



ELSEVIER

Humans cannot consciously generate random numbers sequences: Polemic study

Małgorzata Figurska^{a,*}, Maciej Stańczyk^a, Kamil Kulesza^{a,b,1}

^a *Institute of Fundamental Technological Research, Polish Academy of Sciences, ul. Świętokrzyska 21, 00-049 Warsaw, Poland*

^b *Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK*

Received 17 May 2007; accepted 30 June 2007

Summary It is widely believed, that randomness exists in Nature. In fact such an assumption underlies many scientific theories and is embedded in the foundations of quantum mechanics. Assuming that this hypothesis is valid one can use natural phenomena, like radioactive decay, to generate random numbers. Today, computers are capable of generating the so-called pseudorandom numbers. Such series of numbers are only seemingly random (bias in the randomness quality can be observed). Question whether people can produce random numbers, has been investigated by many scientists in the recent years. The paper “*Humans can consciously generate random numbers sequences. . .*” published recently in *Medical Hypotheses* made claims that were in many ways contrary to state of art; it also stated far-reaching hypotheses. So, we decided to repeat the experiments reported, with special care being taken of proper laboratory procedures. Here, we present the results and discuss possible implications in computer and other sciences.

© 2007 Elsevier Ltd. All rights reserved.

Introduction

The Longman Dictionary of Contemporary English describes “random” as: “happening or chosen without any definite plan, aim, or pattern”. Hence, the randomness is the lack of purpose, cause and order. The sequence of numbers is said to be random if, given all the elements of the se-

quence (*say* n), the next element (*say* $n + 1$) cannot be predicted.

The computers are able to generate pseudo-random sequences of numbers, by means of the specialized algorithms. It should be remembered that those algorithms by their very nature are predictable, so the sequences they generate are not really random. The idea of checking if human could generate truly random sequences of numbers has been around for decades. Since the 1960s Alan B. Baddeley investigated it vigorously [1–4]. Different kinds of experiments were used in subsequent studies to examine human-generated randomness. The experiments varied in base set (the set of elements that subjects get to choose from), which were the letters of alphabet

* Corresponding author. Tel.: +48 228261281x251.

E-mail addresses: mfigur@ippt.gov.pl (M. Figurska), ongrys@fulcrum.acn.waw.pl (M. Stańczyk), kamil.kulesza@damtp.cam.ac.uk (K. Kulesza).

¹ Part of the work on the paper was done when the author was visiting scholar at Department of Applied Mathematics and Theoretical Physics.

[5], numbers [6–10], drum pads arranged around the subject [11] or permutations of set of digits. The rate of generation of random sequences in the experiments was forced externally [5,7–9] or no time limitations were put on the subjects [6,10,11]. Differences among experiments include also the particular element selection method. There are two most common selection methods: calling aloud names of the randomly selected elements or selecting them using the computer keyboard.

During the process of random number generation (RNG), the subjects need to remember the base set and relate it with their own concept of randomness, which is stored in the long-term memory [12]. Part of the generated sequence is then stored in the working memory that facilitates pattern suppression [2].

Random number generation requires a strategy, which enables selection of individual response and inhibition of other responses (habitual and stereotyped). It was proposed, that this part of RNG is the most important for the whole process [13].

The monitoring process is also an important part of the RNG task. It demands that a number of already presented choices is held in mind and compared with one's concept of randomness. The subject then tries to overcome a tendency to produce ordered sequence.

The "quality" of generated sequences is reported to be related to mental disorders [6,7,14] and the age of subjects [5]. The experiments show that neuropsychological patients generate sequences that are less random than those of normal subjects. Hence, results already present in the literature support hypothesis formulated in [10] that this quality might be linked with neurological and psychiatric impairments.

Overall, humans are generally regarded bad random number generators, but an interesting paper published recently by Persaud seems to deny this view [10]. Its author presents a number of hypotheses, which are, in our opinion, controversial. The main one seems to imply that people can be treated as ideal random number generators, better even than computers. These strong conclusions were based on a relatively small amount of experimental data. The paper motivated us to explore the subject of generation of random patterns by humans in a more systematic manner.

Therefore, we have repeated experiments conducted by Persaud. The data in the present paper indicate that the conclusions drawn by Persaud in [10] are not well founded.

Materials and methods

In the experiments made by Persaud only 7 subjects were examined. In our study we examined 37 adult subjects (7 female and 30 male). The mean age of participants in our experiment was 26.5 years (min = 21, max = 68, standard deviation = 10.68).

The experimental method was designed in such a way as to precisely replicate the procedure employed by Persaud, but also some areas of experiments were improved to obtain more reliable results. The subjects were not allowed to ask any question before and during the experiment in order to ensure that every subject had the same knowledge about the experiment. The subjects were asked to generate and dictate aloud a sequence of numbers chosen in the way they perceived as random. The base set was digits "0" to "9". The subjects were told, to generate numbers until they would like to stop. Participants were not given any hints about what length of the sequence is expected nor how long should they keep dictating numbers. Therefore, when the generation of random digits lasted less than 10 min, the sequence was recorded and the subjects were asked to continue generating numbers until the full time of experiment reached 10 min. All experiments were recorded by the computer and were then processed program developed for that purpose.

Results

The lengths of the sequences of random numbers generated by examined subjects were investigated. The voluntarily generated sequences had the length in range 2–922 (average = 269, standard deviation = 325), while the length of entire sequence of numbers (generated during 10 min) was in range 127–1202 (average = 637, standard deviation = 220). The differences among sequence lengths (and in turn, among rates of generation) was considerable. Together, all subjects generated 9953 digits voluntarily and 23,569 digits in total, which corresponds to approximately 10 kB and 24 kB of information. The sequences of random numbers obtained during 'voluntary' part of experiment were significantly shorter than the ones reported by Persaud [10] (in our experiment average length was 269, Persaud reports 387). We did not observe any appreciable difference in the quality of randomness in the sequences of voluntary and non-voluntary (10-min dictation) sequences.

In experiments conducted by Persaud [10] as well as in ours, the mean frequency of any digit, in the sample consisting of all data collected, was close

to that found in ideal random number distribution, or the one generated by computer program (4.5 for computer generator, 4.501 for Persaud experiment and 4.533 for our experiment in full sequences – during 10 min of experiment, 4.537 for voluntary sequences). It suggests that in the whole long sequence generated by all examined subjects all 10 digits were distributed equally. In spite of this uniform distribution of digits we may not conclude that the examined sequences are truly random. The averaging process caused that favouring of different digits by individual subjects was not reflected by such results. It seems, that on the basis of this result, Persaud has drawn very strong conclusion.

Even though overall distribution of the digits was uniform the individual subjects were not random, what we have proven by investigating more closely the obtained data. The same could probably also be done for the data collected by Persaud.

The obtained results of experiments examining human abilities to generate random number sequences were investigated using different factors determining the randomness of sequences. The average relative frequency of pairs of the neighbouring digits in the sequences a, b , where $a = b$ (10% expected for a ideally random sample) was (in the case of full sequences): 7.577%; for pairs, where $a = b + 1$ (9% expected for an ideally random sample) it was 15.443% and for pairs, where $a = b - 1$ (9% expected for an ideally random sample) the average frequency was 16.912%. The corresponding average frequencies in voluntarily generated sequences were 7.584%, 15.442% and 16.925%. These results allow us also to conclude, that the ability of the subjects to generate random digits did not improve nor degrade after the period of voluntary generation.

The factors presented above clearly revealed that subjects examined in our experiments performed poorly as random number generators. We could have easily observed favored digit pairs; the natural sequences of digits and “reverse-natural” sequences were more frequently articulated. The pairs where the adjacent digits had the same value were less frequent than are expected in the random sequence. This can be interpreted as an “overcorrection”, which inhibits “non-random” subsequences so strongly that their occurrence rates become smaller than in the ideally random sequence.

The obtained sequences generated by examined subjects were compared with the pseudorandom sequences produced by computer programs, which are sufficiently close to random sequences for the purpose of this study. This comparison revealed that none of the results obtained by human subjects were truly random.

It should be mentioned that, while majority of subjects in experiments had science or engineering background, we also had some people having less hard science exposure. The results obtained were so different that one might regard people with background in hard science as different species.

Discussion

On the basis of our experiments we found that the conclusions drawn by Persaud [10], that human subjects are able to generate random sequences, do not hold. Even though our experiments were conducted using the same method, the obtained statistical results differ significantly from those achieved by Persaud.

The mean values of different parameters used to measure the randomness cannot be considered proof of randomness of individual subjects. We think that our experiments proved conclusively, that humans could not be treated as good random number generators.

Literature reports indicate that people with mental disorders have impaired abilities to generate random sequences [6,7,14], but it does not mean that healthy subject are able to generate ideally random sequences.

Having dealt with experimental results presented in [10], now it is the time to discuss hypothesis contained in that paper. However, the implications of experimental evidence that humans are not good number generators have more consequences than just negating or disproving hypotheses contained in [10].

First, we observe that sample size considered in [10], and in fact also in our study, was far too small to allow for any positive conclusions on randomness quality as required in by modern complexity based cryptography, see [15]. However, opposite reasoning is possible: in our experiments we have shown that even relatively short sequences of generated random are biased to an extend that disqualifies them from cryptographic applications. In the context of cryptographic protocols this topic was further evaluated in [16].

In [10] it was suggested that random number generation by humans could be “a potential test of purportedly intelligent machine”. We assume that the author was thinking about some type of a Turing Test [17], (also see [18] for more popular treatment of the topic). The experimental evidence disproves the above option. We found that random sequences generated by humans are much “weaker” (more biased) than the ones generated by standard software libraries. However, this still

allows to differentiate computers from humans using the so-called Reverse Turing Test: “the standard form of reverse Turing test is the one in which the subjects attempt to appear to be a computer rather than a human” [19]. In our case one could pass Reverse Turing Test if one can generate random sequences with the quality that matches the one attributed to computers at present.

The next important issue is whether random numbers are generated in brain by arithmetical operations. We cannot be sure whether these operations have arithmetic character, but on the base of experimental data we believe that they are somehow algorithmic. One piece of evidence is the presence of certain numbers favored by some subjects or much different performance of subjects trained to think in the algorithmic or systematic way.

Finally, as for the issue of free will and agency, we think that experimental evidence, neither contained in [10] nor collected by us, permits to conclusively settle that topic. We observe that the above issues are also linked with much more fundamental question: does randomness exists in Nature? We conclude recalling the saying by Ueli Maurer (Professor at ETH Zurich, expert in cryptography and randomness.) that if randomness in Nature does not exist then telepathy is possible, so one can read other’s person’s mind in advance. In our setup it means that generated number would be read before articulated.

Acknowledgements

The authors thank Agnieszka Kozubek for her help in preparation of some of the computer programs used in this study. We also express our thanks to Karina Piwarska and Wojciech Erbetowski for their help in conducting the experiments and processing of the data. Many thanks go to students and staff participating in Summer Research Lab Project 2005 and 2006, for the volunteering to be “guinea pigs” and not asking too many questions that inevitably would spoil the experiments. Last but not least our sincere thanks go to prof. Tim Pedley, Kiran Singh and Tobias Locsei from biomechanics group at Department of Applied Mathematics and Theoretical Physics, for inspiring discussions.

References

- [1] Baddeley AD. Exploring the central executive. *Q J Exp Psychol* 1996;49A:5–28.
- [2] Baddeley AD. Is working memory still working? *Eur Psychol* 2002;7:85–97.
- [3] Baddeley AD. The capacity for generating information by randomization. *Q J Exp Psychol* 1966;18:119–29.
- [4] Baddeley AD. Working memory. Oxford: Oxford University Press; 1986.
- [5] Linden van der M, Beerten A, Pesenti M. Age-related differences in random generation. *Brain Cogn* 1998;38:1–16.
- [6] Brown RG, Soliveri P, Jahanshahi M. Executive processes in Parkinson’s disease – random number generation and response suppression. *Neuropsychologia* 1998;36(12):1355–62.
- [7] Brugger P, Monsch AU, Salmon DP, Butters N. Random number generation in dementia of the Alzheimer type: a test of frontal executive functions. *Neuropsychologia* 1995;34(2):97–103.
- [8] Daniels C, Witt K, Wolff S, Jansen O, Deuschl G. Rate dependency of the human cortical network subserving executive functions during generation of random number series – a functional magnetic resonance imaging study. *Neurosci Lett* 2003;345:25–8.
- [9] Joppich G, Däuper J, Dengler R, Johannes S, Rodrigues-Fornells A, Münte TF. Brain potentials index executive functions during random number generation. *Neurosci Res* 2004;49:157–64.
- [10] Persaud N. Humans can consciously generate random number sequences: a possible test for artificial intelligence. *Med Hypotheses* 2005;65:211–4.
- [11] Schneider S, Joppich G, van der Lugt A, Däuper J, Münte TF. Brain potentials and self-paced random number generation in humans. *Neurosci Lett* 2004;367:51–5.
- [12] Jahanshahi M, Profice P, Brown RG, Ridding MC, Dirnberger G, Rothwell JC. The effects of transcranial magnetic stimulation over the dorsolateral prefrontal cortex on suppression of habitual counting during random number generation. *Brain* 1998;121:1533–44.
- [13] Jahanshahi M, Dirnberger G. The left dorsolateral prefrontal cortex and random generation of responses: studies with transcranial magnetic stimulation. *Neuropsychologia* 1999;37:181–90.
- [14] Pollux PMJ, Wester A, Haan EHF. Random generation deficit in alcoholic Korsakoff patients. *Neuropsychologia* 1995;33:125–9.
- [15] Goldreich O. Foundations of cryptography. Cambridge: Cambridge University Press; 2001.
- [16] Kulesza K. Can Alice and Bob be random: a study on human playing zero knowledge protocols, submitted for publication. Available from: <http://arxiv.org/abs/0708.3230>.
- [17] Turing A. Computing machinery and intelligence. *Mind* 1950;LIX(236):433–60.
- [18] Wikipedia editors, Turing test, <http://en.wikipedia.org/wiki/Turing_test> [accessed 18.02.07].
- [19] Wikipedia editors, Reverse Turing test, <http://en.wikipedia.org/wiki/Reverse_Turing_test> [accessed 18.02.07].