and between plan J and G ($p = 0.042$). Therefore, it could be seen that residents were stressed more in plan B and G than in plan J.

4. 2. 2. Results of quantitative analysis of differences between plan groups based on configuration independent variables

The plans used in this experiment can be divided into groups in terms of configuration independent variables such as "entry lengths," "BK relations," "BK arrangements," and "BK order[11,12]", i.e. short/long length entrance type plans according to "entrance lengths," adjacent/separated type plans according to "BK relations," horizontal/vertical type plans according to the "BK arrangements," and KB/BK type plans according to "BK order." Group analyses based on configuration independent variables were therefore conducted after analyses of individual stimuli. As

[11]Once the path is changed, BK will become KB from the human perspective. However, space itself, which was shaped by the real-location and order of 'B' and 'K' would not be changed (as well as the spatial perception from it). In particular, since 'B' needed to be closed space to perform its architectural function, in the room starting with 'B', people would experience a small and narrow space in the entrance and experience openness for later (Imagine room impression caused by Plan B as the reference). On the other hand, since 'K' does not require closed space to perform its architectural function, it is
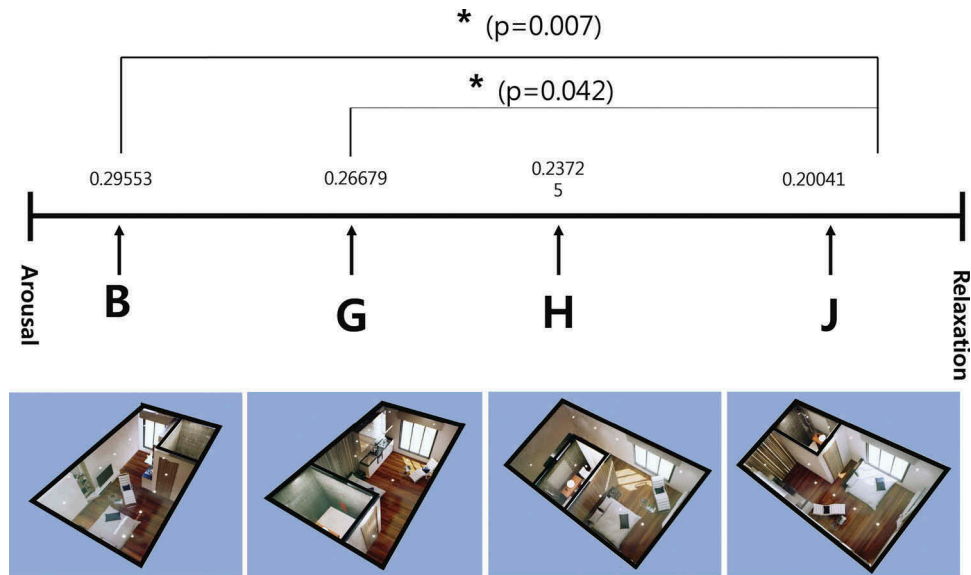
Figure 6. Comparison of four typed floor plan configuration of one-room and post-hoc test according to LF/HF ratio.
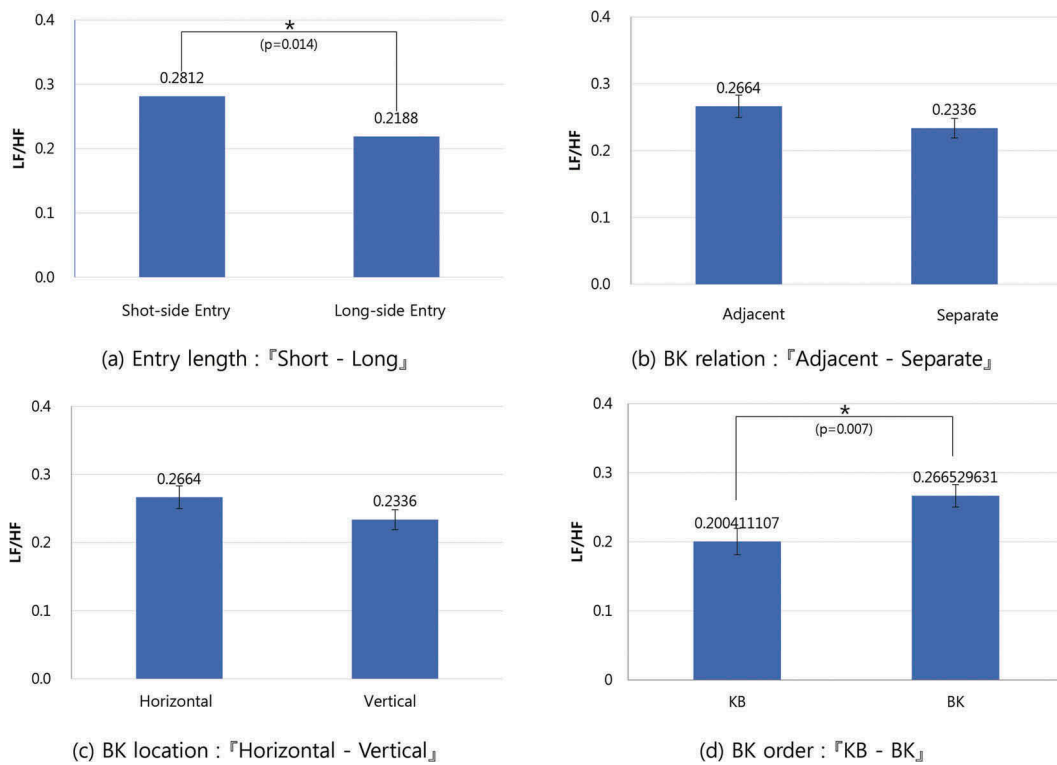

Figure 7. Comparison of LF/HF ratio and post-hoc test according to group analysis of four typed floor plan configuration.

usually planed as open space without the wall (especially in a small room like single-person housing). So in the room starting with 'K', people experience an open space in the entrance and experience blocked space for later (Imagine room impression caused by Plan J as the reference).

[12]Since the "BK" and "KB" variable fixes the shape of the room according to its architectural function, we strongly believe that it is meaningful to discuss is. So, we conducted group anlysis using "BK" and "KB" variable although sample size does not match perfectly (Among the four plans selected in this study, three are "BK" and only one is "KB". "KB" has only one single sample). We agree that the author should consider the number of samples during the plan selection stage. However, it is clearly not always possible in every case. We chose stimuli based on the result of the previous study. In other words, even though it was found that there is a small number of samples in one category, it is impossible to change the stimuli because we can't change the result of the previous study. We believe that the analysis of this section will help people to compare the result of this study to the previous study. Regardless, though, we do aware of the fact that there can be a possible bias on this part of the analysis and we clearly mentioned it in the paper.

a result, as shown in Figure 7, significant differences between the short side/long length entrance type (p = 0.014) and BK/KB type (p = 0.007) plans could be observed.

(1) Comparison of plan groups based on configuration independent variables "short/long length entrance" and "KB/BK"

$$Plan\ G = \textbf{Short length entrance} + +\textbf{BK}$$
$$Plan\ J = \textbf{Long length entrance} + Separate + Vertical + \textbf{KB}$$

Therefore, in the case of plans G and J, since separated and vertical are shared configuration independent variables, it became clear that the configuration independent variable of short length entrance+BK and long length entrance+KB had resulted in significant differences. Throughout this process, it has been found that the short length entrance + BK combination was a relatively more stressful spatial configuration than the long length entrance + KB combination.

(2) Comparison of plan groups where all configuration independent variables are opposite

$$Plan\ B = Short\ length\ entrance + \textbf{Adjacent} + \textbf{Horizontal} + BK$$
$$Plan\ J = Long\ length\ entrance + \textbf{Separate} + \textbf{Vertical} + KB$$

In the case of plan B, in which all combinations were opposite to those of plan J, the degree of stress level was greater than that of plan G (B > G > J: degrees of stress level). This observation demonstrates that, even in the case of the same combination of short length entrance + BK/long length entrance + KB, the effect becomes larger when a combination of other independent variables such as adjacent/separated and horizontal/vertical was configured oppositely.

It could, therefore, be seen that the combination of short length entrance+ BK was a more stressful spatial configuration than the combination of long length entrance+ KB because the associated degree of stress level was higher. In particular, in the case of the configuration of the short length entrance+ BK, it could be seen that the associated degree of stress level was higher when the configuration was adjacent + horizontal than when it was separated+ vertical. Throughout this process, it could be seen that the space comprised of a variable combination, rather than single individual variables, had more significant effects on users.

Based on these results, it became clear that the long length entrance + KB type configuration is more effective for comfortable space design. In addition, based on the fact that the effect of plan configuration becomes larger when all combinations are opposite, it can be seen that the combination of long length entrance+ KB is more effective in terms of representing a more comfortable spatial configuration when it was configured into the separated+ vertical type. These findings suggest that there is a possibility of approaching prospective-resident preferences through continuous improvement of studio space arrangements.

5. Conclusion

This study investigated the effect of single-person residential plan configurations on human bodies by measuring users' stress responses related to different studio plan configurations using ECG under the hypothesis that the physiological changes of residents would differ with plan configuration. The results of the study are as follows.

First, significant differences in the average ratios of LF/HF, as a function of plan configuration, were found between studio types (p < 0.005), indicating that the role of plan configurations is significant with respect to human autonomic nervous system response.

Second, based on the results of post-hoc analysis, there was difference between plans B & J and plans G & J, so plan J was found to have characteristics distinguished from those of plans B and G. These results show that the configuration of plan J (long length entrance-separated-vertical-KB) is effective as a comfortable spatial configuration.

Third, this study supports theory of Ergonomics(Min 2008),[13] meaning that a person's "psychological responses" (e.g. subjective evaluation according to the questionnaire) can be high yet a person's "physiological responses" (e.g. LF/HF ratio) actually can be quite low. Therefore, the result of this paper provides valuable information on how the configuration of the plan can affect the human both "psychologically" and "physiologically".

Fourth, group comparisons were carried out to check the effects of configuration independent variables that constitute the plans, and, based on results of this study, residents were stressed more in a short length entrance type group than in a long length entrance type group and stressed more in a BK type group than in a KB type group, indicating that the former was more stressful spaces. It can, therefore, be shown that designing the long length entrance and KB types is effective for comfortable space design.

Fifth, this study supports the closer theory of Gestalt psychology, meaning that when people perceive

---

[13]The main goal of ergonomics is to examine differences, interpret and integrate them according to people's activity environment by applying both subjective evaluation methods(emotional data) and objective evaluation methods(physiological response data). In fact, the subjective evaluation method (as subjective data) and the objective evaluation method (as objective data) were applied differently in the earlier period of Ergonomics. Recently, however, studies applying both subjective and objective methods have become mainstream.

spaces, they may perceive an area differently as a function of the relationships among the walls that partition the enclosed space. Therefore, in the case of plan J, the length of the wall perceived by the subject at the time of entry into space was relatively longer than that of plans B and G, suggesting that the relevant space perceived as the widest and felt more comfortable.

Sixth, the most noteworthy finding is the identification of significant differences between the plans only when the combinations of at least two out of four components (entrance length, BK relationship, BK position, and BK order), all independent variables, were different. This is consistent with the hypothesis in this study that variables will affect users more in combination than independently.

Seventh, this study is meaningful in that it extends the study by Myung, Kim, and Jun (2019) who measured user responses in three-dimensional spaces using VR video stimuli and found that plan configurations had great effects on humans. Since the ranks do not change significantly in both studies, the foregoing discussion suggests that the plan configuration effect is larger than those related to the precision of furniture placement or the degree of immersion into VR. However, the result of this paper showed that the measurement of user responses becomes more elaborate when they experience VR stimuli than they watch VR video stimuli.

Eighth, since the findings of this study are not related to age, gender, or ethnic background, it can be said that the effects of plan configurations can be applied to the general improvement of studio space comfort. Therefore, it is suggested that plan configurations that reflect the user's bio-responses are necessary at the design stage.

Finally, since this study presented a process for more objectively measuring users' emotional responses to space, if further studies are conducted to verify the effects on users of various architectural design cases or to conduct correlation analyses in related to this topic, this study may provide useful information about design guidelines that are significant if the stress index can ultimately be provided.

In future studies, it would be interesting to analyse the effects of plan configurations on the central nervous system or to analyse the correlation between biometric data and subjective evaluation by conducting both questionnaire surveys and subjective evaluation through the SD method.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Aiello, J., Y. Epstein, and R. Karlin. 1975. "Effects of Crowding on Electrodermal Activity." *Sociological Symposium* 14: 43–57.

Bergamoasco, M., B. Bardy, and D. Gopher. 2012. *Skill Training in Multimodal Virtual Environments*, 255–269. New York: CRC Press (Taylor & Francis Group).

Cho, H., H. Koo, J. Yang, K. Lee, S. Kim, J. Lee, H. Kwak, et al. 2018. "Effect of the Configuration of Contact Type Textile Electrode on the Performance of Heart Activity Signal Acquisition for Smart Healthcare." *Korean Journal of the Science of Emotion & Sensibility* 21 (4): 63–76. doi:10.14695/KJSOS.2018.21.4.63.

Choi, J. 2004. "A Study on the Student's Housing Plan according to the Analysis of the Residential Choice Elements and Interior Environment Satisfaction-Focused on the Students' Housing around Samcheok National University." *Journal of the Korean Housing Association* 15 (1): 103–112.

Corbusier, L. 1974. *Towards A New Architecture*, 43–62. Santa Barbara: Praeger Publishers.

Fisher, J., P. Bell, and A. Baum. 2001. *Environmental Psychology*, 151–580. Seoul: hakjisa.

Han, J., and J. Yoon. 2011. "Unit Planning of Single Undergraduate Student's Rental Housing Corresponding to Their Life Pattern and Housing Needs." *Journal of the Korean Housing Association* 22 (4): 93–102. doi:10.6107/JKHA.2011.22.4.093.

Hayano, J. 1988. "心拍變動□自己回歸□□□□□分析□□□自律神經機能□評價-RR間隔變　　動係數(CV-RR)□□比校 [Evaluation of Autonomic Function by Self-Recurrent Spectral Analysis of Heart Beat and Beat-RR]." *Autonomous God* 25 (3): 334–343.

Heydarian, A., P. Carneiro, D. Gerber, B. Becerik, T. Hayes, and W. Wood. 2015. "Immersive Virtual Environments versus Physical Built Environments: A Benchmarking Study for Building Design and User-built Environment Explorations." *Automation in Construction* 54: 116–126. doi:10.1016/j.autcon.2015.03.020.

Ittelson, W. 1970. "Perception of the Large-scale Environment." *Transactions of the New York Academy of Sciences* 32 (7): 807–815. doi:10.1111/j.2164-0947.1970.tb02755.x.

Ittelson, W. 1978. "Environmental Perception and Urban Experience." *Environment and Behavior* 10 (2): 193–213. doi:10.1177/0013916578102004.

Kieferle, J., and U. Wossner. 2001. "Showing the Invisible: Seven Rules for a New Approach of Using Immersive Virtual Reality in Architecture." *Cumulative Index in Computer-Aided Architectural Design and eCAADe* 19: 376–381.

Kim, S. L., and Choi. 2008. "The Assessment of Dynamic Mental Stress with Wearable Heart Activity Monitoring System." *The Transactions of the Korean Institute of Electrical Engineers* 57 (6): 1109–1115.

Konzett. 1975. "Jahre osterreichischle Pharmakologie." *Wien Med Wochenscher* 125 (1–2 suppl): 1–6.

Lee, G. (1994). "A Study on the Design of One-Room Type Unit Plans in Korea." Thesis, Korea University, 20–23.

Lee, G., and S. Oh. 1995. "A Study on the Design of One-Room Type Unit Plans in Korea." *Journal of the Architectural Institute of Korea Planning & Design* 15 (1): 19–37.

Lee, H., Y. Hong, S. Kim, S. Kwon, and M. Choi. 1999. "A Study on the Direction of Planning for One-Room Type Multi-Family Housing around Campus." *Journal of the Korean Housing Association* 10 (2): 165–173.

Lee, M., and B. Yoo. 2017. "An Analysis of Meaning of Housing and Ideal Housing Environments that the University Students Perceived." *Journal of the Korean Housing Association* 28 (6): 41–52. doi:10.6107/JKHA.2017.28.6.041.

Lee, Y. 2017. "One-person Households and Their Policy Implication." *The Journal of the Korea Institute for Health and Social Affair* (252): 64–77.

Lim, B., and D. Lee. 2018. "An Exploratory Study on Housing Types for Single-person Households." *Asia-pacific Journal of Multimedia Services Convergent with Art, Humanities, and Sociology* 8 (11): 493–511. doi:10.21742/AJMAHS.2018.11.62.

Min. 2008. *Applied Ergonomics*, 3–7, 56–86. Seoul: Kyobobooks.

Morie, J., J. Williams, A. Dozois, and P. Donat. 2005. "Development of a Data Management Tool for Investigating Multivariate Space and Free Will Experiences in Virtual Reality." *Applied Psychophysiology and Biofeedback* 3 (30): 319–331. doi:10.1007/s10484-005-6386-y.

Myung, J., S. Ji, and H. Jun. 2019. "The CNS Responses according to the Plan Configuration of One-room - Focused on 10 Types of Plan Configuration according to the Case Study." *The Korea Association of Art & Design* 22 (3): 153–168.

Myung, J., and H. Jun. 2019. "Emotional Responses toward 3D Space Based on Virtual Reality: Focus on EEG Response to Single-Person Housing with Different Plan Configuration." *The Architectural Institute of Korea* 35 (12): 55-64.

Myung, J., G. Kim, and H. Jun. 2019. "Autonomic Responses according to the Floor Plan Configuration of One-room: Focus on 10 Types of Floor Plan Configuration according to the Case Study." *Science of Emotion & Sensibility* 22 (2): 101–108. doi:10.14695/KJSOS.2018.22.2.101.

Noh, Y., and D. Jeong. 2010. "Development of the Wearable ECG Measurement System for Health Monitoring during Daily Life." *Journal of the Korean Sensors Society* 19 (1): 3–51.

OECD. 2013. *OECD Family Database*. Paris: OECD Publishing. Accessed 28 November. http://www.oecd.org/els/family/database.htm

Park, J., G. Ahn., and Moon. 2010. "Developing a Quantifying Methodology for Stress from Public Transportation Use." *Basic Research Report of Korea Transport Institute*:1–164.

Park, B., D. Lee, and M. Choi. 2005. "A Study on Plan Alternatives for the Improvement of Studio Type Multiplex in Association with Site Condition." *Journal of the Architectural Institute of Korea Planning & Design* 21 (1): 125–136.

Sanchez, M., and M. Slater. 2005. "From Presence to Consciousness through Virtual Reality." *Nature Reviews Neuroscience* 6: 332–339. doi:10.1038/nrn1651.

Schachter, S., and J. Singer. 1962. "Cognitive, Social, and Physiological Determinants of Emotional States." *Psychological Review* 69: 379–399. doi:10.1037/h0046234.

Selye, H. 1956. *The Stress of Life*, 48–190. New York: McGraw-Hill.

Seo, J. 2017. *Single-person Households*, 40–46. Seoul: Communication Books.

Shisuke, Y., and N. Minbo. 1991. "西村敏博: R - R間隔變動□自律神經機能 [R-R Interval Change and Autonomic Function]." *medicina* 28: 158–160. doi:10.11477/mf.1402900688.