Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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http://ansinet.com

Journal of Applied Sciences 8 (1): 68-76, 2008
ISSN 1812-5654

Using Pupil Diameter Changes for Measuring Mental Workload under Mental Processing

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Abstract: In this study, it is aimed to evaluate the mental workload by using a practical way which based on measuring pupil diameter changes that occurs under mental processing. To determine the mental effort required for each task, the video record of subjects' eyes are taken while they are performed different tasks and pupils were measured from the records. A group of university student, one female 9 males participated to the experiment. Additionally, NASA-TLX questionnaire is applied for the related mental tasks. For verification of results obtained from both indices, the correlation coefficient is calculated task base. The results show that there is weak and negative correlation between the indices on task base except 3rd task. By investigating pupil diameter measurements data too, it is founded that pupil dilates under mental workload during performing related tasks. For all tasks, pupil diameters of response periods increased according to reference baseline period.

Key words: Measuring mental workload, pupil measurements, pupillary dilation, mental processing, brain activity

INTRODUCTION

Today, jobs requiring physical activity are gradually leaving their places to the jobs requiring much more mental processing. Job characteristics change from physical aspect to mental aspect, doing the job in person to inspect and control, or to thinking aspect. It is necessary to evaluate the workers not only with job characteristics which has inclined towards investigation and control but also with psychological and mental attributes as speed and correctness of perception, attention, memory, intelligence. It is needed comprehensive methods for analysis and evaluation of the jobs which requires mostly mental processing. A practical way to measure of mental workload that has the ability to evaluate operators' mental effort in a multitask condition would be valuable in a natural working environment, because most such work is composed of multiple tasks. In this study, an approach is described that developed a combined measure of mental workload based on one physiological index one subjective index.

Systems designed which takes care of the results of mental workload measurements can help productivity and motivation. On the other hand, the fields like human-machine output quality, safety, personnel selection and recruitment could refer to the result of this kind of researches. It can be predicted that increasing mental workload can increase the mistakes related to the work and as a result of this, can multiply accidents. So, the mental workload information becomes vital to take actions and precautions related to accident prevention.

Avoiding excessive loading of brain is precedence; the least loading of brain is another important problem. In reality, it is intended that by avoiding mental workload to become excessive or the least, optimum mental workload should be provided which leads to personnel development and it keeps the person far from away upsetting.

Research headlines, defined according to predictions made by the researcher, which are the possible solutions of the problem, before testing without knowing whether they are valid or not (Kaptan, 1993).

The research headlines of this study are defined as, pupil diameter dilates or constricts when subject is performing thinking, time consuming, analyzing, synthesizing, recognizing tasks, with related psychomotor activities and there is relationship between the values measured during performing the related tasks and values found by applying NASA-TLX subjective measurement method in respect of discrepancy or not.

Basic assumptions, on which research is based: 1. Iris diameter, pupil diameter ratio (I/P) is the correct derivation of pupil diameter where the measurements are taken on each picture which makes up the video record (6 pictures sec^{-1}) captured with the head mounted camera, calculated by using the distances between the vertical lines drawn tangent to right and left sides of iris and the vertical lines drawn tangent to right and left sides of pupil. 2. Subjects did not communicate and influence each other on the experiment material and psychomotor task. 3. Subjects performed required activity as it is described on experiment directive. 4. The expert opinion

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on validity of the questions included in test tool is sufficient. 5. Subjects were motivated equally.

Mental workload concept is a multidisciplinary field including ergonomics, psychology, physiology, medicine, statistics, engineering etc. The research made in this field is a multidisciplinary study and the related publications in these fields were tried to be studied.

Mental workload has long been recognized as an important element of human performance in complex systems. Moray (1988) found that the optimization of mental workload could reduce human error, improve system safety, increase productivity and increase operator satisfaction. Mental workload has a direct influence over a user ability to perform tasks and can therefore impact the effectiveness and efficiency of interactions with computers (Vitense *et al*., 2003).

Cognitive (mental) workload has been defined as the interaction between the demand of a task that an individual experiences and his or her ability to cope with these demands. Hence, it arises due to a combination of the task demands and the resources that a particular individual has available (Noyes *et al*., 2004).

The mental workload of a task represents the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support and past experience. One of the hurdles in deriving a subjective measure of MWL is validating it by correlation with other measures (such as physiological evidence) or objective demand (Young and Stanton, 2002).

Even though there are many environmental factors that can increase the mental workload, noise, temperature and light level are the most important. They have important influence on the performance, attention and effectiveness of the worker (Martinez de la Teja, 2001).

Mental workload is a structure assumed as a multidimensional reflection of mental effort and attention directing of an individual. Measurement of mental workload represents enumeration of mental process which occurred during performing a task or task group (Baldwin, 2003).

The response sensitivity to a mental task is different in each person. The physiological responses induced by the same task may differ from person to person. This is the individual difference problem. Furthermore, the physiological response pattern is different from task to task (Miyake, 2001).

Mental workload measurement techniques can be classified in three groups;

- Behavioural measures: including primary task measures and dual task or secondary task measures.
- Physiological measures: including but not limited to neuroergonomic indices of brain activity.
- Subjective measures: have one or multi dimensional scales.

The question Which method of measurements is the best? is open to discussion in respect of aim of experiment, tasks performed and environment in which the experiment taking place with the benefits and limits of the indices (Baldwin, 2003).

Many of the research pertaining to mental workload, has relied on behavioral measures of response time and accuracy. Behavioral measures have enabled substantial progress in systems design. For example, response time and accuracy measures have demonstrated that mental workload increases when driving in urban as compared to rural settings. Some tasks that are time consuming are not very difficult. The monotony of these time-consuming, tedious tasks as well as tasks which demand sustained attention over long periods of time result in increased errors and delayed reaction time due to lapses of attention. Therefore response time and accuracy do not always or necessarily directly assess mental workload and may be insensitive measures of the difference between inherently difficult tasks versus difficult situations requiring sustained attention for extended periods of time (Baldwin, 2003).

Behavioral measurements are made by primary task measurement, two tasks or secondary task measurement methods.

Primary task approach: One of the attempts for quantification mental workload of a task defines workload simply as dividing the time period required to achieve the task to the time available. A few computer modeling program were developed to make such a calculation for a task period.

Secondary task approach: The logic behind the usage of secondary task measurements is that there is spare mental capacity, not directed to primary task, which can be used for performing the secondary task.

Measurement of spare mental capacity is based on the rationale that the operator has limited capacity to process information. One method to measure the mental workload is to give the operator a secondary task in addition to his/her main task the level of performance at secondary task will reflects the difficulty of main task. Secondary task is designed so that performance can be measured objectively by means of performance time and/or number of errors. The measure of secondary task performance can be used as an index of primary task load (Martinez de la Teja, 2001).

The logic behind the physiological indexes used for measuring mental workload is the activities created at central nervous system, on information processing of the brain, which has detectable indications. Heart rate, respiration, blood pressure, breathing, eye blinking, pupil diameter and brain activity level changes are some of the physiological indicators which are emerged in relation with mental workload. Recent advances in technological capabilities, analytical techniques and the increasing availability of equipment for non-invasive, real time assessment of human brain function have led to revolutionary advances in mental workload measurements.

Neuroergonomics, or examination of the changes in brain functioning and levels of brain activity associated with the performance of perceptual, cognitive and physiological tasks during work and leisure, provides an opportunity for a more direct assessment of mental of mental workload. Measurement of how hard the brain is working through neuroimaging techniques, such as Functional Magnetic Resonance Imaging (FMRI), electroencephalography (EEG) and Event-Related Potentials (ERPs), represent a major step forward in advancing proactive science-based system design (Baldwin, 2003).

Electroencephalography (EEG), recording of brain spontaneous activity, is recorded on the surface of haired head skin by surface electrodes or from deep brain structures by electrodes located with stereotactic method. If a physical stimulus (auditory, visual and electrical) applied to a person or an experiment animal from whom his/her EEG is obtained, a change lasting one second occurs in spontaneous activity of the brain. This reaction is called as Stimulus Potentials (SP). The stimulus potentials related with cognition, interpretation, memory and behavior are called as Event-Related Potentials (ERP) (Özesmi *et al*., 2000).

Event Related Oscillations (ERO) appear by decomposing of ERPs. The oscillations which are reliable events of the brain are the basic element of principles explaining brain processing. These oscillations displayed at different frequencies. The oscillations, underlined in respect of brain functioning, are consisting of delta, theta, alpha, beta and gamma. The findings show that frequency bands are divided in to lower level frequency bands as slow, medium fast gamma and slow and fast alpha. If these lower bands are taken into account, the total number of oscillations reaches to ten (Karakaş and Başar 2003).

Subjective mental workload can be defined as the subject's direct estimate or comparative judgment of the mental or cognitive workload experienced at a given moment (Luximon and Goonetilleke, 2001).

Subjective assessment techniques have the advantage of being relatively easy to administer and interpret and they do not require extensive training or equipment. Despite their frequent use in aviation settings, subjective workload measures tend to be situation-specific and most often fail to take into account adaptivity, learning, experience, natural ability and changes in emotional state on the part of the operator. Further, when used alone, subjective measures reveal little in terms of the brain mechanism involved in task performance and, more importantly, from a systems design perspective, can not be used for continuous on-line monitoring of workload (Baldwin, 2003).

Several types of uni and multidimensional subjective scales exist. Examples are Cooper Harper scale, direct scaling, multidescriptor scale, the workload-compensation-interference/technical effectiveness scale, the overall workload scale, the consumer mental workload scale, SWAT and the National Aeronautics and Space Administration-Task Load Index (NASA-TLX). However, results from various studies have shown that NASA-TLX and SWAT are very popular and are widely used. Even though much effort has been made to develop objective measures of workload, subjective workload assessment techniques continue to be popular due to their ease of use, general non-intrusiveness, low cost, high face validity and known sensitivity to workload variations (Luximon and Goonetilleke, 2001).

NASA-TLX is a multidimensional scale for which the overall mental workload is a function of 1. Mental Demand (MD), 2. Physical Demand (PD), 3. Temporal Demand (TD), 4. Own Performance(OP), 5. Effort(EF), 6. Frustration Level (FR)

The degree to which each of the six factors contribute to the workload of the specific task to be evaluated, from the raters' perspectives, is determined by their responses to pair-wise comparisons among the six factors. Magnitude ratings on each subscale are obtained after each performance of a task or task segment. Ratings of factors deemed most important in creating the workload of a task are given more weight in computing the overall workload score, thereby enhancing the sensitivity of the scale. The definitions of NASA-TLX basic factors are given at Table 1. NASA-TLX technique can be applied manually or on PC by filling up the related questionnaire.

Eye is one of the most important information sources to improve a basic methodology for enumerating the psychological data related with stress, fatigue and stimulation. Pupil activity is emerging as a basic field for the related research.

Occipital lobes take place at back of the brain and process the images coming from the eye by providing

Table 1: NASA-TLX rating scale definitions

Title	Endpoints	Descriptions
Mental Demand (MD)	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand (PD)	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand (TD)	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Effort (EF)	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Performance (OP)	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Frustration Level (FR)	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

connection with the images stored at the memory. The reaction of pupil to the stimulus which causes general awakefulness, is controlled by autonomic nervous system. System is alerted by general awakefulness, excitements and some other situations. It is differentiated from the rest of nervous system by serving secretion glands, smooth muscles and cardiac muscle of the heart. The muscles which control the pupil dilation are smooth muscles.

Autonomic nervous system composed of sympathetic nervous system and parasympathetic nervous system. These two system acts antagonistically. For example, the action of sympathetic nervous system tends to increase activity, speed the heart and circulation, to dilate pupil and slow digestive processes. On the other hand parasympathetic nervous system tends to slow down activity in the glands and smooth muscles which the supply, to contradict pupil but promotes digestion. Sympathetic nervous produce noradrenalin and, to a lesser extend, adrenaline. Generally sympathetic nervous system provides general awakefulness, it prepares the organism to meet hasty situations. Parasympathetic nervous system resist to sympathetic nervous system, acts for preserving and saving stored energy (Morgan, 1980).

Associations have been found between human reflexes and measure of cognitive ability. Specifically, pupil reflexes have been related to a vast array of cognitive abilities including short term memory, long term memory, choice reaction time, language processing, attention, mathematical task complexity and individual differences in cognitive ability tests. These studies have consistently found that greater pupillary dilation is observed when cognitive task difficulty is increased and pupil dynamics is claimed to generally reflect human information processing load. The magnitude of pupil dilation has been related to the difficulty of mathematical task being performed and the differences in individual cognitive ability. Pupillary dilation latency has been related to the difficulty of mathematical tasks and inversely related to cognitive ability. Evidence suggest that pupillary constriction latency may also be related to mathematical task difficulty, and therefore, may also be related to cognitive ability (Bryan and Stone, 2003).

The eyes, considered as extensions of the brain to outer world is manifested the secrets of the brain.

Interest value of material viewed: Pupil dilation research initially focused upon emotional reactions and then shifted almost entirely to information processing. Hess and Polt (1960) found that the pupils of women dilated more to pictures of babies, mothers and babies and nude men, while the pupils of men dilated more to pictures of landscapes and nude women.

Hess had emphasized dilation in response to nude opposite-sex pictures (Hess, 1965), Aboyoun and Dabbs (1998) found that pupil dilation to nudity occurred irrespective of the sex of the subject. It appeared that the novelty of nude pictures of either sex produced dilation and the greater novelty of nude male pictures produced greater dilation (Aboyoun and Dabbs, 1998).

Information intake and processing: Kahneman (1973) and Beatty (1982) have utilized pupil diameter changes as reflectors of information processing requirements. Requiring subjects to commit a series of numbers to memory, hold that information in memory for a few seconds and then requiring them to repeat the numbers produced increases in pupil diameter proportional to the numbers of items in the memory set. Larger sets produced more dilation than smaller sets. Requiring subjects to manipulate the information by having them repeat the numbers in the reverse order in which they had been presented produced significantly greater pupil dilation as the numbers were presented with a further increase in pupil diameter during the delay period. Requiring subjects to commit more numbers to memory than they are capable of remembering produces patterns of pupil diameter change reflective of their strategy. Subjects who give up on the task and report that they could not remember the numbers show a different pattern of dilation and constriction than those who report at least some of the numbers in the memory set. The former demonstrate a pattern of dilation until their memory is taxed with a return to baseline levels at this point while those who are able to report some of the numbers show dilation which is maintained until called upon to report the numbers. Thus strategy differences are nicely reflected in pupil diameter changes. Other researchers have looked at variables such as sentence complexity as well as lexical complexity and demonstrated that greater complexity led to greater pupil dilation. These pupil dilation effects occur irrespective of mode of information presentation. Presenting the material verbally produces changes as great as those when the information is presented visually (and light intensity is held constant). The changes in pupil diameter are quite modest when compared to those associated with changes in light intensity. They generally are less than 0.2 mm in diameter (Stern, 1997).

MATERIALS AND METHODS

In this study, made in 2006 at Gazi University, Ankara-Turkey, it is researched the answer of the question Can brain processing (mental workload) be measured by a practical physiological method (measuring pupil dilations) during multitask condition outside laboratory conditions?

Methods: Researches are called, according to environment or medium where they are applied as laboratory and field surveys, according to level as theoretical and applied, according to method and time as historical, descriptive and experimental research. On the other hand, researches can be discussed according to their control feature as survey and experimental (Kaptan, 1993).

This study is a theoretical description and experimental research. The subject was analyzed by trying to investigate related articles and the content was written in this direction.

Experiment was applied individually to each Subject. The changes at pupil during performing the tasks related to the questions given on developed test tool, was recorded by the test camera. At the end, working on these records, the experiment data was formed. Additionally, after completing the related task of each question, NASA-TLX questionnaire was filled, manually, by the subject, these data after completion of the experiment was transferred to NASA-TLX computer program and taken the results by the experimenter. Related internet sites present NASA-TLX program to download and use for the researches, freely. This program was downloaded to PC and used by the experimenter.

Table 2: Test scores and number of students

Scores	9	8	7	6	5	4	3
No. of students	1	1	2	5	7	5	4

Experiment questions: The questions considered that they will cause mental workload are given in 6 category. 1-2. Thinking, 3. Boring, time-consuming task, 4. Recognizing ability, 5. Body analysis and figure coincidence, 6. Attention requiring task with instant decision making.

Thinking questions composed of verbal, analytical and logical commenting questions and cognitively they are at evaluation level, totally they are two questions. Boring, time-consuming question includes counting task of a specific letter and a specific number from a compound series and cognitively it is at knowledge level. Recognizing ability question requires forming a letter by using basic geometrical shapes on PC screen, cognitively at analysis-synthesis level. On the other hand this question due to requiring shapes to move on the PC screen it is a psychomotor task at mouse using level. By turning or moving the geometrical shapes, the target letter is formed. Body analysis question includes separating a body to its parts cognitively it is at analysis level. Figure coincidence question is, bringing two drawings one after another on the same level in the brain, it is at synthesis level, cognitively. A psychomotor task, requiring sustained attention and instant decision making, is playing a computer game on the screen including to meet a moving point with a fixed point, it consists of using arrow buttons to move the active point as psychomotor skill level.

Validity of experiment questions: Experiment questions given as an examination to a group of students (25 people) who are coming more or less the same educational level with the subjects group for validating and the results were evaluated in respect of test evaluation technique (Table 2). Average of group scores is 5.12. On the other hand difficulty level for each question by dividing correct answers to total answers was found as 0.52, 0.28, 0.52, 0.12, 0.82 in sequence from 1st question to 5th question. Because the results of difficulty level scores are between the validation interval 0.1-0.9 the questions are accepted as valid.

Cognitive tasks are sequenced randomly for avoiding learning effect in respect of task difficulty and the same sequence applied to each subject and the results obtained accordingly.

Subjects: Subjects are 2 females 12 male students attending 2nd, 3rd and 4th classes of different faculties of Gazi University-Ankara Turkey. Ages of subjects are between 20-23 years old. All of them use computer and defined themselves as at good or perfect level. Subjects are selected voluntarily and between the students attending the lectures. The video records obtained during experiment 10 records (9 males, 1 female) were appropriate to use for measurements, so they were processed for obtaining necessary data, 4 records can not be processed.

Experiment equipment: One PC and one laptop were used parallel for the experiment, with the web cam camera connected to USB port of the PC computer, the eye video film recorded to PC by the experimenter. Test questions were presented from the screen of laptop to the Subject.

Application of the experiment: Experiment made according to experiment procedure which defines the actions of the experimenter and the Subject step by step. Before the experiment by taking care of Subject's declaration, who are not using contact lens and glasses, eye examination was made by using snellen table for color vision and accommodation and healthy people accepted to the experiment. Camera from more or less a fixed distance, captured the video of the eye (6 picture sec^{-1}), this video was recorded to PC. The video converted to pictures by using the video converter program (ASEKA), as 6 times of answering duration of each question in seconds, the pictures were stored in a file (Fig. 1). On each picture, the time and the order of picture can be seen. The file including pictures was transferred to Photoshop 7 program, here each picture studied to measure the diameter of iris and pupil and the measurements recorded to an excel file one by one.

I/P value obtained by dividing iris diameter to pupil diameter is used for evaluation of experiment results. An excell table designed for recording the measurement values and calculation of I/P. At the beginning of the experiment, to obtain standard I/P value Subject base, Subject asked to look at grey screen of laptop 10 sec, it is assumed that looking at grey screen can not cause mental workload, during this period eye video captured. Using the measurements taking from these pictures, the average measurements of iris and pupil diameters was calculated as the reference I/P values.

On the other hand, I/P values were calculated by using the measurements taken from pictures which are obtained from the video captured during tasks performed in relation with each question. These values are I/P measurement value which is calculated as the average of I/P measurement values, the average of smaller I/P measurement values than I/P reference value and minimum I/P value. The percent change between the reference value and the average of smaller I/P measurement values than I/P reference value shows the pupil diameter changes ratio during mental task for each question, subject base.

Table 3: Sample NASA-TLX overall workload data table (Subject1 GU S3 Nasa Task data)

Scale	Value	Weight
Mental demand	100.00	0.333333
Physical demand	5.00	0.00
Temporal demand	50.00	0.266667
Performance	55.00	0.20
Effort	25.00	0.0666667
Frustration	25.00	0.133333
Total workload	626.667	

Fig. 1: Experiment settlement

So iris diameter is fixed, when pupil diameter increases I/P ratio becomes smaller. The dilation of pupil appears numerically with the decreasing of I/P ratio. It is assumed that the I/P ratio calculated from the measurements taken during task related movements of eye is equal to the ratio calculated with the measurements taken if Subject directly looks at the objective of camera.

In the experiment maximum 2 min were given for each question, at the end of this duration NASA-TLX questionnaire was applied. If solution was given less than two minutes, NASA-TLX questionnaire was applied without waiting. After each question related task, NASA-TLX questionnaire was filled up by the subject. The questionnaire data was entered by the experimenter to the NASA-TLX program and the overall workload value (OWV) was obtained from the software for each question, subject base. Example of Nasa Task Data form obtained from the NASA-TLX software is shown in Table 3.

At the beginning, illumination of environment was fixed and the screen brightness was kept at medium level not to render the measuring because of screen reflection on the eye. It is cared to avoid noise, to prevent light coming directly to the eyes, to comfort the subject and to adjust the armchair seated.

Statistical experiment design: An experiment has at least one independent variable and a dependent variable. The dependent variables of the experiment for each task, which are performance measurements, are the reference I/P value, I/P average measurement value, the average of smaller I/P measurement values than I/P reference value, the minimum I/P value, pupil diameter changes ratio (in %) and NASA-TLX OWV. These values were determined by experimenter studying on the related data after the experiment. The independent variables of the experiment are the questions and subjects.

The correlation was investigated between the data group of I/P average measurement values and the data group of NASA-TLX OWV, for the evaluation of experiment for each question, subject base.

RESULTS

Correlation Between Iris Pupil (I/P) Ratios and NASA-TLX values. The correlation values between the data group of I/P average measurement values which are obtained from the measurements of Subjects for each questions and the data group of NASA-TLX OWV is shown in Table 4.

These values show that there is negative correlation between the data groups except the data groups for 3rd question. There is a weak correlation between the data groups and for the 1st question this correlation is at least level.

Evaluating mental workload reactions of subjects related with experiment tasks I/P ratio values for the mental task related with 1st question is given at Table 5. At the first question, the averages of I/P measurements values of the Subjects 1, 3, 5, 9, 12 and 13 is greater than I/P reference value, minimum I/P values are smaller than I/P reference value, these values and the investigated raw data show that the pupil of the Subjects dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

Table 4: Correlation values

Question	1	2	3	4	5	6
Correlation values	-0.035	-0.39	0.415	-0.271	-0.318	-0.324

The averages of I/P measurements values and min I/P values for the Subjects 2, 4 and 11 were smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 2, 4, 10 and 11 dilated much more long periods, they are loaded much more long times mentally.

The percent ratios in respect to pupil dilation between the average of I/P measurement values smaller than I/P reference values and I/P reference values is given at Table 5 for the 1st question, subject base. It can be mentioned that there is averagely 6.29% dilation at the pupils of the Subjects for this question.

In the same way, I/P values of the Subjects are investigated from the concerned graphic and table which are related with the mental tasks of the 2nd question. The averages of I/P measurements values of the Subjects 1, 5, 10, 12 and 13 is greater than I/P reference values, minimum I/P values are smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

The averages of I/P measurements values and min I/P values for the Subjects 2, 4, 9 and 11 were smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 2, 4, 9 and 11 dilated much more long periods, they are loaded much more long times mentally.

For subject 3, I/P reference value is smaller than minimum I/P value and the average of I/P measurement values, this shows that the pupil of Subject constricts generally and mental workload of the Subject changed for this question. It can be mentioned that there is averagely 5.61% dilation at the pupils of the Subjects for this question.

When I/P values of the Subjects are investigated from the concerned graphic and the table which are related with the mental tasks of the 3rd question. The averages of I/P measurements values of the Subjects 1, 3, 5, 10, 12 and 13 is greater than I/P reference values, minimum I/P values are smaller than I/P reference values, these values and the investigated raw data show that the

Table 5: The data on iris ratio values displaying the mental workload reactions of Subjects to the 1st question

I/P values	Sub.1	Sub.2	Sub.3	Sub.4	Sub.5	Sub.9	Sub.10	Sub.11	Sub.12	Sub.13	
I/P measurement average values	2.83	2.29	1.89	2.39	2.38	2.39	2.15	2.59	2.64	2.19	
Min I/P value	2.39	2.12	1.63	2.10	2.01	2.13	1.90	2.13	2.34	1.73	
I/P ref. value average	2.79	2.44	1.78	2.70	2.37	2.35	2.21	2.78	2.50	2.05	
Average of I/P measurement values which smaller than I/P reference values	2.69	2.20	1.73	2.37	2.27	2.26	2.07	2.47	2.42	1.94	
% change between I/P ref. values and smaller I/P measurement values than ref. values	3.48	9.74	2.67	12.10	4.18	3.98	6.42	11.40	3.26	5.68	6.29

pupil of the Subjects dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

The averages of I/P measurements values and min I/P values for the Subjects 2, 4, 9 and 11 were smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 2, 4, 9 and 11 dilated much more long periods, they are loaded much more long times mentally. It can be mentioned that there is averagely 5.01% dilation at the pupils of the Subjects for this question.

When I/P values of the Subjects are investigated from the concerned graphic and table which are related with the mental tasks of the 4th question. The averages of I/P measurements values of the Subjects 1, 3, 5 and 13 is greater than I/P reference values, minimum I/P values are smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

The averages of I/P measurements values and min I/P values for the Subjects 2, 4, 9, 10, 11 and 12 were smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 2, 4, 9, 10, 11 and 12 dilated much more long periods, they are loaded much more long times mentally. It can be mentioned that there is averagely 6.15% dilation at the pupils of the Subjects for this question.

When I/P values of the Subjects are investigated from the concerned graphic and table which are related with the mental tasks of the 5th question. The averages of I/P measurements values of the Subjects 1, 3, 5, 10, 12 and 13 is greater than I/P reference values, minimum I/P values are smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

The averages of I/P measurements values and min I/P values for the Subjects 2, 4, 9 and 11 were smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 2, 4, 9 and 11 dilated much more long periods, they are loaded much more long times mentally. It can be mentioned that there is averagely 6.65% dilation at the pupils of the Subjects for this question.

When I/P values of the Subjects are investigated from the concerned graphic and table which are related with the mental tasks of the 6th case. The averages of I/P measurements values and minimum I/P values of the Subjects 1, 2, 4, 5, 9, 10, 11 and 13 is smaller than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects dilated in long durations during the mental tasks and the Subjects were loaded longer times mentally.

The averages of I/P measurements values for the Subjects 3 and 12 were greater a bit (0.01 greater) than I/P reference values, these values and the investigated raw data show that the pupil of the Subjects 3 and 12 dilated almost equally with other Subjects and they are equally loaded mentally. It can be mentioned that there is averagely 11.5% dilation at the pupils of the Subjects for this case.

DISCUSSION

- The pupil diameter was changed during looking at grey PC screen without thinking anything, whereas it had been considered that mental workload can not occur, it is considered that these changes were happened for self activation of brain, the average measurement values obtained from this part of the experiment used as reference value for comparing the other pupil diameter changes for the tasks of those related questions.
- When subject is performing thinking, time consuming, analyzing, synthesizing, recognizing tasks, with related psychomotor activities pupil diameter dilates. Pupil diameter changes occurred between 5.01-11.5% according to reference value. The change related with recognizing ability (3rd task) is minimum and the change related with psychomotor task which requires permanent attention and instant decision making (6th task) is maximum.
- Subject reaction models differ from person to person. For example, Subjects 2 and 4 always take in group whose pupil dilated in long durations during the mental tasks. Other subjects show consistency with small exceptions, too.
- However verification (positive correlation) is expected between values of pupil diameter changes measurements and the values obtained by applying NASA-TLX method, they are diversified.

The tasks including mostly psychomotor activity which requiring sustained attention with instant decision making cause the most dilation at Subjects' pupils. It can be said that physical and mental alertness trigger pupil dilations. On the other hand dilations were long lasting. Nobody succeeded the task.

Subject 3 gave a different reaction to boring, time consuming question (3rd task), the pupil of Subject constricts generally and the answers of the questions are incorrect.

Body analysis and figure coincidence questions answered correctly by most of the Subjects and their pupils dilated in short durations and instant periods during the mental tasks and the Subjects were loaded very short times mentally.

The measurement and evaluation of mental workload during activity without effecting the work flow will be very beneficial for designing work systems which are related business life directly, such as establishing a base to wage determination, election and recruitment of personnel, work planning and preventing work accident caused by mental workload and for medical and psychological researches. If mental workload is known previously, which related with a work or process, technological developments can activated for moving some works from mind to hardware by using automation during designing stage.

During the experiment, I/P reference value determined only one time Subject base, at the beginning of the experiment, all I/P values determined for the tasks related with the experiment questions were compared with this value. It was not researched whether the reference I/P value was changed or not by the fatigue caused by the mental workload of previous tasks. In an experiment can make in future, I/P reference value can be determined at the beginning of any task and compare with the I/P measurement value of that task.

In another research, it will be useful to go in deep theoretical investigation and to make mental workload measurements using additional techniques (EEG, MRI etc.) with pupil measurements and to compare the results of these indices. The same research with better experiment conditions, improved micro camera and high RAM capacity PC will provide much more net measurements values.

It is expected that the measuring method applied in this research can be a useful tool, for creating numerical values for designating the people who are effected much more than others for typical works or to define works which requires less workload.

In future with the developments of computer technologies pupil diameter measurements and evaluations can be made simultaneously. This improvement will provide to define mental processing on natural conditions.

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