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QUANTIFYING DESIGNER'S MENTAL STRESS DURING THE CONCEPTUAL DESIGN PROCESS USING KINESICS STUDY

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ABSTRACT

In the present paper, a new approach is proposed to evaluate the designer's mental stress during the conceptual design process. Combined with the designer's sketches, the proposed approach is based on a kinesics study, which looks into body movements. The kinesics data is collected by making a video recording of the designer's behavior during the design process. The sketches are generated in a tablet and recorded by using a screen-recording system. During the experiment, it is observed that the designer's mental stress is closely related to the frequency of the body movements.

Keywords: Designer's mental stress, kinesics, conceptual design, kinesics frequency

1 INTRODUCTION

The present paper aims to propose a new approach for quantifying a designer's mental stress during the conceptual design process by considering his/her body language, i.e., kinesics [1]. Hart and Staveland have defined mental stress as "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task" [2]. The study of a designer's mental stress can help enhance the designer's effectiveness in the innovative design process [3]. Studies have shown that people actually perform better under appropriate pressure. A small amount of pressure does not give people enough incentive to pour their full ability into the task whereas too much pressure will eventually disrupt performance [4]. An understanding of the factors that affect the designer's mental stress will help with the development of future tools supporting design activities. The first step in achieving a better understanding of these acivities would be the quantification of mental stresses.

Although Charles Darwin had done work in the area of nonverbal communicatons around 150 years ago [1], research into the understanding of the meaning of nonverbal communications was established in the middle of the last century [5]. To decode the expressive and communicative aspects of body movement, a serious study requires an interdisciplinary approach. In that regard, decades of research have established that nonverbal communication should be considered as composed of the following eight categories: kinesics, occulesics, artifacts, physical appearance, haptics, proxemics, and chronemics [6, 7]. During the design process, kinesics, namely body movement, provides an abundance of information about the designer's mental activities. Accordingly, we have chosen to study design behavior by looking at kinesics, in addition to continuing our ongoing research into protocol analysis and physiological data analysis.

Some researchers insist that body language should describe involuntary movements whereas others consider that gestures, facial expressions, and poses are intentionally made by a person [8]. In the present paper, we use kinesics to study design behaviors. The word *kinesics*, as the main subcategory of paralanguage, has been used to describe all physical forms of human communication that are not verbal language, such as body movements, gestures, postures, gait, facial expressions, eye behaviors, and some small movements that people are not aware of. Each body-movement conveys a meaning that depends upon the physical, social, and cultural context [9].

The rest of the present paper is organized as follows: Section 2 introduces the method that we have used to collect and analyze the designer's cognitive data. Section 3 gives our observations based on the experimental data. Section 4 discusses some relevant issues and indicates the directions of future research.

Kinesics, similar to a verbal language, has many components such as movements and their sequences. Such components correspond, analogously, to the vocabulary and grammar that build up sentences and paragraphs. In body language studies, people express their invisible minds by arranging the movement components. In order to find the "vocabulary" and the "grammar" in a series of body expressions, the present study abstracts the important factors of the continuous body movements. Meanwhile, a metric system has been used to quantify human mental stress. Therefore, by using the relation between the "language components" and the scaled mental stress, we are able to establish the relation between the body movements and the designer's internal mental stress. Figure 1 shows the relation between four major components in our study. Body movements, which were used to indicate the mental stress, were collected by using the cognitive design process. A kinesics method was used to investigate the design behaviors, and a metric system was established to study the mental stress. Hence, we can get the mental stress level from the kinesics information.

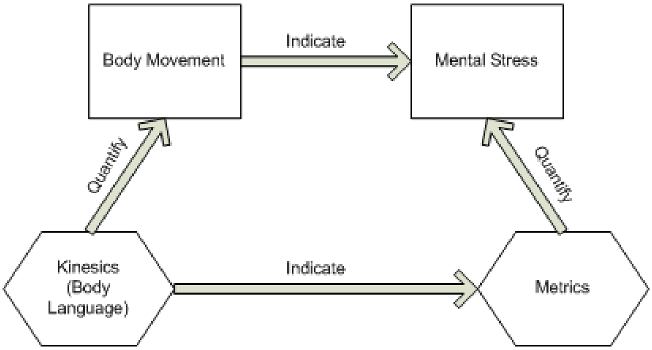


Figure 1. Structure of the Mental Stress Evaluation System

2.1 Selection of participants

In the experiment dealing with body language analysis during cognitive activities, the selection of the participants was based on educational background, engineering design experience, and language ability. Basic knowledge of engineering design and the capability to perform a design task were also required of participants. Human research ethics approval for the study was from the University Human Research Ethics Committee. Seven graduate students with various cultural backgrounds and engineering experience (5-10 yrs) volunteered to be the participants in this study. They were students in mechanical engineering, electrical engineering and computer engineering. The procedures followed in the experiment were explained by Design Lab. All the participants signed a consent form prior to taking part in the study.

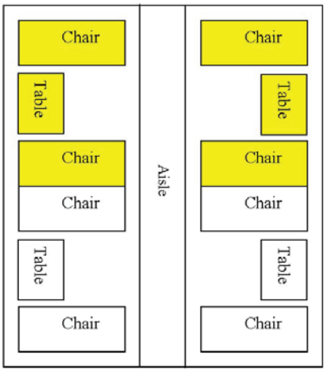


Figure 2. Design problem

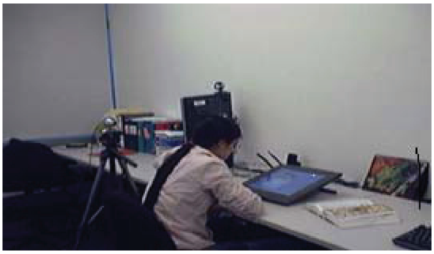


Figure 3. Experiment set-up.

2.2 Materials

To carry out the research of body language analysis during cognitive activities, the design problem used by Dorst and Cross [10] was adapted to our research. To take into account the diverse backgrounds of the participants, a design problem, simple yet challenging, was given to the participants. The design problem was both feasible and realistic. Participants were presented with a pre-prepared description of the design problem as follows:

Design a litter-disposal system for passenger compartments in a train, which is shown in Figure 2. In this system it should be convenient for the passengers to deposit their garbage and for the cleaners to collect the garbage.

Figure 3 shows the set up of the experiment.

2.3 Experiment procedure

During the design process, in order to quantify the designer's mental stress, we must faithfully record the activities that determine the designer's mental stress. Thus, various recording approaches are needed. Meanwhile, the procedures used in the experiment must not interfere with the designer's mental process. In other words, the designer's mental stress is not influenced by the adopted experimental approach.

In our experiment, the researcher presents the description of the pre-prepared problem to each participant and answers any questions regarding the procedures used in the experiment. Set up in a quiet room, the participant then works alone on the design task. S/he can use references or the Internet to find the required information to solve the design problem. The participant is asked to sketch or write anything using a free sketching system installed in a WACOM Tablet; hence, the participant could carry out a design as if s/he were designing by using a pencil and a piece of paper. This natural interface does not add any extra mental workload to the designer [3]. A screen recording system used by the software MyScreenRecorder was used to record everything that the participant did during the design process. This record can be used to analyze the evolving design process. Three webcams have been employed to record the entire process including the audio and video information from different angles. The set-up of the experiment is shown in Figure 3. Figure 4 shows sketches generated during the design process.

Figure 4. Design sketches: examples.

2.4 Segmentation

According to the observations made during the design process, the participants received the design problem and then began their design process with problem decomposition. They divided the problem into parts based on different principles.

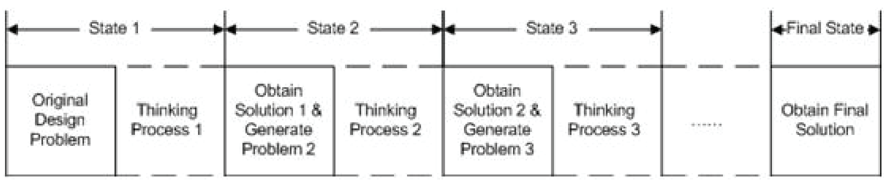


Figure 5. Segmentation of the evolutional design process

Some of them extracted the information by levels, like peeling an onion. Some started with the obvious information and dug deeper into the hidden messages whereas others preferred to use specific design methodology, such as the seventh participant, who used a method she had learned in her courses. Due to the analytic behaviors that were exhibited at the beginning of the process, we defined the beginning stage as the analysis state (State 1 in Figure 5). Figure 5 shows the segmentation of our data. Each segment was separated according to the design product. Thus, the segments were not necessary equal in duration.

Generally, the analysis state consisted of reading the original question and generating ideas in the mind. Sketching and writing on the tablet, on the other hand, represented the beginning of a new state, which is State 2 and which is shown in Figure 5. During the first half of State 2, the solution to Question 1 was generated and was sketched out. Also during this state a new question (Problem 2) appeared, leading the designer to the analysis of Question 2 (State 2 in Figure 5). In the following state (State 3 in Figure 5), the designer produces the response followed by the generation of another question (Problem 3). Thus, designing proceeds as a structure in evolution, as is shown in Figure 5.

Table 1. Segmentation of design process (Record of Body Movements & Sketching Activities)

(By default, the participant is looking at the screen without body movements.)

	Time	Body Movements	Time	Sketch Behavior
State 3			00:07:41-09:03	Read the problem from the screen;
			00:09:03-04	Drawed lines on the screen; Selected one sentence on the screen;
	00:09:05-08	Put right hand fingers under his nose and looked at the screen;		
			00:09:09-10	Cancelled the selection;
			00:09:11-00:10:14	Rolled the pages down to read the problem from the screen;
			00:10:15-00:10:50	Rolled the pages back and forward;
			00:10:50-00:10:54	Rolled the pages back;
	00:10:55-11:26	Asked questions; the experimenter explained it to him;		
State 35	01:32:15-21	Put right hand fist beside his lips;	01:32:15-21	Looked at his product;
	01:32:21-33:12	Moved the chair to the dictionary, and checked for something;		
	01:33:12-14	Moved back to the screen;		
	01:33:14-34:42	Wrote on the screen;		
			01:34:43-45	Rolled down the window;
	01:34:45-35:56	Wrote on the screen;		
			01:35:56-36:06	Rolled down the window;
	01:36:06-16	Wrote on the screen;		
			01:36:16-27	Rolled up and down the window; Looked at his product;
	01:36:28-37:13	Wrote on the screen;		
			01:37:13-18	Erased something on the screen;
	01:37:18-49	Wrote on the screen;		
			01:37:49-38:03	Erased something on the screen;
	01:38:03-18	Wrote on the screen;		
			01:38:18-24	Rolled down the window;
State 51	02:03:38	Covered his lips with his left hand fingers;		
	02:03:38-41	Looked at his product;		
			02:03:41-52	Added something to his product;
	02:03:52-04:02	Looked at his product;		
	02:04:02-20	Wrote on the screen;		
State 52	02:04:20	Talked to the experimenter;		
			02:04:20-24:00	Looked at his product; gave some explanation; erased some words, and modified them; highlighted some words; drew the details of the product; corrected some grammar mistakes;

Table 1 illustrates parts of the design states, along with the body movements and sketching activities of the sixth participant. These states were abstracted from the beginning, middle, and end of the design process. Segmentation was performed based on the evolution of the structure of the design process as shown in Figure 5.

2.5 Analysis method

The use of body movement is an effective approach of non-verbal expression. When compared with the other types of expression, body movement is more connotative, and the stimulation of the movements is more unintentional. When someone feels annoyed, s/he may knit her/his eyebrows with or without being conscious of that movement, and s/he may frown in the same way during deep concentration. In other situations, s/he does the same with no purpose at all. Therefore, Birdwhistell and Fast [11] have pointed out that the meaning of body movements cannot be defined without the context of the movement maker. A body movement may mean nothing in a context, and yet be extremely significant in another [11]. Accordingly, learning of the meaning of kinesics must be performed in terms of the total pattern of movement. We must understand the pattern of movement in terms of the 'spoken language'. The two, while sometimes contradictory, are also inseparable.

In this paper, instead of studying the body movements independently, the analysis was performed combined with the 'spoken language', which are in the recorded sketches and in the verbal protocol. The body movements were divided into two groups according to the design context: Design-related movements; and Design-stimulated movements. Design related movements, such as sketching, reading, and writing, are connected to the purpose of accomplishing the design. However, the stimulated movements, such as scratching, rubbing the chin, biting the lips and other small physical movements, were aroused under the mental load during the design process. D-related movements were seen as direct response of the mental stress of the participant, while the d-stimulated movements were seen as the indirect response of the mental stress. For the reason that the d-related movements determined the design product, this category of movements attracted the primary attention when we started to use the kinetics data for quantifying mental stress. Nevertheless, as the process of analysis improved, we've found that the d-stimulated movements actually took great part in the design process ,and occupied an enormous part of our kinetics data, especially during the poorly productive states. In another word, movements of both categories determine the design product.

Research shows that the human body is *more active* during relaxation, whereas there is *less movement* during concentration [12]. Consequently, the frequency of movements is an important factor in the evaluation of the mental stress. The evaluation equation was proposed base on the theory that the frequency of all movements is low under a high stress circumstance. According to the classification of d-related and d-stimulated movements, the estimate of mental stress was obtained base on the frequency of these two movements. The following equation was used to calculate the relative quantity of mental stress.

$$\text{Mental Stress Level} = \frac{1}{f_r} + \frac{1}{f_s}$$

$$f_r = \frac{E_r}{T_r},\ f_s = \frac{E_s}{T_s}$$

where, E_r and T_r represent the amount and the duration of the d-related movements respectively, and E_s and T_s represent the amount and the duration of the d-stimulated movements respectively.

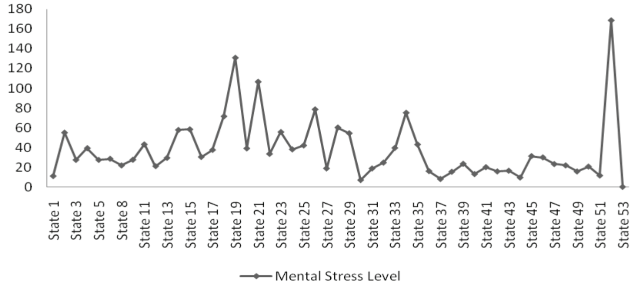
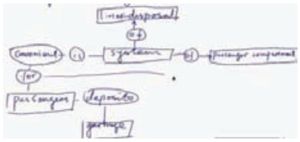
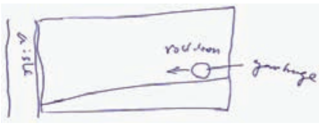
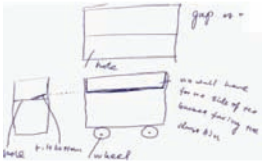
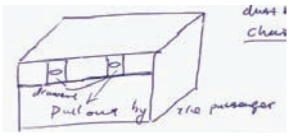
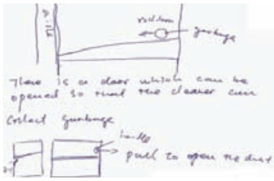


Figure 6. Evaluation result of participant's mental stress

3 RESULT

Table 2 is an example of the experimental results. According to the recorded sketch, the participant had difficulties in performing the design task in the first 10 states. Then he spent 17 states getting prepared for the design, after which he started to generate solutions. The most productive section was States 35-39 and States 47-52, during which the participant generated most of his final solutions. States 40 to 46 were an adjustment period when the participant conducted a lot of refinement work. The mental stress value of a participant is given in Figure 6. State 53 was added to illustrate the end of the design process, for which the mental stress level was set to zero.

Table 2. Record of Body Language and Sketching Activities

Section	Time	Movement Summary	Sketching Activities
1	00:41:16−01:19:09 (Duration: 00:37:53) States 11-28	In this period, he looked at the problem for 9 minutes without any movements or facial expression. Then he changed movements frequently and asked some questions. At first his voice trembled a little. Subsequently, he spoke clearly and confidently.	
2	01:19:50−01:32:10 (Duration: 00:05:20) States 28-35	In this period, the participant touched his lips; touched his hair; put his hand against his cheek; drew on the screen; put his hand on his chin; moved his body back and forth; He drew the position of the bin on the train. And according to the desktop records, he modified the pictures in the tablet, achieving some progress in the design.	 
3	01:33:30−01:42:05 (Duration: 00:09:35) States 35-39	During this period, the participant blinked; drew on the screen; stood up to draw on the screen; looked around; moved his body when moving the chair; touched his lips; touched his face; He achieved some progress on the design and then switched the design window to the Internet.	
4	1:42:05−01:57:32 (Duration: 00:15:27) States 39-47	In this period, the participant frowned; touched his lips; touched his nose; put his hand on his forehead; moved his body back and forth; He modifiedhis design and met some problems. He checked the original question and his design.	
5	01:57:44−02:23:40 (Duration: 00:25:56) States 47-52	During this period, the participant pursed his mouth firmly; touched his lips; touched his nose; put his hand on his forehead; scratched his head and neck; supported his head with his left arm; moved his body from side to side; His design was finished. Then he modified it.	

According to the figure, the participant had steady mental stress in the first 15 states. Then from States 17 to 29, the fluctuation of the mental stress value indicated the unstable design creativity in this period; during this section, the participant started to generate some solutions and began to face even more interferences. Subsequently, we can observe a slight wave motion from State 37 to State 52. These wave motions represented the beginning of a new concept generation process, which is the most productive of the states. The participant was under a constant mental workload in this period. The last wave indicates the completion of the design task.

4 DISCUSSION

4.1 Culture and Individual differences

Research in the past decades has indicated that, though some gestures are genetic, such as smiling, most gestures are learned, such as nodding and thumbs-up. Therefore, body movements have different meanings depending on the learning system. Head movements “up and down” normally mean agreement in many countries; however, it means no in some parts of Indian culture. Fast [11] believed that cultural indoctrination in terms of body language is very difficult to overcome. As a consequence, we have defined the semantics of body movements in the context for each individual participant.

4.2 Number of participants

There are two issues concerning the determination of the number of subjects in our study. The first issue concerns the category of subjects in terms of knowledge level, experience/expertise level, and cultural differences. Usually the experience level (expert versus novice) and the knowledge level may be of interest. The second issue is the number of subjects (also referred to as the sample size). Generally speaking, the sample size is dependent on the design of the experiment [13]. In a design study, the response cannot usually be represented by a crisp value.

Table 3 shows some examples of how many participants are chosen in ergonomic domains. Given the fact of complexity in human factors-related experiments, Kotval determined the number of participants in his study of eye movement parameters by simply surveying about 181 published papers in the area of eye movement [14]. He found that the best number of participants was 13; and that number was indeed used for his experiment design. Paquet used five male college students to simulate 3 of 6 construction job tasks [15]. Ryan presented concurrent and retrospective verbal protocol methods, which were used to collect thoughts from 18 participants during a manual handling task involving the repeated transfer of loads between locations at two tables [16]. To explore the interplay between designers' representations and their design activities, and investigate the use of external representations by engineering students, Cadella selected four students (two seniors and two freshmen) from the original dataset [17]. This method was used due to the difficulty of determining the sample size using those standard principles in statistics [13].

Table 3 Number of participants

Authors	Number of participants	Year
Kotval	13	1998
Paquet et al., 2001	5	2001
Ryan and Haslegrave	18	2007
Cadella	4	2006

5 FUTURE WORK

The research results presented in the present paper are preliminary. Statistical analysis is underway based on all the participants’ design data. Mental stress is reflected in various body reactions, such as changes in the heat rate, blood pressure, blood volume, electrical properties of the skin, brain waves, temperature and eye behaviors. These physiological changes can be measured through physiological parameters thanks to modern technologies. For example, it is widely accepted that heart rate variability (HRV) is an indicator of mental stress. Many clinical studies have been done using this technique. The eye gaze tracking system can be used to measure pupil size, blinking frequency, blinking duration, etc.

These experiments are currently underway in the author's research lab. The results will be used to verify the conclusions from this present research.

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