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Exploratory Study: The Random Number Generator and Group Meditation

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Abstract—Experiments using truly random number generators (RNGs) have reportedly demonstrated anomalous deviations in various group settings. To explore these claims, group meditation (average 261 females, 398 males) was tested as a venue for possibly inducing these deviations using a true RNG located in a large meditation hall. A total of 94 hours and 33,927 trials, each trial consisting of 1,000 random bits collected in 10-second periods, were recorded during meditation (Transcendental Meditation and advanced techniques). Cumulative deviation results were in accordance with chance expectation for baseline data, but showed significant non-randomness for the first ($p < 0.00001$) and second set of meditation data ($p < 0.00001$). A sub-section of the meditations, known as "yogic flying," showed significant deviations for both the first ($p < 0.000001$) and the second data sets ($p < 0.000001$). Results at a second test location known as the Vedic Observatory were significant for the first ($p < 0.01$) and second data collections ($p < 0.05$). All results were analyzed for any possible mean drift by subtracting differences in the pre- and post-test baseline slopes. After the adjustment for any drift, the direction and the experimental results were still significantly atypical, with a greater number of zeros being generated than ones. The use of non-exclusive-or-ed methods to eliminate drifts of the mean of the random data is discussed as well as the use of RNGs for measuring changes in collective consciousness associated with standardized meditation.

Keywords: random number generator—random event generator—group consciousness—global consciousness—meditation—Transcendental Meditation—human/machine interactions

Introduction

The putative anomalous influence of groups of humans on truly Random Number Generators (RNGs) have been used to measure the effect of global and group consciousness in a variety of settings including meditations, meetings, ceremonies, sports events, and tragedies (Bierman, 1996; Jahn et al., 2000; Nelson 1997; Nelson, 2001; Nelson et al., 2002; Nelson et al., 1998; Radin, 1997, 2002, 2006; Radin et al., 1996). RNGs have also been used with individuals and pairs to study the effect of human intention and human/machine interactions (Dunne, 1998; Jahn et al., 1997; Nelson et al., 1998; Radin & Nelson, 1989). Nelson has reported that RNGs or random event generators in group situations were found to act non-randomly with significant deviations of the means (or in some cases, variance) in situations involving "calm but unfocused subjective resonance" and those "that foster relatively intense or profound subjective resonance" (Nelson et al., 1998: p. 425).

Of the various contexts tested thus far, perhaps group meditations are closest to Nelson's (Nelson et al., 2002) prescription for the optimal environment to produce deviations in the RNG outputs. Previous research has suggested that time-synchronized as opposed to non-synchronized meditation appears to influence the RNG to a greater extent. That is, a meditation involving a large number of people worldwide practicing an assortment of types of envisioning, prayer and meditations at the same time reached significance ($p = 0.047$) (Nelson et al., 1998), as did another group meditation with a coordinated time ($p = 0.012$) (Nelson, 2002a). However, a third group meditation with a non-synchronized time yielded a non-significant result (Nelson, 2002a). It should be noted that the meditations in these tests included a wide variety of mental activities, from casual and celebratory to formal meditation techniques. The present study explored whether the group consciousness effect might be enhanced by using a single, standardized form of meditation practiced by hundreds of people at the same time and place.

Radin (2001, 2002), reported the effects of the violent events on 9/11/01 in the U.S.A. on a collection of international RNGs from the Global Consciousness Project (GCP) (Nelson, 2002a) that became significantly non-random with increasing variance. May and Spottiswoode, (2001) have presented a reanalysis of that data and contest the original interpretation of the results. In contrast to May and Spottiswoode (2001), four researchers independently report significant anomalies in the data (Nelson et al., 2002).

In response to 9/11/01 over 1700 practitioners of Transcendental Meditation gathered together from 9/23/01 to 9/27/01 at Maharishi University of Management (MUM) in Iowa. Additional meditations and extended group meditations with varying numbers of participants were organized in addition to their normal meditation schedule. The normal daily schedule called for group meditations to begin at 7:05 AM CST (except on Sundays, which were to begin at 7:35 AM) and at 5:20 PM CST.

RNG data from the GCP were analyzed from 37 RNGs located at different locations around the earth, but not including Iowa (Nelson 2002c). Significant deviations from chance were not achieved when evaluating all 735 minutes of data collected over the five days of meditations. On the day of the peak number of meditators (over 1800), there was an exploratory significant result ($p = 0.0012$). A trend was also reached for a specific section of the meditation period known as "yogic flying" when cumulated over the 5-day period. Nelson reported that the relatively small number of days, five, ruled out further analysis of the yogic flying deviations, underscoring the need for a longer multi-day study to allow for more extensive investigation. Nelson (2002c) noted that during the yogic flying portions of the meditations the significant deviation was in the direction opposite to that observed in the majority of data from the Global Consciousness Project and from Princeton University's Princeton Engineering Anomalies Research (Jahn, 2002). This atypical direction result was also reported by Nelson during a Silent Prayer on 9/14/01, Full Moon ceremonies, sacred sites in Egypt, and a prayer vigil (Nelson, 2002a; Nelson et al., 1998). Because of these directional effects, Nelson (2000c) discussed including directional predictions in future meditation studies. Nelson (2006) stated "that a little more than half the events for the GCP that are somewhat like meditation show the downward trend."

There is an independent body of experimental evidence supporting the idea that large groups of meditators practicing a single type of meditation (Transcendental Meditation and advanced meditation practices) at a synchronized time have been found to decrease violence, crimes, car accidents, hospital admissions, alcohol consumption (Dillbeck, Landrith, & Orme-Johnson, 1981; Hagelin et al., 1999), war casualties (Orme-Johnson, et al., 1988), and improve the stock market performance (Cavanaugh, Orme-Johnson, & Gelderloos, 1989). A time lag or carryover effect that diminishes over months has been measured in studies evaluating the effect of group meditation on societal indexes (Dillbeck, 1990; Dillbeck et al., 1987; Hagelin et al., 1999; Orme-Johnson et al., 1988). The effects of these group meditations appear to involve a distance factor, with the effect being greater in the vicinity of the meditation groups (Hagelin et al., 1999). Similarly, RNG research has shown potential distance effects with peak effects closer to the source of large global events as measured by hemispheres, continents, country and region (Radin, 2001), but further research is necessary because distance effects in research involving intention typically have not been found when experimenting with individual subjects (Radin, 1997; Jahn and Dunne, 1987). The use of both local RNGs as well as distant RNGs with meditation groups would be necessary to conduct a systematic study of the role of distance.

The objective of the present study was to extend the previous research on RNGs and meditation by 1) expanding the number of meditation sessions, 2) incorporating a local RNG at the site of interest, 3) measuring a standardized type of meditation practiced at coordinated times, with a precise count of participants, and 4) taking note of the direction of the non-random nature of the response. Three predictions were made:

a) groups of people practicing the same meditation simultaneously in one location would result in a significant departure from chance expectation (50% ones and 50% zeros, an 0.5 expectation), specifically the cumulative deviation of the percent zeros would be greater than chance expectation obtained on a local RNG as measured over the whole meditation, b) particularly for a specific subsection of the meditation known as yogic flying, and c) the direction of the non-randomness would show a decrease in ones and thus an increase in zeros.

Equipment and Methods

A laptop computer and a truly Random Number Generator (Orion V1.2) was employed. The Orion RNG uses noise-based analog signals that are converted into random bit streams. These bits are transmitted in the form of random bytes to a standard RS-232 serial port. According to the manufacturer's manual (Orion 2006) the baud rate is 9600 characters per second and the device is capable of supplying about 960 random bytes or 7600 random bits per second. Co-author Radin notes that transmission of a byte in the context of serial communications takes 10 bits, not 8, so the Orion provides about 9600 random bits per second.

The RS-232 port was tested for accurate minimum voltage (> 5V) with the actual voltage at 8.9 volts. The field recordings used a battery source for the laptop and a time-stamped marker for recording sections of interest.

Additionally, a second type of RNG (Mindsong, Inc. Research, microREG) was used for a limited time. The Mindsong is described by the manufacturer as incorporating, "Brownian movement of electrons using a Junction Field Effect Transistor (JFET) in a high gain circuit that generates the Noise signal" (Haarland, 2003). Non-deterministic randomicity is assured by the electron noise in this JFET circuit. According to the Mindsong's manufacturer, (Haarland, 2003) the bits are transmitted to a standard RS-232 serial port with a baud rate of 9600 characters per second and a 2600 bits per second sampling rate. The majority of research involving RNGs and consciousness has been done with additional software to apply exclusive-or (xor) logic to the data. In the xor technique, the raw data from the random number generator is "masked" or "exclusive ored" (xored) either against a pseudo random byte or a regular 0/1 sequence. According to the RNG manufacturers, the advantage of xoring is to ensure randomness with less chance of a bias; specifically, it eliminates systematic drifts in the mean. A disadvantage of xoring the data against a fixed mask is that the output is no longer raw binary data, and it may constrain long-term changes in the mean numbers of ones and zeros. Scargle (2002) has proposed using non-xored data. Scargle (2006) explains that using a logical xor operation and reversing of the data in the bit stream may totally eliminate according to the design philosophy anomalous effects and all physical effects in consciousness research. Nelson (Nelson et al., 2002) emphasizes the existing large database of RNG studies that use xoring and have significant experimental effects contradicts Scargle's viewpoint.

The RNGs manufactured by Mindsong have additional hardware xoring (Bradish et al., 1998; Haaland, 2003). As stated in the patent, "the analog output of this random signal is converted to a random binary stream ... and further treated with a selective inverter that inverts some but not all of the series of data values according to a pseudo-random sequence mask. The selective invertor coupled to a sampler that inverts some, but not all, of the series of digital data values to produce a selectively inverted series of digital data values is an essential feature of the patent and our device. One of the benefits of this is the prevention of baseline drift."

In conclusion, a comparison of software xored and non-xored data initially at baseline was conducted. This was followed by the use of non-xored data (no additional software for xoring) for the rest of the experiments based on the design specification of the RNG: to avoid altering the original data with a mask (Scargle, 2002).

One trial with the Orion and the Mindsong RNGs consisted of 1000 bits collected every 10 seconds with 1000 trials per run (approximately 10,000 seconds/run or 1,000,000 bits/run) for 2.78 hours. This configuration was chosen for its capacity to capture one complete meditation period (approximately 120 minutes which is well within the 2.78 hours limit), in one run, and within the capacity of the laptop batteries. Acquisition and analysis software (Watson, version MREG00s1, 2001) provided the total number of bits counted, and the calculation of the deviation of ones (likewise zeros) from the RNG. Count mode was set for ones to indicate a positive, increasing direction, and conversely increased zeros to indicate a decreasing, negative direction. RNGs with increasing ones means there is less randomness due to generating more ones than zeros. In the acquisition software used this was designated by an increase in the positive upward direction as represented on the analysis graphs. Increasing zeros means there is less randomness due to generating more zeros than ones. This is represented by an increase in the negative downward direction of the graphs. This was a mean-shift analysis not an analysis of variance. The information in cumulated deviation (in reference to 50% ones, an 0.5 expectation) of the ones counted from the trials consisting of 1000 bits every 10 seconds was used for the statistical analysis.

Data analysis followed procedures previously described (Jahn and Dunne, 1987) for single RNG use and with Z-scores (Radin, 2002). Specifically sequential samples of 25 bytes were collected from the RNG since each byte consists of 8 bits and each sample yields 200 bits of ones and zeros. The number of ones beyond 100 (100 is the theoretically expected mean) were counted in each sample and this number was added to the previous accumulated number. The total number of bits counted was calculated, the percent deviation of ones was calculated, and the sums of the deviation were calculated. Z scores based on 95% confidence levels were calculated. The Z scores $= x - \mu/\sigma$, where x is the sample value, $\mu =$ mean, and $\sigma =$ standard deviation. All tests are reported as one-tailed.

Please note the term "xored" as used here refers to additional software xoring. Likewise "non-xored" refers to not using additional software for xoring. No changes were made internally to any of the RNGs as described above which employ internal xoring techniques.

Four main tests were run (See Chart 1):

- a pre-test baseline "control" period in our laboratory comparing xored and with no additional software xoring (non-xored) data for the Orion RNG as well as a pretest baseline "control" period in our laboratory for the Mindsong RNG with no additional software xoring (non-xored).
- experiment **A,** consisting of recordings of a meditation group, a subsection

PROCEDURE NON-XORED RNG (ORION)	**LOCATION**	**SLOPE**	**SLOPE MINUS PRE-POST DIFFERENCE**
PRE-TEST "CONTROL" 5/15/02-5/30/02	IN LABORATORY	-0.20	
EXPERIMENT A 6/16/02-6/27/02	1.IN MEDITATION HALL 2.YOGIC FLYING 3.VEDIC OBSERVATORY	-2.18 -9.52 -2.09	(-1.08) (-8.42) (-0.99)
EXPERIMENT B 7/15/02 - 8/1/02	1.IN MEDITATION HALL 2.YOGIC FLYING 3.VEDIC OBSERVATORY	-2.03 -9.30 -1.81	(-0.93) (-8.20) (-0.71)
POST- TEST "CONTROL" 8/6/02-1/12/03	1.IN LABORATORY 2.SHIELDED RNG	-1.34 -1.10	

Chart 1: Shows a summary of the procedures of the experiments and the resulting slopes. Slope is the number of excess ones beyond expectation when random, per one thousand bits.

of the group meditation known as yogic flying and also a site known as the Vedic Observatory for the Orion and Mindsong RNGs.

- experiment B, consisting of a replication of experiment A but for a longer period using the Orion RNG.
- a post-experimental "control" period in our laboratory/offices using the Orion RNG.

No formal predictions were made for the post-experimental "control" results. The experimenters in this exploratory research decided they did not have enough information to precisely predict a possible lag effect, but a lag effect was considered as previous studies had reported "carryover" effects after the meditations had ended (Dillbeck, 1990; Dillbeck et al., 1987; Hagelin et al., 1999; Orme-Johnson et al., 1988.) The effects do not appear to end immediately when the group meditation is over, just as the music does not immediately end when a coherent orchestra stops playing. We hear the music for a few moments after the musicians have stopped playing, the sound lags or carries over. Likewise the effects of the meditation as recorded by the RNG may not end when the meditation recordings are over but also carry over or lag.

The control condition in this experiment was defined in purely operational terms, i.e., data collected while not "exposed" to meditation. Nelson et al. (1998, p. 452) notes "that even in laboratory experiments there is evidence that traditional control data may not be immune to anomalous effects of consciousness."

The Laboratory Pretest Baseline Control Comparison of Xored and Non-xored Data

The Orion RNG was run in our University device lab in a small office, 5' X 7', used occasionally as a library and 3' from the first author's desk. Data collection consisted of 30 hours xored, 30 hours non-xored and an additional 89 hours non-xored with the Orion RNG. As noted previously, non-xored in this paper refers to no additional software xoring masking of data. These were considered the pretest "control" baseline samples for an inactive period. A Mindsong RNG non-xored was also run in our lab.

Experiment A in the Meditation Hall for Group Meditations Including Yogic Flying

Location of the RNG was at Maharishi University of Management, (MUM) in Fairfield Iowa, a rural university town with a population of approximately 10,000, with two meditation halls 0.25 km apart and designated by gender. RNG recordings took place in the first hall with an average of 261 female meditators (range 178–356, sd = 42). Attendance numbers are methodically tallied before each meditation for the purposes of future research at MUM. Collection during the summer was practical due to our laboratory's overall research schedule, even though fewer meditators were present because of their summer vacation schedules. It should be noted that in addition to the meditators in the first hall where the RNG was located, there were male meditators in the adjacent meditation hall (average 398) during the recording periods on the same time schedule practicing the same meditation techniques. Only the first two authors and a research officer (from MUM) were aware of the recordings taking place. The meditation group was not aware of the experiment and the RNG located in the woman's meditation hall was not visible to the participants. Since the participants were not aware of the RNG experiment the participants did not use intention to attempt to influence the results.

Meditation recording sessions lasted approximately 2 hours each and began at 7:05 CST (Sundays at 7:35 AM) and 5:20 PM CST. Our schedule and budget estimates allowed us to collect in two trips for a total of 94 hours of meditation data. This would expand the previous research done at MUM of 58.75 hours over 5 days (Nelson, 2002c). It would also exceed the RNG meditation research conducted elsewhere that used multiple meditation techniques including a single 3-minute period, a single 10-minute period and a single 1-hour period (Nelson, 2002a).

Extended and additional smaller group, meditations scheduled before and after the main group meditations (7:05 AM CST and 5:20 PM CST), in the meditation halls made planned comparison before or after the meditation periods impractical. Furthermore, others have discussed a residual effect or lag effect of the group meditation predicted to last even after the daily meditation time is finished (Oates, 2002). The meditation hall has been used for meditation for over 20 years, 365 days a year and accordingly may not qualify as a neutral non-active control site even during non-meditation periods of the day.

Analysis was planned for the entire meditation period as a whole and then following Nelson (2000c) to analyze a specific section of the meditation known as yogic flying. Phenomenological reports of yogic flying include descriptions of waves of bliss (Alexander and Langer, 1990). Yogic flying is based on the ancient Yoga sutras of Patanjali (1978) and is predicted to create peace in the collective consciousness (Hagelin et al., 1999).

Experiment A in the Vedic Observatory. Within 5 kilometers of the meditation hall is an open-air site known as the Maharishi Vedic Observatory. It consists of ten precisely designed and positioned astronomical instruments based on ancient designs of sundials or "yantras," each about 2 meters high (Global Vedic Observatories Corporation, 1996). Observing the instruments is predicted to create psycho-physiological balance (Global Vedic Observatories Corporation, 1996) as well as development of "peak experiences" (Maslow, 1962) and stabilized "higher states of consciousness" (Alexander & Langer, 1990; Mason et al., 1997; Travis et al., 2002).

Each recording session using the RNG located in the center of the Vedic Observatory was approximately 90 minutes long. The majority of sessions involved only the first author at the Vedic Observatory site, although there were short periods of unscheduled visitors in a minority of sessions. The majority of sessions were recorded between 1:00 PM CST and 3:00 PM CST with a few exceptions due to weather and schedule conflicts. None of the recordings at the Observatory were made during the same time as the meditation recordings.

Experiment B

Replication of experiment A with increased data collection for 18 days.

In the Laboratory Post-experimental "Control"

Non-xored recordings in our laboratory repeated the pre-test baseline "control" recordings.

Results

Laboratory Pre-test Baseline "Control" Comparison of Xored and Non-xored Data

The baseline for both xored and non-xored data in the laboratory setting were random for the RNG (Orion). Results show no significant terminal (end of interval) non-randomness in the 30 hours, 10,883 trials, or 10,883,000 bits of xored data ($Z = 0.834$, $p = 0.798$) (Figure 1A). Likewise, there was no significant

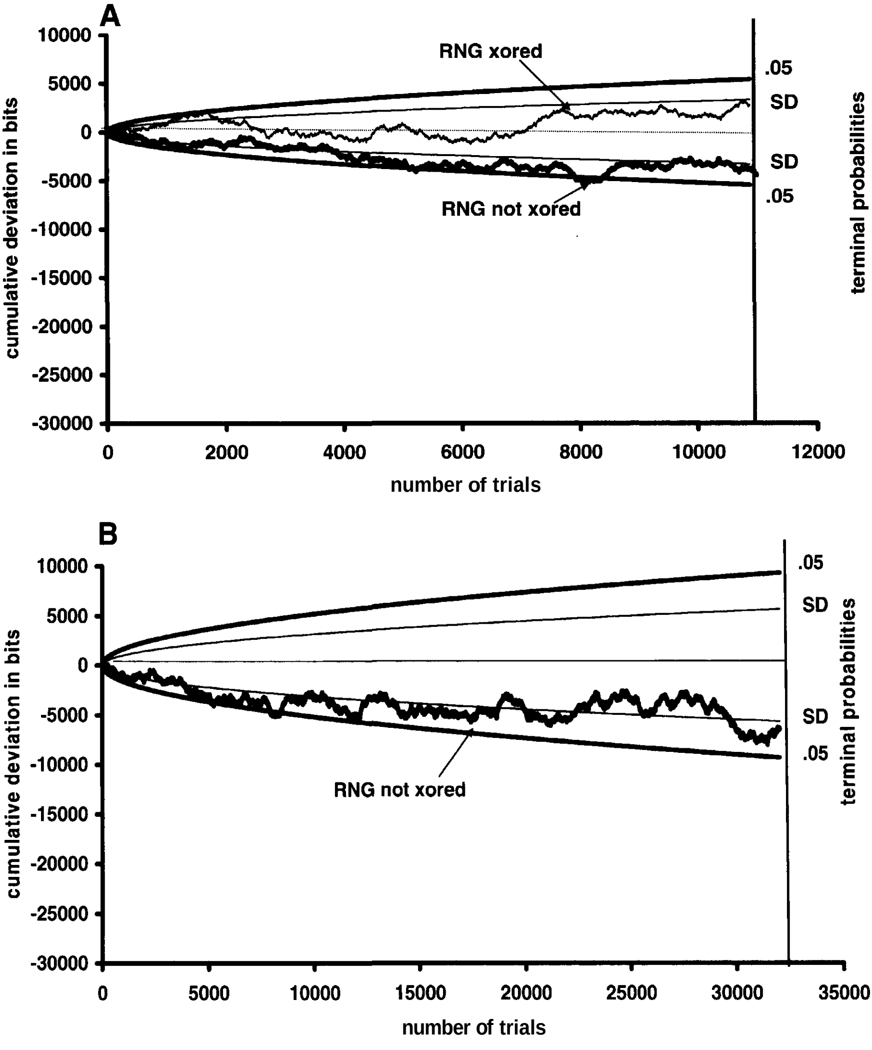


Fig. 1A. A pre-test control period showing non-significant deviations from a RNG. Pre-test RNG xored shows 30 hours of data, 10,883 trials, 10,883,000 bits of xored data. Pre-test RNG non-xored shows 30 hours, 10,883 trials, 10,883,000 bits of non-xored data using the same equipment, RNG and location in our lab. As expected the RNGs did not reach terminal significance at the $p = 0.05$ level in the control period.

Fig. 1B. An additional pre-test control RNG non-xored period of 89 hours, 32,000 trials, 32,000,000 bits of non-xored data from a RNG in our lab. As expected there is no significance for the control period at the $p = 0.05$ level. The cumulative deviation plots show parabolic lines for one standard deviation and $p = 0.05$ for a chance criteria as a function of increasing trials. The jagged solid lines show the cumulative deviations over all the trials. SD = standard deviation. RNG = Random Number Generator.

terminal non-randomness for 30 hours, 10,883 trials, 10,883,000 bits of non-xored data (terminal $Z = -1.33$, $p = 0.091$) (Figure 1A) and for 89 hours, 32,000 trials, 32,000,000 bits of non-xored data (terminal $Z = -1.138$, $p = 0.127$) (Figure 1B).

Experiment A in the Meditation Hall for Group Meditations

Results included significant anomalies (terminal $Z = -8.434$, $p = 1.697 \times 10^{-17}$) for nineteen group meditation sessions from experiment A totaling 32 hours, 11,360 trials, 11,360,000 bits of data. As described below, data were reanalyzed to take into account a possible mean drift and still maintained significance (terminal $Z = -4.726$, $p = 1.1449 \times 10^{-6}$) (Figure 2A). The results were in a decreasing direction indicating increasing cumulative zeros.

The reanalysis for a possible mean drift involved finding the linear regression slope of the cumulative pre-test data (using the Orion) and subtracting it from the slope of the cumulative post-test data. This reanalysis was performed because a difference was found between the pre- and post-data terminal Z scores. Slope was calculated on the cumulative deviation scores for both the pre-test data and post-test data non-xored. The comparison involved the non-xored pre-test data of 89 hours and the non-xored post-test data of 89 hours. The slope was determined by using regression data analysis in Excel 2000 with a zero intercept. The input ranges were the cumulative deviation in bits and the number of trials. The output variable represents the slope. The difference pre-post in the slopes were subtracted from each cumulative bits deviation score for each trial during the experimental phase. Specifically in this case the difference in the slopes pre- and post–test was subtracted from the meditation cumulative bits per trial scores.

Experiment B in the Meditation Hall for Group Meditation

Data collection consisting of 32 group meditation sessions totaling 63 hours, 22,567 trials and 22,567,000 bits of data from experiment B is also significant (terminal $Z = -9.068$, $p = 6.126 \times 10^{-20}$). The data was reanalyzed for a possible cumulative drift and remained significant (terminal $Z = -3.872$, $p = 5.397 \times 10^{-5}$), (Figure 2A.) The results were in a decreasing direction, indicating more zeros than ones.

Experiment A in the Meditation Hall for Yogic Flying

The yogic flying portions of the meditations are also highly significantly non-random (terminal $Z = -14.046$, $p = 4.12 \times 10^{-46}$) for the first set of data from experiment A consisting of 5 hours of data, 1728 trials, 1,728,000 bits. It maintains significance (terminal $Z = -12.600$, $p = 1.061 \times 10^{-36}$) after reanalysis for a possible cumulative drift (Figure 2B).

Experiment B in the Meditation Hall for Yogic Flying

The data for the yogic flying portions of the meditations from experiment B are also significant (terminal $Z = -14.774$, $p = 1.087 \times 10^{-49}$) for 8 hours, 2,971 trials, 2,971,000 bits and maintains significance (terminal Z = −12.639, $p = 6.471 \times 10^{-37}$) after reanalysis for a possible cumulative drift (Figure 2B). The direction for the yogic flying data for experiments A and B is an atypical decreasing direction indicating more zeros than ones. The yogic flying slopes (−9.52 and −9.03) are higher (see Chart 1) as compared to the slopes of the meditations as a whole (−2.18 and −2.03).

Mindsong RNG

Figure 2C represents trials with a second type of RNG by Mindsong. The pre-test RNG Mindsong data used no additional software to xor the data. The pre-test data was taken in our laboratory's office at pre-test and was non-significant (Z = 0.222, p = 0.5878) for 23.5 hours of data, 8470 trials, and 8,470,000 bits. Meditation RNG Mindsong in Figure 2C was acquired without using software xoring and recorded in the meditation hall and is significant (terminal Z = −5.248, $p = 7.6951 \times 10^{-8}$) for 23.5 hours of data, 8470 trials, and 8,470,000 bits. The Mindsong RNG stopped functioning after 8000 trials and was unable to output data. There was no graphical display or numerical data display from the RNG.

Experiment A in the Vedic Obsewatory

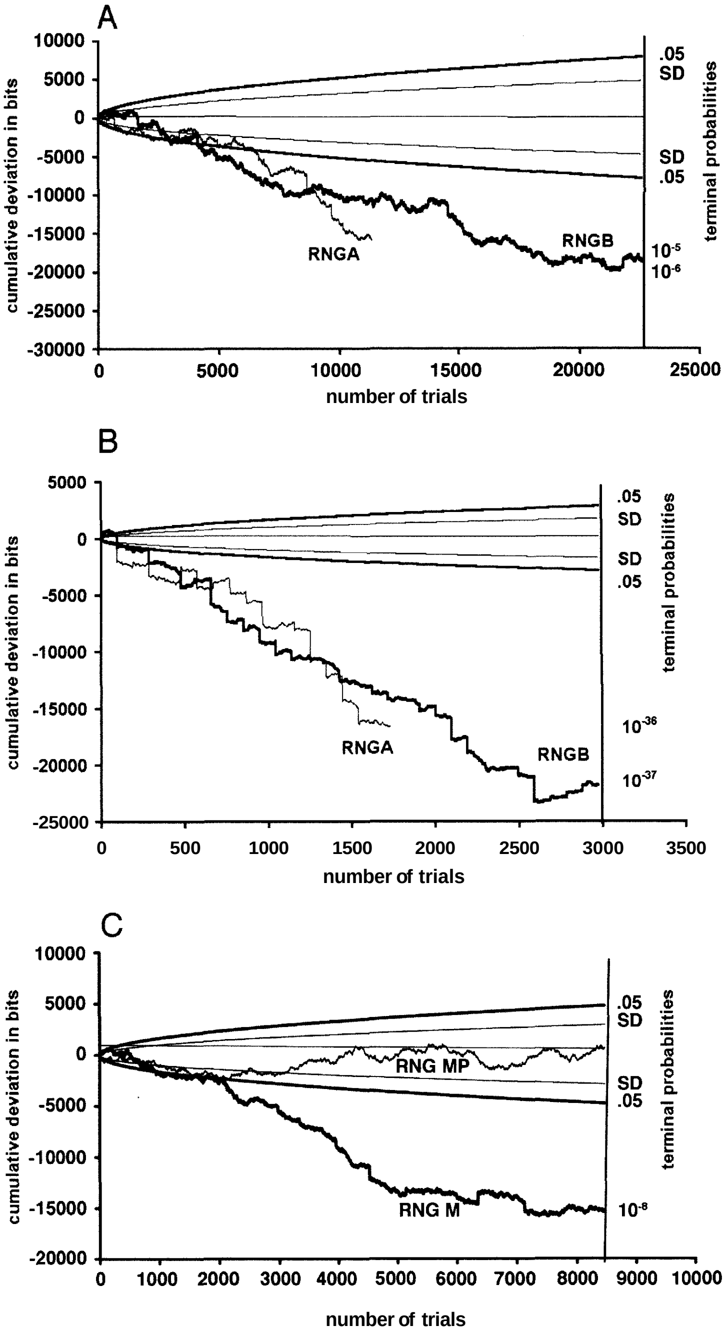
The Vedic Observatory recordings for experiment A consisting of 24 hours of data, 8,918 trials, 8,918,000 bits are significantly non-random (terminal Z = −5.950, $p = 1.378 \times 10^{-9}$) and was significant after reanalysis for a possible cumulative drift (terminal Z = −2.64, p = 0.004) (Figure 3).

Experiment B in the Vedic Obsewatory

Experiment B consisted of significant Vedic Observatory recordings for 31 hours of data, 11,271 trials, and 11,271,000 bits, and were significantly random before (terminal Z = −5.440, $p = 2.664 \times 10^{-8}$) and after reanalysis for a possible cumulative drift (terminal Z = −1.75, p = 0.040) (Figure 3).

The Laboratory Post-experimental "Control"

Possible cumulative drift. The RNG (Orion) after approximately 480 hours of data collection consisting of 80–90 hours per month over 6 months did not appear to behave as it did before recording in the meditation hall and the Vedic Observatory. Specifically, when the RNG was rerun non-xored in our laboratory it showed a possible cumulative linear downward drift as compared to the pre-test non-xored control baseline in our laboratory. The slope was calculated as excess ones greater than expected if random, per 1000 bits. A negative number indicates an increased proportion of zeros. At post-test, 89 hours of post-test control data collection for 32,000 trials, 32,000,000 bites was significant (terminal Z = −7.28, $p = 1.70 \times 10^{-13}$) with a slope equivalent to −1.3 excess ones/1000 bits (Figure 4). At baseline before the experiment there was not a significant terminal Z score


A
cumulative deviation in bits
10000
5000
0
-5000
-10000
-15000
-20000
-25000
-30000
0
5000
10000
15000
20000
25000
number of trials
.05
SD
SD
.05
RNGA
RNGB
10^{-5}
10^{-6}
terminal probabilities
B
cumulative deviation in bits
5000
0
-5000
-10000
-15000
-20000
-25000
0
500
1000
1500
2000
2500
3000
3500
number of trials
.05
SD
SD
.05
RNGA
RNGB
10^{-36}
10^{-37}
terminal probabilities
C
cumulative deviation in bits
10000
5000
0
-5000
-10000
-15000
-20000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
number of trials
.05
SD
SD
.05
RNG MP
RNG M
10^{-8}
terminal probabilities

downward trend (Figure 1B). At the end of the post-test period the RNG had not returned to pre-test baseline behavior. However, the terminal Z scores were not significantly different pre and post when run xored.

Electronic devices are more likely to fail or develop drifts in the early part of their operating life, then level off and then again increase in failures when they become older (US government inspector's technical guide, 1987). The new RNG (Orion) could have developed a cumulative drift with use. However, the manufacturer prior to shipping reported they tested the device for randomness. Co-author Radin reports continued randomness after 5 years of use with the same type of RNG. It is conceivable but not likely that both internally built-in xored independent random data streams in the Orion RNG developed similar biases resulting in more zeros than ones.

No formal predictions were made for the post-experimental results. The experimenters in this exploratory research decided they did not have enough information to precisely predict a possible lag effect. A lag effect was considered as previous studies with this type of meditation had reported a carryover or lag effect on the experimental measurements even after the experimental period of meditation had ended (Dillbeck, 1990; Dillbeck et al., 1987; Hagelin et al., 1999; Orme-Johnson et al., 1988).

Regardless of the reason for the possible mean drift the difference of the slope of the post-test data (–1.3 excess ones/1000 bits) from the pre-test control data

←

Fig. 2A. Shows significant deviations from randomness ($p = 1.1449 \times 10^{-6}$ adjusted), for Meditation RNG Experiment A during 19 group meditation sessions for a total of 32 hours, 11,360 trials, 11,360,000 bits of data. The 2-hour sessions of group practice of Transcendental Meditation and advanced practices involved an average of 261 females and 398 males. The results were replicated ($p = 5.397 \times 10^{-5}$, adjusted) as shown in Meditation RNG Experiment B with 32 group sessions for a total of 63 hours of meditation, 22,567 trials, and 22,567,000 bits of data. RNGA = Random Number Generator Experiment A, RGNB = Random Number Generator Experiment B.

Fig. 2B. Shows the concatenated accumulated deviations from a more advanced section of the meditations known as yogic flying. Yogic Flying RNG Experiment A shows nineteen, 15-minute sections, 4.7 hours, 1728 trials, and 17,280 bits. Yogic Flying RNG Experiment B shows 32 sections, 8 hours, 2,971 trials, and 29,710 bits. The yogic flying portions of the meditations are highly significantly non-random for both experiments ($p = 1.061 \times 10^{-36}$ and $p = 6.471 \times 10^{-37}$, adjusted) respectively and the slopes (Chart 1) are eight times more significant than the meditation data (Fig. 2A). The direction of the data is an atypical decreasing direction indicating increasing zeros. RNGA = Random Number Generator Experiment A, RGNB = Random Number Generator Experiment B.

Fig. 2C. Shows a second type of RNG by Mindsong. Pre-test RNG Mindsong shows a control period of 23.5 hours of non-xored data collection, 8470 trials, and 8,470,000 bits recorded in our laboratory and as expected, it is not significant. Meditation RNG Mindsong shows 23.5 hours of non-xored data collection, 8470 trials, and 8,470,000 bits taken during meditation that are significant ($p = 7.69 \times 10^{-8}$, adjusted). The cumulative deviation plots show parabolic lines for one standard deviation, and $p = 0.05$ plot of chance criteria as a function of increasing trials. The jagged solid lines show the cumulative deviations over all the trials. SD = standard deviation, RNGMP = Random Number Generator Mindsong Pretest, RNGM = Random Number Generator Mindsong.

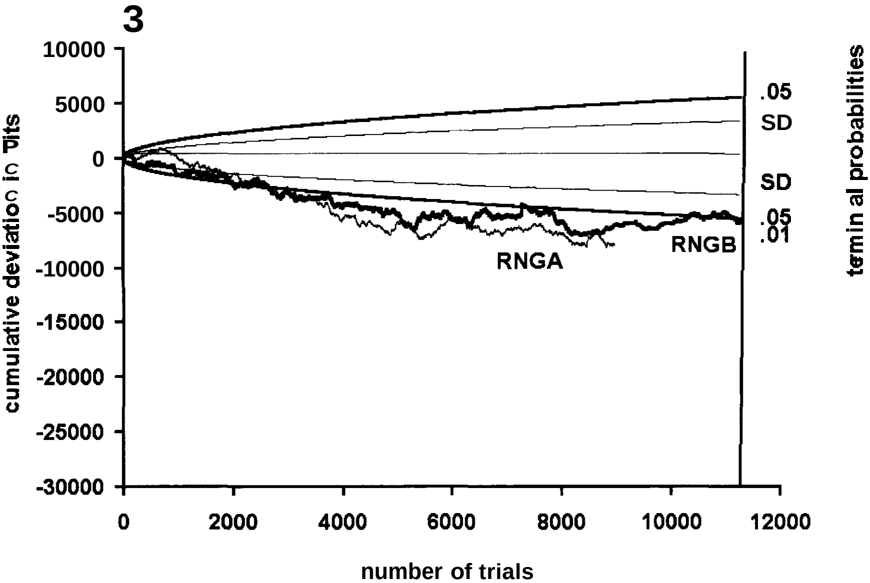


Fig. **3.** Data collected at the Vedic Observatory for RNG experiment **A** shows 24 hours of 8,918 trials and 8,918,000 bits and for RNG experiment B of 31 hours, 11,271 trials, and 11,271,000 bits. Both experimental results are significantly non-random ($p < .01$ adjusted), ($p < .05$ adjusted) respectfully.

The cumulative deviation plots show parabolic lines for one standard deviation, and p = 0.05 plot of chance criteria as a function of increasing trials. The jagged solid lines show the cumulative deviations over all the trials. SD = standard deviation, RNGA = Random Number Generator Experiment A, RNGB = Random Number Generator Experiment B.

(-0.2 excess ones/1000 bits) was calculated and this slope was subtracted from the original data for the meditation, yogic flying, and Vedic observatory (Chart 1). The difference in the slopes was subtracted from each cumulative bits deviation score for each trial during the experimental phase. The reanalyzed data takes into consideration a possible mean drift and is presented in Figures **2A,** 2B and 3.

Malfunctioning and equipment failure was checked by substituting an alternate laptop and connector post-test. This did not change the post-test results which continued to have a significant terminal Z score. There was no indication of computer or connector failure. Bierman (2002) offered the opinion that if the RNG is terminally significant for some runs and non-significant for others in the upward direction and terminally significant and non-significant in the downward direction for others, this would not indicate a malfunctioning. In his viewpoint, if the RNG is malfunctioning, all the individual runs would be expected to be similar as opposed to a variety of results across runs. However, non-symmetrical distributions could affect outcomes.

Additional testing was performed for electrical and magnetic interference by running the RNG without additional software for xoring in an electrically

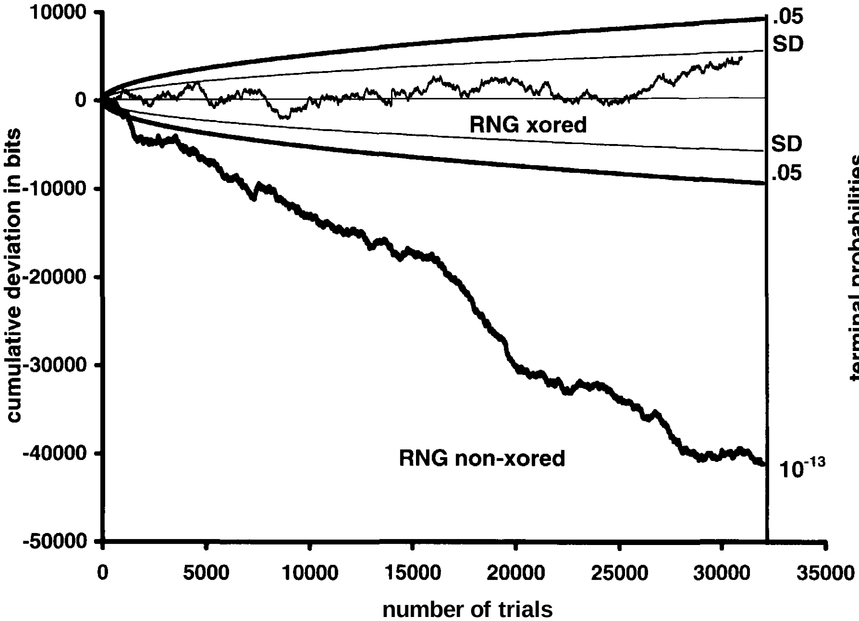


Fig. 4. Shows post-test RNG xored, **89** hours of xored data collection, 32,000 trials, 32,000,000 bits in our lab. The results are not significant. Post-test RNG non-xored, shows **89** hours of non-xored data collection, 32,000 trials, and 32,000,000 bits in our lab. The non-xored results are significant and could indicate a cumulative or mean drift or a lag effect of the meditation.

The cumulative deviation plots show parabolic lines for one standard deviation, and $p = 0.05$ plot of chance criteria as a function of increasing trials. The jagged solid lines show the cumulative deviations over all the trials for data set 1 and data set 2. SD = standard deviation, RNG = Random Number Generator.

shielded isolated room for 48 hours post-test. The RNG (Orion) was run for 48 hours in a Faraday cage for electrical shielding with mu foil for magnetic shielding and then placed for 48 hours in a Faraday cylindrical cage with a height of 25 centimeters and diameter of 12 centimeters for electrical shielding with a 37 centimeters connector cord to distance the RNG from the laptop. The results using the Faraday cage (without additional software xoring) had a slope of −1.10 similar to the experimental post-test slope of −1.34 without the Faraday. The concern of electrical and magnetic interference was not supported.

Z Score ***Analysis***

Following Radin (2002) percentages of significant Z scores at the 0.05 level for the pre-test, meditation, and yogic flying for experiments A and B were calculated to test for outliers. The purpose was to examine if many of the group meditation sessions and yogic flying sessions were significantly contributing to the outcome, and not just a few highly significant meditation or yogic flying sessions skewing the results. A window of 115 minutes was selected because it is the length of

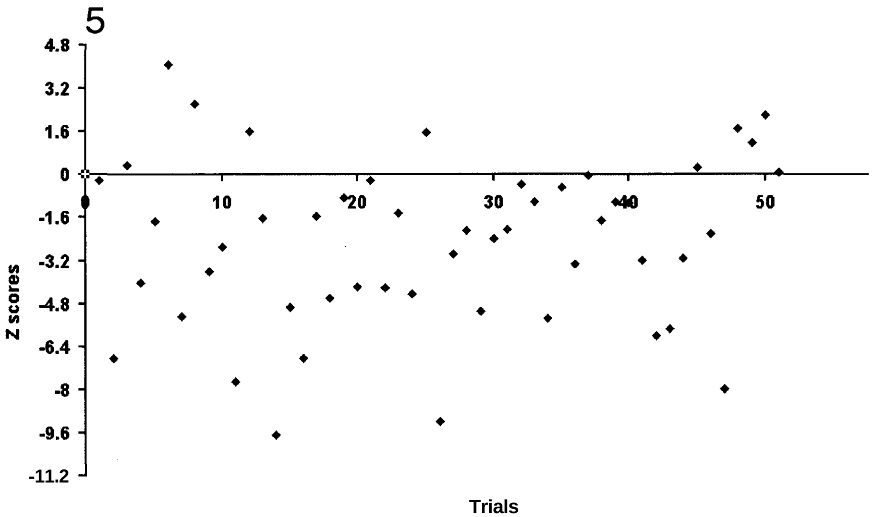


Fig. 5. Z scores using a window of 15 minutes for all the yogic flying sessions (experiments **A** and B combined). This indicates that a majority of the yogic flying sessions were significant at the 0.05 level.

a typical meditation session. A reanalysis to control for a possible cumulative drift was performed and are presented in parenthesis below. In the pretest control 8% of the non-xored data were significant at the 0.05 level, 58% (28%) for Experiment A of meditation sessions, and 44% (26%) for Experiment B of meditation sessions and 19% of the shielded post-experimental control data. Using a 15-minute window (length of a typical yogic flying session) the yogic flying section of the meditation for Experiment A was 79% (68%) significant and 61% (61%) for Experiment B. The percentages for the yogic flying indicate a majority of the Z scores for individual sessions were significant at the 0.05 level (Figure 5).

Discussion

As predicted, the meditation and yogic flying data are significantly anomalous (meaning more zeros than ones in the random binary stream) even after statistically controlling for a possible cumulative drift. The meditation data consisted of a total of 94 hours of standardized group meditation (average 261 females, average 398 males in adjacent meditation hall) recorded in two experiments, at uniform times, collected over a total of 30 days with a RNG on-site in the females' meditation hall. The two experiments are both significant and therefore the second experiment offers a replication of the anomalous results. Our results extend and support previous work (Nelson, 2002c, 2006) involving the same type of group meditation. The Vedic Observatory data was also significant after reanalysis for a possible cumulative drift, for the two experiments but less so than the meditation. Future work could include subjects with the Vedic Observatory recordings as a more appropriate test of the putative influence.

Direction of Results

The direction of the anomalies in our work is similar to RNG research involving prayer, full moons and sacred sites in Egypt, but unlike that typically observed in the majority of work involving tragedies as seen in the Global Consciousness Project data (Nelson et al., 1998) and Princeton University's Princeton Engineering Anomalies Research labs. Nelson et al. (1998) note that often in past RNG research the focus has been on the variance and mean shift direction is ignored, so the methods in certain studies may make it inappropriate to infer any meaning from the direction. Our work adds supports to the premise that activities with "calm but unfocused subjective resonance" (Nelson et al., 1998, p. 425) or those that foster transcendental experiences (Alexander & Langer, 1990; Mason et al., 1997; Orme-Johnson et al., 1988; Travis et al., 2002), or "flow experiences" (Csikszentmihalyi, 1990) may reflect a more decreasing directional trend for the RNG. Specifically there is less randomness due to generating more zeros than ones. This can be represented by an increase in the negative downward direction of the graphs. By contrast, events that "foster relatively intense or profound subjective resonance" (Nelson et al. 1998, p. 425) involving emotionally laden environments, such as tragedies, may result in less randomness with deviations in the increasing direction.

Nelson (2006) notes that "Despite the accumulations of more than 200 events over the past 8 years we can not definitively interpret the negative versus positive slopes in either case there is a change toward less randomness." Many of the 200 events used variance measures so caution is advised in generalizing to studies involving mean shifts. If the present preliminary findings are supported with further formal confirmatory research in the future, this could lead to the use of RNGs as a potential means of measuring the intentional "direction" for collective consciousness.

Alternative Explanations of Results

What possible alternative explanations of the anomalous data could be responsible for the results? The following is an examination of other potential explanations including an experimenter effect, temperature bias, a trial density bias, insufficient number of sessions, non-xor influence, equipment failure, electro-magnetic interference, statistical bias, related factors, and lag effects.

Experimenter effect. In regards to the experimenter effect, various RNG experiments (Jahn & Dunne, 1987; Jahn et al., 1997; Nelson et al., 1998; Radin & Nelson, 1989) have shown a significant effect of individual intention on the RNG. It is possible that the conscious or unconscious intention of the experimenters influenced the results (Wisemen & Schlitz, 1997). This study could be replicated and designed specifically to test for experimenter effect including using other experimenters with pre-registered intentions. However, an exploration with RNGs (Nelson, 2002b) found no definitive evidence for experimenter effects in a situation where the experimenter had a personal involvement in the subject matter and expectations about the outcome. Significant outcomes were not reached and the author concluded in this single study that there was no clear evidence of an experimenter effect for this deeply important personal event (Nelson, 2002b). A previous pilot study (Nelson, 2000c) conducted by a non-meditator testing the same meditation technique occurring in the same meditation halls, as the present study, did attempt to control for experimenter bias. Those data were collected first without any predictions, then before data analysis predictions were made by a meditator blind to the data. Those results were significant and do not lend support to an experimenter bias explanation for the present results. Likewise, the participants of the present study were not aware of the experiment and therefore had no specific intentions or subject bias for the results. The experimenter effect cannot be completely ruled out as the first two authors were aware of the time of the recordings but previous studies (Nelson, 2002a, 2000c) do not support this alternative explanation.

Temperature. Temperature biases do not appear to be a likely alternative explanation as all recordings were within the 4" to 32° Celsius range prescribed by the manufacturer's specifications. Furthermore, the recording temperatures for the pre-test control, meditation, yogic flying and post-test were all similar but the results vary for these different venues and cannot be explained by temperature effects. The alternative explanation of temperature being responsible for the results does not appear to be supported.

Trial density. A trial density of 1000 bits per trial was selected in order to capture the whole meditation period in 1000 trials. A trial density of 1000 has been previously used for RNG research without any reported concerns for trial density influencing the results (Nelson et al., 1998). The research on trial number bias density issues is still limited (Ibison, 1998), and future experiments could directly compare 1000 bits to other density levels to test the influence of particular random processes on statistical outcomes. The alternative explanation of trial density being responsible for the results does not appear to be supported.

Number of sessions. Were there sufficient meditations to accurately measure an effect? Other meditation research has involved multiple RNGs but the length of meditation ranges from a single 3-minute period (Nelson, 2002a), to 58.75 hours over 5 days of recording (Nelson, 2002c). In comparison to other meditation recordings the present study is longer, with a total of 94 hours of meditation sessions (51 meditation sessions), and appears sufficient within the context of the literature. The alternative explanation of the number of sessions being responsible for the results does not appear to be supported.

Non-xoring. Non-xor (no additional software for xoring) was used as there was no evidence in our baseline control tests to support using additional software xor data. In the baseline control tests (Figures 1A and 1B) there was no significance for the xor (xor refers to additional xoring software) and the non-xor data. Further exploration of the advantages and disadvantages of using non-xored data appear to be warranted.

Assuming a cumulative drift exists, if non-xoring is responsible for the drift it would be expected to equally affect the non-xored control baseline data, and non-xored meditation test data. This is not what was found in the results. The pre-test baseline control data terminal Z score is not significant while the meditation data is significant, even though both are not xored. The validity of the baseline recordings can also be examined. However, the pre-test baseline control recordings (Figures 1A and 1B) are typically random as expected for RNGs and appear valid. Hence, the alternative explanation that not including additional software xoring being responsible for the results does not appear to be supported. Nonetheless we have reanalyzed the data for any possible cumulative drift and it remains significantly anomalous.

Equipment Failure. The pre-test non-significant baseline data is more random than the significantly non-random test data recorded during meditation and the post-test results. It is conceivable that our relatively new RNG was experiencing an electronic "burning-in period" that resulted in a difference in the pre-test control baseline with the post-test (US government inspector's technical guide, 1987). If the results were completely due to a linear bum-in there would not be significance after controlling for pre and post differences, but there is. Also if equipment burn-in was responsible for the results we would not expect the different results for the meditation, yogic flying and Vedic Observatory that were taken on the same days with the same RNG.

While the post-test software xored data is similar to the pre-test xored baseline data, the post-test non-xored data is clearly different from the pre-test baseline non-xored. At post-test the equipment was tested, and no evidence of equipment failure was found for the RNG or associated computer and connector. The alternative explanation of equipment age or equipment failure being responsible for the results does not appear to be supported.

Electro-magnetic interference. To determine if electro-magnetic interference was the source of the results the RNG were run electrically and magnetically shielded as well as unshielded. No evidence for electro-magnetic interference as an alternative explanation of the results was found, especially since the experimental data was taken with batteries as the power source. The alternative explanation of electro-magnetic interference being responsible for the results does not appear to be supported.

Statistical bias. For RNG research in general, a Bayesian statistical analysis as opposed to the null hypothesis with independent running means (not cumulative deviations) (Scargle, 2002) has been suggested as a more stringent approach to the results (Sturrock, 1997). Sturrock (1997) emphasized the limitations of Z scores and analysis using p values. In this study, it was thought prudent to use the accepted to date statistical methods (Radin, 2002). Future research will have to clarify this line of Bayesian inquiry. All data windows reflected the length of real-time events, not arbitrary times, and no data was excluded from the analysis, therefore the results are not related to data manipulation or "data fiddling" (Scargle, 2002).

Related factors. Though the results are supportive of our exploratory predictions, at this point, it cannot be definitively concluded that the results are due to an influence of group meditation and/or the Vedic Observatory. Other factors besides meditation or related auxiliary factors to meditation could be involved. Further research could include ruling out the simple effect of large numbers of people in silence, or numbers of people sitting non-actively. However, no significance has been found for relatively silent non-mobile audiences at conferences (Nelson et al., 1998).

Lag effect. The post-test results of this study could be interpreted as a candidate for a carryover residual effect, lag effect or entrainment effect. Could using the RNG, during the meditations or at the Vedic Observatory create a lag effect or alter the results of RNG? A new RNG (Orion) developed possible cumulative drifts after exposure to the group meditation, but not before. Intentional time delay effects have been previously reported in the literature involving single subject studies (Dunne and Jahn, 1992). A time lag or carryover effect that diminishes over months has also been measured in studies evaluating the effect of group meditation on societal indexes (Dillbeck, 1990; Dillbeck et al., 1987; Hagelin et al., 1999; Orme-Johnson et al., 1988). Extensive longitudal research would be needed to support or dismiss the lag effect or entrainment effect as an alternative explanation of the results.

Co-author Radin, reports continued randomness after up to 5 years of use with multiple Orion RNGs when run non-xored. However two of these RNGs were used for experiments involving meditation. Co-author Radin notes these two RNGs then developed in the post-test a downward drift similar to that reported in the present experiment. Preliminary reviews found no downward drift in subsequent non-meditation related experiments with these RNGs. Radin's investigation and reanalysis of this previous data (Radin 2006; Radin & Atwater, 2006) is underway in order to discover if there is a meditation and RNG interaction responsible for the drift in the mean/variance or a lag effect or some other possible mundane answer.

It is not clear there is a cumulative drift involved or what the source of the drift is or if there is a lag effect. At this point, the difference in post-test data from pre-test baseline "control" data is not clearly accounted for, therefore a statistical control for any cumulative drift regardless of the source was used. The experimental data was still significant after reanalysis for a possible drift for the meditation, yogic flying and Vedic Observatory for both the initial experiment and its replication.

Conclusion

Our predictions for the meditation data, yogic flying and Vedic observatory data were significantly supported and were in the predicted direction. Our work adds to the premise that certain activities that foster transcendental experiences

(Alexander & Langer, 1990; Mason et al, 1997; Orme-Johnson et al., 1988; Travis et al, 2002) may reflect a more decreasing directional trend (increased proportion of zeros) in RNG outputs. Alternative explanations do not clearly account for the observed results. The results were still significant even after controlling for a possible cumulative drift of the mean from an unknown source.

To our knowledge this is the first experiment with specific predictions for the direction of a mean shift, and it involves the largest number of synchronized meditations recorded with a local RNG on site. Having a population doing a standardized mental technique on a regular basis is advantageous in studying various aspects of the phenomenon. Further research appears warranted to explore group meditation as a venue for anomalous results with the RNG. Future research could test the direction of the results, distance effects from the group, possible lag or entrainment effects, experimenter effect, non-xoring data techniques, group size effects, number of RNGs and possible auxiliary factors. Theoretical questions could include a continued inquiry (Hagelin, 1987; Nader, 2000; Nelson, 2002d; Radin, 2002; Routt, 2005) as to whether or not consciousness is a causal factor.

What is the possible practical contributions and application of this research? It is conceivable that RNGs could be used to indicate directional changes in a proposed global collective consciousness. Just as changes in seismic meters are used to detect high and low indications of impending earthquakes, RNG outputs could warn us of changes in collective consciousness while considering any anticipatory effects. RNGs could also be employed to evaluate preventive and ameliorative measures that utilize collective consciousness. For example, the RNG could evaluate the efficacy of various technologies from many traditions, including group meditations to reduce collective stress in global consciousness in order to prevent and reduce local and global tragedies.

Acknowledgments

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COMMENTARY

Comments on Mason, Patterson & Radin

Experiments on physical random number generators are fascinating for a very specific reason. In a general sense, we use the term "random" to refer to events that happen over time and/or space, for which we have no causal explanation. When we observe regularities between physical random number generators (RNGs) and events in the world, especially if they happen in experimental settings, we have to take notice. The reason is obvious; whatever influence the world events have on the physical RNGs must operate along causal pathways that we have not yet discovered. Surely, finding new causal pathways must be a central issue in scientific exploration.

Although I am enthusiastic about research on the effects of world events on physical RNGs, I am not as impressed as I would like to be with the results in the RNG literature, as are the authors of the various papers that make up this literature, many of which have appeared in JSE. The reason is based on my feeling that there is much room for improvement in the experimental designs and methods of analysis that RNG researchers use, and so I would like to use the Editor's generous offer to comment on the Mason et al. article in order to make points in general about RNG research, some of which are illustrated in the article.

Computations Related to RNG Data

One of my general criticisms of the RNG literature is that the computational procedures are frequently described in ordinary language, which does not always translate unambiguously into actual computation or statistical analysis. In my opinion this tradition is continued in the Mason et al. article. For this reason, I think it is worthwhile to make some of the computational issues more precise.

The raw data in an RNG experiment consist of a binary sequence; that is, a sequence x_i for $i = 1 \ldots n$, in which each component x_i is either 0 or 1. It turns out to be far easier to analyze binary data if we apply the "sign" transformation, $s(x) = 2x - 1$. This leaves 1's alone, but transforms 0's to -1. Thus, $s(x_i)$ for $i = 1 \ldots n$ is a sequence of 1's and -1's. Note that summing $s(x_i)$ gives the excess of 1's over 0's in the underlying x-sequence (where a negative excess is interpreted as an excess of 0's over 1's), and that sums like this are routinely portrayed in RNG articles.

To reverse the 1's and 0's in the underlying x-sequence, we simply replace x by $1 - x$. Since $s(1 - x) = -s(x)$, the reversal process for the signed sequence is just accomplished by multiplying by -1. There are other interesting algebraic properties of the sign function that are related to whether applying the exclusive-or operation is a good idea or not, one of the issues raised by the Mason et al. article. Define the eq operation on two binary numbers x and y so that x eq y is 1 when x and y are equal, and 0 when they are unequal. Then $s(x \text{ eq } y) = s(x)s(y)$, as can be easily checked. It would have been nice if the RNG scientists had combined sequences with eq, but instead they chose the xor operation (exclusive-or), defined by $x \text{ xor } y = 1$ if x and y are unequal, and 0 if they are equal. Obviously $x \text{ xor } y = 1 - (x \text{ eq } y)$, and so $s(x \text{ xor } y) = -s(x)s(y)$. The take-away point from this is that it is easier to study the effects of xor-ing two binary sequences using the sign transformation, although we do have to put up with an annoying sign change (which has implications, as we will see).

Combining binary sequences with xor happens in two places in RNG research. Evidently all putative physical RNGs actually generate two binary sequences internally, and then xor them for their output. This is done in hardware, so there is nothing anyone can do about it. I believe that the reason RNG manufacturers do this is because their goal is to offer a genuine random number source, which is not influenced by world events. To see why this makes sense, take expected values to show $E[s(x)] = s(E[x])$, and note that $E[x]$ is the probability of a 1 for the binary x-sequence. If x and y are two independent binary sequences, then $E[s(x)s(y)] = s(E[x])s(E[y])$. Now $E[x] = 1/2$ corresponds to "pure randomness", and $s(1/2) = 0$. Therefore, the closer the expected value of the sign-transformed sequence is to 0, the closer it is to pure randomness. Since $E[x \text{ xor } y] = -s(E[x])s(E[y])$, it follows that the x xor y sequence will always be closer to pure randomness than either x or y are (an order of magnitude closer). In fact, even if only one of the sequences is purely random, then the xor-ed sequence will also be purely random. Therefore, the RNG manufacturers can claim that by xor-ing they are delivering on their claim to produce a purely random number sequence. There are two aspects of this we need to keep in mind. (1) This is, of course, the opposite of the aims of RNG scientists, who want to be able to detect departures from pure randomness, so it is strange that they have chosen to use RNGs with hardware xor-ing, and this substantiates Scargle's criticism, cited in the Mason et al. article. (2) All of the above assertions depend on the assumption that the x and y sequences are independent, which is perhaps somewhat less than obviously true.

The second place that the xor operation appears is in software "masking" of the sequence generated by the RNG. Evidently the most common scheme is to xor the signal x from the RNG with an alternating sequence of 0's and 1's. If we let a_i for $i = 1 \ldots n$ denote this sequence, then $s(a_i) = (-1)^i$. Thus, $s(x \text{ xor } a) = s(x_i)(-1)^{i+1}$.

We now have all the machinery we need to analyze RNG signals. First, the RNG internally generates binary sequences x and y, and puts out x xor y. The RNG scientist can either use this signal or xor it with the alternating binary sequence, to obtain x xor y xor a. The sign-transforms of these signals are

$$s(x_i \textit{ xor } y_i) = -s(x_i)s(y_i)$$
$$s(x_i \textit{ xor } y_i \text{ xor } a_i) = s(x_i)s(y_i)(-1)^i$$

In has become quite conventional in RNG research to sum the sign-transformed version of a binary sequence for use in assessing non-randomness. Plots of cumulative sums have been much used in the RNG literature, and although Mason et al. repeat this, they base their conclusions on the "terminal" values of the sums. While this analysis seems to have served Mason et al. well, in general it is simplistic. One of the important ways that an RNG can fail to produce a random number sequence x is that the sequence $p_i = E[x_i]$ of probabilities of 1 may depart from ½. Mason et al. refer to the situation $p_i = p$ # ½ as "drift". (The reason this is a misnomer is that the sum of sign-transformed values can drift for other reasons.) The expected value and variance of the sum of the sign-transformed sequence are ns(p) and 4np(1 – p), assuming $p_i = p$ for all i and independence.

Because it will turn out to be important below, let us just consider the case $p_i = p$ for the moment. Large-sample theory says (assuming the components of the binary sequences are independent) that approximately

$$\frac{S - ns(p)}{2\sqrt{np(1-p)}} = Z$$

where S is the sum of the sign-transformed sequence, and Z represents a Normal chance variable with mean 0 and variance 1. Rewriting,

$$S = 2\sqrt{np(1-p)}Z + ns(p)$$

The reason this is important is that RNG scientists regularly plot S vs. n. If p = 112, then S = Z√n, which explains why the curved lines in the plots shown by Mason et al. are proportional to √n. The curves in the plots represent something about what we expect when p = 112. In order to see what would happen when p ≠ 112, note that $2\sqrt{p(1-p)}$ is actually very close to 1 for values near p = 1/2. Thus, for small departures of p from ½ we have nearly

$$S = \sqrt{n}Z + ns(p)$$

To summarize, the sum of a sign-transformed binary sequence should behave like the square root of the number of components times a standard Normal chance variable, but if the probability (p) of a 1 in the underlying binary sequence deviates from ½, then S should in addition have a component linear in n and proportional to s(p).

This sheds a bit of light on the issue of software *xor*-ing. No matter what the value of p in the original sequence, *xor*-ing with the alternating sequence changes p to ½ (without changing the variance). Consequently, any software-xor-ed signal that gives a statistically significant result is rather hard to interpret, because (as Scargle argues) exactly what we might want to see has been completely removed. Needless to say, this makes previous positive research with software-xor-ed

TABLE 1
Estimated slopes and probabilites from graphs in the paper

Figure	s(p)	P
2A	−20000/(22500 × 1000)	0.49996
2B	−24000/(3000 × 1000)	0.49600
2C	−17500/(8500 × 1000)	0.49897
4	−44000/(32500 × 1000)	0.49932

sequences difficult to understand. I believe it is one of the major strengths of the Mason et al. article to have departed from the previous, convention-driven practice.

Before leaving this section, I want to point out that there is another very important point that is not addressed by this analysis. It is the possibility that the twin binary sequences x and y, generated internally by the RNG, are not temporally independent. That is, pairs (x_i, y_i) generated at one time might be correlated with pairs generated at other times, and of course each x_i could be correlated with its paired y_i. This is, in fact, an entirely plausible way in which RNGs might produce non-random numbers, but the conventional analysis, based on partial sums of sign-transformed sequences, will never sort it out, because the method is too simple.

Issues Raised by the Paper

1. All of the experimental results reported by Mason et al. show plots of S vs. n with what appears to be very nearly a linear trend. In the light of the above analysis, this is consistent with the original binary sequence (from the RNG) having a departure from $p = 112$, in the direction of $p < 112$. The slope of each line is the value of s(p) for that experiment. I estimated these from the figures in the article (in the version I had), and came up with Table 1.
   If this is accurate, then a typical effect on the probability of a 1 in the underlying binary sequence is to shift it from 0.50 to something like 0.4986, a deviation of -0.0014.
   In my opinion, one of the weaknesses of the RNG research program is that it focusses on being able to collect sufficiently large numbers of bits to show that such tiny effects are real. It cites the "odds against chance" for its findings, and shows impressive-looking figures like those in the Mason et al. article, while underplaying just how miniscule the findings really are. If we want to assert that there are causal pathways that are undiscovered by conventional science, but which can be detected by RNG experiments, and that these causal pathways might actually have effects worth paying attention to in the world we live in, then the current path of RNG research does not seem to be taking us where we would like to go.
2. The authors say that a surfeit of 1's in a bit-stream indicates more randomness, while a surfeit of 0's indicates less randomness. No reason is

offered for this assertion, and indeed it is hard to imagine that simply reversing the sense of the data (multiplying the sign transformation by –1) would interchange things on some "randomness" scale. Given the analysis I set out above, I would offer a different view of the dominant negative trend in the Mason et al. results. A negative trend in the hardware-xor-ed binary sequence output by the RNG implies that both of its internal binary sequences have shifted in the same direction (both of their p's above ½, or both below ½). If this is true, then the negative trend is more plausibly interpreted as a trend in the same direction by both internal sequences. What this might mean depends on how those internal sequences are physically generated, a fact not revealed in the Mason et al. article.

3. I find the authors' interpretation of the post-experiment results a bit strange. In seems disingenuous to say that there were no predictions about this phase of the experiment. An obvious reason for doing a post-experiment is to see that the RNGs returned to normal after the circumstances in which they showed an influence. When this fails, then introducing "entrainment" as a supportive explanation for the results in effect means that there is no way that the post-experimental results could ever falsify an RNG influence, raising a question about their scientific standing. Moreover, if "entrainment" were a serious explanation, we would have expected Mason et al. to report carefully on the prior history of the RNGs before their periods of data gathering, and we would have also expected to see cumulative "entrainment" accounted for somehow in the results during the meditation intervals. My conclusion is that while an "entrainment" hypothesis is appealing ab initio, it loses some of its luster post *hoc*.
4. In this paper (and virtually every other one I have seen on RNGs) the experimenters select a segment of bits from the underlying bit-stream, in some way that is not entirely clear. In other words, not all of the data generated by the physical random number generator are used. This amounts to applying a data "mask" that literally removes large amounts of data from the experiment. I am not suggesting that this was done in some sinister fashion, but I am claiming that this process is poorly described, and its effect on the statistical results has evidently never been tested. This is related to the next point.
5. I found the method of statistical analysis to be more obscure than I would have liked. At one point a "trial" is defined as 1000 bits collected over 10 sec, and a "run" is 1000 trials. But then in the description of the statistical method, 200 bits are sampled in an undescribed way over an undefined time period. If Fig. 1A (in the version I have) is to represent about 30 hours of sampling, then the sampling rate might be 0.1 Hz but with 200 rather than 1000 bits, or maybe with 1000 bits, or maybe at some other sampling rate—we cannot tell. Given that there is no deficiency of critics

of RNG research, it would be a good idea for RNG scientists to be more careful in describing what they have done.

6. A peculiarity of the pre-experimental data is this. If the original bit-stream is purely random, then after an alternating mask xor-ing it is still purely random. This is a result of probability theory, not something that needs to be tested empirically. It is not clear why one would test things known to be true, except as a negative control (which in this case would be a test that the software did the xor-ing correctly, something that could probably be more reliably checked directly).
7. It would seem to be useful in RNG research to have more controls than are usually employed. In this paper, for example, although there was suspicion that the continuous usage of the meditation hall for this purpose might have suggested an RNG influence from the site itself, no test of this hypothesis was made. Having *simultaneous* control RNGs in different locations would also, in general, seem to be a worthwhile enhancement.
8. Over the years I have been struck by how primitive and ritualized the analysis of RNG data has become. RNG experiments produce a very large amount of data, and many scientists (especially certain kinds of engineers) have an impressive armamentarium of tools for assessing and interpreting influences on signals. The use of terminal standardized statistics, as in the current paper, seems to waste a valuable opportunity for more informative analyses. I fully concede, however, that in the Mason et al. article the main results are so simple and compelling that probably nothing more elaborate is needed to make the points that they emphasize in their article. Nonetheless, the linear departures from randomness that they have found, while supportive of a constant p_i model, never test that model. Thus there seems to remain, at this late stage, room for fundamental analyses of how p_i values fluctuate over time.
9. Mason et al. very properly examine some potential influences on RNGs from known sources, such as electromagnetic fluctuations. This is a definite step forward in RNG research, and one that should be investigated more systematically.
10. As a tiny terminological quibble, I would suggest that RNG researchers stop referring to "unconscious" mental effects on RNGs. The subjects of these studies are always fully conscious, but the phenomenon referred to is supposed to be below their level of conscious perception; that is, it is "subconscious".

Suggestions

Finally, in the spirit of supporting research into world event influences on physical RNGs, I would offer some personal recommendations for future research.

- Abandon the path of trying to mount ever more statistically significant results to prove that the RNG phenomenon exists. Although the "odds against chance" may be steadily rising over time, they are already high enough, and we are not learning anything more in the process.

- Efforts need to be made to understand how physical random numbers are generated and to develop some hypotheses about what kinds of influences might cause them to shift. Up to now RNGs have mostly been black boxes, which doesn't push the science very far forward. Do temperature, pressure, ambient light, variation in the electromagnetic field, or the force of gravity, or any of a host of other physical characteristics produce an influence? Do RNGs "age" in some way (as Mason et al. suggest), and if so, how do we take that into account? The evidence so far seems fragmentary; we need it to become systematic.
- The experimental designs need to be much stronger. Simultaneous controls, duplicate RNGs, and balancing the use of different RNGs over the experimental design (to take out the effects of an idiosyncratic RNG, for example) are all strongly indicated. There seems to be a rather large amount of ad-hoc-ness to many of the RNG experiments.
- Search for something that does a better job of capturing whatever influence we are seeing. Ultimately one would like to measure it over shorter periods of time, to relate it to changing conditions, and to therefore study its properties. If 3 hours are necessary to even see whether an influence is present, it is going to continue to be difficult to do interesting experiments.
- What kinds of human events influence RNGs? Do they have to be spiritual or "alternative" in some sense, or would one see a bigger effect, say, at a political rally, or a marriage counseling session? Some systematic research along this line might be useful.
- Research physical RNGs should simply put out the physical signal, and not somehow pre-process it in hardware. Hardware xor-ing may have done considerable damage to RNG research, and one can only wish that RNG researchers had been more critical of it before the Mason et al. article.
- It would seem to be useful to have more people involved in RNG research. By standards in other areas, RNG research is very inexpensive, and reasonably easy to do. Seeing results from more groups, in a variety of settings and with a variety of approaches, might be a very good thing.

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