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Random number generation and creativity

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Summary A previous paper suggested that humans can generate genuinely random numbers. I tested this hypothesis by repeating the experiment with a larger number of highly numerate subjects, asking them to call out a sequence of digits selected from 0 through 9. The resulting sequences were substantially non-random, with an excess of sequential pairs of numbers and a deficit of repeats of the same number, in line with previous literature. However, the previous literature suggests that humans generate random numbers with substantial conscious effort, and distractions which reduce that effort reduce the randomness of the numbers. I reduced my subjects' concentration by asking them to call out in another language, and with alcohol — neither affected the randomness of their responses. This suggests that the ability to generate random numbers is a 'basic' function of the human mind, even if those numbers are not mathematically 'random'. I hypothesise that there is a 'creativity' mechanism, while not truly random, provides novelty as part of the mind's defence against closed programming loops, and that testing for the effects seen here in people more or less familiar with numbers or with spontaneous creativity could identify more features of this process. It is possible that training to perform better at simple random generation tasks could help to increase creativity, through training people to reduce the conscious mind's suppression of the 'spontaneous', creative response to new questions.

It is 'well known' that people are very poor random numbers generators (RNGs). Methods used for statistical randomization do not rely on people's idea of randomness, but uses randomizing methods such as drawing balls from a bag [1], genuinely random electronic systems or computational pseudorandom number generators [2]. The inability of humans to generate genuinely random numbers was first noted in 1949, and a wide range of studies in the 1950s and 1960s confirmed this [3]. It was therefore surprising and provoking for Persaud to report that, in a simple task, he found that humans *did* generate sequences of numbers that were, at least to an approximation, random [4]. He related this to genuinely random processes going on in the brain, which his simple protocol unlocked, and suggested that this could be used to probe mental functioning and possibly distinguish human from artificial intelligence.

Persaud's protocol, of asking people to call out numbers, is well-known, and has been tried many times before in various versions [3], including the test by Figurska et al. [5] who specifically set out to replicate Persaud's experiment, and found that the numbers generated by this process were non-random in several respects. As [5] comment, this attribute can be used to distinguish between man and machine, but only because humans are, in this regard, substantially inferior to machines — it is

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therefore rather easy for a *machine* to mimic a *man* in its incompetence as a RNG.

Given that Persaud's result is at variance with so many other results, I also tried replicating his experiment, to try to discriminate between two possible explanations for Persaud's result. It is possible that unknown experimental bias was creating an artefact. For example, if people are 'cuing' their answers from a pseudorandom environmental cue, such as a computer display or fast-running clock. My discussions with Persaud on the context of his experiment make this seem unlikely. So the two explanations remaining are:

1. that people cannot generate random numbers, but with some thought they can generate numbers that are sufficiently random to 'fool' basic statistical tests, and that Persaud's experiment was a 'lucky' example.
2. that people can generate random numbers as a low level mental function, but usually suppress this ability: in this case, some aspect of the environment in Persaud's test removed this suppression.

Hypothesis (1) is the view of most researchers in the field (see, for example, [5,6]). The reason that Persaud's subjects could do this unusually well could be related to their environment — a waiting room where they had been waiting for some time for (unrelated) tasks in which the boredom of waiting focussed their mind on a task that otherwise would have commanded little mental attention. This would be a non-conscious version of 'mental maths' described by [5].

Hypothesis (2) might seem foolish. Why would people suppress a 'natural' ability to generate random numbers? A strong thread of Western belief is that 'random' means 'non-repeating', typified in such sayings as 'lightning never strikes in the same place twice', and the unfocussed but very common belief that once an essentially random adverse event (such as illness or accident) has happened to a person then they have 'had their bad luck' and another, random adverse event will not happen to them [7]. Thus the series 163852 is seen as 'more random' than 777777 or 234567, although any of them could be outputs of a random number generator, because the second series is repeating and the third, while not repeating individual numbers, repeats the gap between each number. If asked to generate random numbers this mental bias could suppress such sequences.

Under both models, humans have an underlying mechanism for generating 'a number' — a truly random mechanism in Persaud's model, a deterministic model in the conventional view. The output is them modified by the conscious mind to fit a preconceived notion of randomness. If the numbers are not written down, then the mind can only review those numbers held in short term (executive) memory, and the degree to which this randomizes or de-randomizes the 'baseline' output will therefore depend on concentration and the ease with which numbers are coded into executive memory, the latter roughly equivalent to familiarity with numbers, i.e. 'numeracy'. Analysing random numbers to probe executive memory function and attention is a well-explored area of psychological research [8]. Baddeley et al.'s series of papers show that 'distractions' that compromise executive memory, such as concurrent tasks that take up memory or powers of concentration [6], reduce the amount of randomness in a series. In addition, when asked to produce random sequences at speed subjects tend to produce series according to the conventional sequence — 1234, 7654 etc., as if the mind has saturated its ability to screen the numbers fast enough, relying on simpler default orders to deliver a number in time. All these types of observation strongly supports the conventional view, and have been elaborated by Baddeley into a model in which learned systems for handling numbers generate stereotypical series of numbers (known series such as 12345, phone numbers, birthdates etc.) which are modulated by a Supervisory Attentional System according to high level models of what 'random' means.

I decided to follow up on Persaud's original observation with some tests of the two hypotheses above. After discussion with Persaud, I followed a version of his protocol. Small groups of individuals were asked to speak a random string of digits from 0 to 9 inclusive in a relaxed social setting, usually a pub., which was recorded and transcribed later. Their boredom threshold seemed lower than that reported by Persaud or Figurska et al, so sessions were 60 seconds, which were recorded and transcribed later. 21 subjects provided a total of 56 runs with an average of 85 digits per run. Test subjects were mostly drawn from graduate students on Cambridge's MPhil in Bioscience Enterprise[1] (MBE) course, and were science graduates aged between 25 and 30: all were highly numerate. In addition four older test subjects and four 15-year-olds were tested. In agreement with Persaud, the subjects found this exercise entertaining, both for participants and onlookers waiting their turn.

Statistical testing methods for random number generators are well known[2]: in this case I chose

[1] http://www.biot.cam.ac.uk/mbe

to test the deviation of: (a) the frequency of numbers, and (b) the frequency of pairs of numbers from the expected random distribution. Other tests based on information theoretic measures of entropy are usually not appropriate as they rely on logarithmic functions, which fail if counts are 0 [8].

With one exception, digits were generated with a 'flat' spectrum, and individuals' spectra did not deviate significantly from random ($p > 0.05$, Chi-squared), which is in agreement with many previous studies although not with [5]. The exception was that some respondents generated very few zeroes, due to misunderstanding the instructions.

However, the sequence of numbers was highly non-random. The first few digits generated are different from the others: subjects are more likely to repeat a sequence of 4 digits that occurs in the first ten numbers than a sequence of 4 that occurs anywhere else (Fig. 1): this is not a profound effect, but the first 6 digits were omitted anyway from subsequent analysis. The first ten or so digits were usually spoken faster than the others.

The greater 'non-randomness' arises from biases in choices of which number will follow another. Table 1 summarises a simple measure of this, showing that the frequency with which one number follows another is not at all random: the incidence of doublets (a number followed by the same number) is substantially lower than a truly randomly generated sequence, as has been found in many studies, and the frequency of sequential numbers (N is followed by $N + 1$ or $N - 1$) is substantially higher. This latter is also a well-known phenomenon (see for example [9]) The deviations are highly significant under Chi squared. Interestingly, Persaud said that he did not observe this deviation (per comm), although many others have.

We can probe the role of concentration (more accurately a combination of executive memory and concentration) by reducing the concentration that people can give to the task. I tried two ways of doing this. The first was to ask the respondents to call out numbers in a language other than their native tongue, which would require additional mental resources to conjure up the numbers. This has been tried before by Strenge and Bohn [10], who found that random number generation in non-native languages decreases randomness and increases 'counting', i.e. generation of serial strings of numbers. The second was to ask them to repeat the task after a couple of pints of beer, which would reduce all mental functions to a degree (the teenage subjects were not asked to do this). I note that, as the test session progressed and each participant drank another pint of beer, the amount of background distraction also rose so any effect may not be entirely due to alcohol. I tried to measure the effect of the alcohol using a reaction time test, but this was not very satisfactory.

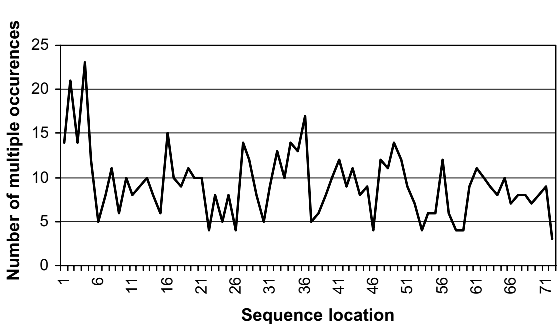

Figure 1 Seeding the sequence. The total number of times (Y-axis) that the sequence of four numbers at a specified position in their series of numbers (X-axis) was repeated somewhere in the subject's number series.

Fig. 2 summarises the result. Rather than just look at the sequence of pairs of numbers, I looked at the frequency of the sequences AnB, where A and B were identical (termed a doublet) or where the difference between A and B was 1 (termed a sequential pair), and 'n' was between 0 and 9 digits. A truly random number generator (i.e. one in which each number is generated without reference to the previous number(s)) would have doublet frequency = 0.1 and sequential pair frequency = 0.19 (because all numbers except 0 and 9 can be followed by either of two sequential numbers, one higher and one lower). The values for $n = 0$ correspond to conventional measures of non-randomness. As would be expected from the 'working memory' analysis of random numbers, there is significant non-randomness where $n < 4$, essentially random correlations with $n > 8$, and an intermediate level in between.

Data in Fig. 2 was separated according to five categories — whether the subjects were sober or mildly intoxicated, whether they were using their birth (native) language or a second language in which they were fluent, and whether they were adults or teenagers. Early results with the first 20 runs on the first 10 experimental runs (Persaud used 7 subjects) suggested all sorts of exciting correlations, but when the number of subjects was increased these all disappeared, and the only group to have a noticeably different pattern were the four 15-year-olds tested: it is not clear whether this is meaningful or not, but differences between adult and child random number generation have been noted in the past[11].

This attempt to replicate Persaud's study has therefore failed to do so, and my attempt to discriminate why Persaud found the result he did were also not very successful: a plausible explanation is

Table 1 Frequencies of doublets Relative frequency {as (observed−expected)/Expected} of pairs of digits in the data set. The 'expected' values are those calculated from the observed frequencies of individual digits as generated individually by the subjects: thus if a subject used no zeros, their 'expected' row for zero would be empty

THIS NUMBER	is followed by THIS NUMBER									
	0	1	2	3	4	5	6	7	8	9
0	−0.36	**1.92**	0.38	−0.11	−0.20	−0.02	−0.42	−0.03	−0.20	0.26
1	**1.79**	**−0.64**	**0.59**	**0.80**	0.21	−0.02	−0.25	−0.49	−0.11	0.11
2	0.12	**1.88**	**−0.65**	**0.41**	0.16	−0.06	−0.29	0.00	−0.19	0.00
3	−0.43	0.12	**1.54**	**−0.74**	**0.82**	0.30	−0.17	0.14	−0.41	−0.02
4	0.05	0.09	0.11	**1.28**	**−0.60**	**0.63**	0.27	0.08	−0.21	−0.14
5	0.32	−0.13	−0.22	0.28	**1.05**	**−0.57**	**0.93**	0.25	−0.36	0.25
6	−0.14	**−0.51**	0.21	0.02	0.37	**1.24**	**−0.75**	**1.04**	0.08	−0.35
7	−0.21	−0.37	−0.18	−0.07	−0.01	0.04	**1.01**	**−0.61**	**1.59**	**0.67**
8	−0.24	−0.27	−0.14	−0.39	−0.12	−0.02	**0.85**	**0.89**	**−0.77**	**1.72**
9	0.36	−0.13	−0.10	−0.16	−0.03	0.25	−0.13	**0.56**	**2.04**	**−0.68**

Data is for the entire experiment, omitting the first 6 digits from each sequence. Negative values indicate less AB pairs than expected. Values in bold are those >0.5 or <−0.5. Statistical significance cannot be ascribed to individual values.

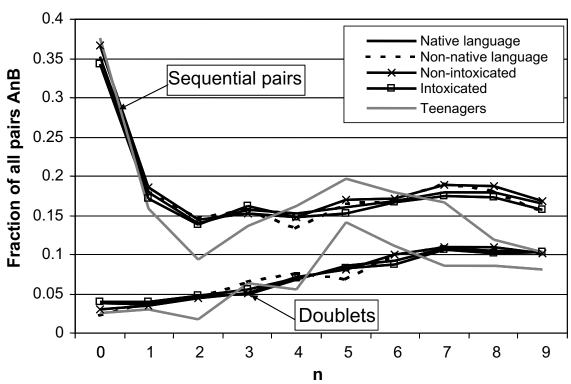

Figure 2 Effects of language and beer on randomness Plot of the fraction of all pairs of numbers A*n*B in the random number sequences generated that conform to A = B ('doublets') or |A−B| = 1 (Sequential pairs). *Y*-axis − fraction. *X*-axis − *n*. Plots are separated into plots for those for adults who were mildly intoxicated or not, and speaking their mother tounge or not, and into teenage subjects.

that his results were due to small sample size, but even a sample of one person should not be able to generate a string of 200 or more genuinely randomized digits.

However the results in Fig. 2 do not match well with the model of [6] either (a variety of variants of the analysis shown in Fig. 2, such as overall Chi-squared difference of AnB pair frequencies from expected (not shown) show essentially the same patterns). My study seems to show that people do not generate genuinely random numbers, but the numbers they do generate are generated by a mechanism that is not easily distracted. Does this suggest a 'low level' system in the brain for generating 'random' results, or more generally for creating novelty? That is consistent with the results here: that there is a 'creativity centre' in the brain which this method taps into, which is supervised by higher conscious function. This is analogous to Persaud's random number generator, but has different statistical properties from a true random number generator.

The method of analysis of random numbers generated by humans used here appears not to have been used before, and is a direct probe of the role of working memory in ordering random numbers. Several improvements could be made. A range of studies suggest that response speed is important in determining the randomness of series — this was not controlled here. In addition, neither the extent of fluency in a second language nor the extent of alcohol intoxication were measured effectively. If this approach adds anything to the literature, then these variables should be eliminated, and in particular people with limited familiarity with a second language should be asked to generate numbers in that language. More profoundly intoxicating subjects would also be valuable providing the ethical issues in doing so were addressed. Several respondents forgot to include '0', and one included '10' — it is suggested that 'numbers one to ten' would be easier to grasp and more natural that 'numbers 0—9'. It is clear that pubs are not well controlled experimental environments.

Workers in the past have suggested that it would be useful to test patients with psychological illnesses for their ability to generate random numbers [3,4,8,12]. This study strongly supports this, in suggesting that other (mild) influences on RNG do *not* affect number patterns, but that differing mental processes (assuming teenagers think differently from adults) do. My hypothesis here is that this is also correlated with elements of the creation of spontaneous actions in the brain. The results suggest that there is a mechanism in the brain which is not easily distracted or affected by low levels of intoxication which generates 'novelty', i.e. makes choices (in this case between the numbers 0 through 9) without substantial concern for what has gone before. Whether the numbers generated are 'random' or not is not actually relevant: it has the function of providing 'random' answers (i.e. answers not obviously related to previous answers) when required. I suspect that this is related to the proper functioning of the mind. Many formal representations of computers (such as Alan Turing's Turing Machine) suffer from the problem that they cannot complete the solution of some classes of problem, because they never terminate the calculation. While the brain is clearly not a well defined, formal, digital computer, it could well benefit from a mechanism that can insert non-linear, unconnected thoughts into the 'stream of thought' to terminate unnecessarily prolonged computational loops.

Previous studies suggest that the ability of people to generate random numbers declines in some mental diseases [3,8,12], but that there is an association between creativity and mental disorder [13]. However, 'creativity' in this context is the result not just of the ability to come up with new ideas, but also of developing them, implementing them, and (most importantly) not suppressing them because they are unconventional. This work suggests that Baddeleys' SAS [6] plays a major role in suppressing 'creative' answers in the RNG task. So perhaps the key to creativity is not only the inherent brain mechanism but the supervision of that mechanism. With this in mind, the existence and role of such a 'creativity centre' might be testable repeating this experiment (with the improvements suggested above) on less numerate individuals who were more or less used to spontaneous creativity, such as jazz musicians or politicians. If there is a 'novelty engine' in the mind/brain, and it has this role, this suggests that the same mechanism might be present in animals as well: it is not clear how one would test this, but primates could in principle be trained to provide symbol series in a manner analogous to this experiment. It is also possible that people could be trained to perform better at random generation tasks, i.e. to generate more nearly random strings of elements (numbers, letters, geometric shapes or others), and that this would relate to their ability to be creative. Such training could be done by using computer feedback to tell the user whether their 'random' series was becoming more or less mathematically random, without telling them whether the last few digits in particular (i.e. those held in working memory) were 'random' or not.

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