The Experimental Research of Task Load Quantitative Analysis Based on the Pupil Diameter

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Abstract. The aim of this paper is to do experimental research of task load quantitative analysis based on the pupil diameter. Two sets of experiments were designed from several task elements: (1) Visual Tracking, Visual - Cognitive, Visual - Cognitive – Response; (2) Auditory-Cognitive, Auditory - Cognitive - Respond. In the experiment, the pupil diameter was obtained by eye tracker. From the experimental results, the change of pupil size in visual tracking experiment is the same as in visual cognition experiment, which can indicate the load of these two tasks being the same. The increasing size of the pupil diameter aroused by task of responding, in the experiments of Visual-Cognitive-Respond and Auditory-Cognitive-Respond, is also in the same. The results showed that pupil diameter can be used as the index for task load quantitative analysis.

Keywords: pupil diameter, task elements, eye tracker.

1 Introduction

While a precise definition of a workload is elusive, a commonly accepted definition is the hypothetical relationship between a group or an individual human operator and task demands. Relative aspects of workload seem to fall within three broad categories: the amount of work and the number of things to do; time and the particular aspect of time one is concerned with; and, the subjective psychological experiences of the human operator (Lysaght, Hill et al. 1989[1]). Hart and Staveland (1988) [2] describe workload as "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task". Cognitive task analysis is to systematically define the decision requirements and psychological processes used by expert individuals in accomplishing demands [3]. “Mental workload refers to the portion of operator information processing capacity or resources that is actually required to meet system demands.” (Eggemeier et al., 1991) [4]. Most of the definitions, workload, metal workload, cognitive workload represent the same meaning. The definition of Task Load is resources required to meet demands [5], which is one of the factors to construct workload, combining with individual skills and experience. The task load is just the resource requirements based on task nature. Task Load

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Prediction is a critical aspect of design; it is a construct related to performance measures and subjective workload ratings that may help spot design defects.

Kevin M. Corker in NASA[6] established the MIDAS, which includes the workload assessment model, predicting the workload through the establishment of the task load. Bierbaum(1987)[7] has also established a workload prediction model and applied it to the design of the UH-60 aircraft with task load. Johnson (1990) [8] used the same method to establish a workload prediction model, and did a compare analysis of the aircraft design between MH-47E and CH-47D on operator workload in 1991[9], and applied to predict pilot operation workload of AH-64A aircraft. The studies above have established the workload assessment and prediction method by analyzing the task load value from subjective evaluation.

A lot of researches have been done on physiological measurements of workload (eye movement measurement, ECG measurement). We found that the pupil diameter is one of the most sensitive indices to workload. Ahlstrom (2006) [11] has studied different cognitive activity, eye movement parameters with sensitivity to mental workload changes; Van Orden[12] applied eye activity measures, and accurately estimated changes in sustained visual task performance. In the process of our experimental researches, we found that the pupil diameter can change between the task units with little task difficulty difference. It is feasible to use the eye movement technique as the task unit load measurement in this research program.

In the beginning of the design of man-machine interface, workload can only be evaluated by analyzing the tasks, so the measurement of workload is very important. However, usually the measurement is carried out by subjective estimates. The question is: could workload be quantitative measured by physiological measurement?

Eye tracking is an effective method, which could show the changes of tasks sensitively; especially when the task load is low or its changes are not obvious. In the circumstances, could eye tracking be used as a method of quantitative measurement of task load?

Therefore, this article researches by the two questions above. The design of the eye tracking experiments is based on the processing stages (perception, cognition, responding) of resources model [13, 14] to obtain the pupil sizes under different tasks.

2 Experiments

The four dimensions of four- dimensional multiple resource model includes: (1) processing stage: perception, cognition, responding; (2) perceptual modalities: visual, auditory; (3) visual channels: focal and ambient vision, and (4) processing codes: spatial and verbal.

The experiment was designed based on the above classification. This paper intends to use two simple sets of experiments to accomplish the quantitative analysis of the workload by pupil diameter. The first set included three different basis tasks: Visual Tracking, Visual - Cognitive, Visual - Cognitive – Response. The second set of experiments included two different basis tasks: Auditory-Cognitive, Auditory - Cognitive - Respond.

2.1 Experimental Contents

(1) The First Set of Experiments

Visual Tracking: The cursor "+"was shown on the computer screen randomly. The switching interval of two "+" can be set. In this experiment, there are four trials the time interval "2000ms" "1000ms", "600ms", "300ms", the total duration of each trial is 60 s. Subjects were required to do visual tracking “+" cursor on screen.

Visual - Cognitive: Letters were shown on the computer screen randomly. In this experiment, there are four trials with the time interval "2000ms" "1000ms", "600ms", "300ms", the total duration of the each trial is 60 s. Subjects were required to see the letters and try to recognize them.

Visual - Cognitive - Respond: Letters were shown on the computer screen randomly. In this experiment, there are four trials with the time interval "2000ms" "1000ms", "600ms", "300ms", the total duration of each trial is 60 s. The subjects were required to see the letters and cognitive and respond on the keyboard with the right keys.

(2) **The Second Set of Experiments.**

Auditory - Cognitive: Subjects were required to recognize after hearing the letters via sound. The experiment included three trials with interval time of "2000ms" "1000ms", "600ms". The experimental requirements were based on hearing letters and to identify them.

Auditory - Cognitive - Respond: Subjects were required to respond after hearing the letters via sound. The experiment included three trials with interval time of "2000ms" "1000ms", "600ms". The experimental requirements were based on hear letters to identify them. Subjects were required to see the letters and respond on the keyboard with the right keys.

2.2 Apparatus and Environment

Apparatus: two pieces of black paper, Eyelink II eye movement measurement system(shown in Fig. 1).

Experimental environment: experiment required to keep the light environment unchanged with illumination about 120 LUX.

2.3 Subject

10 students (undergraduate and graduate) participated in this experiment, male, age 19-25, visual acuity 1.0-1.5.

Fig. 1. Eyelink II eye movement measurement system

3 The Real Value of Pupil Diameter

Since the design theory of Eyelink II eye tracker is optical reflection and the units of pupil size Recorded is in pixels, the relative position of the collecting equipment in eye instrument and the pupil will affect the pupil diameter size recorded. Every time put on the eye tracker, the relative position between pupil-infrared of the head and eyes are different. So pupil diameter values recorded in difference experiments cannot be analyzed together. Therefore, only the pupil diameter recorded by eye tracker is translated into real size, which can provide the possibility of analysis between pupil diameter data of different experimental tasks.

3.1 Calculation of Ratio

After subjects closed their eyes, two eyelids of the subject are pasted on two black-round pieces with the diameter known after, the real diameter defined as dz. The diameter measured value of two black-round pieces by eye tracker is defined as dc. Then the ratio is defined as the division of measuring value and real value of black-round piece, as in:

$$r = dc / dz \tag{1}$$

This ratio value is just the same with the current measurement position, the relative position between the infrared camera and eyes unchanged.

3.2 Conversion Method

After measuring the diameter of black-round piece, with the relative position the infrared camera of the head and eyes being unchanged, it can be measured with eye tracker. The pupil diameter under the task experiment recorded by eye tracker is

Dc .So the real pupil diameter value(D) can be obtain through the value of ratio and measuring value, as in:

$$D = Dc/r \tag{2}$$

4 Data Processing

The pupil diameter collected by eye tracker was processed through formulas (1), (2), mentioned above. The result of one subject was shown in Table 1and Table 2.

As the size of the pupil diameter varies with light intensity, little position change of stimulator can arouse the change of pupil. In order to analyze the various value of pupil diameter due to the task load, it is a must to control other factors affecting the pupil size. Thus, we need to record and analysis the pupil diameter in the natural state in the current task (the current light and distance to the pupil) when processing the data. For a different task, when their data of natural state is different, we need to amend the data with the pupil diameter of natural state, as shown in Table 1.

Table 1. Data processing results of on subject of the first set experiment

	natural state	Trial 1 (2000ms)	Trial 2 (1000ms)	Trial 3 (600ms)	Trial 4 (300ms)
Visual tracking	3.313	3.322	3.375	3.358	3.273
Visual cognition	3.292	3.506	3.516	3.449	3.355
Visual cognitive operations	3.684	4.265	4.303	4.354	4.357
Difference between natural state	0.383				
Visual cognition (as amended)	3.300	3.881	3.919	3.970	3.973

Taking the experimental data of one subject as example, the results of the first set experiment are shown in Fig.2, the amending data shown in Fig.3. The experimental data amended of the second set experiment are shown in Fig.4.

Table 2. Data processing results of on subject of the second set experiment

	Natural state	Trial 1 (2000ms)	Trial 2 (1000ms)	Trial 3 (600ms)
Auditory-cognitive	3.645	4.155	4.307	4.381
Auditory-cognitive-operation	3.519	4.708	5.295	5.454

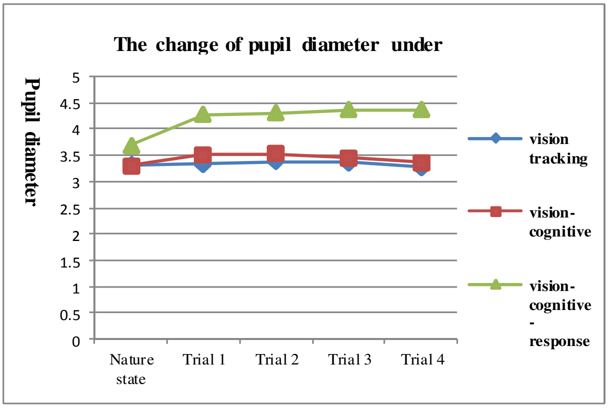

Fig. 2. The change curve of pupil diameter of the first set experiment of one subject

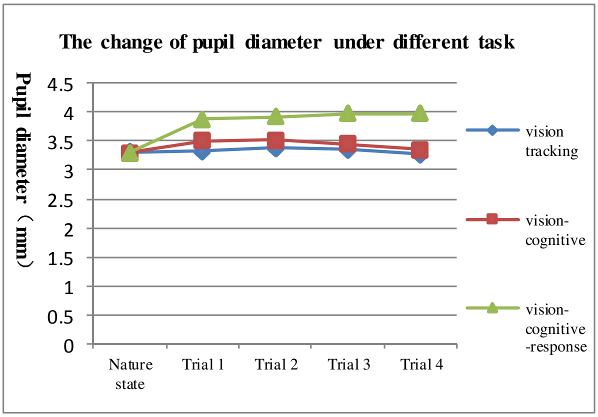

Fig. 3. The change curve of pupil diameter of the first set of experiments of one subject (having mended)

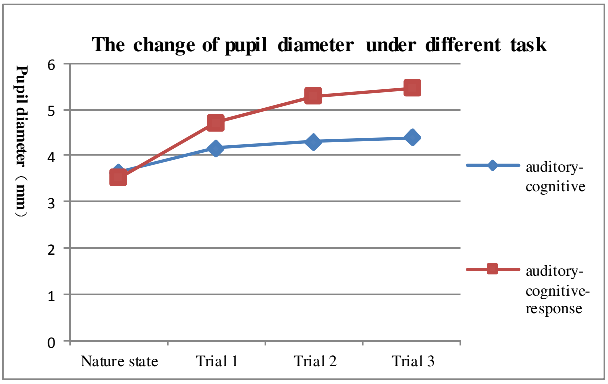

Fig. 4. The change curve of pupil diameter of the second set of experiments of one subject

The experimental data of other nine subjects were processed by the same method, and then average all the data of each task. The processing results are shown in Figure 5 and Figure 6.

As shown in Figure 5, we know that when the interval was set to 600ms and 300ms, with the increase of time pressure, pupil size stays in a relatively stable size.

Shown in Figure 6, the pupil diameters in Auditory-cognitive and Auditory-Cognitive-Respond tasks are increasing very obviously with the time pressure, and very regularly.

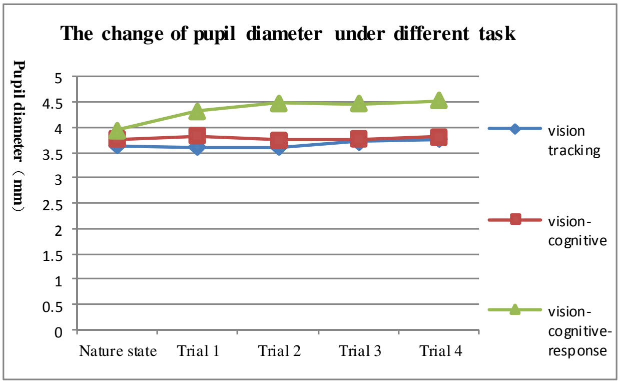

Fig. 5. The average value of pupil diameter of the first set of experiments of 10 subjects

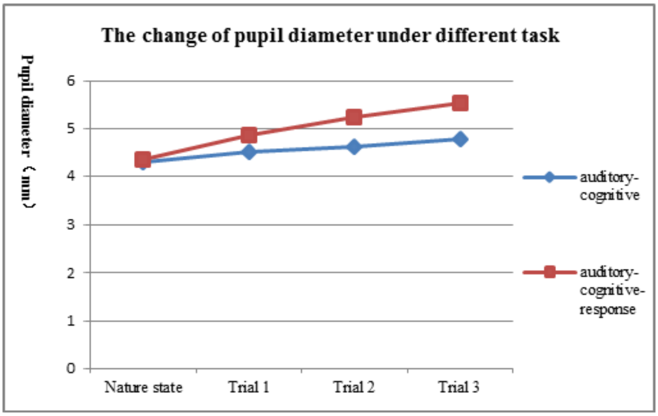

Fig. 6. The average value of pupil diameter of the second set of experiments of 10 subjects

5 Conclusion

In visual tracking experiments and visual cognition experiments, pupil size changes did not differ much from the results, which can determine the load of these two tasks being the same. Visual-Cognitive and Visual-Cognitive-Respond tasks caused by the pupil diameter changes were about 0.7mm or so.

For the tasks of Auditory-cognitive and Auditory-Cognitive-Respond tasks, both the slope of the curve and change size value can be used to represent the task load. The change values of pupil diameter between the two tasks are 0.75 mm.

The respond task of operation can be expressed by the value (0.7 +0.75) / 2 = 0.725 mm of the pupil diameter changes.

The result shows that pupil diameter can be used as a good index to study task load quantitative analysis. There are some difficulties to establish the principle for giving task value, so the research for the task load quantitative analysis by pupil diameter has to continue for a long time.

6 Discussions

In the process of our experiment, we used three methods to measure task load, including subjective measurement, ECG measurement, and eye tracker measurement. From the measurement results, we found that subjective measurement and ECG measurement can't change accurately with the change of task load. So we can't to verify the experimental data by another method. So this paper has not presented the verification of the result. However, in the experiment, we can verify the data by doing different task by the subjects and doing the same experiment by the same subject in different time.

There are some difficulties to establish the principle for giving task value, so the research for the task load quantitative analysis by pupil diameter has to go on for a long time.

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