




The Effects of Weight on Comfort of Virtual Reality Devices

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Abstract. With the development of technology, the virtual reality (VR) headsets are widely accepted and used for leisure activities and training. However, research about the comfort of the VR headsets was rarely done. The study investigated the relationships between weight of VR headsets and subjective discomfort and pressure load on the head. One-way within-subject ANOVA was conducted to test statistical differences of subjective discomfort scores and pressure loads against weight. In all three types of VR headsets, the overall subjective discomfort and pressure loads are increasing with weight. Generally, the lower weight made users feel better when wearing VR devices. Meanwhile, the integrated head-wear headset felt more comfortable than the soft belts headset as a whole. Some suggestions about improving comfort of VR device is presented.

Keywords: VR devices · Weight · Subjective discomfort evaluation

1 Introduction

The concept of virtual reality (VR) was proposed several decades ago [1]. VR devices generate a virtual environment to replicate a real environment and provide users with a variety of experiences [2]. With the development of technology, the VR headset has become more widely available [3]. The miniaturization and portability of the VR visual devices have promoted the development of the VR industry dramatically [3, 4]. The VR has already changed human life in widely application areas such as education and training, engineering, architectural and urban design, heritage and archaeology, medical science, entertainment, and so forth [5].

Most of the research about VR are related to its application in different industries, such as improving construction safety [5], and acting as a laboratory tool in economics [6]. Kim [7] investigated the motion sickness in a virtual reality environment by using virtual reality sickness questionnaire (VRSQ). However, the research on the comfort of VR headsets is still a blank.

The VR devices use head-mounted display (HMD) worn on the head as image display monitor [8]. According to the study of Baber [9] and MaCauley-Bell [10], an increasing on the mass of HMD may affect the physical workload of wearers because of increased moment of inertia of the neck and lumbar joints. Melzer [11] said that weight balance in head-wearing products is very important for long-term use, since these products impose additional loading on the head and may shift the centre of mass for the

head away from neutral position. Therefore, weight has a great impact on the comfort perception when wearing the VR devices.

In summary, it is necessary to determine the proper weight of virtual reality headset to reduce the physical workload on neck and musculoskeletal disorder risk. The objective of this study is to quantitatively evaluate the effects of weight of VR headset on physical workload on head and comfort perception. Three different kinds of headsets were considered, and proper ranges of weight were discussed.

2 Materials and Methods

2.1 Apparatus

Three types of VR headsets differed in wearing were developed and latten (each weight is 100 g) are used to control weight of VR headsets. The headset A (MINISO), headset B (MINISO), and headset C (XIAOMI) were taken out of the cover part and installed with two screws on it, which is shown in the Fig. 1. The size of headset A/B and headset C is $W185 \times D145 \times H105$ mm and $W200 \times D295 \times H156$ mm respectively. The original weight of headset A, headset B, and headset C is 110 g, 110 g, and 230 g respectively. The headset A is with three soft belts, while headset B is with two soft belts. The headset C an integrated head-worn device made from plastic.

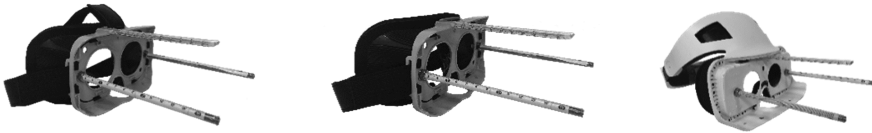


Fig. 1. Headset A, Headset B, Headset C

Three FSR film sensors (FlexiForce A201 1 lbs, Tekscan Inc, USA; $\pm 3\%$ accuracy) were used to measure the contact physical loads on head when wearing VR headset. The thin film sensor is in a flat circular shape with thickness of 3 mm and radius of 7 mm. The FSR film sensors were calibrated to convert the voltage value (unit: V) measured into a force value (unit: N). Serial numbers of sensors are 31,52 and 40.

2.2 Experimental Environment

The experiment was conducted in a dark room to prevent the external interference.

2.3 Subjective Comfort Evaluation

The Borg's CR-10 scale (0 = no discomfort, 10 = extremely discomfort; Borg's 1998) was used to evaluate subjective discomfort (shown in Fig. 2).

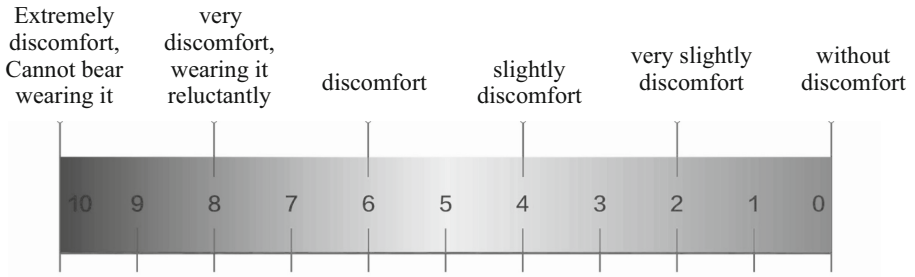


Fig. 2. Borg’s CR-10 scales

2.4 Pre-experiments

According to LeClair [12], the maximum mass of a helmet with ear protection and a cap lamp is about 1000 g. While, the virtual reality devices should be lighter than that. In this case, four weight conditions (100 g, 300 g, 500 g, 700 g) are measured by adding latten (each one is 100 g) on the headsets. Hence, the total headset weight would be added weights plus the original weight (headset A/B: 110 g, headset C: 230 g).

As the contact area of the FSR film sensor is quite small, a preliminary experiment was conducted to determine three test-regions of the head. There are seven main regions on the head which are covered by VR headsets, including bridge of nose, cheekbone, eyebrow, forehead, temporal bone, top of the head, back of the head. Six users (4 female and 2 male; average age: 23.7 years with SD = 1.5) were recruited to wear each headset under three weight conditions (200 g, 400 g, 600 g) for two minutes and report their subjective discomfort evaluation scores on the seven regions. The mean scores are shown in Table 1.

Table 1. Mean of the subjective evaluation scores of the seven regions

Mean score	Headset A			Headset B			Headset C		
	200 g	400 g	600 g	200 g	400 g	600 g	200 g	400 g	600 g
Bridge of nose	1.83	2.50	2.67	2.34	3.00	2.50	3.34	5.50	8.50
Cheekbone	6.17	8.17	9.50	6.83	9.33	9.83	5.33	5.33	6.83
Eyebrow	2.67	4.83	6.00	5.00	5.83	6.33	1.33	1.83	3.83
Forehead	3.00	4.50	6.17	4.17	4.17	5.17	3.17	3.00	3.33
Temporal bone	3.00	3.67	3.50	2.67	3.33	4.00	3.50	3.67	3.50
Top of the head	3.50	5.83	6.17	0.00	0.00	0.00	0.00	0.00	0.00
Back of the head	4.67	5.00	6.17	4.00	6.17	5.67	4.67	5.17	6.50

Overall, for the headset A, the highest scores appear in cheekbone, top of the head and the back of the head; for the headset B, the cheekbone, temporal bone and back of the head are the highest three regions; differently, the nose, cheekbone and back of the head shows as the uncomfortable regions when wearing headset C.

Once the three test regions of each type of headset were determined, further pre-experiment was made to identify test spots on face and head. Four students (2 female and 2 male, average age: 22.25 years with SD = 0.75) wore each type of headsets with four FSR film sensors which are linear aligned on three head regions. The sensor with the highest pressure value in each region was defined as the test spot in the main experiment, which are shown in the Fig. 3.

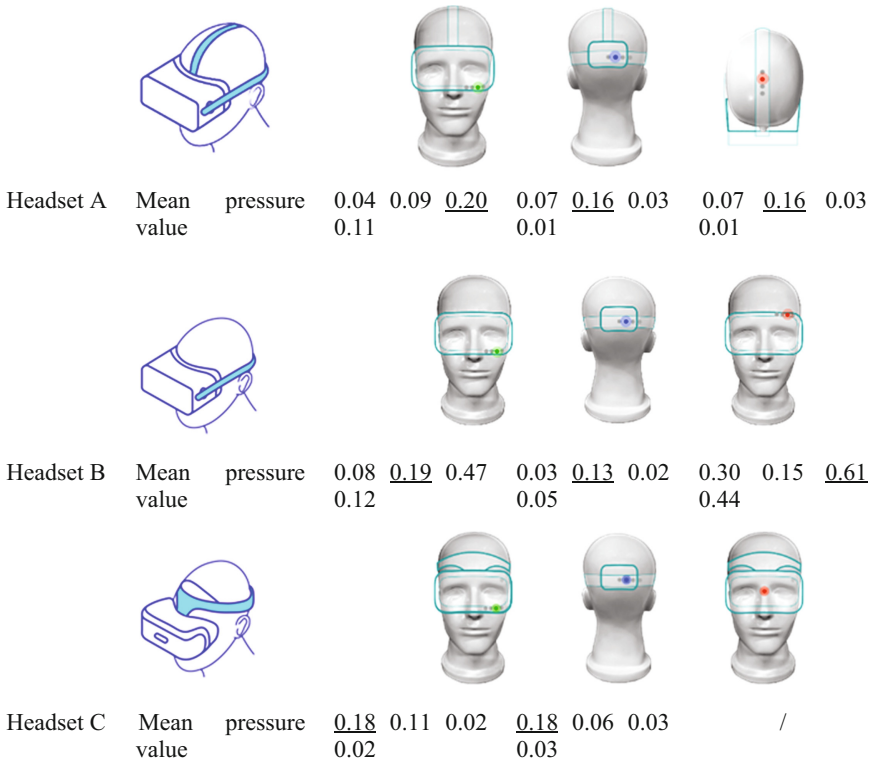


Fig. 3. Mean pressure load value of three regions

2.5 Subjects of Main Experiment

Twenty-six university students (13 female and 13 male) aged between 19 and 30 years participated in this experiment. Their average age was 22.42 (Standard Deviation = 2.344). None of them had any discomfort or medical problems. All participants were provided with a description of the study procedures and signed an informed consent form.

2.6 Page Numbering and Running Heads

The experiment is a within-subjective design. Each participant experienced 12 conditions in four different weights with three headsets differed in type of wearing and was asked for comfort sensation under each condition. Participants spent approximately 5 min becoming accustomed to the controlled environment, while the researcher introduced the experiment and collected demographic information. The participants were instructed to wear the headsets with the help of the researchers.

The contact pressure loads on the three head regions were recorded by three FSR film sensors. There were 10 min break after wearing each headset. Overall, it took about one hour for each participant to complete the whole experiment.

One-way within-subject ANOVA was conducted to test statistical differences of subjective discomfort scores and pressure loads against weight. Besides, Pearson’s correlation analysis was conducted to identify statistical relationships between subjective discomfort ratings and pressure loads on the head. All the data were analysed using IBM SPSS statistics 24.

3 Results

3.1 Overall Subjective Discomfort Evaluation

The overall subjective discomfort ratings are growing up with added weight (Fig. 4). It is illustrated that the subjective discomfort core is significantly and positively related to weight ($p < 0.000$).

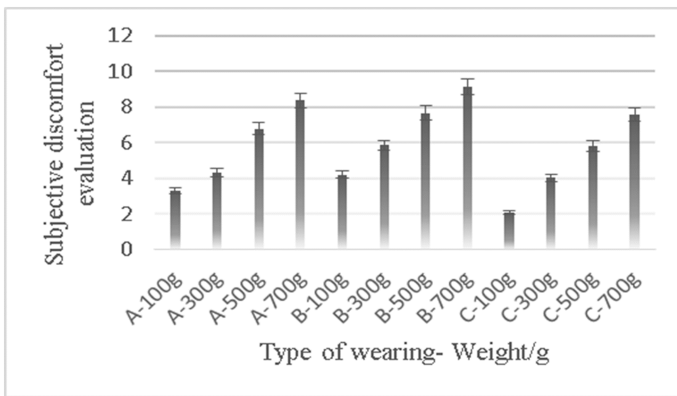


Fig. 4. Mean value of subjective discomfort among three types of headset

In comparing with three types of VR handset, the subjective discomfort rating is highest with the headset B (mean score = 6.746), followed by the headset A (mean score = 5.756). The headset C has the lowest score in subjective discomfort (mean score = 4.888). Although the headset C has the lowest core in subjective discomfort (mean score = 4.888), a small increase in weigh would invoke more discomfort perception.

3.2 Pressure Load Datum

Pressure Load Datum of Headset A. For the headset A, the pressure load on the top of head (31), cheekbone (52) and back of the head (40) were recorded. It is obvious that the pressure load datum of cheekbone (52) is growing up remarkably with increased weight (Fig. 5), while the increases in pressure load of the top of head (31) were slight. Surprisingly, the pressure load of back of the head (40) were almost the same in four different weight conditions. The pressure load of cheekbone (52) is used for further correlation analysis.

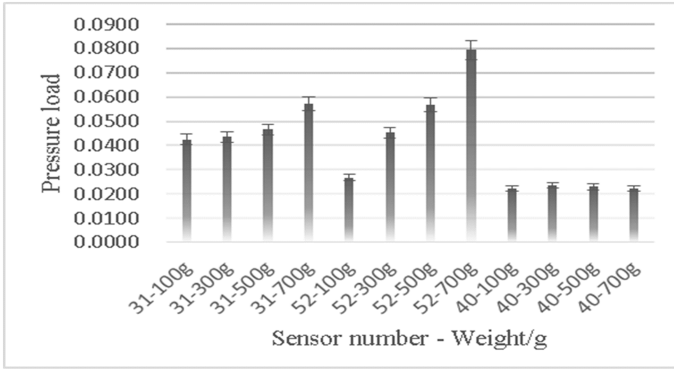


Fig. 5. Mean value of pressure load datum for headset A

Pressure Load Datum of Headset B. For the headset B, the pressure load of eyebrow (31), cheekbone (52) and back of the head (40) were recorded. It is shown that the average pressure load of eyebrow (31) is higher than that of cheekbone (52) and back of the head (40) (Fig. 6). However, the pressure load of three regions didn't grow up

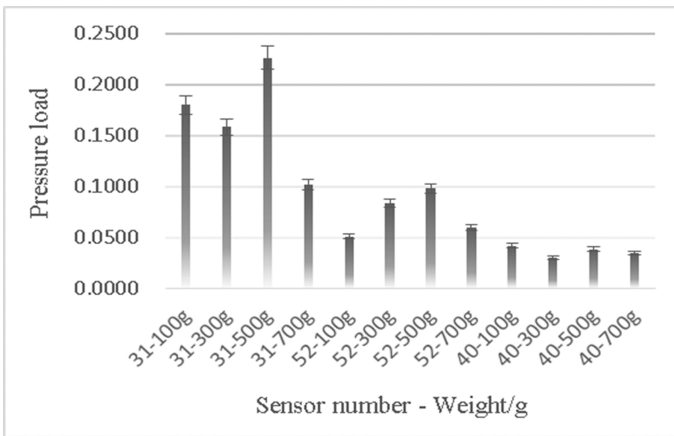


Fig. 6. Mean of the pressure load datum for headset B

steadily with weight increment. For the pressure load of eyebrow (31) and cheekbone (52), the peak pressure value appears in the weight of 500 g. The pressure load of the back of the head (40) keeps stable at around 0.04 N in four weigh conditions. Therefore, the pressure load of eyebrow (31) is selected for further correlation analysis.

Pressure Load Datum of Headset C. For the headset C, the pressure load of bridge of nose (31), cheekbone (52) and back of the head (40) are recorded. It illustrates that the pressure load datum of bridge of nose (31) rises up conspicuously with weight (Fig. 7), whereas the pressure load datum of cheekbone (52) and back of the head (40) remain stable. Hence, the pressure load of bridge of nose (31) is used for correlation analysis.

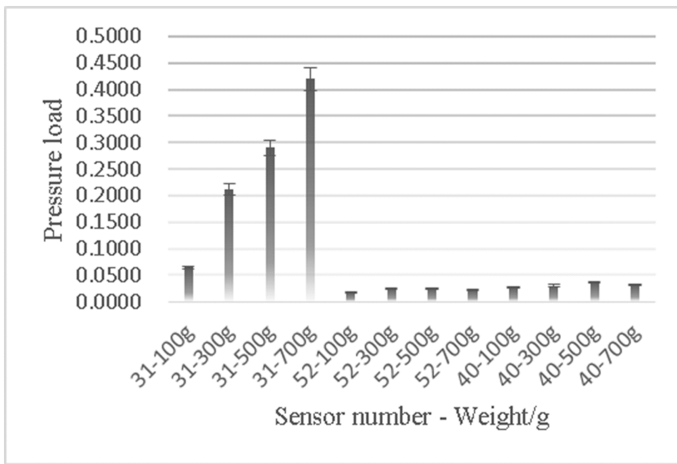


Fig. 7. Mean of the pressure load datum for headset C

Overall Pressure Load Datum. For three types of headsets, it is shown that the pressure load is significantly and positively related to weight ($p < 0.01$). As expected, the recorded regional pressure loads are increasing with weight.

3.3 Relationship Analysis

To find out the relationship between the subjective discomfort and pressure load of the selected regions (headset A: cheekbone (52), headset B: eyebrow (31), headset C: bridge of nose (31)), Pearson’s correlations analysis was conducted. The results indicated that the subjective discomfort is significantly and positively correlated with pressure load on head for headset A ($r = 0.348$) and headset C ($r = 0.347$), but the correlation is not significant for headset B.

4 Discussion

4.1 Weight

On the whole, the subjective discomfort is rising when the weight grows up. The finding confirms results from previous studies that lower mass makes users feel more comfortable. According to the research of LeClair [12], the maximum acceptable mass of the helmet system was roughly 1000 g. The lower HMD mass, the less reported subjective difficulty in all test postures in the research of Chihara [8]. Our result is consistent with the above studies. According to the statistical analysis, the weight of headset is positively correlated to the subjective discomfort evaluation. The weight changes have greater influence on subjective discomfort evaluation in headset C compared with headset A and B.

4.2 Wearing Ways

In comparison with three different types of headsets, the subject discomfort evaluation showed remarkable variation. The integrated head-wear device got lower score on subjective discomfort ratings than the soft belts headsets. Meanwhile, the headset with three belts got lower discomfort evaluation score than the headset with two belts.

4.3 Pressure Load

In the study of the Chang [13], the nose pressure load was strongly relevant to the overall discomfort. Similarly, in this study, the pressure load datum is positively correlated to the subjective discomfort evaluation for all types of headsets. Hence, the pressure load can be used as an objective indicator of comfort in further research.

For the headset A and C, the results show that subjective discomfort evaluation is increasing with the rise of the pressure load. But for headset B, there is no significant relevance between subjective discomfort evaluation and pressure load. As the headset B is a device with only two belts for attaching to a person's head, its affordable weight is less than that of headset A and C apparently. Besides, the contact between the sensors and the participants' skin is getting loose when the weight came to more than 500 g. Thus, the pressure load record of the headset B does not show the real pressure precisely.

4.4 Recommendation

The pre-experiment result indicates that for different types of head-worn devices, the subjective discomfort evaluation on different regions of head is diverse with increase in weight (Headset A: cheekbone, top of the head and the back of the head, Headset B: cheekbone, eyebrow and back of the head, Headset C: bridge of nose, cheekbone and back of the head). Thus, the regions with higher subjective discomfort ratings where is cheekbone and back of the head in this study, should be given more attention when designing similar types of devices.

Besides, the maximum acceptable weight of different VR devices is different. Based on the experiment results, for the headset A (device with three belts), the maximum weight which can be accepted by users is around 400 g. When the weight reaches 500 g, the participants reported discomfort and almost cannot bear with it. The recommendatory weight of headset B (device with two belts) is about 300 g. While, the maximum weight can approximately reach 500 g for headset C. Heavier weight is acceptable when wearing the integrated head-wear device. Generally speaking, the integrated head-wear device provides more comfort feeling for users. The weight of 300 g and less is regarded as a comfort for three types of VR devices.

5 Conclusions

The study investigates the relationships between weight of VR headsets and subjective discomfort and pressure load on the head. The lower weight made users feel better when wearing VR devices. Meanwhile, the integrated head-wear headset felt more comfortable than the soft belts headset in general. The result implies a potential method to improve the physical comfort of VR headset by reducing weight and designing the headset with the integrated shape. The study has several limitations: only three types of headsets were studied in this research which cannot represent all VR headsets in the market. The weight balance of VR devices should be investigated as well.

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