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Exploring the Subjective Response of Keyboard Key Sounds on Individuals' and Susceptibility to Interference and Sensitivity to Noise

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ABSTRACT

This study, rooted in the discipline of human factors engineering, endeavors to investigate the threshold of decibel variance in tolerable interference across diverse activity states by scrutinizing individual subjective responses to keyboard keystroke sounds. The overarching goal is to furnish a more human-centered framework for keyboard design. Study One undertakes a meticulous analysis of 321 questionnaires and 66 noise sensitivity scales, revealing a noteworthy positive correlation between individuals' susceptibility to interference and their sensitivity to noise. The broad spectrum of individuals exhibiting heightened noise sensitivity validates the generalizability of the experimental findings, thereby reinforcing the significance of the research endeavor. Study Two adopts a multifaceted approach involving a first-round controlled experiment and randomized controlled trials encompassing 52 subjects, alongside a subsequent round of scenario simulation tests involving 18 subjects. This comprehensive methodology is employed to assess the impact of varied activity states and keyboard decibel levels on individual susceptibility to interference. Data processing and statistical analysis employ advanced techniques such as fuzzy mathematics and rank-scale methods. Utilizing a stepwise estimation methodology, the study delineates the thresholds of decibel variance in interference tolerance across distinct states: 59.98 dBA for highly concentrated states, 60.79 dBA for moderately concentrated states, 62.91 dBA for lightly concentrated states, and 59.61 dBA for sleep states. Study Three further validates the findings through rigorous Ridit analysis, affirming the reliability of the data provided and positioning it as a valuable reference for pertinent domains. Furthermore, the research findings exhibit a high level of reliability and applicability. These results pave the way for further exploration of additional factors impacting keyboard design, thereby broadening the research domain and enhancing both user experience and health perception. Consequently, this study offers a solid foundation for practical design and management decisions. In conclusion, this study not only addresses theoretical gaps in relevant fields but also provides valuable reference points for keyboard design in practical applications, underscoring its promising prospects and potential for real-world impact.

Keywords: Ergonomics, Subjective response, Individual level of interference, Keyboard key tone decibels, Humanized design

INTRODUCTION

At present, physical environmental pollution is becoming more and more common, and the threat of noise pollution to the well-being and public health of urban residents is increasing (Ising and Kruppa, 2004). The impact of a sound environment on human health has become a growing concern around the world (Tong, 2022). According to the World Health Organization (WHO), exposure to noise levels above 24 dB for more than 70 hours may impair human hearing sensitivity, causing adverse health effects (Qingg, 2016) and long-term exposure to noise can lead to hearing loss (Parsons, 2000). Existing surveys of noise in open work environments in China show that noise is a significant impact and is one of the most annoying sounds (Parsons, 2000).

We analyzed the current research hotspots in the field of keyboards, and found that most of the studies focused on the user experience of keyboard users and the structure of the keyboard itself, the former focusing on the psychological and physiological aspects of user comfort, posture, muscle activity, and trauma (Catherine, 2004), and the latter focusing on the structure and key layout of the keyboard (Hugh, 2009), and the comprehensive research of the two is the impact of keyboard design on users, such as the impact of key spacing on typing results (Pereira, 2013) and the impact of keyboard design on typing activities (Sauter, 1997) and so on. Through keyword search, it was found that it is currently classified as external noise with ventilation systems and office equipment (Mei, 2012), and the research environment has strong limitations.

In this paper, control and control experiments are set up by using questionnaires, explanatory mathematical statistics, fuzzy language sets, etc., to obtain the decibel difference threshold that people in different activity states can not be disturbed. The results are helpful for the R&D side to carry out more reasonable design, and the management strategy to better formulate and implement, and provide a basis for creating a better sound environment.

EXPERIMENTAL DESIGN

In order to explore the impact of different keyboards on people with different activity states in real use scenarios, this paper selects 17 commonly used keyboards for experiments. The experiment consisted of three steps: questionnaire design and distribution, recruitment of experimenters, experimental equipment and environmental testing, the first round of experimental control experiments and randomized controlled trials for a total of five days, and the second round of scenario simulation experiments after the authenticity test of the first round of experimental data. Finally, the data is processed and analyzed, conclusions are drawn and recommendations are made for future keyboard design.

Questionnaire Design

A comprehensive questionnaire was distributed before the experiment to collect information such as how users feel when using the keyboard as a user and the degree of interference when they are disrupted. The collected questionnaire data will be quantitatively analyzed. Using statistical software such as SPSS, we will analyze and synthesize the data to obtain objective data and quantitative results on the perception and impact of keyboard key sounds.

Questionnaire Recovery

A total of 350 questionnaires were distributed and 321 were recovered, with a recovery rate of 91.71%. 90 copies of the noise susceptibility scale were distributed and 66 copies were recovered, with a recovery rate of 73.33%. The reliability coefficient value was 0.722, which was greater than 0.7, indicating that the data reliability quality was very good, and the KMO value was 0.722, ranging from 0.7 ∼ 0.8, indicating that the data was suitable for information extraction.

Table 1. Cronbach's reliability analysis.

Cronbach's Reliability Analysis		
Number of Items	**Sample Size**	**Cronbach's Alpha Coefficient**
22	66	0.722

Table 2. KMO and Bartlett's test.

KMO and Bartlett's Test		
KMO Value		0.722
Bartlett test of sphericity	Approximate chi-square	2405.467
	df	231
	p-value	0

Questionnaire Analysis

The questionnaire was linearly fitted to the parts of the noise sensitivity scale, and the formula was: disturbance degree = −1.686 + 1.329 * noise sensitivity, and the R square value was 0.833. There is a significant positive correlation between the degree of nuisance and noise sensitivity.

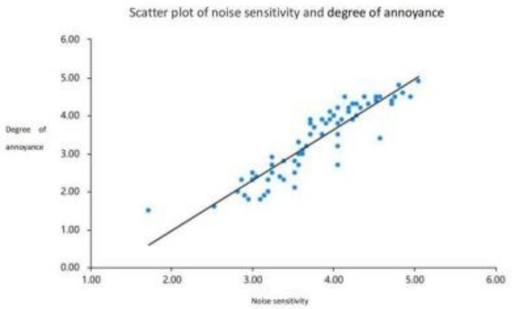

Figure 1: Scatter plot of noise sensitivity and annoyance levels.

It was found that 99% of people have varying degrees of sensitivity to noise. In addition, most people are more sensitive to noise and have a high sensitivity, which verifies the necessity of the experiment.

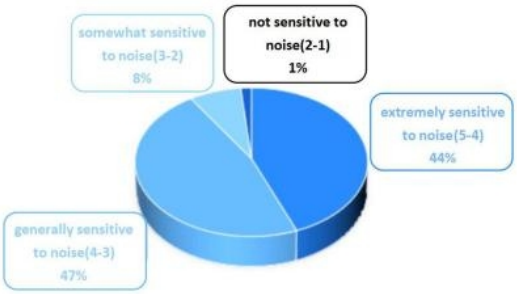

Figure 2: Noise sensitivity ratio analysis.

Experimental Methods and Procedures

Control experimental methods. Each team was asked to test five keyboards with different decibel levels over a five-day period. Administrators are to record the level of keyboard and time period of use, and subjects are to be able to live a normal life and record the current activity and degree of interference when they perceive key sounds.

Figure 3: Controlled and randomized controlled trial records.

Randomized controlled trial methods. The control group was randomly issued with a record sheet and compared with the data of the control experiment to verify the rationality of the control experiment.

Scenario simulation experimental method. The experiment simulated four different concentration states, and the simulation was performed every ten minutes. The experimental data can be combined with comparative verification statistics to obtain the most authentic and effective experimental data.

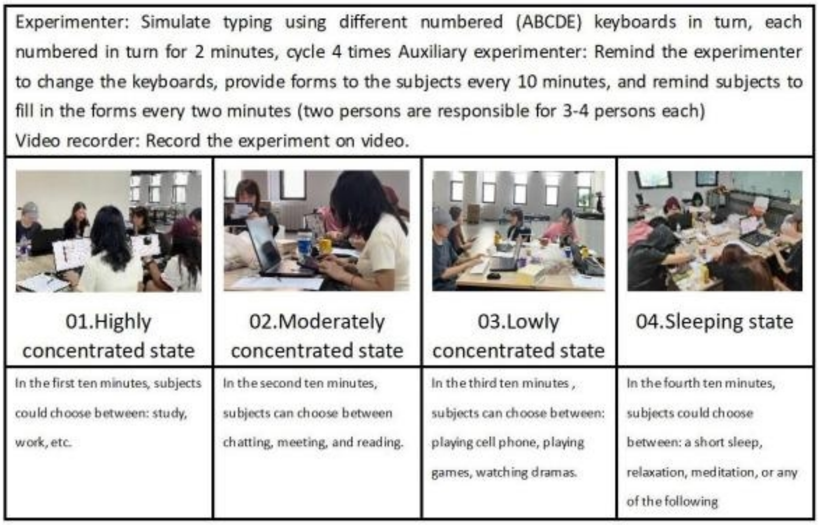

Figure 4: Scenario simulation test record.

Participants on Measurements

In this study, teachers and students of Beijing Institute of Technology were used as experimental subjects, and all of them obtained and signed informed consent. The task is to test the influence of keyboard key sounds in the environment in different set states, and the independent and dependent variables are shown below.

Table 3. Description of independent variables.

Independent Variable	Number of Levels	Explanation
State level	4	Lowly concentration state, Moderately concentration state, highly concentration state, sleep state
Key tone decibel level	5	Level A (35~50db), Level B (50~55db), Level C (55-60db), Level D (60~65db), Level E (65~70db)

Table 4. Dependent variable description.

Independent Variable	Number of Levels	Explanation
Interference level	5	"No interference" 0-1, "Slight interference" 2-3, "Moderate interference" 4-5, "Severe interference " 6-7, "Extreme interference" 8-10
Noise sensitivity	5	Very insensitive, insensitive, generally sensitive, sensitive, very sensitive

Apparatus and Procedures

Before the experiment, a decibel meter was used in a silent chamber to test and classify according to the average decibel value.

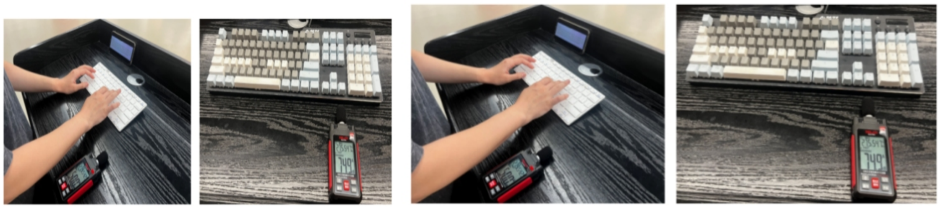

Figure 5: Equipment and procedure test preparation.

Research Results and Analysis

Psychological studies have shown that the limit of people's ability to distinguish information levels is 7±2, so the AHP method uses a maximum nine-percentile scale when evaluating the relative importance of each indicator (Li et al., 2004). By using the rating scale method, the degree of interference is divided into five levels: "no interference", "slight interference", "moderate interference", "severe interference" and "extreme interference". Based on subjective experience, the subjects made judgments according to the level and filled in the questionnaire.

A total of 108 valid experimental forms were recovered (4 invalid forms were removed), and a total of 205 valid experimental records were recorded. The results of mathematical statistical processing are shown in the following table.

Table 5. Statistics of subjective responses to the degree of disturbance.

Keyboard Type i		A	B	C	D	E
Average sound level L_i		**42.5**	**52.5**	**57.5**	**62.5**	**67.5**
Highly concentrated state	No interference	9	7	1	2	3
	Slight interference	1	5	4	2	3
	Moderate interference	1	1	2	5	5
	Severe interference	0	0	3	3	4
	Extreme interference	1	0	0	1	1
	Sum of frequencies n_i	12	13	10	13	16
Moderately concentrated state	No interference	5	3	2	0	0
	Slight interference	1	2	1	1	1
	Moderate interference	0	2	0	3	2
	Severe interference	0	1	2	1	1
	Extreme interference	0	0	0	0	0
	Sum of frequencies n_i	6	8	5	5	4

(Continued)

Table 5. Continued

Keyboard Type i		A	B	C	D	E
Lowly concentrated state	No interference	12	13	9	4	3
	Slight interference	1	3	4	6	7
	Moderate interference	0	0	1	3	5
	Severe interference	0	0	0	2	2
	Extreme interference	0	0	0	0	1
	Sum of frequencies n_i	13	16	14	15	18
Sleeping state	No interference	4	1	1	1	0
	Slight interference	2	2	0	2	1
	Moderate interference	1	2	1	3	1
	Severe interference	0	2	0	3	2
	Extreme interference	0	3	0	0	5
	Sum of frequencies n_i	7	10	2	9	9

Calculation of Difference Threshold

Differential Threshold (Differential Sensory Threshold): Also known as the minimum perceptible difference, it refers to the value of the stimulus that can cause differential sensation in 50% of the number of experiments.

Disturbed Affiliation Function

The subjects are highly confident in their judgment of "no interference" and "extreme interference", so the affiliation degree of "no interference" is set to 0, the affiliation degree of "extreme interference" is set to 0, and the affiliation degree of "extreme interference" is set to 0. Therefore, the affiliation degree of "extreme interference" is set to 1, and the confidence level of "slight interference", "moderate interference", and "severe interference" is low. Accordingly, the affiliation function of the subjective response to the keyboard noise is given by the step-by-step estimation method as follows:

$$\begin{aligned} F = {} & 0/\text{no interference} + 0.3/\text{slight interference} \\ & + 0.6/\text{moderate interference} + 0.8/\text{severe interference} \\ & + 1.0/\text{extreme interference} \end{aligned} \tag{1}$$

Probability of Being Disturbed

Keyboard noise's subjective reflection of the information fed back in the survey not only includes ambiguity, but also there is a great deal of randomness, and this ambiguity and randomness can be interpenetrated. The annoyance probability of each center sound level reflects all the information of the subjective psychological response of the respondents, and the annoyance probability is calculated by the following formula:

$$\text{Pi} = \frac{\sum \mu_j n_{\text{ij}}}{\sum n_{\text{ij}}} \tag{2}$$

Where Pi is the probability of annoyance for the keyboard type of the serial number i, n_{ij} is the frequency of the occurrence of the jth evaluation level under the ith sound level, and μ_j is the degree of affiliation of the jth evaluation level to the degree of interference.

Table 1 substitution data into the (2) formula to find the probability of the subject's degree of annoyance to different types of keyboard sound in each state is listed in Table 6 below:

Table 6. Interference probability of each average sound level in each state.

Average Sound Level (dBA)	Probability of Interference(%)			
	Highly Concentrated State	Moderately Concentrated State	Lowly Concentrated State	Sleep State
42.5	15.83	5	2.31	17.14
52.5	16.15	32.5	5.63	64
57.5	48	38	12.86	30
62.5	53.85	58	34.67	53.3
67.5	50.63	57.5	42.78	83.3

Differential Threshold of Disturbance

The disturbed probability for each average sound level combines all the information about the subjective response of the subject at that sound level. The disturbed difference threshold value should fully reflect this information and is calculated by the following formula:

$$E = \frac{\sum L_i P_i}{\sum P_i} \tag{3}$$

Where $\boldsymbol{E}$ is the average sound level corresponding to the annoyance threshold of keyboard noise; $\boldsymbol{L_i}$ is the $\boldsymbol{i}$th center sound level; and $\boldsymbol{P_i}$ is the probability of annoyance at the $\boldsymbol{i}$th center sound level.

Due to the "highly concentrated state" and "sleep state" under the E-type keyboard annoyance probability being too large, in order to maintain the accuracy and validity of the results, these two states of the E-type keyboard data are not included in the calculation process. Substitute the relevant parameters in Table 2 into formula (3), and the thresholds of the annoyance difference in each state of the interference are: 59.98dBA in the highly concentrated state, 60.79dBA in the moderately concentrated state, 62.98dBA in the lowly concentrated state, and 59.61dBA in the sleep state, respectively.

Ridit Test

Ridit analysis is a hypothesis testing method for comparing the comparison group with the standard group of grade data, which has the advantages of simplicity, clarity, and quantification [15] .

The standard group was selected as the standard group with the same frequency number of the name level and the group with a certain frequency of each evaluation grade, and the high to low grades E, B, E, and B were respectively, and the Ridit value of each standard group was calculated.

$$R = \frac{\sum_{j=1}^{m} C_j \cdot R_j}{N} \tag{4}$$

Where: C_j is the total number of cases of j evaluation level, that is, the frequency of the jth level occurrence; N is the total frequency; R_j is the Ridit value of each level. The Ridit value is obtained by adding half of the frequency number of each level of the standard group and the cumulative frequency number (shifted to the next line), and dividing it by the total frequency number, and the calculation of R_j is shown in Table 7 .

Table 7. Ridit value calculation table for each judgment level.

Interference Level	Total Number C	C1=C/2	Cumulative and Shifted Down One Row	D=③+④	Ridit Value=D/N
①	②	③	④	⑤	⑥
No interference	80	40	0	40	0.1951
Slight interference	49	24.5	80	104.5	0.5098
Moderate interference	38	19	129	148	0.7220
Severe interference	26	13	167	180	0.8780
Extreme interference	12	6	193	199	0.9707
Total N	205	-	-	-	-

From equation (4), the average R-value of each standard group can be derived, and also, the average R-value of each comparison group is demanded with the following formula:

$$R_i = \frac{\sum_{j=1}^{m} n_{ij} \cdot R_j}{N_i} \tag{5}$$

Where: n_{ij} is the frequency number of evaluation grade j under the center sound level of the sequence number; R_j is the Ridit value of each grade; N_i is the total frequency number under the ith average sound level.

Since the theoretical basis of the Ridit test is to transform the original distribution into a uniform distribution from 0 to 1 after R-value conversion, the standard error of the uniform distribution is 1/12. Therefore, the 95% confidence limit of the average Ridit value of each comparison group can be derived from the following equation (6):

$$95\% \quad \text{confidence limit} = \overline{R_i} + 2/\sqrt{12n_i} = \overline{R_i} + 1/\sqrt{3n_i} \tag{6}$$

The obtained average R-value and 95% confidence limit calculation results are summarized as a whole in Table 4 below .

The average R-value in the table has the significance of the probability of interference. The R-values of the standard groups in the four states were 0.6247, 0.4757, 0.5828 and 0.7223, respectively.

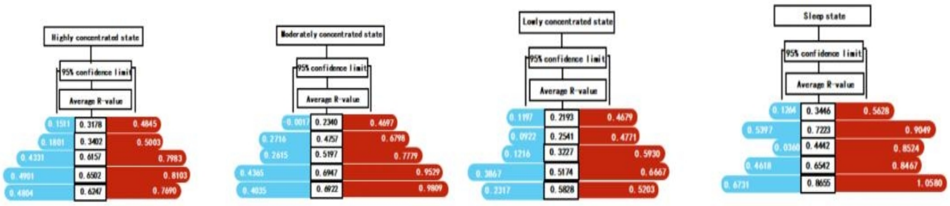

Figure 6: Average value and confidence limit of each average sound level R.

CONCLUSION AND RECOMMENDATIONS

This study aims to investigate the effects of different decibel keyboard noise on people in different activity states. Multiple experiments were conducted to arrive at a recommended shortcut noise limit that could be undisturbed by others. Finally, through data analysis and calculation, it was concluded that the difference threshold of disturbance of people in different states was 59.98 dBA in the highly concentrated state, 60.79 dBA in the moderate concentrated state, 62.91 dBA in the low concentration state, and 59.61 dBA in the sleep state.

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