The Effect of Cognitive Manipulation on Pupillary Diameter and Evoked Vertex Potentials*

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The phenomenon of pupillary dilation to fear, pain, discomfort and strong emotion has been known for centuries. Lowenstein was probably the first to produce objective evidence of this dilation by cinephotographic recordings and his experiments led to further exploration of the anatomical and psychological connections mechanism of this phenomenon. Loewenfeld in 1958 in a brilliant dissertation summarized the research findings on the dilation mechanism and added important findings of her own.

It was however Eckhard Hess, who for better or worse left an indelible imprint (pun intended) on the research on pupillary motility by some rather striking demonstrations of the pupillary dilations as a correlate of strong emotions. It was the right demonstration performed at the right time in an age where the general public and psychologists were looking for objective indicators of emotions, fears, eye detection, etc. The pupil as “a window to the soul” appeared to be a welcome addition to our research arsenal in the area of public opinion, consumer research, lie detection, personality research, sexual behavior and social attitudes. Hess’ experiments generated an enormous interest in all of these areas. But as so often in psychological research, after a strong beginning things turned out to be not so simple as they appeared at first. Contradictory and inconclusive results by other researchers led to contraversies and polemics which were at times rather vitriolic, to say the least.

The problem of data recording and analysis added to the difficulties in this field and it can be observed that there is presently a decline in the number of research laboratories and commercial outfits who concern themselves with the phenomenon of pupillary motility. Although this has the advantage of shooing the fly-by-night operators away from this field, it would be very regrettable if the baby would be thrown out with the bath water. There is no doubt a kernel of truth in it.

After working on the problem of pupillary motility for some fifteen years I am convinced that the dynamics of the pupillary movement can give us interesting and important data on such psychological events as information processing, decision making, attitudes and others. Some recent work with monozygotic and dzyzygotic twins has even led to some new speculations about the genetic determination of complex conceptual processes and already has plunged me into some heated controversy on the age-old subject of nature and nurture.

I would like to present today, without going into details of specific experiments, an overall view of the research strategies and procedures we are employing in our laboratories. I should add, that during the last three or four years we are recording simultaneously pupillary reactions and evoked vertex potentials in

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nearly all our experiments. This developed from my close collaboration with Dr. Samuel Sutton who is using evoked potential in the study of similar problems. At first we conducted parallel experiments and until we were able to solve the technical (and financial) problems of simultaneous recording of pupillary and evoked cortical potentials. I should say that the results so far, have fully justified the investments.

One of the reasons I was dissatisfied with the methods used by Hess and his followers was, aside from the accuracy of measurements, the known fact that pupil diameter under nearly all conditions fluctuates. It is also a well known fact that the extent of these fluctuations is in part dependent on the luminance of the environment. The function describing this relationship is U shaped, that is in extreme light and in complete darkness these fluctuations are smallest. In our 1966 study on visual thresholds we showed that the dilation responses we could obtain in "emotion arousing" situations could be extremely small, of the order of 0.1 millimeter. Our overall experience led us to several fundamental decisions on research strategy. (1) To stay away from visual stimuli at least until we would be able to control luminances and other aspects of the visual percept. (2) Conduct all experiments in complete darkness. That is without ambient light. These two strategy decisions naturally require that the stimuli to be presented by us are other than visual. For the most part we used auditory stimuli. It is also assumed that the pupil of the completely dark adapted eye still can dilate in response to auditory or conceptual stimuli. That this assumption was correct has been shown in many of our experiments. A 9 millimeter pupil still can dilate, and the extent of this dilation is largely independent of the pupil size of the dark-adapted eye. I doubt whether the law of initial value can be applied to the pupil in our experimental conditions. (3) Since the pupil dilation to our stimulus conditions is probably smaller than the random fluctuations of the pupil diameter we used so called averaging procedures. I am well aware of all the arguments pro and against these procedures and have always yearned for standard deviations and medians, skewness and kurtosis. Only recently we have developed digital computer programs which will allow us to compute all these elements. I can now report that the computations indicate the CAT computer and the Fabritek to be quite acceptable instruments. This is a rather surprising finding after worrying for 10 years whether our data were really valid. As a matter of fact I am now rather concerned, for a number of reasons, why that should be so. I had expected, with good reason, some differences between mean and median. I also expected variations in the standard deviation. (4) The fourth research strategy was dictated by the use of the averaging procedure and the nature of the emotional or conceptual stimuli we were interested in. We had to find a stimulus situation and an experimental paradigm which was not subject to adaptation. Since we had to repeat the stimulus situation numerous times, the element of novelty, surprise, shock or pleasantness, was naturally removed after 10 or 20 presentations. We thus came upon our present betting and guessing paradigm. We simply ask our subjects to bet or guess the characteristics of the next stimulus. The amount of information given to the subject is part of our experimental variables and could range from complete knowledge in Certain Conditions, where we told the subject what the next stimulus would be to rather complex probability situations where the subject had to develop by experience the odds for each of several different stimuli. To add some more complexity, the value of the subjects guess or the bet, could be manipulated by different pay-off schedules.

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This overall paradigm has worked extremely well. There is something in the neuronal set-up of the spacious "homo sapiens" which compels him to play the probability game. In all our experience with this paradigm we have not had a single subject who did not play the game and play it wholeheartedly. Even under conditions where the odds were extremely small (on an 80/20 probability) or where the risk of being wrong was high, did the subject "cease his attempts to beat the system". There was never a let-up either in the effort of the subject even in experimental sessions which lasted three to four hours. Our recently started work with children, aged 7 to 11 shows that these kids just love to guess and bet. If you get a real "gambling man" into this situation you have trouble terminating the experimental session.

Thus the selection of this paradigm was a lucky one. If one analyzes all the psychological processes involved here, strategy formation, risk taking, stimulus evaluation, to name a few, one can appreciate the usefulness of this paradigm. Sutton has written a paper on specifications of psychological variables in average evoked potential experiments, in which he discusses in more detail the problem and prospects of such methods.

The fifth strategy decision concerns the use of group vs. individual data. The data obtained in our experiments from both pupil and evoked vertex potentials has shown a high intra-individual reliability and a low interindividual reliability, or in other words: variance is small within a subject and very large between subjects. Though certain elements of the response curves are common in nearly all subjects (the temporal dilation characteristics and some basic positive and negative components of the evokable potential) the differences in amplitudes and slopes can be very large in different subjects. Thus it is not prudent and often misleading to present group data. We have not yet found an appropriate statistical procedure to adequately describe our data. In this sense we are still in the dark ages and much of our material still has to be evaluated by "eyeballing" or other not very sophisticated statistical methods. Fortunately, most of our data are so "clear cut" that one can put much trust into them, but clearly caution is in order.

I mentioned earlier that for several years now we have also recorded the evoked vertex potentials. In comparing certain components of the evoked vertex potential, especially the so called N1-P3 components, with pupillary dilation amplitude and the CNV (contingent negative variance) with certain pre-stimulus dilation characteristics of the pupil we have found much similarity. So much communality indeed, that I have been tempted to call the pupil a permanently implanted electrode. These findings allow for speculation on common neural

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Fig. 1. Typical stimulus pattern in guessing paradigm. Subject is asked to guess which of the stimulus patterns will be presented
elements represented in both measures, but much more work has to be conducted before definite statements as to the causality can be made.

I would like to present now, the results of several representative experiments to illustrate my points.

Fig. 1 shows a typical stimulus pattern. Either a single, a double or a triple click pattern is presented. The interval between click one and click two is twenty milliseconds, the interval between click two and three is nine hundred and eighty milliseconds. Click duration is about two milliseconds. The clicks are presented via an overhead loudspeaker and are about sixty db above threshold. I should mention here that click intensity turned out to be an irrelevant variable. In any given trial either the single, double or triple click pattern is presented. The subject is asked before the trial is presented to guess which pattern will be presented. In this specific experiment the probability of each pattern to occur was equal. In the control condition the subject is told which stimulus will be presented. We called this the Certain or Told condition. In the Uncertain condition, the subject had to guess what the next pattern will be and is instructed to report after the end of the trial which stimulus pattern it was, and whether his guess was right or wrong. Actually, in this experiment, the subject was asked whether the next pattern would be a triple click or not. Note the information content in each situation: if he heard a single click it was clear that there would not be a triple click, thus one hundred percent of the information concerning his guess was available to him and the uncertainty was resolved at this point in time. If the first burst was a double click, fifty percent of the information was given here: “it is not a single click”. The uncertainty would be resolved only by the presence or absence of the third click which in this case occurred 980 milliseconds later.

![Fig. 2. Pupillary reaction to the Certain and Uncertain (guessing) conditions](image)

Fig. 2 shows a typical pupillary response to such a situation. In order to examine the possibility that the difference between these response patterns is the result of heightened attention, a third set of instructions was introduced: the subject was asked not to guess but only to report after the stimulus presentation what he had heard. We thereby eliminated the guess component.

Fig. 3 shows the result of such an experiment. It is quite clear that there is a quantitative difference in the dilation amplitudes. In all our subjects, and we have tested over sixty by now, we have found this rank order in dilation amplitude.
Smallest dilation or none in the told condition, more dilation in the report and greatest dilation in the guess condition. It is quite clear that in addition to the instructions given to the subject by the experimenter we are dealing with self instructions by the subject. In post-experiment interviews the subjects reported that they at times made guesses about the next stimulus pattern in the report, to themself. Sutton has pointed to this factor and has urged to design experiments in which the “option” of the subject are controlled or reduced.

Fig. 3. Pupillary reaction to Certain, Uncertain and Told conditions. In the Told condition the subject reports, after the stimulus presentation, what the pattern was. He is not instructed to guess.

Another interesting finding concerned the differences between the response curves of trials where the subject’s guess was correct and those where his guess was incorrect (hits and misses). In nearly all subjects we found a difference in the slope.

Fig. 4. Pupillary reactions to single, double and triple clicks, averaged separately by right guesses and wrong guesses.
of the decreasing pupil size after it had reached its peak dilation. This is shown in Fig. 4. In most cases the slope was steeper in the hits but in a few subjects the opposite was the case. It should be noted that a given subject would be consistent in his response to the hits or misses.

The evoked vertex potential which we recorded simultaneously with the pupillary reaction showed a difference between the three experimental conditions (told, report and guess) in the amplitude of the N1-P3 component. Sutton and his co-workers have shown that the N1-P3 amplitude is related to the “saliency” of the stimulus. After many variations of pay-off, risk taking, stimulus values and task difficulty in our experiments, we clearly could show a variation in amplitudes of both pupil dilation and N1-P3 component but we found it awfully hard to find a semantic term which would adequately describe the characteristics of the psychological process. Jeness used the adjective “salient” to describe the relation of the stimulus characteristics to the subject.

![Graph showing pupilary reactions to different guessing conditions.](image)

Fig. 5. Pupillary reactions to 2 different guessing conditions. In Guess 3 the subject was asked “Will it be a triple click or not?” In Guess 1 the subject was asked “Will it be a single click or not?”

Fig. 5 shows a series of experiments in which we varied the instruction to the subject in the following way: in one part of the experiment the subject was asked to guess whether it would be “triple click or not”, and in the other part he was asked to guess whether it would be “a single click or not”. The results show clearly a certain aspect of this “saliency” of the stimulus to the subject. Clearly in the “guess 1 or not” situation the third click was less salient than in the other experimental condition. It should be noted that the two different guess conditions were presented in blocks or forty trials, randomly distributed over the experimental session.

We have done some further complication of this design by adding specific contingencies such as for example: a triple click will never be followed by a double click.

I would like to discuss one other finding in this series of experiments, which I think is a very important finding. We had noted the rather striking intra-individual reliability of our response curves, both in the pupil recordings and the evoked vertex potential. Subjects, retested after several months in the same experiment, showed near identical results. This, in addition to some other considerations of the data led to the question of whether the characteristics of the response curve are the results of life experience and learning or whether the whole
process of handling such complex situations was dependent on a system of neuronal connections which are inborn or possibly inherited. We called it the "Neuronal Hook-up" hypothesis.

We investigated this question by testing a series of identical and fraternal twins. It has been reported by Lowenstein that identical twins show similar pupillary responses to light. Other reports indicate that evoked potentials and EEG records to sensory stimuli in identical twins are alike. It was however hard to conceive of identical responses to the complex betting and guessing situations that we presented to them. However, the data in an admittedly small sample showed a striking similarity of the response curves of the monozygotic twins while considerable discrepancies existed in the dyzygots. At the present time we are conducting a well controlled study of identical and fraternal twins, siblings and unrelated subjects. Should the results of that study follow those of our pilot work we might have to rethink some of our developmental theories.

In summary I think we have shown that the pupillary response and the evoked vertex potential to complex conceptual tasks reflect some of the psychological processes which go into resolving such situations. It is quite possible and even probable that such elements as social attitude, preferences and value judgement are imbedded in these response curves but we should be cautious in interpreting the data at this time.

As always much more work is required to disentangle this mess.

Aussprache

Herr Bouma (Eindhoven):
Es hat mich gewundert, daß die normale Fluktuation der Pupille (einige Zehntel mm) nicht in Ihren Ergebnissen anwesend erschienen.

Herr Hakerem zu Herrn Bouma:

We are using averaging procedures and the fluctuations are averaged out. The number of trials which have to be averaged in order to get a straight line depends on the size of the fluctuation.

Herr Peaveler (New Brunswick):

Did you have the opportunity to examine the relationship between an individual's pupil diameter characteristics and ability to discriminate stimuli or estimate probability correctly?

Herr Hakerem zu Herrn Peaveler:
The answer to this question is yes. We looked at the data and there is no relation between pupil diameter and ability to discriminate.