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# A Low Light Level Diffraction Experiment for Anomalies Research

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Abstract — Some interpretations of quantum mechanics assert an active role for human consciousness in actualizing the results of measurements on quantum systems. At the same time, some empirical studies have claimed positive results in testing the abilities of human subjects to bias randomly generated events i.e. those governed by Gaussian statistics. Experiments have been conducted using a different probability distribution i.e. the digitally recorded diffracted light intensity from a single slit. This normalized distribution is conventionally interpreted as the probability of locating a photon in a specified location in the observation plane. Human subjects have been invited to attempt to bias this distribution in a prescribed way. The experiment is tightly controlled against any artifacts generating very high data rates with high statistical accuracy. Calibrations show that any displacement of the diffraction pattern relative to the detector of order $1.6 \times 10^{-5}$ cms should be detectable. Of twenty subjects tested, none has produced a detectable displacement corresponding to this upper limit.

## Introduction

The idea that consciousness may play a role in the determination of physical phenomena is not alien to physics but has been seriously considered by a number of authors primarily in the context of attempting to resolve the paradoxes of quantum mechanics (von Neumann 1955, Wigner 1962, London and Bauer 1939). For some authors, consciousness enters into quantum processes at the point of measurement when allegedly the "wave function collapses" suddenly and stochastically.

It should be pointed out that this sudden and stochastic collapse of the wave function is inherent in a sub-class of the various interpretations of quantum mechanics that have been advanced. For this sub-class, it is not clear whether the conscious act of measurement is a passive act and that what changes discontinuously at the time of measurement is the observer's knowledge or if the role of consciousness is active and, as some authors have suggested, is deterministic to a degree in actually affecting the outcome of a quantum mechanical measurement.

Other interpretations of quantum mechanics avoid the difficulties associated with the consciousness resolution of the measurement problem by either asserting that all possible outcomes of a quantum mechanical measurement are in fact realized at the point of measurement (the Many Worlds Interpretation (Everett 1957)) or that quantum processes are in fact causal and in principle describable by causal processes with no special status assigned to the observer (Bohm and Hiley 1978, Philippidis, Dewdney and Hiley 1979). In attempting to connect the disciplines of physics and biology in an intimate way, suggestions have been made in the literature that perhaps matter has a rudimentary degree of consciousness, volition or self-activity (Cochran 1971). This suggestion resolves the double-slit paradox in a novel way, i.e. the electron which goes through hole 1 really does know if hole 2 is open or closed. Such ideas argue against a truly objective material world and are difficult to reconcile with the fact that repetitions of a double-slit experiment always yield the same interference pattern which is mathematically characterized by the physical parameters of the apparatus and the wavelength of the radiation being employed.

Josephson and Pallikari-Viras (1991) have recently argued that biological systems have, in the course of evolution, learned to exploit the non-local interconnections implicit in the work that has been done on Bell's Theorem.

Over the past 20 years, there have been two major groups using sophisticated random-event generators in order to investigate what we shall refer to (following Hyman (1987)) as ostensibly anomalous phenomena i.e. the assertion that human operators can without any sensorimotor contact influence probabilistically governed phenomena. Schmidt (1972) has reported extensively on the use of electronic random event generators triggered by the random radioactive decay of strontium 90. Jahn (1982) has employed primarily a Random Event Generator which counts noise pulses from a diode. Both groups have reported results that defy chance expectations by large margins. ($p < 2.10^{-9}$ Schmidt (1972), $p < 2.10^{-6}$ Jahn (1982)). The results of both groups have been criticized both in terms of the methodology and the statistical analysis employed (Alcock 1981, Jeffreys 1990). Both groups claim that some operators can bias the probability distributions of randomly governed events in accord with pre-declared intention.

A few experimental physicists have attempted empirical investigations in this area (Hall, Kim, McElroy and Shimony 1977). Radin and Nelson (1989) have attempted a meta-analysis of hundreds of experiments in this area published in a wide variety of journals and have concluded "it is difficult to avoid the conclusion that under certain circumstances, consciousness interacts with random physical systems".

Jahn (1986) and others have suggested that the claimed effect exists at the level of "information", i.e. it is the statistical distribution of possible outcomes from the apparatus that is affected by the operators intentions and thus the claimed effect is not seen as purely physical. In a similar vein, Eccles (1986) has suggested that intention may influence neural events in the brain by analogy with the probability fields of quantum mechanics. According to this view (the weak violation hypothesis (Schmidt and Pantas 1972)), there is no violation of conservation laws of physics.

The claims advanced have been based on studies using a variety of experimental techniques. If true, then any process governed by probabilistic laws should be amenable to demonstrating the claimed effect. We have devised a simple optical experiment based on the phenomenon of single slit diffraction to examine these claims. This experiment comes closer to the alleged links with quantum mechanics since the modern theory of quantum mechanics arose from attempts to explain a variety of puzzling empirical facts including diffraction and interference phenomena.

Our experiment yields high data-rates in computer compatible form and has been designed to meet various methodological criticisms.

The essential claim which has been advanced is that some human operators can produce a statistically significant shift of the mean of a given distribution generally in accord with intention. The other moments of the statistical distribution remain unaffected. In our experiment, the relevant distribution is the digitally recorded single slit diffraction pattern. This is recorded with high accuracy with a short integration time. The centroid of the pattern is determined. Many repeated measures allow for the study of their statistical distribution.

## Diffraction and Interference Phenomena: An Overview

When electromagnetic radiation meets an obstacle the shadow cast by the obstacle does not, in general, have sharply defined boundaries due to the phenomenon of diffraction. The conventional account of diffraction phenomena (found in all elementary texts on Optics) invokes Huygen's Principle which states that the incident radiation sets up secondary wavefronts at the diffracting obstacle and the subsequent sum in amplitude and phase of the secondary wavefronts when squared yields the intensity distribution behind the diffracting obstacle. The intensity variation in the observation plane is thus conventionally accounted for by invoking a wave model for the incident radiation. However, if a photomultiplier tube is used to detect the diffracted radiation then at low light levels individual pulses arising from the incidence of individual quanta of radiation are detected indicating that the radiation is quantized i.e. consists of spatially and temporally located packets of electromagnetic radiation i.e. photons.

These alternate accounts of electromagnetic radiation have given rise to a dualistic view in which radiation (and particles) can, at different times, exhibit wave-like properties or particle-like properties but not, according to the well-known Principle of Complementarity of Bohr, both at the same time (see Milloni 1984 for a recent review). The phenomenon of diffraction is "explained" from the photon point of view by assigning complex probability amplitudes to individual photons which are subsequently added and squared to yield the observed distribution in the observation plane. Thus, the intensity distribution (normalized) is interpreted as the probability of locating a photon at any location in the observing plane. Diffraction phenomena have been studied at very low flux levels (corresponding to the passage of, on average, one photon at a time through the apparatus). Most of these studies (Taylor 1909, Pipkin 1978) with the exception of reports from Panarella (1985) and Dontsov and Baz (1967) have concluded that diffraction occurs even at the level of one photon at a time. Several studies aimed at checking the contradicting claims of Panarella have failed to confirm his findings. (Jeffers, Hunter and Wadlinger 1991, Sinton, Gardenier and Bares 1985, Ohtake and Sugiyama 1985). In this work, the conventional view of photon diffraction is

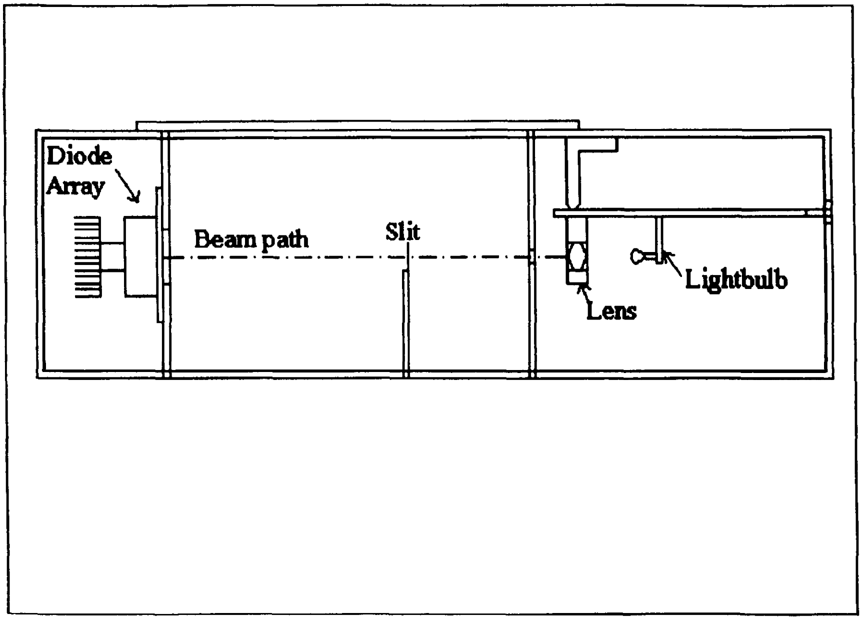


**Fig. 1. Diagram** of **experimental apparatus.**

adopted but it should be pointed out that other accounts have been proposed. Lande (1975) suggested that the diffracting obstacle transferred momentum to the incident photons in a quantized manner such that the periodicities (fringes) seen in both diffraction and interference phenomena arise from periodicities in the diffracting obstacle. While this account can explain diffraction by a regular structure such as a crystal it cannot account for diffraction at an edge. A more classical account has been given by Prosser (1976) who solved Maxwell's equations using the diffracting obstacle as a boundary condition and obtained plots of the Poynting vector past the obstacle which exhibited undulations which could be interpreted as flow lines of energy.

Similar considerations apply to the well known double slit interference experiment. Interference effects are seen at flux levels corresponding to the passage of a single photon/particle through the apparatus. The wave model accounts for the observed fringes seen in the observation plane behind the slits but cannot yield precise information with respect to which slit the photon actually passed. Feynman has stated that the double slit experiment "has in it the heart of quantum mechanics; in reality it contains the only mystery." (1951). When physical phenomena are poorly understood then a wide range of possible accounts are advanced. The most extreme positivistic accounts of quantum mechanical phenomena envisage an active role for human consciousness in microphysical phenomena. Thus, it has been claimed (Wigner 1962) that the conscious act of observation causes the "collapse of the wave function", i.e. the entity under examination exists potential-

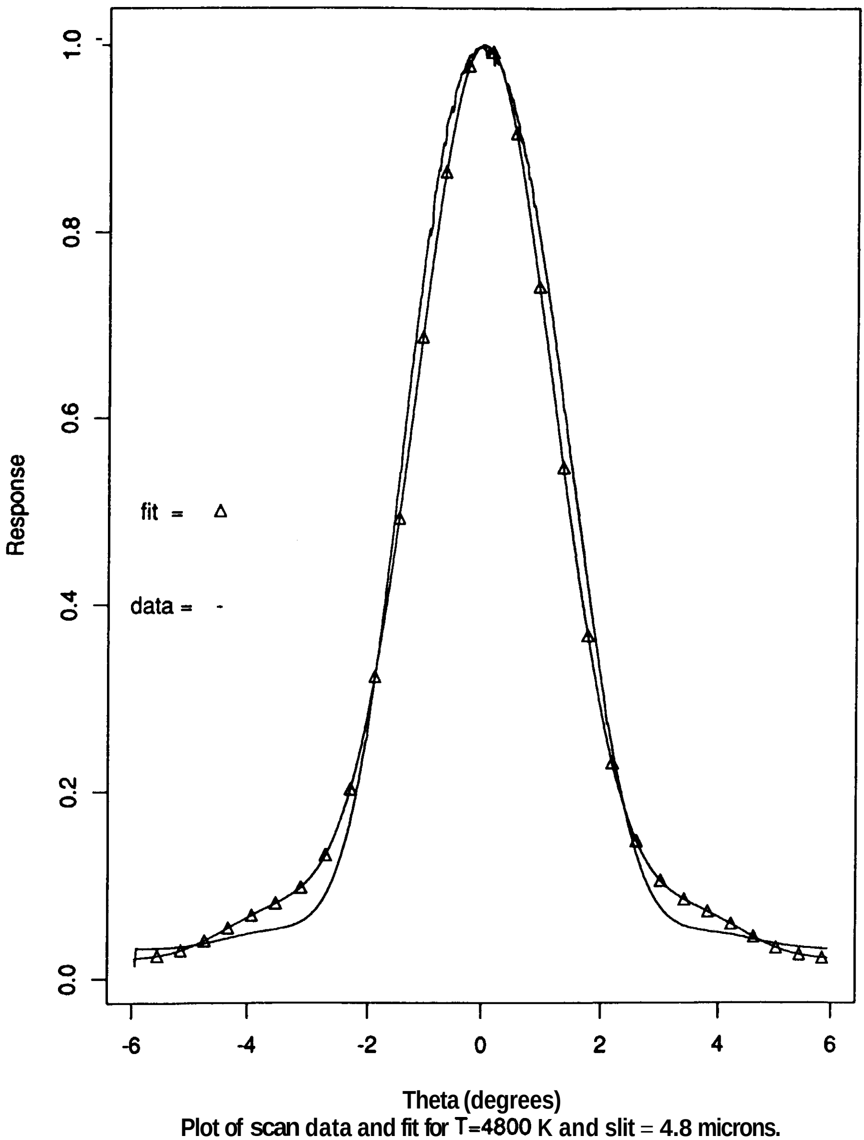


Fig. 2. Plot of single slit intensity pattern for white light at 4800K and experimental output.

ly everywhere (is spatially distributed as a wave) but becomes spatially localized as a particle by the very act of observation. At the other end of the philosophical spectrum, realist (local and non-local) accounts of the double slit experiment have been advanced (Vigier 1986, Bohm 1987, Prosser 1976) that deny the Principle of Complementarity and assert the simultaneous existence of wave and particle.

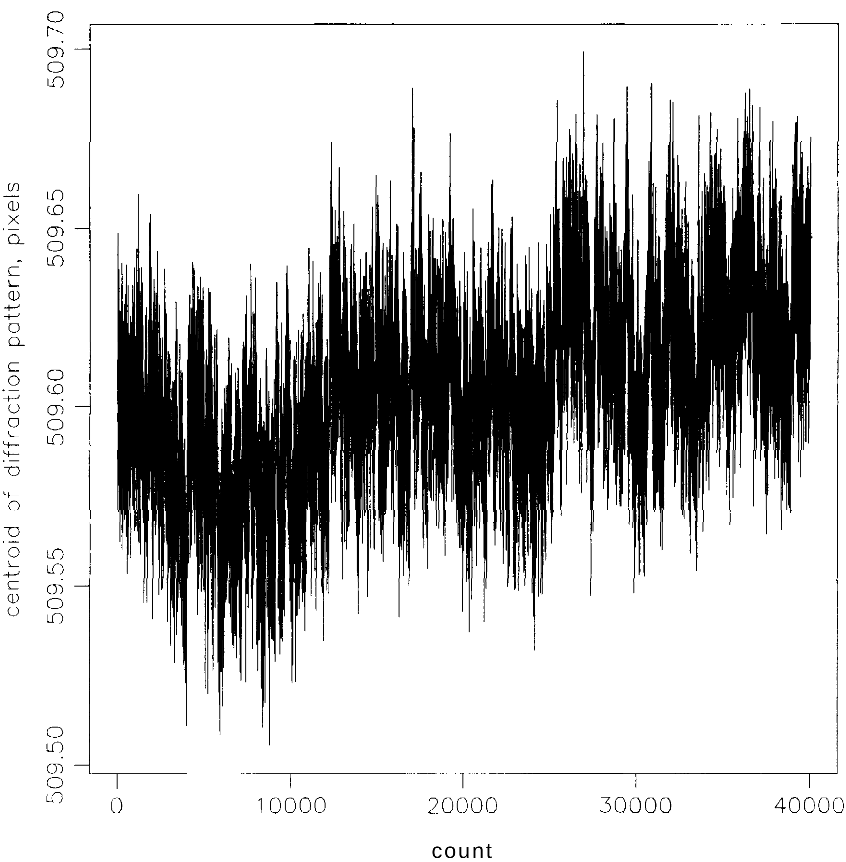


Fig. **3.** Time series plot of the centroid of the diffraction pattern over a nine hour period.

## Experimental Apparatus and Methodology

Other experimenters have used essentially Random Number Generators either based on radioactive decay (Schmidt and Pantas 1972) or the noise output from a diode (Jahn 1982) to create statistical distributions upon which consciousness could act in an experiment.

The statistical distribution employed in our experiment is the single slit diffraction pattern produced by illuminating (using an incandescent bulb powered by a stabilized power supply) a commercially available slit *(5* microns wide). The Fraunhofer diffraction pattern falls on to a linear photodiode array (Princeton Applied Research Model #1453A with 1024 diodes) controlled by a micro-computer. The entire experiment is software controlled. The apparatus is shown in outline in Figure 1.

The box housing the equipment consists of 1/4" aluminium plate with three sections separated by bulkheads. The first section contains the light source and lens

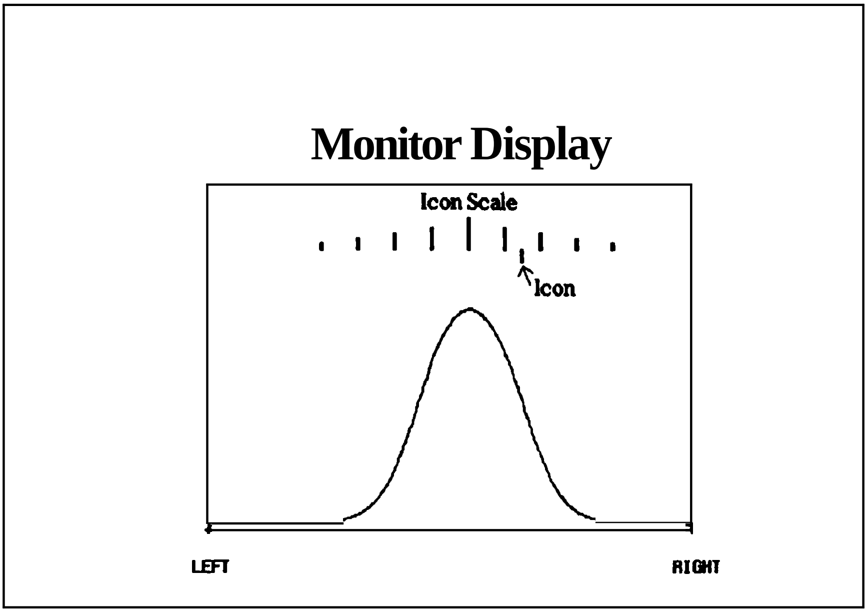


**Fig. 4. Image of the display as seen by the experimental subjects during the experiment.**

mounted on an platform which is externally adjustable in position. The middle section encloses mountings for the slit or other apparatus needed for the experiment on carriers adjustable for position. The final section encloses the detector itself, and is open past the detector, to allow air to flow past the cooling fins on the refrigerator section of the detector. An electromagnetic shutter is built in which is software activated to record the output of the detector with no illumination falling on the detector. Integration times as short as 1.2 seconds are used giving a high rate of data accumulation. We are using the light from this source unfiltered. Hence we are recording the white light diffraction pattern. The intensity of the bulb is adjusted to give a maximum count/per read of approximately 10,000 counts. This is well within the linear range of the detector performance.

Figure 2 shows a typical readout from the detector (solid line). This has had the background subtracted and has been corrected for the instrumental response function. Assuming a black body spectrum for the spectral distribution of the lamp, the intensity as a function of wavelength is given by the well known Planck's formula:

$$B\lambda = \frac{2\pi hc^2}{\lambda^5}\frac{1}{\exp\left(\frac{hc}{\lambda kT}\right)-1}$$

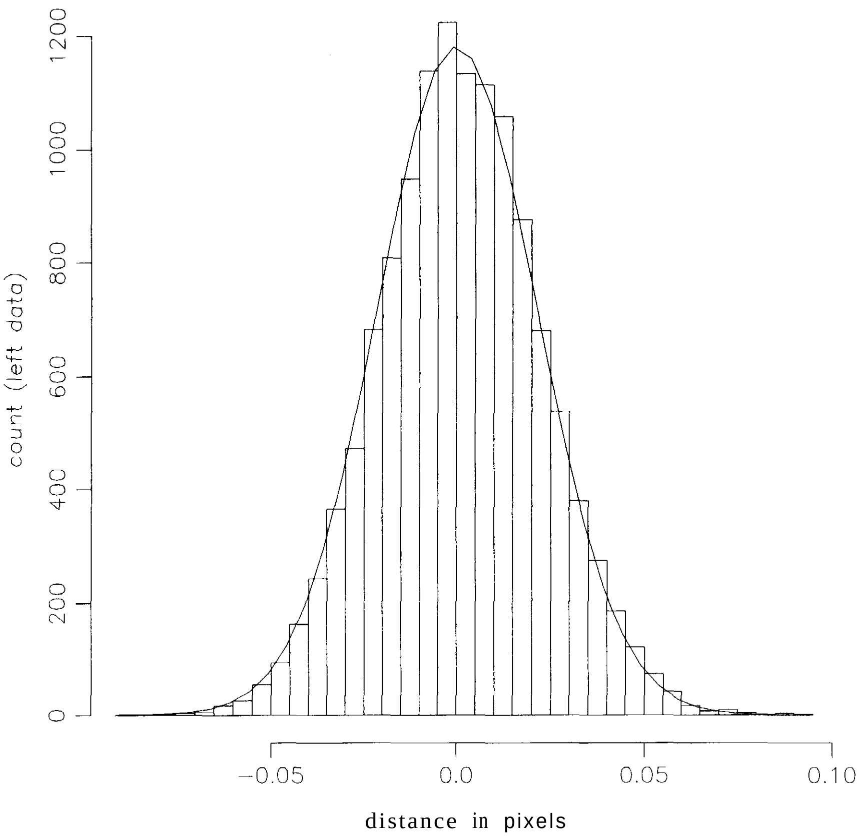


Fig. 5(a). Histograms of residuals for control data residuals with a Gaussian fit.

Using the standard formula for Fraunhofer diffraction, the white light diffracted intensity is given by :

$$I = \int_{\lambda_1}^{\lambda_2} I_o \left( \frac{\sin\left(\frac{\pi b \sin\theta}{\lambda}\right)}{\frac{\pi b \sin\theta}{\lambda}} \right)^2 B_\lambda \, d\lambda$$

Where b is the slit width, $\lambda_1$ and $\lambda_2$ are the minimum and maximum wavelengths detected by the detector and $\theta$ is the angle of diffraction.

We have numerically computed this function and fitted it to our observed distribution for a lamp temperature of 4800K. We obtain good agreement between theory and observation as shown in Figure 2.

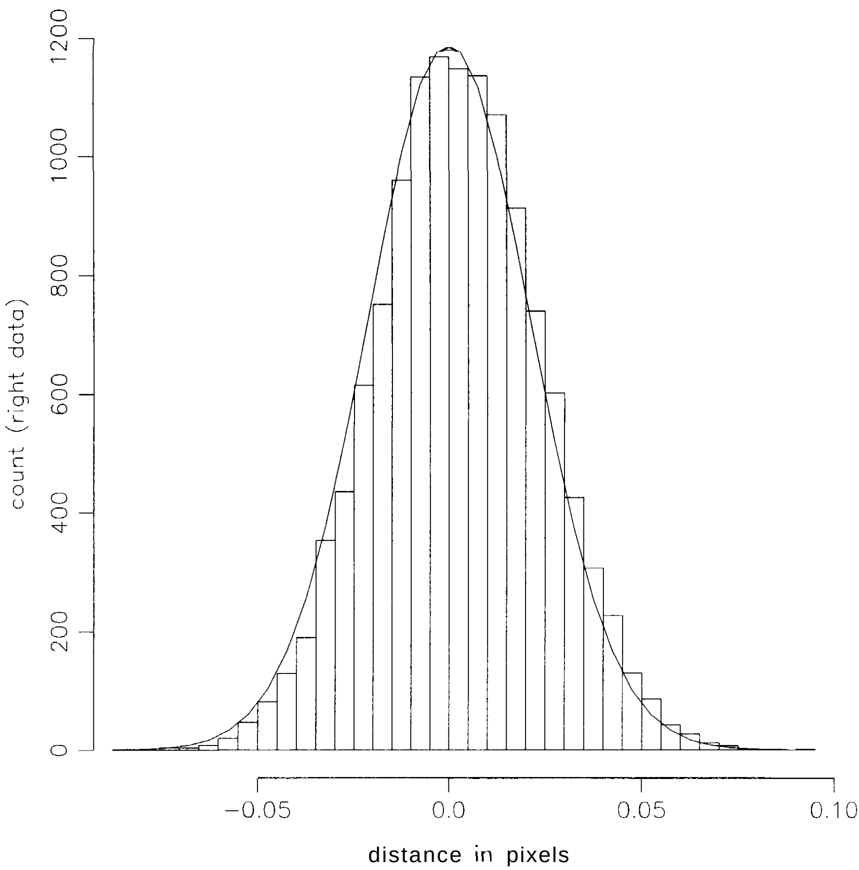


Fig. 5(b). Histograms of residuals for control data residuals with a Gaussian fit.

## Software

Software has been developed to control the experiment in a rigorous manner. Prior to experimental runs with operators, the equipment is left running with continual detector readout for several days. During this period, long runs of data are accumulated (typically 40,000 readouts) both overnight and during the day. Our prime measure is the centroid of the diffraction pattern, which we measure as the first moment of the third power of the distribution. The centroid of the third power is determined to minimize the noise in the wings of the diffraction pattern. Jahn et al (1982) claim that the effect is one of a lateral displacement of the mean of the expected statistical distribution with the other moments of the distribution being unaffected. **A** typical long run is shown in Figure 3.

In Figure 3 the centroids are plotted as a function of time. Typically for a 10 hour run, the maximum drift of the centroid is .02 pixels. In an actual experimental run we adopted the following methodology :

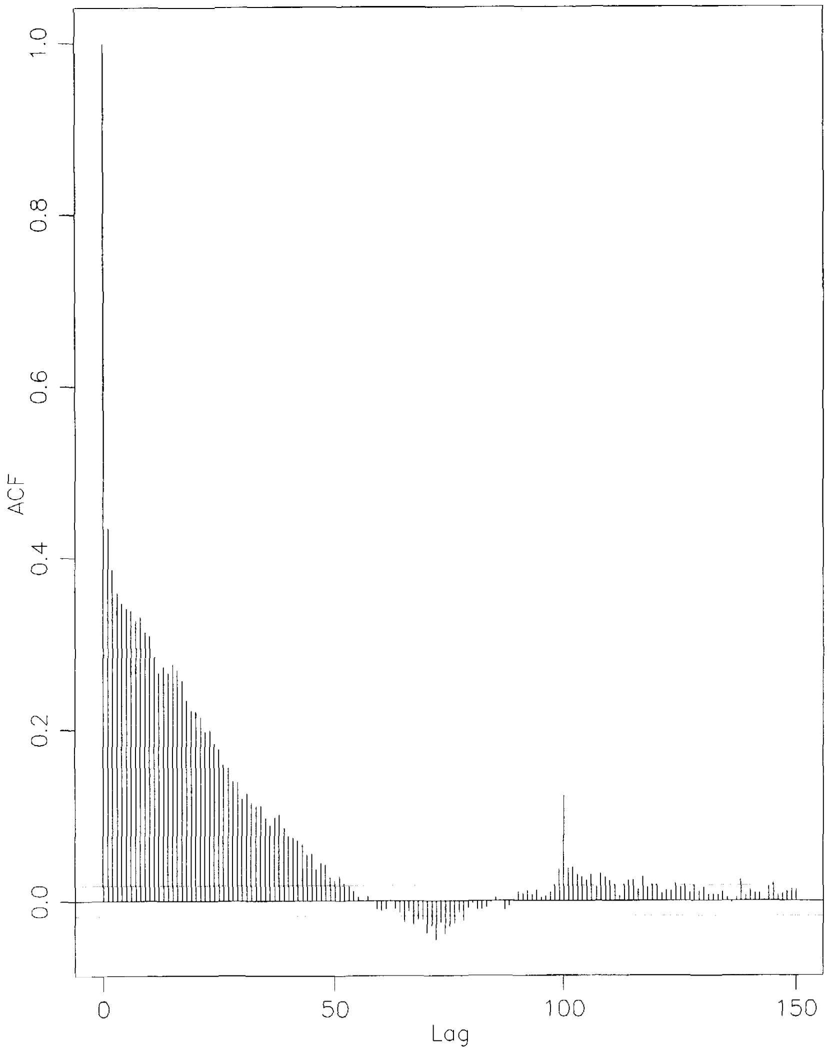


Fig. 6(a). Autocorrelation plot for the control data residuals with 95% confidence limits indicated.

The photodiode array (comprising a total of 1024 pixels with 25 micron spacings) is scanned 6 times. The data from the first scan is discarded with the sum of the remaining 5 scans returned from the detector interface. The data is written to fixed disc and any calculations or display work is done. This process takes 1.2 seconds. The first 10 data sets are taken with the electromechanically operated shutter closed. These data sets are averaged and then subtracted from all subsequent data sets to eliminate the dark current of the array from the data. The next 100 data sets (we refer to a block of 100 data sets as a "bin") are taken and not displayed. These serve as calibration data for the icon which is displayed to the operator as shown in

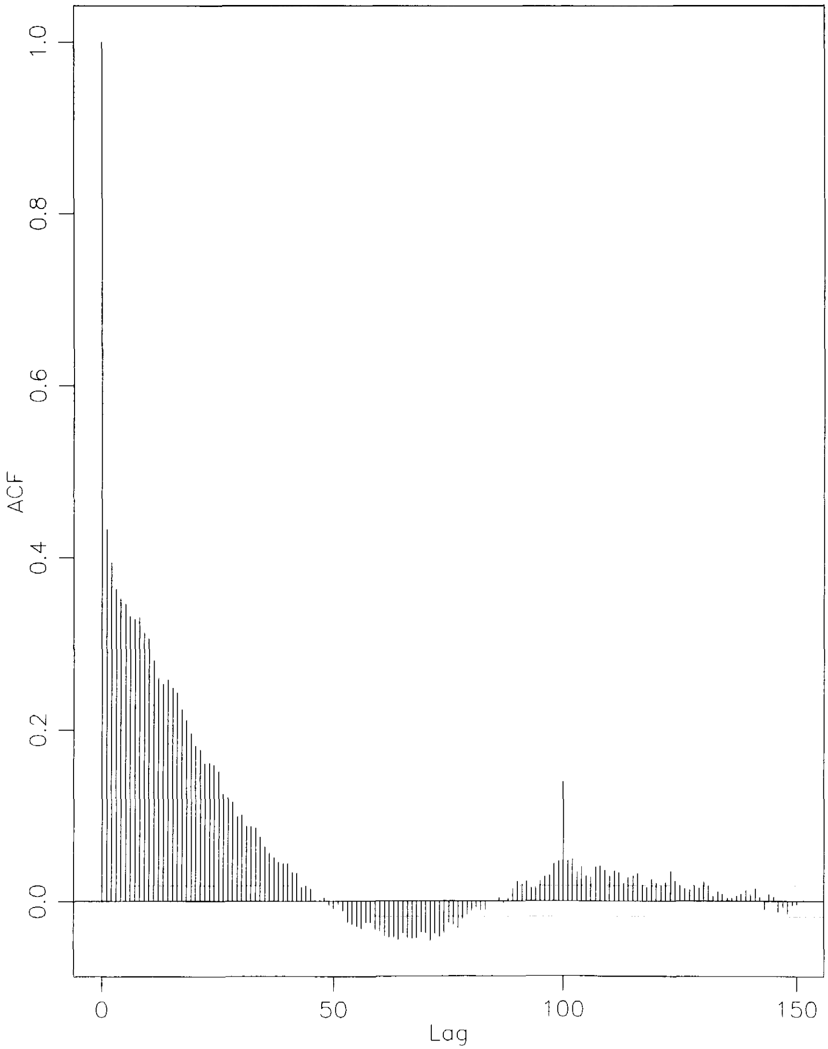


Fig. 6(b). Autocorrelation plot for the control data residuals with 95% confidence limits indicated.

Figure 4. Then 9 sets of 3 bins are taken, where the first bin of each three is always with no attempt at biassing. The next 2 are either with a left or right attempted bias or vice versa, the order being randomly selected. Before the start of each run, 5 data sets are taken while a prompt is displayed stating the direction of effort desired for the upcoming bin in order to give the subject 5 seconds to get ready. After the last group of three runs is taken, one last no-effort run is taken for calibration. This entire sequence takes 1 hour. With this protocol, the no-effort scans are regularly interspersed with attempts to bias the data and thus we can track any short term drift in the instrument. During the experiment the operator is seated comfort-

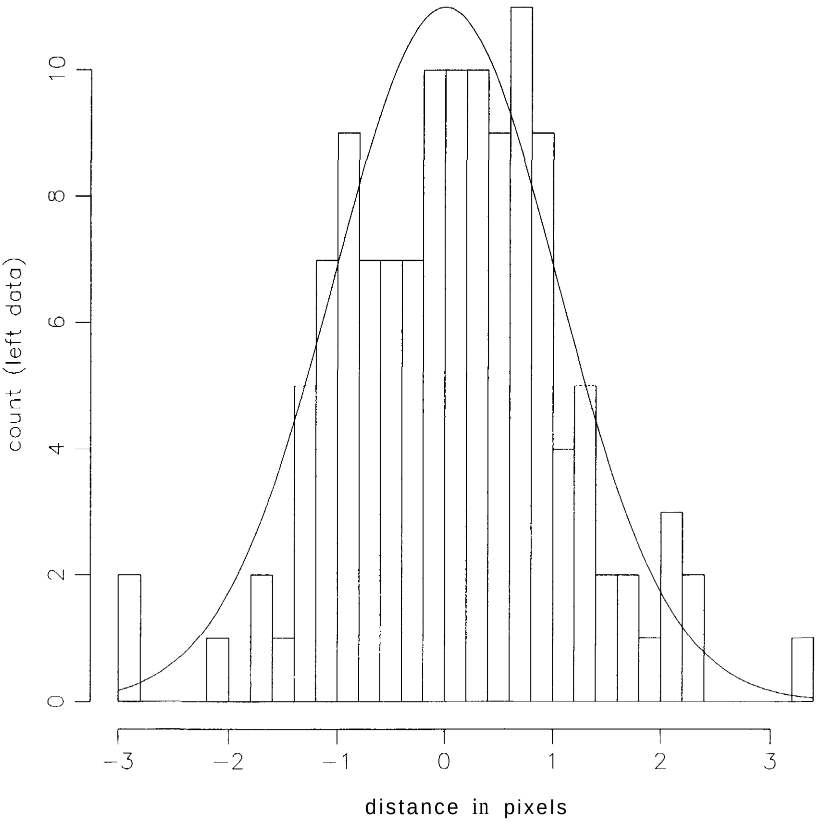


Fig. 7(a). Histograms of residuals for control data SBP with a Gaussian fit.

ably end on to the apparatus with the computer monitor arranged at eye level. The monitor displays the diffraction pattern together with an icon (see Figure 4).

The scale of the icon is calibrated in the following manner. The computer calculates the mean and standard deviation of the centroids recorded for the no effort sequence at the beginning of the session as mentioned above. These computed values are used to calibrate the icon scale in terms of two standard deviations per division. These calibrations are updated for each no effort sequence. The operator thus has some visual feedback as to the efficacy of their effort. Each hour long series generates 17 MBytes of data, including the raw data, a log of the time each data set was taken and a log of the computed centroids of each recorded pattern. Typically, we do two complete sessions with subjects in a day. Interspersed between these sessions, an entire session is run in the absence of any operator attempting to bias the outcome. Thus, for each session with operator bias present, we have one entire data set taken the same day recorded with an operator absent. These data provide control data against which any claims of operator influence can be assessed.

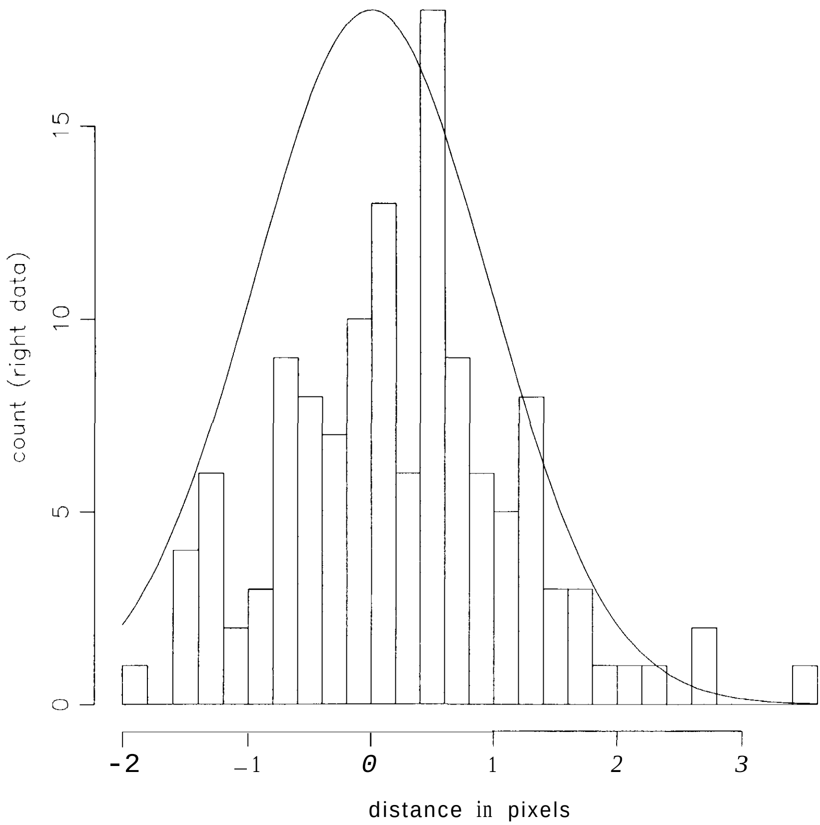


Fig. 7(b). Histograms of residuals for control data SBP with a Gaussian fit.

In our experiment, the relevant statistical distribution is recorded very quickly and with high accuracy. We can thus study the statistical distribution of the primary experimental parameter which, it is claimed, shows variations correlated with operator intention. Unlike other experiments of this type, we can assess the statistics of our statistics to place experimentally determined limits on the statistical parameter which, it is claimed, is subject to operator influence. The experiment is only run in the mode described to maintain consistency of methodology.

## Calibration Data

The equipment is allowed to run for long periods unattended; typically 10 hours overnight, generating 40,000 data sets. The calibration data recorded from these long runs has been analyzed in the following way in order to estimate realistic values for the smallest off-set we can unambiguously recover from our experimental data. These data are not used to decide whether our human operators have influenced the equipment. The data is binned into groups of 100 data points with 5

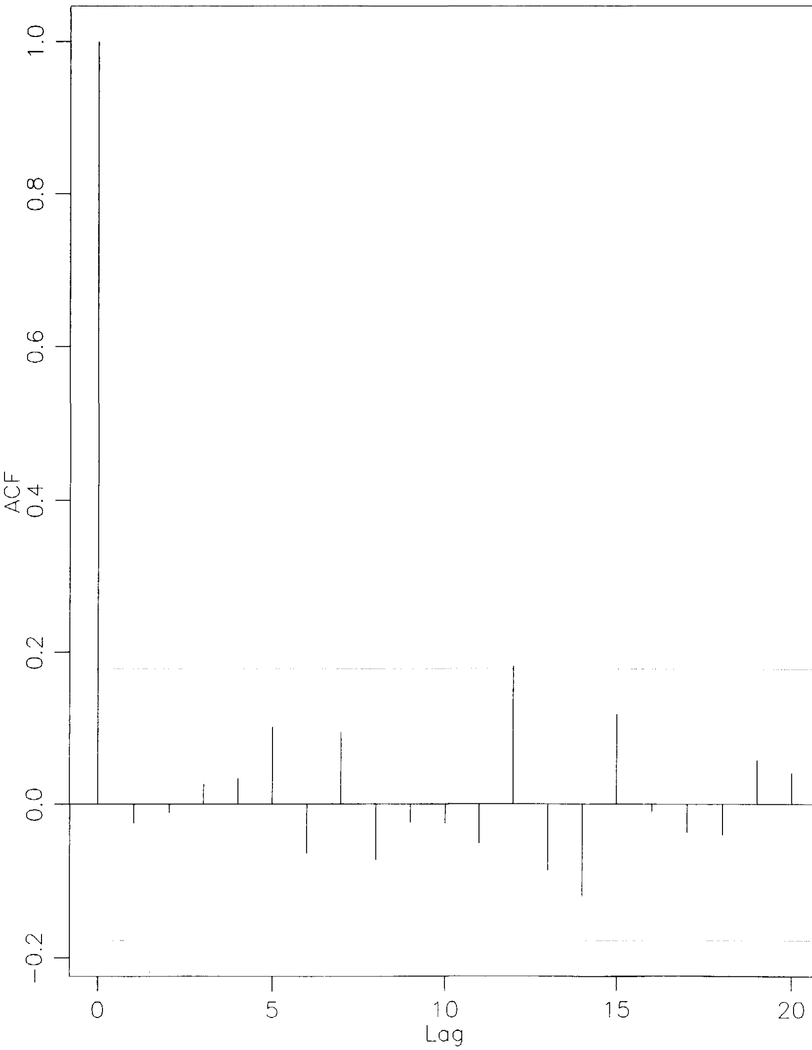


Fig. 8(a). Autocorrelation plot for the control data SBP with 95% confidence limits indicated.

points between each bin ignored corresponding to data recorded under actual experimental conditions for a given protocol. The bins are then grouped in threes, with the first bin designated as "no effort" and the second and third bins designated as "left effort" and "right effort" with the order of "left effort" then "right effort" or vice versa chosen randomly. We then analyze the bins in groups of four, made up from one group of three bins as outlined above along with the first bin of the next group of three, considered as a "no effort" bin. The first and fourth bin are "calibration" bins and the second and third are "data" bins. The "residual" for the Nth value in one of the data bins is the difference between the data value for the Nth position in that data bin and a linear interpolation between the Nth value in the

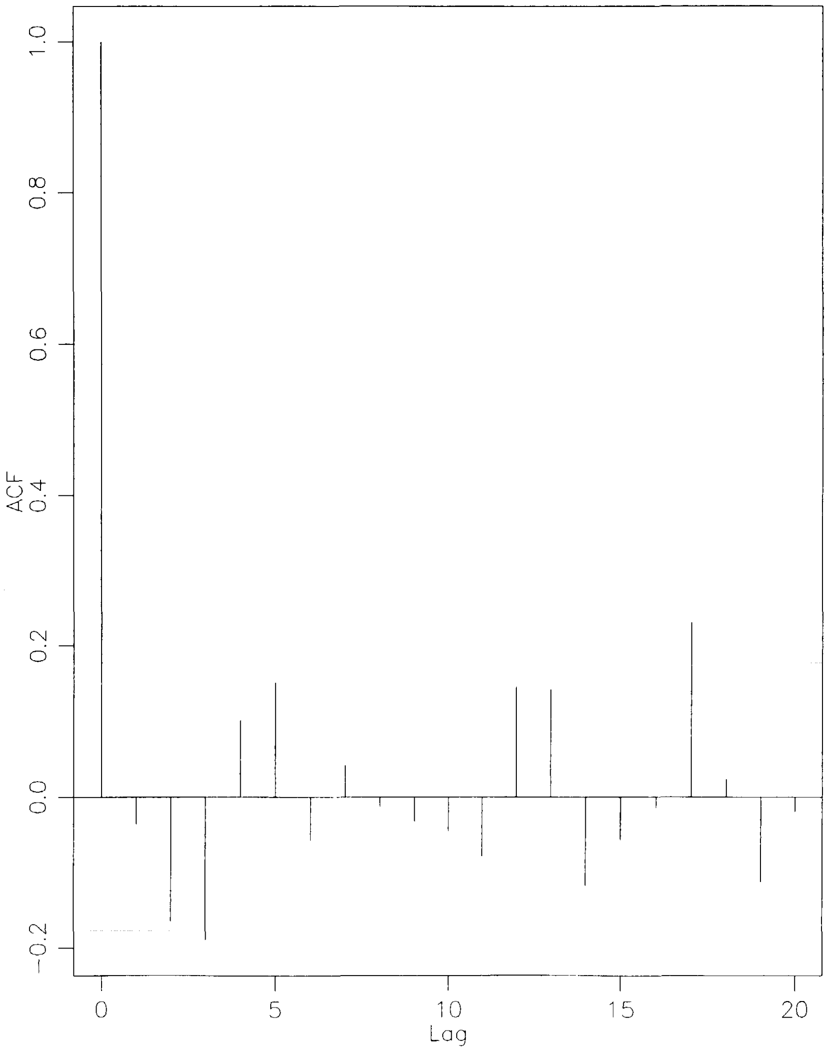


Fig. 8(b). Autocorrelation plot for the control data SBP with 95% confidence limits indicated.

first (calibration) bin and the Nth value in the fourth (calibration) bin. These residuals (100 residuals for each of the two data bins) are then saved. This procedure removes, to first order, short term drift in the instrumental performance. This completes the first step in the data reduction. Means and standard deviations for all the residuals are computed together with a histogram of their distribution. Figure 5 shows such data and Figure 6 shows the auto-correlation function of the data (residuals) in Figure 5.

We consider it very important in this type of study to check for auto-correlation in the data stream. Data can exhibit Gaussian or near-Gaussian statistics in the ag-

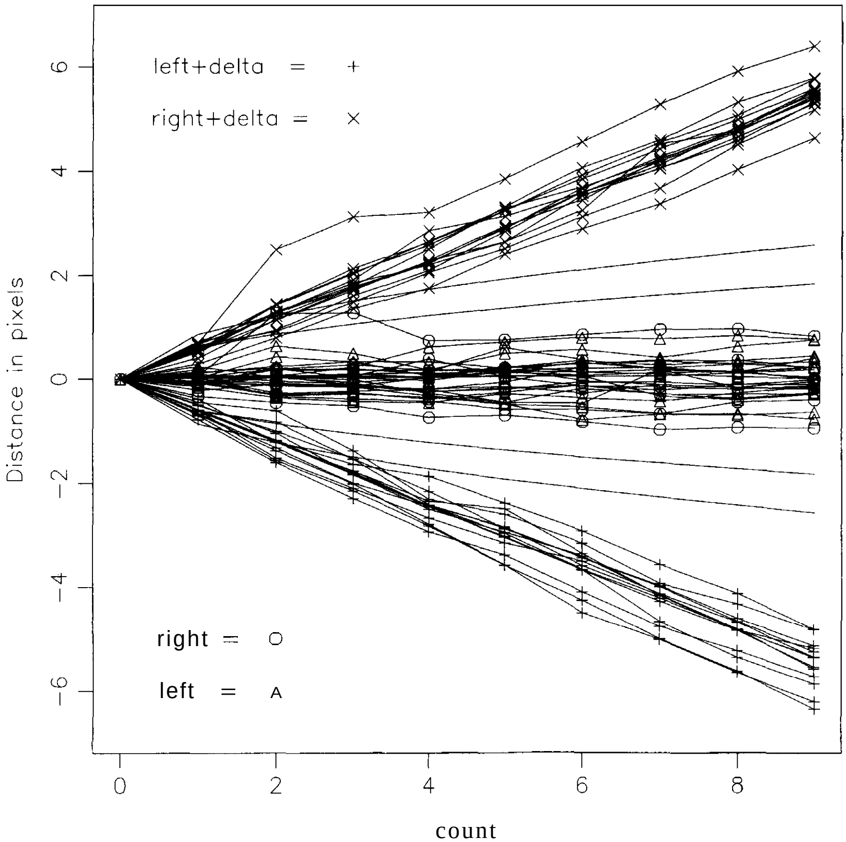


Fig. 9. Plot of the cumulative sum of the SBP for control data for several control runs, and the same data plotted in the same way with a very small offset added or subtracted to the centroid measure. Also plotted are the random walk envelopes for 5% and 1% terminal probability.

gregate and yet be auto-correlated. Any cumulative deviation plots for auto-correlated data can exhibit spurious effects that lie well outside expectations from purely Gaussian statistics.

For our data we note that there is strong correlation between successive residuals up to 50 scans of the detector. Physically this implies that the centroid of the diffraction pattern dwells on the target for a time scale long compared to the readout time. We derive a useful parameter in deciding whether there is in fact an influence due to operator intention by summing residuals over one bin (i.e., 100 successive scans). For brevity, we will call this parameter "SBP, for "Sum over Bin Parameter". This parameter does not show significant auto-correlation. A histogram of the sums over residuals for the bins we designated as left or right together with their auto-correlation functions is shown in Figure 7 and Figure 8. We note that these measures are uncorrelated and approximately Gaussian distributed.

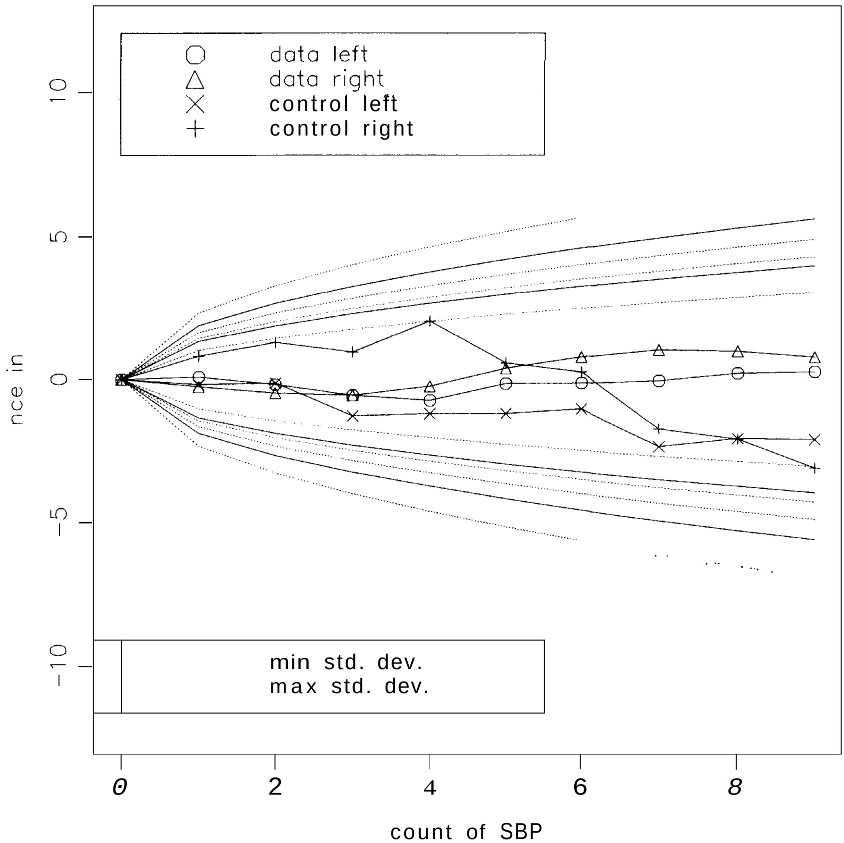


Fig. 10. Plot of the cumulative sum of the SBP for a typical experimental run, showing the random walk envelopes for 5% and 1% terminal probability.

In one hour of experimental data collection, we can take 9 bins of 100 data points for "right effort" and the same number of data points for "left effort". We then plot the cumulative sum of the SBP for these 9 bins and if there is an offset in the data, it will show up clearly in this plot. We compare the plot to the envelope for a random walk. We plot this envelope for the standard deviation of the SBP derived from residuals generated from control experiments, i.e. experiments performed without a subject. In Figure 9, we show the envelope for a random walk at 1.64 standard deviations (5% probability) and 2.32 standard deviations (1% probability), along with 14 sets of data taken from the long run data, along with the same data biased by adding the value "delta"= .0062 pixels to each data point for "right effort" and subtracting delta from each "left effort" data point. This corresponds to a displacement of the centroid in the required "effort" direction by 1.6 X $10^{-5}$ cm. The plot shows that this is clearly discernable, indeed the distance the walk the cumulative sum takes is about 15 standard deviations from the mean i.e. 5 times the expected wander for a random walk.

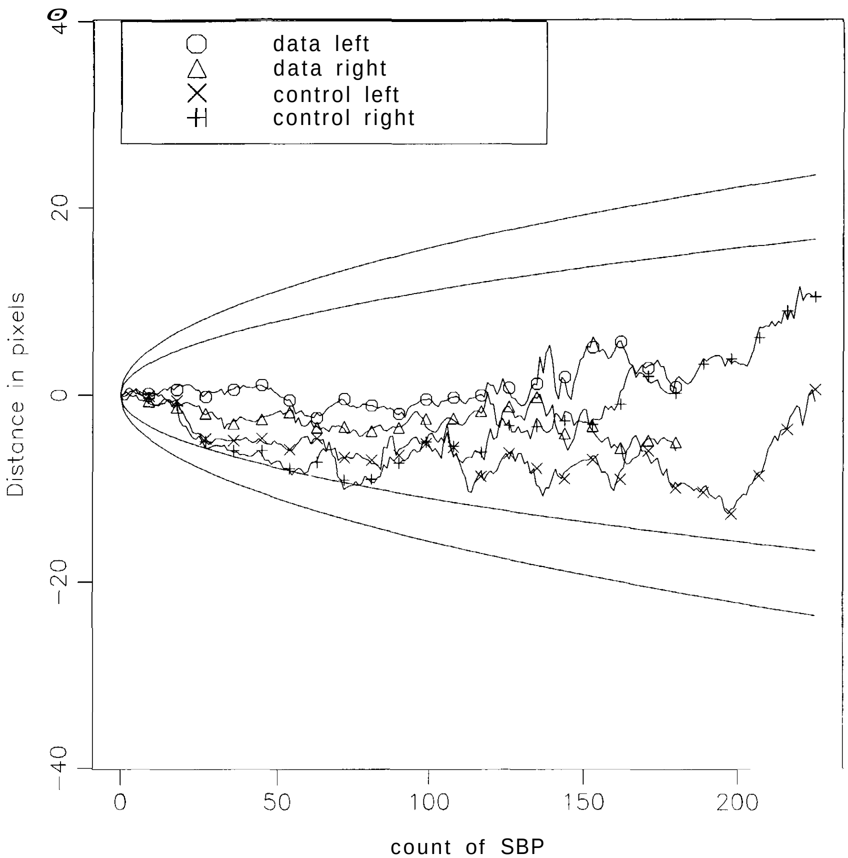


Fig. 11. Plot of the cumulative sum of the SBP for all 20 experimental subjects along with the same parameter for the *25* control runs taken on the same days as the experimental runs. Also plotted are the random walk probability envelopes for 5% and 1% terminal probability.

It is clear that an offset of the order of .0062 pixels should be unambiguously recovered from our data corresponding to a linear offset of $1.6 \times 10^{-5}$ cms.

## Experimental Results

This experiment has been performed for 20 human subjects chosen in the following manner. An advertisement was placed on bulletin boards on campus inviting participation in the experiment. When respondents called, they were told that no physical effort would be required of them along with the relevant information as to when, where, etc. There was no screening of applicants. All scheduling was conducted on a first-come, first-served basis. When respondents arrived for their appointed session, they were told the purpose of the experiment, then asked if they were comfortable with the situation or had any questions before they began. During each day, one person performed the experiment in the morning, then one control session was taken with no subject, and finally one person performed the experiment in the late afternoon. There were several occasions when subjects did not arrive for their session, and control runs were taken instead. This process went on for two weeks resulting in a database of 20 sessions with subjects, and 25 control sessions with no subject. During the nights one long run would be taken.

The data for each subject was analyzed, and we show in Figure 10 a plot of the cumulative sum of the SBP for the 9 bins during one typical session. Included in this plot is the cumulative sum of the SBP calculated for a control session taken on the same day. The smooth curves indicate the random walks at 1.64 standard deviations (5% terminal probability) and 2.32 standard deviations (1% terminal probability). The standard deviation is calculated from the experimental data and has an error of $1/(18)^{1/2}$. All three cumulative sums lie within the random walk for 1.64 standard deviations.

In Figure 11, we show the cumulative sum of the SBP for all 20 experimental sessions along with the cumulative sum of the SBP for the control session data that was taken on the same days as the experimental data. This plot indicates that, after 20 subjects, there is no significant indication of the subjects' "influence" effort having any significant influence on the cumulative sum.

## Conclusions

Apparatus for the generation and recording of white light single slit diffraction effects has been constructed for the purpose of investigating claims of ostensibly anomalous phenomena. A rigorous and consistent experimental protocol has been developed. The equipment has been extensively calibrated against the claimed effect. The experimental methodology allows for the tracking of any short term drift in equipment performance. None of twenty subjects tested to date has produced a displacement of the diffraction pattern exceeding an upper limit of $1.6 \times 10^{-5}$ cms.

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