Journal of Scientific Exploration, Vol. 21, No. 4, pp. 689–705, 2007 0892-3310107

Is the Psychokinetic Effect as Found with Binary Random Number Generators Suitable to Account for Mind-Brain Interaction?

WOLFGANG HELFRICH

Fachbereich Physik
Freie Universitat Berlin, Arnimallee 14, 14195 Berlin, Germany

Abstract—Numerous studies during the last fifty years have shown that mental intention has a psychokinetic (PK) effect on binary random number generators (RNGs). The effect is minute, but does not discriminate between different types of RNGs and appears insensitive to distances in space and (at least for days) in time. Involving a few thousand test persons, in general unselected, the studies also suggest that PK is a common phenomenon. Some years ago, a meta-analysis by Radin and Nelson of then-available data resulted in odds against chance of about 10^{50}.

The studies are reviewed before applying them to the problem of mind-brain interaction. A recent meta-analysis by Bosch et al. questioning the existence of the PK effect on RNGs is shown to be inconsistent. Subsequently, I point out similarities between an RNG experiment adding thousands of bits (0 or 1) and a cortical neuron summing the electric signals from thousands of probabilistically transmitting synapses. A quantitative comparison indicates that the PK effect might be of the right size to generate in a neuron an additional voltage on the order of the statistical noise. The effect could thus decide whether the neuron reaches the threshold of the action potential.

Keywords: mind-matter interaction—psychokinetic effect—random number generator--cortical neurons—probabilistic synaptic transmission

1. Introduction

It has been a long-standing problem of philosophers and scientists whether there is an effect of the conscious mind on the human brain. Materialism negates the question. Its adherents, in the forefront today neuroscientists, view the mind as an epiphenomenon of the workings of the exceedingly complex network of neurons in the brain.[1–3] Modern philosophers of mind hold a variety of views. Some are proponents of straight materialism.[4] There is also the idea of a material brain endowed with mysterious, possibly unintelligible properties.[5] Similarly, sensing fundamental differences between consciousness and neuronal activity, many philosophers avoid definitive statements.[6] The viewpoint taken in the present paper is dualism, today often regarded as obsolete, which considers mind and brain to be different entities. In a late effort to defend it, Popper, a philosopher with a special interest in the interpretation of quantum mechanics, and Eccles, a neuroscientist, presented and discussed in a joint book (1977) their views on mind-brain interaction.[7] Although no longer up-to-date on brain physiology and undecided about the physics of the interaction, their treatise is still a fascinating starting point for a study of these questions.

Dualism presupposes indeterminism in the realm of physics. Quantum mechanics has indeed abandoned the causality of classical physics. Instead, it features the uncertainty relation and propensities, i.e. probabilities or rate constants, of events to happen. Another requirement of dualism is the ability of the mind to interact with matter. This is where parapsychology comes into play, in particular psychokinesis (PK) if the mind is to act on matter. The least problematic way for the mind to intervene seems to be an influence on the quantum events which are random, apart from being governed by propensities.

The purpose of the present article is to estimate the psychokinetic effect on cortical neurons, applying the results of statistical PK studies done on binary random number generators (RNGs). The estimate suggests that PK might be suited to explain mind-brain interaction. Plenty of background is required because the subject matter is diverse and in parts controversial. Accordingly, the second section of this article is devoted to quantum mechanics, i.e., its interpretation and ideas, mostly of physicists, on its possible relationship to mind-matter interaction. The third section is a review of PK experiments with binary RNGs. It is quite extensive because to most scientists this area represents unknown and dubious territory. Complementing a PK meta-analysis on the way raises the odds against chance, i.e. the reciprocal of the chance probability, roughly from 10^{50} to 10^{100}. The experiments provide values of the average magnitude of the PK effect as a function of experimental conditions. They also reveal features of PK which appear to be independent of equipment and basic experimental parameters. The fourth section starts with an outline of the switching properties of a cortical neuron and its synapses, which is used to point out similarities in functioning between the neuron and an RNG. In a successful PK experiment on a binary RNG, the test person achieves by mental intention a significant preference for one kind of bit over the other. In a neuron, an ensemble of synapses replaces a single RNG and the probabilistic signal transmission of a synapse acts like a bit. Neuron and RNG can be compared directly if the numbers of synapses and pulses happen to be equal. Such a comparison with successful PK experiments and a formal estimate based on the statistics of the PK data known to date finally suggest that the PK effect on neurons could be significant.

2. Quantum Mechanics and Mind-Matter Interaction

Quantum mechanics is an exact theory and leaves no open questions in the case of stable or oscillatory states. However, its correct interpretation when a system evolves, undergoing irreversible transitions from one state to the next, has been the subject of heated debates. These debates concern, e.g., the role of an observer, non-local correlation, decoherence, the question of hidden parameters, and the possibility of branchings into many worlds existing side by side. The modern quantum experiments with photons, particles and large molecules have been helpful in clarifying the situation.[8] Today, there seems to be wide agreement that physical systems evolve in a probabilistic but objective manner through sequences of events called quantum jumps or collapses of the wave function. This interpretation goes back to the early years of quantum mechanics. In a theoretically complete way, it was probably formulated first by Born in 1926. In his treatment of particle scattering he distinguishes a probabilistic change of momentum from the causal evolution of the wave function.[9] In 1927 Heisenberg extended this idea to chains of events, his favorite example being the trace of a fast particle in a cloud chamber or photographic plate.[10] The trace is recorded without requiring the presence of an observer. Heisenberg elaborated on this objective interpretation of quantum mechanics on later occasions.[11]

Clearly, quantum jumps occur not only in the well-defined examples of radioactivity and delayed photon emission. They also take place, but are often poorly separated, in the excitation and de-excitation of molecular vibrations, the tunneling, passage through bottlenecks, and scattering of electrons and protons, chemical reactions, and the motion of molecules in a fluid. It seems that the role of quantum jumps is often played down in the literature to assert the validity of classical physics in the "chemistry" of the brain or life in general.

The probabilistic character of quantum jumps offers an easy gateway for mind-matter interaction or any other non-physical influence on matter. The only "action" required would be to choose one of an infinite number of possible pathways of evolution. This could be done without grossly deviating from statistical averages. The selection leaves no mark, except in a statistical sense, and in particular does not violate energy conservation. Ideas of this sort are not new. There have been speculations on a possible connection of consciousness with quantum jumps. Some authors, like Wigner,[12] consider this an extension and completion of quantum mechanics. Others, like Squires[13] and Stapp,[14] emphasize implications for mind-brain interaction. Remarkably, Walker, a physicist with many other interests, suggested as early as 1977 that synaptic signal transmission is triggered by electron tunneling that is influenced by the mind.[15,16] The physicist Beck and Eccles, the neuroscientist, proposed many years later a similar model, in which a particle of proton mass replaces the electron, to define the probabilistic elementary step of mind-brain interaction.[17]

Curiously, of all these scientists only Squires accepted without reservation PK experiments with RNGs as a valid illustration of mind-matter interaction. Stapp was a monitor in a PK experiment conducted by Schmidt[18] and in an article speculated on an explanation of PK in terms of a modification of quantum mechanics.[19] However, there seem to be no references to PK or parapsychology in his later writings. In their joint book, Popper and Eccles decided in the preface not to deal with parapsychology because of inexperience. Popper added in his part that he found the subject scientifically wanting. Although an advocate of quantum propensities,[20] Popper did not propose them in his discussion with Eccles as a means of mind-brain interaction. He felt the randomness of quantum jumps to be in conflict with free will.

Recently, a model of mind-brain interaction assuming PK to order, by means of quantum fluctuations, molecular motions which then open ion channels, was proposed by Burns.[21,22]

3. Psychokinesis and Random Number Generators

a. Definitions, Results, and a Meta-Analysis

In the last fifty years the great majority of PK studies have been carried out on RNGs. These devices produce random sequences of positive and negative electric pulses occurring normally with equal probability. Often the pulses are called hits and misses or are regarded as the binary numbers 1 and 0. As the machine runs, a test person tries by mental intention to increase the number of pulses of one kind at the expense of those of the other. Usually the excess is monitored, e.g. by plotting it as a function of n where $n = 1, 2, \ldots, N$ is the instantaneous number; while N is the typically pre-set total number of pulses. N ranges from less than 10 to 10^8, with some experiments extending over ten or more years. The technical details and precautions taken may be found in the papers by Schmidt and the Princeton Engineering Anomalies Research (PEAR) group of Jahn, Dunne and coworkers (see below). The result of a PK experiment is measured by the z-score and can also be expressed by the effect size or the hit rate. The z-score is the deviation of a quantity from its mean value divided by the statistical standard deviation. For instance, in an experiment with a total of N pulses, the difference $\Delta N = N_+ - N_-$ of the numbers of positive and negative pulses has the mean value zero and the standard deviation $\sqrt{N}$ so that

$$z = \Delta N/\sqrt{N} \tag{1}$$

Alternatively, if only the N_+ hits are registered and the negative pulses discarded, the mean value of the number of hits is $N/2$ and the actual and standard deviations are half as large as before, but the z-score remains the same. (N is assumed to be large here and in the following.)

For each value of z there is a probability

$$\mathrm{P}(z) = \int_z^\infty \mathrm{w}_0(\mathrm{t})\mathrm{dt} \tag{2}$$

that this value or higher ones occur by chance. Here $\mathrm{w}_0(\mathrm{t}) = (2\pi)^{-1/2} \exp(-\mathrm{t}^2/2)$ is the standard Gaussian distribution function whose integral from $-\infty$ to $+\infty$ is unity. Often, z-scores are regarded as statistically significant for $z \geq 1.96$, which corresponds to $\mathrm{P}(z) \leq 0.025$. Technically speaking, a signal of this magnitude is above statistical noise.

TABLE 1
Data of Four Successful RNG Experiments

N	z	P(z)	e_{PK}	h (%)	Reference
12,800	5.3	6×10^{-8}	4.8×10^{-2}	52.4	23
32,768	3.3	4×10^{-4}	1.8×10^{-2}	50.9	23
2.4×10^{7}	4.7	1×10^{-6}	1×10^{-3}	50.05	24, 25
1.68×10^{8}	3.3	4×10^{-4}	2.6×10^{-4}	50.013	24, 25

Note: N = total number of pulses; z = the deviation of a quantity from its mean value divided by the statistical standard deviation; P(z) = probability that the z-score equals or exceeds z; e_{PK} = size of the psychokinetic (PK) effect; h = hite rate.

The size, e_{PK}, of the **PK** effect,

$$e_{\mathrm{PK}} = \Delta N/N, \tag{3}$$

is defined on the assumption that the probabilities are biased equally for all pulses in an experiment. However, e_{PK} may depend on N. Because of Equation 1, Equation **3** may be rewritten as

$$e_{\mathrm{PK}} = z/\sqrt{N} \tag{4}$$

Accordingly, if the effect size is independent of N, the average z-scores should obey $e_{\mathrm{PK}}\sqrt{N}$, thus increasing without bound as N is made larger and larger. The hit rate, h, is 0.5 or 50% without bias and

$$h = 0.5 \times (1 + e_{\mathrm{PK}}) \tag{5}$$

with a nonvanishing e_{PK}. Of course, in referring to a single experiment, effect size and hit rate are useful concepts only if the z-score is above noise.

The data of four RNG experiments with z-scores distinctly above the limit of significance are listed in Table 1. Two of them were conducted by Schmidt and were performed by two and 15 selected test persons in the first and second case, respectively.[23] The much longer series of pulses of the PEAR group were influenced by a single obviously talented test person in the first experiment and 91 "ordinary" test persons in the other experiment.[24–26] As in Schmidt's case and elsewhere, individual contributions were concatenated in experiments involving more than one test person. The results of the experiments are impressive, especially when the four chance probabilities P(z) are multiplied to give an overall chance probability of $P \approx 1 \times 10^{-20}$.

However, reproducibility can in no way be expected. There are differences between test persons and the performance of a single test person varies in equal experiments, negative z-scores being frequent. What has been obtained is a statistically highly significant piece of evidence for PK.

A broader view emerges in a meta-analysis carried out by Radin and Nelson.[27] Searching the English-language literature from 1959 to 1987, they collected 597 experiments conducted by 68 different investigators. Based on the multitude of z-scores they showed that the PK effect can be approximated by a shift and a widening of the unbiased, standard distribution. (The z-scores were rendered by the standard distribution with the tails cut off when they had only been reported to be insignificant.) In remarkable contrast, the scores of 235 control experiments run with no bias very well reproduced the standard distribution $w_0(z)$, except perhaps for a slight narrowing. From Radin and Nelson's modified distribution one reads a shift of $(z) = 0.6$ and a widening by the factor $a = 3/2$. The meta-analysis disregards N, thus giving the impression that the z-scores do not depend on the number of pulses in an experiment. This could be a first sign of the so-called decline effect, i.e. a decrease of e_{PK} with N, which will be discussed below.

Using the data from the 597 experiments, Radin and Nelson derived the effect size $e_{\mathrm{PK}} \approx 3 \mathrm{X} 10^{-4}$ when all of the total number of pulses were weighted equally.[27] Including experimental quality in the weighting practically made no difference. Because of Equation 5, this effect size corresponds to the hit rate $h = 50.015\%$. However, elsewhere Radin gives $h = 50.9\%$ for the same collection of data.[28] This is the average of the mean hit rates of the experiments, each experiment being weighted equally, except for the 258 experiments of the PEAR group, which were excluded. The difference between the averages is another indication of a decline effect.

The shift of $(z) = 0.6$, despite being much less than 2, is highly significant. Even though most of the z-scores constituting the modified distribution are insignificant or negative, overwhelming evidence for PK can be deduced from the small modifications of the standard distribution because of the enormous number of experiments involved. In a follow-up[29] of their meta-analysis Radin and Nelson derive a cumulative z-score, z_{cum}, for Ω experiments from Stouffer's formula, $z_{\mathrm{cum}} = \langle z\rangle \Omega^{1/2}$. With $(z) = 0.6$ and $\Omega = 597$ one obtains $z_{\mathrm{cum}} = 14.66$, which, when inserted in Equation 2, yields the remarkably low chance probability $P(z_{\mathrm{cum}}) = 6 \times 10^{-49}$. Stouffer's formula ignores any dependence on N of the distribution of z-scores. Moreover, it takes account only of the shift, but it disregards the widening of the distribution. In their follow-up, Radin and Nelson[29] added 175 newly collected PK-influenced experiments, while the 258 experiments of the PEAR group were collapsed into a single one. This brought the total number to 515 and the cumulative z-score to 16.1.

Let me calculate here the chance probability of finding the modified Gaussian distribution, taking into account both shift and widening. Once more, the distribution is assumed to be independent of N. The modified distribution may be written as

$$w(z) = \alpha^{-1}(2\pi)^{-1/2}\exp[-(z - \langle z\rangle)^2/(2\alpha^2)] \tag{6}$$

Its integral over z is unity and $w(z)$ is, of course, identical to $w_0(z)$ for $(z) = 0$ and $a = 1$. The quantity of central interest is the mean square of the z-score, (z^2). A large number of experiments are required to determine the modified distribution function with reasonable accuracy. The chance probability of a particular z-score is proportional to $\exp(-z^2/2)$. If Ω is large enough, the product of all these exponential functions will be, to a good approximation, $\exp(-\langle z^2\rangle\Omega/2)$. Accordingly, a mean factor $p(\langle z\rangle,\alpha) = a \times \exp[-(\langle z^2\rangle - 1)/2]$ may be defined by which the chance probability of the modified distribution function is reduced per experiment. The prefactor a is introduced here on the right-hand side of the equation to allow for the increase in the number of values which z can assume as the distribution is widened. Integration of $z^2 \times w(z)$ yields $(z^2) = \alpha^2 + \langle z\rangle^2$, so that p may be given the final form

$$p(\langle z\rangle, \alpha) = \exp[\ln \alpha - (\alpha^2 - 1 + \langle z\rangle^2)/2] \tag{7}$$

With $(z) = 0.6$ and $a = 3/2$ one has $p(\langle z\rangle,\alpha) = 0.671$. The overall chance probability $P_\Omega = p(\langle z\rangle,\alpha)^\Omega$ that Ω experiments produce the modified Gaussian distribution instead of the standard one assumes for $\Omega = 597$ the infinitesimal value of 3×10^{-104}. Considering shift alone, i.e. putting $a = 1$, one finds 2×10^{-47}. The last number is similar to the result obtained before from Stouffer's formula, which is based on a slightly different definition of the chance probability. Incidentally, a direct way for a physicist to derive Equation 7 is to regard the z-scores as the positions of the particles of a one-dimensional ideal gas in a harmonic potential.

b. The Decline Effect Versus the Assumption of Constant Effect Size

The term decline effect typically denotes a decrease of e_{PK} with the pre-set number of pulses in an experiment. If the z=const. hypothesis applies, i.e. if the frequency of the z-scores is independent of N, such a decline effect must obey

$$e_{PK} \sim 1/\sqrt{N} \tag{8}$$

because of Equation 4. Exactly this form was put forward, apparently between 1985 and 1987, by May et al.[30] and von Lucadou[31] on the basis of theoretical models. In fact, in the follow-up of their meta-analysis Radin and Nelson[29] noted that the z-score frequencies of the experiments reported up to that date did not significantly depend on N. In particular, the increase of N by orders of magnitude from 1959 to 2000 was without noteworthy effect.

In contrast, the PEAR group has preferred to maintain the assumption of an effect size independent of the number of pulses. Let me discuss their reasons for adopting the e_{PK}=const. hypothesis on the basis of their experiments, which are exemplary in scope and multitude of pulses. Being rather recent, their articles also refer to the relevant work of others. It will be useful in the following to distinguish two types of experiments: In the "flexible" experiments the automatic operation of the RNG is interspersed with choices to be made by the test person(s). The most common of them are the timing of button pushes and selecting the intention (high z, low z, or baseline) for the next automatic sequence of pulses. The "rigid" type of experiments is without any choices for the necessarily single test person, apart from the moment of triggering. The experiments of Schmidt and the PEAR group, and those as defined by Radin and Nelson for their meta-analysis, were in general of the flexible type.

An interexperimental decline effect may occur between an experiment and subsequent ones. This case is treated first because it was studied fairly early by PEAR. Dunne et al. employed altogether 1.7×10^8 pulses for each intention,[32] dividing them between several dozen series. On averaging, they found a depression of e_{PK} as a function of position in a series of nearly equal RNG experiments. The (positive) cumulative z-score falls from a significant level to a minimum at about the third experiment, apparently straying into the wrong sign, but returns to the intended side later in the series. The recovery may not be complete. Incidentally, the effect sizes were the lowest and the cumulative z-scores well below significance in the subset with the smallest number of choices. The effect sizes averaged over the pulses of all experiments were $e_{PK} = 2.6 \times 10^{-4}$ and 1.6×10^{-4} for positive and negative intentions, respectively.

The regular decline effect, i.e. the dependence of e_{PK} on N in experiments of the rigid type, was studied by Dobyns and Nelson.[33] They took data of the PEAR group[25] published by 1997, decomposing flexible experiments into pulse sequences of the rigid type. A summary of this work was given by Dobyns.[34] The authors analyzed sequences of N = 20; 200; 1000; 2000; 10,000; 20,000; 100,000; and 200,000. The numbers of some of these experiments were extremely large, ranging from 1200 at N = 1000 to 163,350 at N = 200. The effect size varied only from 3.9×10^{-4} to 1.2×10^{-4} between N = 200 and N = 200,000. This variation is much nearer to $e_{PK} = \text{const.}$ than to $e_{PK} \sim 1/\sqrt{N}$. A plot of z vs. $\sqrt{N}$ suggests a leveling off at $\langle z \rangle = 0.06$ between $N = 10^4$ and 10^5. Was it the crowding of experiments that prevented all over the examined range of N the rise to $\langle z \rangle = 0.6$, the value expected on the basis of Radin and Nelson's meta-analysis?

The recovery from the interexperimental decline effect and the near independence of e_{PK} from N in the experiments of the rigid type support the $e_{PK} = \text{const.}$ hypothesis. However, the accord was lost in later experiments. For a thorough check that e_{PK} is practically independent of N, Ibison[35] and, in an affirmative replication, Dobyns et al.[36] eventually employed exceptionally high pulse rates and numbers. The standard procedure at PEAR was to generate blocks of 200 pulses at the rate of 1000 s^{-1}, with breaks of 0.7 s or longer in between. Ibison and Dobyns et al. were in a position to increase the rate of generation and thereby the number of pulses by the factor 10^4, leaving the block otherwise unchanged. In this study, the number of blocks was always 1000 per intention (high z, low z, baseline). Consequently, the maximum number of pulses in an experiment amounted to 2×10^9, a record mentioned only rarely in the rest of the present article. Most of the experiments allowed a (varying) number of free choices. These and other details are omitted here for brevity. With the same equipment the authors could also apply the factors 0.1 and 10. The z-scores measured with the three lower rates are consistent with $e_{PK} = 3 \times 10^{-4}$ for the mean of positive and negative intentions, as measured with the greatest accuracy at N = 200. Because of large standard errors (due to still-insufficient numbers of experiments) they seem equally compatible with $e_{PK} - 1/\sqrt{N}$. When the rate was raised from 10^3 s^{-1} to 10^7 s^{-1}, the average z-score increased only by a factor of roughly 2, while a value of 100 would be expected at constant e_{PK}. This speaks for a decline effect at very large N that nearly satisfies $e_{PK} \sim 1/\sqrt{N}$. However, $\langle z \rangle$ and thus e_{PK} mysteriously changed sign. One may wonder if it was the extreme pulse rate rather than the decline effect that diminished and inverted e_{PK}.

In an effort to demonstrate the existence of the PK effect in a spectacular way, PEAR and two groups in Germany, one in Freiburg and the other in Giessen, decided in 1996 to perform practically identical RNG experiments at the three locations.[37] The studies resembled the preceding twelve-year study at PEAR with 91 test persons. Each of the three groups comprised between 69 and 80 test persons and accumulated ca. 5×10^7 pulses for each of the three intentions, i.e. almost a third as many as in the successful original study. The intentional results of the three groups, separate or concatenated, were without success, i.e. well below significance. The concatenated z-scores were an order of magnitude below the previous, significant values. The absence of a PK effect on the z-scores would be less striking if each of the six intentional scores could be regarded as a single experiment. However, the many test persons, the large pulse numbers, and the consequent expectation that $e_{PK} = 10^{-4}$ to 10^{-3} should apply, make the outcome appear strange. Only additional studies of the same type could show if the decline to zero is perhaps followed by a recovery.

c. *An Attempt to Explain Away the PK Effect*

The disappointment caused by the failure of the triple experiment stimulated Bosch, Steinkamp, and Boller to engage in a new meta-analysis of the RNG data.[35] (The first author and the last had taken part in one of the failed experiments.) Their approach is a new mathematical formulation of the old argument that the PK effect is still unproven because it could be due to biased reporting and publishing. Although their work most likely misses its purpose (see below), it has several merits. The authors are very selective in their quality control. They allow flexibility like Radin and Nelson,[25,27] but they admit only 380 experiments from a newly retrieved database. They give references to the sources of the data and show a funnel plot of $\log N$ vs. e_{PK}. This plot and the summary data on quartiles of the experiments are especially useful in the present context. The division by pulse numbers indicates that $\langle z \rangle$ has a weak maximum in the quartile of smallest N. (N starts at 20 and has a mean of 490 in this quartile of 95 experiments.) The maximum is ascribed by Bosch et al. to the fact that the quartile contains most of the experiments of Schmidt with selected test persons.[38] The experiments with exceedingly high pulse numbers (2×10^9) disrupt the statistics. When omitting them, the authors expressly found the (z) = const. hypothesis reconfirmed. The data given do not permit one to calculate

TABLE 2
Data Points (e_{PK}, N) from the Funnel Plot of Bosch et al. with the Largest $|z|$ and Smallest $P(z)$ Values. The first four points are on the intended side ($e_{\mathrm{PK}} > 0$), the last three on the side contrary to intention ($e_{\mathrm{PK}} < 0$). The effect size e_{PK} is derived by use of Equation 5 from the hit rate h

e_{PK}	N	z	$2000 \times P(z)$
0.14	6000	10.8	3×10^{-24}
0.49	300	8.5	2×10^{-14}
0.063	15,000	7.7	1×10^{-11}
0.16	1500	6.2	6×10^{-7}
−0.089	40,000	−17.8	7×10^{-68}
−0.18	9000	−17.1	2×10^{-62}
−0.079	17,000	−10.3	7×10^{-22}

Note: Bosch et al. use π to designate the hit rate, called effect size in their terminology. e_{PK} = size of the psychokinetic (PK) effect; N = total number of pulses; z = the deviation of a quantity from its mean value divided by the statistical standard deviation; $P(z)$ = probability that the z-score equals or exceeds z.

precisely the average shift of z under the influence of PK, but it seems to be close to $\langle z \rangle = 0.6$, the value found in the first meta-analysis of Radin and Nelson.[27]

Bosch et al. attribute the deviation of the z-score distribution from normal statistics to a suppression of disappointing scores by PK researchers and publishers alike. They describe the degree of elimination by a step function consisting of four steps at fixed values of z. A Monte Carlo simulation applying the step function to otherwise chance distributions of z seems to lead to a good match with the distribution underlying the meta-analysis, if one assumes that about 1500 experiments have been discarded. The procedure is ad hoc and the distrust in the objectivity of those who handled the data seems exaggerated, but the approach of Bosch et al. is more persuasive than the usual treatment of possible data suppression in terms of the so-called file drawer effect. The funnel plot of $\log N$ vs. e_{PK} demonstrates $e_{\mathrm{PK}} \rightarrow 0$ for $N \rightarrow \infty$, which of course also follows directly from $\langle z \rangle = \mathrm{const.}$ and from Equation 8 for the decline effect.

However, the display of the data points in the plot may be used for an alternative check. Deriving the z-score from e_{PK} and N by means of Equation 4, one can calculate $P(z)$ for any of the points. The product of $P(z)$ and the hypothetical total number of experiments, that I take to be 2000, is the probability for a given point to occur by chance. Whenever it is smaller than 0.025, it may be regarded as significant. There are several such data points in the plot. Those with the four highest z-scores are listed in Table 2. Clearly, each of the chance probabilities, and even more so their product, is small enough to demonstrate a significant PK effect. Curiously, there are highly significant data points also on the side of negative e_{PK}, three of which are presented in the lower part of Table 2. They provide an argument against the suspicion of much tampering with the data. Instead, they suggest that the meta-analysis of Bosch et al. ignores the widening of the Gaussian distribution of z-scores by the PK effect.

The chance probabilities of two of those points are exceedingly small. It is tempting to disqualify both as outliers, but this remains to be justified. A general conclusion is that in checking for PK the simplest and most reliable method is to first look for singular z-scores, i.e. those of very low chance probabilities.

d. Summary of Numbers and Indifference to Basic Physical Parameters

For later use, let me recapitulate and attempt to interpret the "quantitative" results of PK studies on RNGs in a few statements: (I) The z-score of an isolated experiment aiming at high or low z does not depend on N, which implies $e_{\mathrm{PK}} = 1/\sqrt{N}$. Isolation, a concept that remains to be verified, is thought to mean as little overlap as possible with other experiments in terms of motivation, personnel, apparatus, time and perhaps other factors. Some of the z-scores which seem to have been obtained in isolation are significant with $z \geq 2$, while their average is $\langle z \rangle = 0.6$. (II) Repetition, routine, or crowding of RNG experiments reduce the effect size to $10^{-4} < e_{\mathrm{PK}} < 10^{-3}$, even when N is small enough to give $\langle r \rangle \ll 0.6$, and they almost delete the decrease of e_{PK} with N up to a range where statement I may be expected to apply and beyond. (III) The quantity $\langle z \rangle$ changes sign in certain circumstances, such as with multiple repetition of equal experiments or excessively large N, e.g. 2×10^9 pulses. I will make use of statements I and II in the following, although there can be no guarantee that new experiments will replicate the numbers. Introducing in statement I isolated experiments as a special class may seem far-fetched, but I see no other way to reconcile the results of the meta-analyses with the measurements of the PEAR group. As mentioned before, the average effect size of the data underlying the meta-analysis of Radin and Nelson is 3×10^{-4} in the case of equal weight for all bits. This number lies within the above limits, but it may decrease further when N is made larger and larger in future experiments, since those with the largest values of N count the most.

Another method of studying PK that can be automatized is the fall of dice. It is older, slower and more complex than the use of binary RNGs. In a meta-analysis of 148 experiments done from 1935 to 1987, by hand or by machine, Radin and Ferrari[39] found again a shift and a widening of the standard distribution of z-scores when a preselected die face was aimed for, while 31 control experiments without mental influence confirmed the standard distribution. The effects were about twice as large as in the RNG studies. Could it be that the effect size is increased because there are two choices to be made, one among three axes and the other between two directions? The highest z-score obtained in experiments with dice was 7.5.

The values of z and e_{PK} measured in PK experiments are in general blurred not only by Gaussian statistical scatter but also by differences in performance between test persons and, for the same test person(s), between positions in series of experiments and generally between different times. The various kinds of scatter impair the evaluation and utilization of a number of interesting special phenomena which have been noted in explorative RNG studies of the PEAR group. For instance, they found that two test persons joining their efforts were, on the whole, only slightly more successful than singles.[24,25] However, male/female pairs achieved on average four times and, if "bonded", six times higher z-scores than did single test persons.

On the other hand, there are extraordinary properties of PK that do not require numbers to characterize them. They consist of an indifference to the apparatus used and to some basic physical parameters.[24-26] From the physics point of view these features are outright unacceptable. The apparent absence of a dependence of the PK effect on the type of RNG employed is perhaps the most frequently documented of these features. The random events determining the sign of the next pulse were radioactive decay, electron tunneling, or thermal noise of a resistor. Even a mechanical device employing plastic spheres trickling through a two-dimensional lattice of pegs to create a Gaussian distribution did not differ dramatically in PK response from the electronic RNGs.[40] This independence implies that it makes no difference for the average z-score whether the PK-influenced pulse involves a single quantum jump or many of them. Another incredible property of the PK effect is the absence of a dependence on the distance between test person and RNG, which varied from a few feet to thousands of miles.'' Even causality is questioned: Positive or negative time shifts of hours or days between mental intention and operation of the RNG were found not to weaken the PK effect.[18,23–25,41]

This multiple indifference to physical parameters of the PK effect on RNGs in conjunction with small z-scores hovering at or below the limit of significance provokes one of two equally radical reactions: either rejection of PK as a conscious or unconscious fraud collectively committed by its investigators, or a deliberately naive search for a broader role of PK involving more than physics. An application for which its properties seem to be well fitted might be mind-brain interaction. It is the subject of the next section.

4. Psychokinesis and Cortical Neurons

Random number generators are an established tool for studying the psychokinetic effect. The question arises whether there is a place in nature where this kind of mind-matter interaction could noticeably influence the course of things. The number of pulses involved should preferably be large, since in the experiments of the PEAR group $\langle z \rangle$ increases with N, following almost $\sqrt{N}$ up to at least $N = 2 \times 10^5$.

It seems that the mammalian cortical neuron of the pyramidal type, the neuron for short, is a possible candidate. Let me describe how it functions in a simplistic manner capturing only what is employed in the present context. **A** neuron will emit an electric nerve impulse, the so-called action potential, into its axon when the voltage of the cell body reaches a certain threshold. That voltage consists of the resting potential and another part stemming from an enormous number, i.e.

about 10^4, of synapses. They are arranged on the cell's dendrites and connect them to the axons of (other) cells. The total signal from the synapses is often assumed to be the sum of their potentials. Actually, the integration of the postsynaptic potentials is a more complex process being studied by sophisticated techniques.[42,43] The neurons are known to form minicolumns (or bundles) normal to the cortex. **A** minicolumn contains 80 to 100 neurons which are assumed to operate more or less in synchrony.[illegible] Accordingly, the total number of synapses capable of contributing to the voltage of a neuron could be as large as 10^6 if the neurons of a minicolumn are electrically connected by gap junctions.[42] (The voltage produced by a single synapse should be inversely proportional to the number of neurons.)

The synapse can transfer an electric signal from an axon to a dendrite by means of chemical transmission. The process begins with voltage-induced exocytosis on the presynaptic side. A vesicle containing neurotransmitter molecules fuses with the membrane bordering the synaptic cleft, thereby releasing its contents into the cleft. The neurotransmitter in turn gives rise to a positive electric potential on the postsynaptic side. Exocytosis is a chance event, and probabilities not much below 50% per arriving nerve impulse have been reported.[45,46] Equal chances for the two responses imply that the synapse may be regarded as a one-pulse binary RNG. In a PK experiment, a single RNG produces a series of N pulses or bits. In the case of a cortical neuron, the RNG is replaced by N synapses, each producing a single bit. Instances of neurotransmitter release may be counted as hits. The superimposed signals result in an increase of the voltage of the cell body that will be associated with a Gaussian distribution of statistical scatter about its average. A PK-induced shift of the average increase, if of the size of this noise or larger, may cause an otherwise inert cell to surpass the threshold of firing a new nerve impulse.

For simplicity, it is assumed that without PK bias precisely 50% of the N relevant synapses transmit a signal and that they do so in perfect synchrony. If there is a sequence of nerve impulses, as is common, they are thought to be separated by at least a few milliseconds, allowing the electric voltage generated by the signals to fall back to zero before the next volley of signals arrives. The fact that many of the synapses produce negative potentials strongly reduces the average sum, but does not change the noise if both types of potential are of equal magnitude. Typical values are ±0.2 to 0.4 mV for the postsynaptic potentials arising from a single synapse in a single neuron and 10 mV for the distance of the threshold of the action potential from the resting potential.[42] If the various types of postsynaptic potentials are all equal in magnitude, the average z-score may be expected to exactly satisfy Equation 4 in the presence of a psychokinetic effect of size e_{PK}.

When applying PK data to the neuron, one has to assume that the non-discrimination of the PK effect between different binary RNGs includes the ensemble of one-pulse synaptic RNGs contributing to a cell body's potential. In contrast to an electronic RNG, these signals arrive at practically the same time, not as a regular sequence. The equivalence seems to be supported by the insensitivity of PK experiments on RNGs to time shifts between intention and operation, which was mentioned above.

The pulse numbers of three of the experiments listed in Table 1 are near 10^4 or 10^6 and their z-scores, being distinctly larger than 2, are highly significant. Direct comparison leads immediately to the idea that mind-brain interaction by means of the psychokinetic effect might be possible. In the case of constant e_{PK} the effect size required for a signal above noise, i.e. $z \geq 2$, should obey the inequality $e_{\mathrm{PK}} \geq 2/\sqrt{N}$ because of Equation 4. Inserting either 10^4 or 10^6 for the number of synapses, one obtains $e_{\mathrm{PK}} \geq 2 \times 10^{-2}$ or 2×10^{-3}, respectively. (A detailed discussion of the probability of firing will have to include (z), the noise, and the difference between threshold and resting potentials.) Interestingly, a decline effect at large N satisfying $e_{\mathrm{PK}} - 1/\sqrt{N}$ would imply that a further increase in the number of synapses contributing to the neuron's voltage makes no difference for its PK sensitivity. Therefore, it is difficult to judge whether the sensitivity to PK is augmented by the envisaged increase of the number of contributing synapses by the factor of 100 that may be associated with the synchrony of the neurons belonging to a minicolumn. In both cases, the PK effect appears to be a conceivable agent of mind-brain interaction which, however, is rather unreliable, with the effect sizes of 10^{-3} to 10^{-4}, as reported by the PEAR group. A speculative argument, in terms of mind-brain interaction, related to why a larger PK effect would quickly cause problems is given in the next section.

5. Concluding Remarks

Let me finish with a question and a proposal of more measurements. Why are significant z-scores so rare in PK experiments? An anthropomorphic and simple answer might be that PK should not permit enslaving the minds of others. The indifference of the PK effect suggests that it can influence not only one's own brain but anybody's brain. As we feel in control of ourselves, the "own brain" may seem somewhat more sensitive to PK than are RNGs and the brains of others. Alternatively, intrapersonal PK could be helped by normal neuronal activity. In the world outside one's own brain, the PK effect as measured to date is pervasive and elusive at the same time. It can influence but does not control evolution toward an intended goal. The elusiveness of the paranormal in general has frustrated generations of researchers. A vivid and critical survey of the situation was given by Beloff.[47]

The notion that PK mediates mind-brain interaction is substantiated here by a practical estimate. It may still be an accident that the PK effect on binary RNGs approaches the order of magnitude required for mind-brain interaction when the neuron with its synapses is mapped on such an RNG. For a fully satisfactory correspondence it would be necessary to replace today's RNGs that emit pulses sequentially with others that are capable of generating 10^4 and more pulses simultaneously. PK experiments on synapses or whole neurons seem difficult but not impossible. For instance, the firing of a single cortical neuron can be monitored (in experiments locating the seizure focus in the brains of epilepsy patients).[48] The firing rate of some of these neurons increases dramatically when pictures of particular persons or objects are shown. It may be interesting to determine whether such neurons are sensitive to a PK effect.

It is my hope that I have shown that psychokinesis is a worthwhile subject of research, one which eventually might help bridge the gap between mind and brain. In my opinion, the evidence for the PK effect on RNGs in terms of odds against chance is convincing. It seems to be a mistake, or at least premature, to dismiss PK as wishful thinking or as a hobby of fools. With rather little financial support it would be possible to do more experiments in a field that may be very different from physics but abounds with open questions of broad interest."

Acknowledgments

I am grateful to W. von Lucadou for critical comments on an earlier version of this manuscript and for inviting me to the Workshop of the WGFP (Wissenschaftliche Gesellschaft zur Forderung der Parapsychologie) in Offenburg, Germany, 3 to 5 November 2006, where, thanks to a presentation by H. Bosch, I became aware of the work of Bosch, Steinkamp and Boller. Also, I thank J. Burns for critical comments and helpful information.

Note

* Note added after completion of the manuscript: There is a new paper by Radin et al.[49] in which these authors deal with a meta-analysis of PK experiments on binary RNGs by Schub.[50] Schub's stance seems to be similar to that of Bosch et al.,[38] while the objections of Radin et al. concerning the conclusions of Schub are similar to mine concerning those of Bosch et al. An additional line of reasoning, independent though related, may be useful in the debate about the validity of the PK effect.

References

1. Crick, F. (1994). *The Astonishing Hypothesis.* Simon & Schuster.
2. Edelman, G. M., & Tononi, G. (2000). *A Universe of Consciousness: How Matter Becomes Imagination.* New York: Basic Books/Perseus Book Group.
3. Singer, W. (2002). *Der Beohachter im Gehirn.* Frankfurt am Main, Germany: Suhrkamp.
4. Dennett, D. (1991). *Consciousness Explained.* Boston: Little, Brown & Co.
5. McGinn, C. (1999). *The Mysterious Brain: Conscious Mind in a Material World.* New York: Basic Books/Perseus Book Group.
6. Sturma, D. (Ed.). (2006). *Philosophie und Neurowissenschaften.* Frankfurt am Main, Germany: Suhrkarnp.
7. Popper, K. R., & Eccles, J. C. (1978). *The Self and its Brain: An Argument for Interactionism.* Springer-Verlag.
8. Bouwmeester, D., Ekert, A., & Zeilinger, A. (Eds.). (2000). *The Physics of Quantum Information.* Springer-Verlag.
9. Born, M. (1926). Zur Quantenmechanik der Stossvorgänge. *Zeitschrift fur Physik,* **37,** 863–867.

10. Heisenberg, W. (1927). Über den anschaulichen Inhalt der quantenmechanischen Kinematik und Mechanik. *Zeitschrift für Physik, 43,* 172–198.
11. Heisenberg, W. (1958). *Physics and Philosophy.* New York: Harper & Row.
12. Wigner, E. P. (1961). Remarks on the mind-body question. In Good, I. J. (Ed.), *The Scientist Speculates* (pp. 284–302). London: Heinemann.
13. Squires, E. (1990). *Conscious Mind in the Physical World.* Bristol, *UK:* Adam Hilger.
14. Stapp, H. P. (1993). *Mind, Matter and Quantum Mechanics.* Springer-Verlag.
15. Walker, E. H. (1977). Quantum mechanical tunneling in synaptic and ephaptic transmission. *International Journal of Quantum Chemistry, 11,* 103–127.
16. Walker, E. H. (2000). *The Physics of Consciousness.* Cambridge, MA: Perseus Publishing.
17. Beck, F., & Eccles, J. C. (1992). Quantum aspects of brain activity and the role of consciousness. *Proceedings of the National Academy of Sciences USA, 89,* 11357–11361.
18. Schmidt, H. (1993). Observation of a psychokinetic effect under highly controlled conditions. *Journal of Parapsychology, 57,* 351–372.
19. Stapp, H. P. (1994). Theoretical model of a purported empirical violation of the predictions of quantum theory. *Physical Review A, 50,* 18–22.
20. Popper, K. R. (1967). Quantum mechanics without the observer. In Bunge, M. (Ed.), *Quantum Theory and Reality* (pp. 7–44). Springer-Verlag.
21. Bums, J. E. (2002). Quantum fluctuations and the action of the mind. *Noetic Journal,* 3, 312–319.
22. Burns, J. E. (2006). The arrow of time and the action of the mind at the molecular level. In Sheehan, D. P. (Ed.), *Frontiers of Time, Retrocausation—Experiment and Theory* (pp. 75–88). American Institute of Physics.
23. Schmidt, H. (1987). The strange properties of psychokinesis. *Journal of Scientific Exploration, I,* 103–118, and references cited therein.
24. Dunne, B., & Jahn, R. G. (1995). *Consciousness and anomalous physical phenomena.* Technical Note 95004. Princeton Engineering Anomalous Research, and references cited therein.
25. Jahn, R. G., Dunne, B. J., Nelson, R. D., Dobyns, Y. H., & Bradish, G. J. (1997). Correlation of random binary sequences with pre-stated operator intentions: A review of a twelve-year program. *Journal of Scientific Exploration, 11,* 345–367.
26. Jahn, R. G., & Dunne, B. (2005). The PEAR proposition. *Journal of Scientific Exploration, 19,* 195–245, and references cited therein. Numerous articles by PEAR authors are available at: http://www.princeton.edu/—pear.
27. Radin, D. I., & Nelson, R. D. (1989). Evidence for consciousness-related anomalies in random physical systems. *Foundations of Physics, 19,* 1499–1514.
28. Radin, D. I. (1997). *The Conscious Universe.* San Francisco: Harper.
29. Radin, D. I., & Nelson, R. D. (2000). Meta-analysis of mind-matter interaction experiments: 1959–2000. Saratoga, CA: Boundary Institute, via www; print version (2003). Research on mind–matter interaction: Individual intention. In Jones, W. B., & Crawford, C. C. (Eds.), *Healing, Intention and Energy Medicine: Science Research and Clinical Implications.* (pp. 39–48). Edinburgh, Scotland: Churchill Livingstone, Elsevier.
30. May, E. C., Utts, J. M., & Spottiswoode, S. J. P. (1995). Decision augmentation theory: Towards a model of anomalous mental phenomena. *Journal of Parapsychology, 59,* 195–220.
31. von Lucadou, W. (1995). *Psyche und Chaos: Theorien der Parapsychologie,* and references cited therein. Frankfurt am Main, Germany: Insel.
32. Dunne, B. J., Dobyns, Y. H., Jahn, R. G., & Nelson, R. D. (1994). Series position effect in random event generator experiments. *Journal of Scientific Exploration, 6,* 192–215.
33. Dobyns, Y. H., & Nelson, R. D. (1998). Evidence against decision augmentation theory. *Journal of Scientific Exploration, 12,* 231–258.
34. Dobyns, Y. H. (2000). Overview of several theoretical models on PEAR data. *Journal of Scientific Exploration, 14,* 163–194.
35. Ibison, M. (1998). Evidence that anomalous statistical influence depends on the details of the random process. *Journal of Scientific Exploration, 12,* 407-423.
36. Dobyns, Y. H., Dunne, B. J., Jahn, R. G., & Nelson, R. D. (2004). The megaREG experiment replication and interpretation. *Journal of Scientific Exploration, 18,* 369–397.
37. Jahn, R., Dunne, B., Bradish, G., Dobyns, Y., Lettieri, A., Nelson., R., Mischo, J., Boller, E., Bosch, H., Vaitl, D., Houtkooper, J., & Walter, B. (2000). Mind/machine interaction consortium: PortREG replication experiments. *Journal of Scientific Exploration, 14,* 499–555.

38. Bosch, **H.,** Steinkamp, F., & Boller, E. **(2006).** Examining psychokinesis: The interaction of human intention with random number generators. *A* meta-analysis. *Psychological Bulletin, 132,* **497–523. (2006).** *[I* have used the preliminary publication available from the journal online in November **2006.1**

39. Radin, D. **I.,** & **Ferrari,** D. C. **(1991).** Effects of consciousness on the fall of dice: A meta-analysis. *Journal of Scientific Exploration, 5,* **61–83.**

40. Dunne, B. J., Nelson, R. D., & Jahn, R. G. **(1988).** Operator-related anomalies in a random mechanical cascade. *Journal of Scientific Exploration, 2,* **155–179.**

41. Dunne, B. J., & Jahn, R. G. **(1992).** Experiments in remote **human/machine** interaction. *Journal of Scientific Exploration, 6,* **311–332.**

42. Kandel, **E.** R., Schwartz, J. H., & **Jessell,** T. M. **(Eds.).(2000).** *Principles of Neural Science* (4th ed.). McGraw-Hill Medical.

43. **Polsky,** A., Mel, B. W., & Schiller, J. **(2004).** Computational subunits in thin dendrites of pyramidal cells. *Nature Neuroscience,* 7, 621–627.

44. Buxhoeveden, **D.** P., & Casanova, M. F. **(2002).** The minicolumn hypothesis in neuroscience [Review]. *Brain, 125,* **935–951.**

45. **Redman,** S. J. **(1990).** Quanta1 analysis of synaptic potentials in neurons of the central nervous system [Review]. *Physiological Review,* 70, **165–198.**

46. **Eccles,** J. C. **(1994).** *How the Self Controls its Brain.* Springer-Verlag.

47. Beloff, J. **(1993).** *Parapsychology:* **A** *Concise History.* St. Martin's Press.

48. Kreiman, ***G.,*** Fried, I., & Koch, C. **(2002).** Single neuron correlates of subjective vision in the human medial temporal lobe. *Proceedings of the National Academy of Sciences USA, 99,* 8378–**8383.**

49. Radin, D., Nelson, R., Dobyns, Y., & Houtkooper, J. **(2006).** Assessing the evidence for mind-matter interaction effects. *Journal of Scientific Exploration, 20,* **361–374.**

50. Schub, M. H. **(2006).** A critique of the parapsychological random number generator meta-analyses of Radin and Nelson. *Journal of Scientific Exploration, 20,* 402–419.