Affective imaging: Psychological and physiological reactions to individually chosen images

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ABSTRACT

In a series of experiments, observers' cognitive and psychophysiological responses to pictorial stimuli were evaluated. In the first experiment, subjects were viewing a set of randomly presented images. After each image presentation, they rated every image on a number of cognitive scales. In the second experiment, images producing certain physiological effects — deactivating, neutral, or activating —were individually selected based on the results of the first experiment and shown to the subjects again. Psychophysiological measurements included electrocardiogram, hand temperature, muscle tension, eye movements, blood oxygen, respiration, and galvanic skin response. Our results indicate that images produced significant emotional changes based on verbal and physiological assessment. The changes were in agreement with the predictions derived from the metric that we developed in a number of cases that exceeded the chance level. The direction of changes corresponded to previous findings reported elsewhere[1,2,3,4.]

Keywords: Emotions, physiological reactions, digital images.

1. INTRODUCTION

A very important feature of the new generation interactive computerized systems will be a capability of assessing individual physiological and emotional states while performing various tasks. Recent studies in the area of affective computing[,5,6,]show growing interest and progress in this direction. For instance, at MIT media lab, researchers are working on systems that will collect various information about the person to optimize the working environment. As a future product, one might develop "a desk that acts like a good office assistant. Such a desk should know your work habits and preferences, remember where you put things, know when you are feeling frustrated or tired, and know enough about your work to anticipate many of your needs" [7]. The concept of affective computing can be applied to the imaging systems that have the capability of assessing a person's physiological and psychological states. This information can be used to help the user to optimize his or her mental, emotional, and physiological processes while interacting with images.

It has been shown that one could measure a reliable physiological response for images that differ in valence and arousal [1,8]. Images, which were rated differently with respect to perceived activation and pleasantness, elicited physiological responses of different magnitude. For example, magnitude of the skin conductance response correlated with perceived arousal level produced by pictorial stimuli. At the same time heart rate acceleration during the first 4-5 s of image presentation reflected "valence" or degree of perceived pleasantness of a picture. Authors described other parameters that reflect observers' psychophysiological reactions towards images as well and demonstrated significant stability of those reactions using the International Affective Picture System (IAPS), standardized image library [2]. Experimental research has also shown that the presentation of images (still images or movies) of similar affective content may cause significant shifts in physiological reactions [3,9]. Ulrich *et al.*[10] have demonstrated that different visual environments affect viewers' emotional state. Emotional impact of images and video is well known from the influence of the artwork, movies, commercials, etc. on one's mood and arousal level.

Described observations suggest that for an individual viewer, images could be classified based on a subject's physiological reactions in terms of emotional arousal. This paper presents an attempt to develop a method of image selection that reliably identifies certain emotional reactions in subjects.

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2. EXPERIMENTS

Two experiments will be described below. The goal of the first experiment was to identify for every individual a set of images that evoked a strong reaction of preference and physiological arousal. Based on the results of this experiment images were classified in five groups: activating/preferred, de-activating/preferred, activating/not preferred, de-activating/not preferred and neutral. In the second experiment images were presented in these groups. The goal of that experiment was to verify our physiological classification. We also assessed subjects' mood changes using questionnaire administered before and after presentation of image groups.

2.1. Experiment 1

2.1.1. Experimental procedure

Seventy five subjects participated in two sessions of this experiment in which numerous images were shown. The images were presented in a random order and were the same for each subject. As a stimulus material in these experiments, 82 images and 115 images were chosen for sessions 1 and 2 respectively. To choose the images, we identified a set of characteristics of various levels of description that could potentially influence a subject's emotional response and preference based on the data obtained by Lang *et al.*[2] and our own data. Examples of such characteristics are: dominant hue, lighting characteristics as perceptual attributes; landscape, cityscape, people as cognitive descriptors of main subject matter; happy or unhappy events such as a wedding, birthday party, funeral or happy/unhappy facial expressions for emotional content.

During the entire time of the session, the subject's physiological responses were monitored, and after each image, the subject reported his or her cognitive (mental) reaction to the image along three scales: attached/detached, calm/exciting, and happy/sad. The physiological measures collected were ECG, EMG, eye movement acceleration, peripheral temperature, blood oxygen (SpO_2), respiration, and galvanic skin response (GSR). In addition to the measures shown above, values were calculated from the raw data, such as the heart inter-beat interval (IBI), to provide summary and additional measures of physiological responses.

At the beginning of each of the two sessions in this experiment, the subject was connected to the physiological sensors, and then a baseline period of data was collected. This baseline was typically 10 minutes, during which the subject saw no images and received no instructions. Then images were shown to the subject for 8 seconds in session 1, or 15 seconds in session 2, separated by short blank periods (4 seconds in session 1, and 8 seconds in session 2). Finally, one or two stress tests (latter - only in the first session) were performed. One stress test was to have the subject count backward from a predetermined number by seven [11]. In the other stress test, the subject had to describe an emotionally painful experience[12]. Following the stress tests, the physiological sensors were removed. Thus, for the baseline period, for each image and for each blank between images, and for the stress test periods, physiological data is available for each of the measures.
In addition, the subject scored each image on three cognitive scales: Calm/Excited, Happy/Unhappy, and Attached/Detached. The scale went from +4 to –4, with –4 indicating calm, unhappy, or detached, respectively. The scale selection was based on the affective dimensions of arousal and valence for objects and events identified by Russell and Mehrabian[13] and others, and successfully used by Lang *et al.*[1] We used the third dimension of connectedness to reflect personal meaning and involvement.

2.1.2. Physiological image selection

Images in the first series of experiments were classified based on the subject's physiology as being activating, de-activating, or neutral. The method to be described could be used on any combination of sensors' input and calculated measures. However, for this analysis, only eye movement, electrocardiogram, and muscle tension were used. Data from the baseline period were divided into non-overlapping segments of 15 seconds each. In addition, the first two minutes of the baseline data and the last two minutes of the baseline data were not used. It was thought that the first two minutes of data represented a time when the subject was reacting to the new experimental environment, while the last two minutes might contain anticipatory effects. This left 6 minutes, or 24 segments. Segmenting the data this way provides us with some measure of the normal repeatability of the baseline data. Similarly, for the stress periods, data were divided into non-overlapping 15-second segments, but no data were discarded. Data from the image segments were used in their entirety.

A set of pertinent features of the physiological responses had to be extracted from each sensor and each segment. Although literature data identify specific physiological signals[1] that reflect emotional responses to pictures, we were not sure whether these measures will apply to: a) images that produce rather subtle responses; and b) the data for every subject on an individual basis. Moreover, based on the literature[14], we would expect that physiological responses of individuals might differ. Therefore, a histogram was computed for each segment of data, using the eye movement and muscle tension variables.

The bin sizes and locations for the histogram were fixed in advance, so that the histogram from each segment's data aligns with the histogram from every other segment's data. Spectral densities (from a Fourier analysis) were computed for the heart rate data for each segment. As with the histograms, the spectral densities had to be aligned across segments, so each spectral density was interpolated and then measured at the same predetermined frequencies. Finally, the two histograms and the spectral density were horizontally concatenated, so that the resulting long string of numbers would represent the features for that data segment.

Principal Components Analysis (PCA) [15] was then performed on the baseline and stress period data, and the vectors and scores were saved. As is typical in PCA, the histogram or spectral data was centered to have a mean of zero. In addition, the data was scaled so that the sum of all the variables (histogram bins or spectral density frequencies) for a given sensor had a variance of one. This gives each sensor an equal *a priori* weight in the PCA analysis, regardless of the number of bins or frequencies used. This is known in the literature as "block scaling" [16].

Using the vectors computed from PCA, the scores for each image segment data were computed. A typical plot of the scores is shown below in Figure 1. One can see that the baseline data (denoted by +) and stress data (denoted by X) are clearly separated in this view, while the images (denoted by o) tend to be scattered in between the baseline and stress. Thus, to the extent that we find separation of the baseline and stress period data, we say that we have determined a metric for that subject that enables us to separate activating (stress) physiology from deactivating (baseline) physiology.

Two points should be mentioned here. First, it is not necessarily true that deactivating physiology is associated with baseline physiology. Consequently, this might imply that all images were somehow activating and no relaxation is possible below the baseline. This is probably an unrealistic assumption. Second, it is not a simple question what to use as the baseline: baseline before the experiment, or blank period before presenting a particular image.

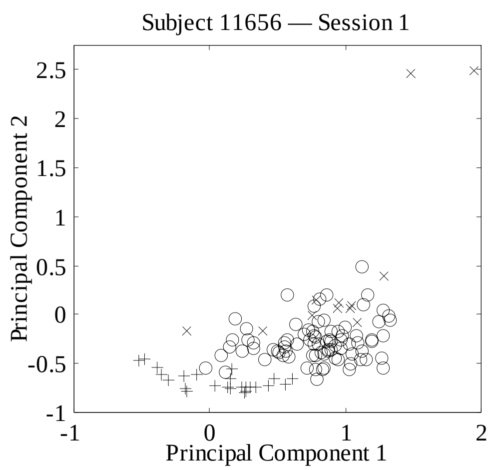

Figure 1

In the typical plot, one can also see that the images are sprinkled in between the baseline and stress clusters. Thus, we conclude that the images had varying effects upon physiology; some images produced physiological reactions very close to stress; while others produced physiological reactions very close to the baseline. The metric devised was the ratio *dB*/*dS*, where *dB* was the distance of the image from the centroid of the baseline data cluster, and *dS* was the distance of the image to the centroid of the stress cluster. Images were then ranked according to this ratio, and the smallest were selected to be deactivating and the largest were selected to be activating. The remaining images were selected to be neutral. The cutoff value to determine what was largest or smallest was often changed from subject to subject, sometimes necessary because a fixed cutoff value did not allow a sufficient number of images to be selected.

2.1.3. Cognitive image selection

Ratings along the above-mentioned scales (namely, valence scale) were used to classify images as preferred or not preferred, based upon the cognitive responses for that image. The valence scale (positive or negative emotion) in combination with the connectedness scale determined whether an image was considered as preferred or not preferred. From the literature data, it is known that certain autonomous physiological measures such as heart rate acceleration[1] correlate well with the emotional valence. This information is based on the group data analysis. Healey and Picard[17]reported that discrimination between physiological responses related to positive and negative emotional states such as anger and joy presents a very difficult task compared to arousal discrimination, when performed for an individual subject. That is why we decided to use cognitive ratings of valence in our experiments, leaving a task of physiological differentiation for future experiments.

As a result of selection processes described above five categories of images were identified for every individual: activating preferred, activating not preferred, deactivating preferred, deactivating not preferred, or neutral. Our data reveal a large amount of individual variation across subjects in their responses to images. Thus, among all images chosen for the deactivating preferred group, 51% of them were chosen only by a single subject. For other groups the numbers were 57% - activating preferred, 37% - activating not preferred, 26% -neutral. Deactivating not preferred group was very scarcely populated or, frequently, empty. Images were migrating from one group to another for different subjects. For example, the overlap between activating/preferred and deactivating/preferred groups was 28%; between activating preferred and activating not preferred – 9%. The numbers presented were estimated only for the group of individuals who participated in the Experiment 2.

2.2. Experiment 2

2.2.1. Method

The goal of this experiment was to confirm that we could select images to produce the desired effects. Images were selected from Experiment 1, via the selection process described above, using both cognitive and physiological results for each subject. Thus, each image appeared in one of five categories, activating preferred, activating not preferred, deactivating preferred, deactivating not preferred, or was classified as neutral.

Similar images were found to increase the number of images that could be shown to each subject. The similarity was determined based on the set of the characteristics we used for image description. The original selected image was known as a “same” image. Thus, if the process described above selected a colorful beach scene, additional similar beach scenes would be used in the experiment. Two additional similar images were added to the set, if such images could be found. Sometimes, one of the similar images was a moving image. During Experiment 2, each same image and its similar images were shown together in a sequence, with the same image always shown first. Furthermore, all images in a group (for example, activating not preferred images) were shown together. Within each group, the ordering of the same/similar sequences was randomized.

There were three sessions for each subject in this experiment (Sessions 1, 2, and 3), and the types of images shown are indicated in the table 1 below. Furthermore, in Sessions 1 and 2, the order of the groups of images was selected randomly. Thus, some subjects would see all of the “activating” images in Session 1 first, followed by all of the deactivating images. Other subjects would see the groups of images in the opposite order. Similar randomization of image groups occurred in Session 2. In the experiment, subjects again were monitored during a baseline period, an image period, and then a single stress test period.

Table 1. Image groups presented in three sessions of the Experiment 2

Session	Image Group 1	Image Group 2
1	Deactivating Preferred	Activating Not Preferred
2	Activating Preferred	Neutral
3	Activating Preferred	Deactivating Preferred

During every session a questionnaire assessing the subjects’ mood was administered. Subjects had to fill the questionnaire three times: before the first image group, after the first image group and after the second image group.

When a subject was shown the group of “activating” images, and our analysis of the physiological data classified the subject’s physiological response as activating during this time, we considered this a confirmation. If the subject saw activating images and the subject’s physiological response was classified as either neutral or “deactivating”, then we considered this a case where the method of selecting images and/or analyzing the physiological data had failed. The method of data analysis was the same as for Experiment 1, with PCA performed on the baseline and stress data and then the images were placed in the same space using the loadings found.

Similarly, if the subject saw preferred images, we expected emotions such as happiness to increase and sadness to decrease, and vice versa for not preferred images.

A total of 25 subjects participated in Experiment 2. Each of the 25 had previously participated in Experiment 1. Due to time constraints, a few subjects did not participate in all three sessions. Among 25 subjects, there were 14 females and 11 males.

2.2.2. Separation of baseline and stress physiological responses

The ability to determine if we can separate baseline physiology from stress test physiology is one of the key objectives of this study. We used the same Principal Components Analysis method on Fourier spectra and histograms as mentioned in Experiment 1 to see if baseline and stress physiology would indeed be separate. The Principal Components Analysis method does not require a predetermination of which sensor will enable us best to make this separation, and the use of histograms and Fourier analysis allows us to avoid prespecifying which features might work for a given individual. Thus, the method is flexible enough to change from subject to subject and within a subject over time.

The results show that in most cases, we can find differences between the baseline and stress physiology score means. In a small percentage of the cases, we could not find such a difference. The table 2 below shows, for various different sensor combinations, the percent of sessions in which the baseline and stress physiology had different mean scores from the Principal Components Analysis (with $\alpha \leq 0.05$).

Table 2. Percent of Time Baseline and Stress Test scores have significantly different means

Sensors	Percent
GSR	95.7
Heart Rate	78.9
HR, GSR	85.5
HR, EMG	90.8
HR, EMG, GSR	98.7
HR, EMG, Eye	93.4
HR, EMG, SpO2	94.7
EMG	88.2
EMG, IBI	96.7
EMG, GSR	100.0
SpO2	88.2
SpO2, IBI, GSR	96.7

This table demonstrates that GSR (96%) performs the best of any single sensor separating stress-baseline. Moreover, it performs better than the combination of three sensors HR-EMG-Eye (93%) used in the first experiment. This result agrees with the data known from the literature that GSR measurement provides reliable information about level of arousal evoked by pictures[1].

2.2.3. Cognitive results

A "Personal Feelings Survey" (PFS) questionnaire[18] was administered to each subject prior to viewing images in each group, and immediately after the viewing of images in each group. The difference in the results would then be attributed to the effects of the images upon the subject's emotions. Nine broad categories of emotions were analyzed from the PFS survey. They were: nervous, happy, sad, caring, angry, relaxed, clearheaded, fatigued, activated.

For each subject, one could compute the effect of each image group upon these emotions. Analysis of Variance (ANOVA) was used to determine if, across all subjects, the emotions changed because of seeing a particular group of images. The table 3 below shows the changes in emotions for the activating not preferred versus deactivating preferred images in Session 1. An asterisk next to the mean changes indicates that the effect of the images on the specific emotion was significantly different zero (with $\alpha \leq 0.05$). One can see that for many emotions, the change was in the anticipated direction (*e.g.*, preferred images increased the levels of happy, caring, relaxed), and in many cases, the effect of the images and the difference between the two different images on emotion was statistically significant (with $\alpha \leq 0.05$).

Table 3. Changes in the verbal scores for emotional categories in Session 1

Emotion	Activating Not Preferred	Deactivating Preferred	Image Groups Diff?
Nervous	0.16	–0.25	N
Happy	–0.41*	0.30*	Y
Sad	0.31*	–0.29	Y
Caring	–0.45*	0.15	Y
Angry	0.25	–0.09	N
Relaxed	–0.56*	0.36*	Y
Clearheaded	–0.23*	–0.09	N
Fatigued	0.15	–0.11	N
Activated	–0.18	–0.08	N

Similarly, the table 4 below shows the results for Session 2, with the activating preferred images again producing results usually in the predicted direction. Fewer of the differences between the image groups were statistically significant (with $\alpha \leq$ 0.05), but this was anticipated, as the activating preferred images were compared to neutral images.

Table 4. Changes in the verbal scores for emotional categories in Session 2

Emotion	Activating Preferred	Neutral	Image Groups Diff?
Nervous	–0.17	–0.04	N
Happy	0.25*	–0.21	Y
Sad	–0.08	0.04	N
Caring	0.24	–0.22	N
Angry	–0.04	0.00	N
Relaxed	0.17	–0.23	N
Clearheaded	0.00	–0.16	N
Fatigued	0.01	–0.06	N
Activated	0.14	–0.15	Y

The results for Session 3 (Table 5) showed small emotional changes on average, and they are never statistically significant ($\alpha \leq 0.05$). However, the difference between the preferred activating and the preferred deactivating images was small, and this shows up in the table — none of the emotions show a statistically significant change from one image group to another. This may be because all of the images in Session 3 were preferred, and so there should be little difference between the two different image types on the subject’s emotions.

Table 5. Changes in the verbal scores for emotional categories in Session 3

Emotion	Activating Preferred	Deactivating Preferred	Image Groups Diff?
Nervous	–0.01	–0.15	N
Happy	0.07	–0.01	N
Sad	–0.00	–0.05	N
Caring	0.01	0.05	N
Angry	–0.04	–0.01	N
Relaxed	–0.07	0.18	N
Clearheaded	–0.02	–0.03	N
Fatigued	–0.11	0.03	N
Activated	0.00	–0.09	N

In addition, since the exact same images in Session 3 were previously shown to each subject in either Session 1 or Session 2, we can compare the emotional change in Session 1 or 2 to the emotional change in Session 3. In most cases, the emotional change in Session 3 was closer to zero than the change for the corresponding images in Session 1 or 2. This was unexpected. Possible explanations for these small emotional changes the second time the subject sees the images are:

There is some type of order effect, in other words, the order that one sees the groups of images has an effect.

The subjects tire of answering the PFS questionnaire so many times, resulting in less precise answers.
There may be carry-over effects from Session to Session.
The set of images and similars chosen may not have been the most adequate.
Habituation — the images have a smaller effect the second time the subject sees the images.

An answer, which of these explanations is the likely cause of the small non-significant effects in Session 3, requires further experimentation.

One additional finding from the cognitive data was that the order of the image groups sometimes had an effect upon the changes in emotions. For example, in Session 1, seeing activating not preferred images first had a different effect on some emotions than when these images were seen following the group of deactivating preferred images in Session 1.

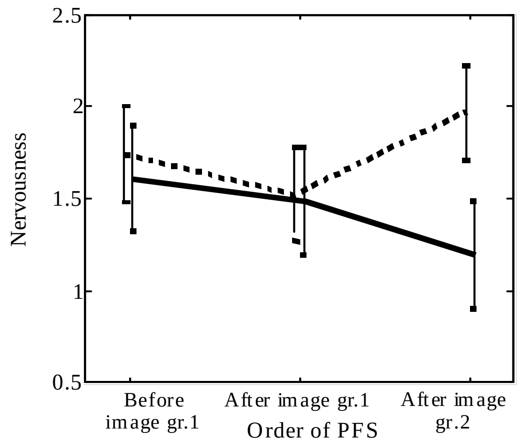

Figure 2
Mean nervousness change ± 2 standard errors in Session 1,
Deactivating, then activating shown by dashed line,
Activating, then deactivating shown by solid line.

A thorough review of Session 1 PFS data results reveal numerous examples of what we might call “order effects.” For example, the PFS scale nervousness will be used to describe the effect seen (see Figure 2). Two sets of images were presented to research subjects. During image set 1, the mean of all subjects’ responses to this scale revealed no significant changes in nervousness. Looking at the results from the first image set data, we might conclude that the images had no significant impact on nervousness. However, when we include the data from subject responses after the second set of images, the picture is much different. We can see (dashed or top line) that subjects responded with significant increase in nervousness when activating images were presented after deactivating images ($p = 0.02$), but not when activating images were presented first (solid or bottom line). This suggests a differential response to images based upon the order of presentation, which might be attributed to “emotional contrast”.

Based upon the results from the first image set (activating, not preferred, or deactivating preferred) we might conclude that we had failed to demonstrate one of the objectives, decreased nervousness. However, we can see that if we were to first present activating, not preferred images followed by deactivating preferred images we get a significant decrease in nervousness ($p=0.05$). It must be kept in mind that these results are revealed in *post hoc* analyses. These findings will be followed up with further research.

2.2.4. Physiological results
The physiological data were analyzed in the same fashion as during Experiment 1. Three sensors were used, muscle tension, eye movements, and heart rate. Principal Components Analysis was performed upon the histograms of the muscle tension and eye movements data, plus the spectral densities of the heart rate data. The plots of the scores again showed that the images most often were scattered in between the baseline and stress test data. Since the images were presented in groups, it was hypothesized that the physiological response for one image group in one session would be different than for the second image group in the same session. Furthermore, when shown activating images, it was hypothesized that the image scores

would be “close” to the stress test physiology scores; and the deactivating images’ physiology scores would be “close” to the baseline physiology scores. Neutral images’ scores would not be “close” to either the baseline or stress test scores.

An *ad hoc* rule was devised to determine if the scores for the group of images were “close” to either baseline or stress test scores. One could have also used a formal discriminant analysis to do this. The *ad hoc* rule is as follows:

The baseline and stress test mean scores had to be statistically significantly different ($\alpha \leq 0.05$). If not, then the baseline and stress could not be separated, and so the groups of images could not be classified.
If the mean scores for the two groups of images were statistically different ($\alpha \leq 0.05$), then the group closest to baseline was classified as deactivating and the group closest to the stress test mean was classified as activating.
Otherwise, if the mean of a group of images was not statistically different ($\alpha \leq 0.05$) from the baseline, then the group of images was classified as deactivating. If the mean of a group of images was not statistically different ($\alpha \leq 0.05$) from the stress test data, then the group of images was classified as activating.
Otherwise, if the group of images could not be classified as either activating or deactivating under rules 2 or 3 above, then the group of images was classified as neutral.

Using this classification scheme, and the three channels mentioned (muscle tension, eye movements, and heart rate), we obtained the classification percents shown in the table 6 below (may not add to 100% down the columns due to rounding).

Table 6. Percentage of times image groups were physiologically classified into three categories, across all sessions

	Image Group		
Physiology	Activating	Deactivating	Neutral
Activating	44.1	33.3	20.8
Deactivating	19.4	35.4	45.8
Neutral	36.1	31.3	33.3

Naturally, higher rates of classification were hoped for, but this still was significantly better than chance classification, which would have resulted in 33.3% in each cell. Furthermore, it was clear that our methods performed better for activating images than it did for deactivating or neutral images. Another result from this analysis was that very often the opposite physiological response is observed, and it is not known at this time why this happened.

By session, the results from Session 3 showed the best classification (Table 7). This is somewhat paradoxical when viewed with the cognitive information, because the cognitive results showed that the images appeared to have no effect upon emotion. In other words, the images shown in Session 3 had the clearest effect on physiology, but no effect on emotion. (Note: there were no neutral images used in Session 3.)

Table 7. Percentage of times image groups were physiologically classified into three categories. Session 3 only.

	Image Group	
Physiology	Activating	Deactivating
Activating	65.2	30.4
Deactivating	17.4	47.8
Neutral	17.4	21.7

These physiological results reported so far were all done using baseline and stress periods as “anchors” on the PCA scale. However, analyses were also done comparing each image to a blank period immediately prior to the image. The idea was that any change in physiology between the image and the blank period would indicate the effect of the image over and above the physiology that existed during the blank period. These results were all inconclusive; few trends or statistically significant differences were found. One possible explanation for this is: the changes in physiology over such a short time span might be too variable for us to detect trends or patterns. Or, once a set of images achieves physiological activation, additional images show no change or random noise compared to the blank period before the image.

3. CONCLUSIONS

From the results of the described experiments, the following conclusions can be made.

First, we could indeed find in the data a specific metric that separates baseline and stress physiology. This metric is specific to the subject and can change over time.

Second, we were able to significantly influence a subject's verbal emotional responses in the predicted direction by showing individually selected images, as seen particularly in the Session 1, Experiment 2 results.

Third, we were able to influence a subject's physiological responses in the predicted direction by showing individually selected images.

In all cases, additional work needs to be done to more fully understand the results.

Finally, we need a better method of image classification/description that will allow us to identify more profound image attributes and thus introduce an "emotionally stronger" image set. Although the effects were statistically significant, a stronger image set would presumably produce more clear results.

5. REFERENCES

1. P. J. Lang , M.K. Greenwald, M.M. Bradley, and A.O. Hamm, "Looking at pictures: Affective, facial, visceral, and behavioral reactions", *Psychophysiology*, **30**, pp. 261–273, 1993.
2. P.J. Lang, M.M. Bradley, and B.N. Cuthbert, *International Affective Picture System (IAPS): Technical Manual and Affective Ratings.* NIMH Center for the Study of Emotion and Attention, University of Florida, Gainesville. 1997.
3. S. E. Rimm-Kaufman, and J. Kagan, "The psychological significance of changes in skin temperature", *Motivation and Emotion*, 20 (1), pp. 63-78, 1996.
4. B. H. Detenber, R. F. Simons, and G. G. Bennett, "The Effect of Picture Motion on Emotional Responses", http://www.udel.edu/psych/rsimons/rollem.htm , 1999.
5. R. Picard, *Affective Computing*. Massachusetts: The MIT Press, 1997.
6. R. Picard, and J. Healey, "Affective Wearables", *Proc. of the First International Symposium on Wearable Computers*, Cambridge, MA, IEEE Computer Society Press, Oct. 13-14, 1997.
7. *SmartDesk Home page*, http://flavia.www.media.mit.edu/vismod/demos/smartdesk/, 2000.
8. B. N. Cuthbert, M. M. Bradley, and P. J. Lang, "Probing picture perception: Activation and emotion", *Psychophysiology*, **33**, pp. 103-111, 1996.
9. M. M. Bradley, B. N. Cuthbert, and P. J. Lang, "Picture media and emotion: Effects of sustained affective context", *Psychophysiology*, **33**, pp. 662-670, 1996.
10. R. S. Ulrich, R. F. Simons, B. D. Losito, E. Fiorito, M. A. Miles, and M. Zelson, "Stress recovery during exposure to natural and urban environments", *Journal of Environmental Psychology*, **11**, pp. 210-230, 1991.
11. L. A. Pennington, "The Serial sevens test as a psychometric instrument", *American Journal of Orthopsychiatry*, **17** (3), pp. 488–499, 1947.
12. L. A. Gottschalk, C. N. Winget, and G. C. Gleser, *Manual of Instructions for using the Gottschalk-Gleser Content Analysis Scales: Anxiety, Hostility, and Social Alienation — Personal Disorganization*, University of California Press: Berkeley, 1969.
13. J. A. Russell and A. Mehrabian, "Evidence for a three-factor theory of emotions", *J. of Research in Personality*, **11**, pp. 273-294, 1977.
14. J. T. Cacioppo, G. G. Berntson, and S. L. Crites, Jr., "Social neuroscience: Principles of psychophysiological arousal and response, in Higgins, E. T. and Kruglanski, A. W. (Eds.): *Social Psychology: Handbook of Basic Principles*, pp. 72-101, New York: Guilford Press, 1996.
15. J. E. Jackson, *A User's Guide to Principal Components*, John Wiley and Sons, New York, 1991.
16. J. A. Westerhuis, T. Kourti, and J. F. MacGregor, "Analysis of multiblock and hierarchical PCA and PLS models", *J. of Chemometrics*, **12**, pp. 301–321, 1998.
17. J. Healey and R. Picard, "Digital Processing of Affective Signals", *Proceedings of ICASSP'97*, Seattle, Washington, May 12-15, 1998.
18. R. McCraty, B. Barrios-Choplin, M. Atkinson, and D. Tomasino, "The effects of different types of music on mood, tension, and mental clarity", Alternative Therapies, **4** (1), pp. 75-84, 1998.