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Humans can consciously generate random number sequences: A possible test for artificial intelligence

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Summary Computer algorithms can only produce seemingly random or *pseudo*random numbers whereas certain natural phenomena, such as the decay of radioactive particles, can be utilized to produce truly random numbers. In this study, the ability of humans to generate random numbers was tested in healthy adults. Subjects were simply asked to generate and dictate random numbers. Generated numbers were tested for uniformity, independence and information density. The results suggest that humans can generate random numbers that are uniformly distributed, independent of one another and unpredictable. If humans can generate sequences of random numbers then neural networks or forms of artificial intelligence, which are purported to function in ways essentially the same as the human brain, should also be able to generate sequences of random numbers. Elucidating the precise mechanism by which humans generate random number sequences and the underlying neural substrates may have implications in the cognitive science of decision-making. It is possible that humans use their random-generating neural machinery to make difficult decisions in which all expected outcomes are similar. It is also possible that certain people, perhaps those with neurological or psychiatric impairments, are less able or unable to generate random numbers. If the random-generating neural machinery is employed in decision making its impairment would have profound implications in matters of agency and free will.

Introduction

The generation of random numbers is of practical importance in industrial and academic settings. Tables of random numbers are used for a variety of purposes including numerical methods of integration (such as the Monte-Carlo method), randomising of experiments, testing of computer programs and cryptographic key generation. One common method of random number generation employs computer programs which are started or ''seeded'' with a number that is then mathematically manipulated and, perhaps after many iterations, a string of digits is produced. The problem with this method is that it is based on mathematical operations and therefore, the sequence of apparently random numbers produced can always

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be predicted or codified (and are, therefore, referred to as *pseudo*random). There also exist mechanical or observational methods of producing random numbers by exploiting what is referred to as ''source entropy'' in natural phenomena. For example, the time interval between successive emissions of particles from a radioactive substance is truly random and cannot be either predicted or codified. Measuring these intervals gives a series of truly random numbers. Recently, several creative groups have attempted to use the interval between keyboard strokes or the number of visits to websites to generate random numbers, and these numbers have passed various tests of randomness [1]. Human behaviour and neural function clearly influences the latter methods of random number generation but only in an indirect and unconscious manner.

Humans can consciously produce a series of seemingly random numbers in response to a command. The question addressed herein is whether those numbers are merely pseudorandom or if those numbers are truly random (such as those produced by the decay of radioactive particles). Also discussed are the possible neural substrates involved in the conscious production of random numbers. Randomness is defined throughout in the common usage of the word, which is the absence of predictability or order.

Methods

Subjects were all adults who spoke English as their first language and who had no known neurological or cognitive impairments. Ages ranged from 21 to 54 years old with four male and three female participants. Subjects were given the instructions, ''Continue generating and dictating a sequence of random numbers, using the digits 0–9, until you would like to stop.'' Subjects were not told what ''random'' meant, nor were they allowed to ask questions. Further, each subject denied any formal training or particular interest in the fields of chaos, dynamics, cryptography or random number generation. Random numbers were transcribed immediately by the experimenter on a personal computer and sessions were audio-recorded. Subjects were allowed to proceed at a pace of their choice. Experiments were performed at room temperature and the ambient noise was kept to a minimum. No feedback was given to the subject during sessions. The subjects were not interrupted during sessions and once the subjects stopped, the session was concluded.

The string of generated numbers was analysed for uniformity, independence and information density [1]. A χ^2 test was used to compare expected and observed frequencies of occurance of each digit. Independence was tested by comparing the occurrence of a given digit to the occurrence given the previous digit. That is given the preceding number was a three, the probability that the subsequent number will be a zero, one, two, ..., or nine was calculated and compared. The serial correlation coefficient was also calculated.

Results

Subjects generated between 332 and 531 numbers with a mean of 387 ± 22, for a total of 2709 digits generated by all subjects combined. No subject reported any difficulty or discomfort during a session. In fact, two subjects had difficulty controlling their laughter, especially early in the session. The rate of number generation declined throughout sessions, beginning at 105 digits per minute in the first minute and falling to 96 digits per minute during the last minute.

The mean of the generated numbers was 4.501293 while for a truly random string of numbers the expected mean would be 4.5 exactly. For the χ^2 test, the expected values for the frequency of each digit appearing was the total number of digits divided by 10 (270.9). The χ^2 value n of 0.9825 which is very close to one suggests uniformity of distribution, that is, each digit was represented equally. The serial correlation coefficient of 0.0231 which is close to zero implies a lack of dependence of successive digits. This is supported by the lack of significant difference between the occurrence of a given digit and the probability of that digit given the preceding one (student's t-test p value of 0.65). The entropy value of 7.974 bits per character which is close to eight suggests a lack of pattern in the generated data. The sequence was also tested for duplication (expect consecutive repeats in one out of every 10 pairs of consecutive numbers) and summation (expect the sum of consecutive pairs of digits to be odd as often as it is even).

Discussion

These results suggest that humans can generate a string of random digits that are uniformly distributed and have no pattern. Although the sample size was quite small, no evidence was found that the generated numbers were not uniformly distributed based on the χ^2 measure. Even the digit zero was equally represented despite the fact that it is not a natural number. No subject showed a tendency to favour a certain digit over others. Perhaps this is surprising given that people report having ''favourite numbers''. The issue of independence is particularly relevant for random numbers produced by humans. For example, one might expect that when trying to create a string of random numbers, subjects might be biased against repeating the same digit twice in succession. Remarkably, no such bias was observed and subjects repeated a digit at a frequency that is not suggestive of a genuine bias.

Instead of being asked to produce numbers between zero and nine, subjects could have been asked to produce a string of binary numbers (i.e., ones and zeroes), or to choose between two options (e.g., up and down, or red and blue) and these choices could have been mapped to binary numbers. The results could have been different, especially since the frequency of duplications would be greater.

Related methods for the unconscious generation of random numbers by humans include measuring the interval between mouse clicks and keyboard strokes. While the subject is not intentionally attempting to create randomness, randomness in some aspects of neural functioning presumably underlies the randomness in movement. Randomness in these types of movements suggest random variation in the activity of one or more of the motor cortex, premotor cortex, basal ganglia, cerebellum, or other areas involved in motion. This type of random number generation is confounded by potential randomness or unpredictability in the activation of spinal cord and peripheral motor neurons as well as muscle fibres, and perhaps even the unpredictability of bone and connective tissue movement. It might appropriate to think of this type of random number generation as mechanical.

For the conscious production of random numbers that are dictated orally, presumably the only source of randomness is in the brain. The precise physiological substrate of this ''source entropy'' is unknown, but arithmetical operations involve the prefrontal, premotor and parietal cortices bilaterally [2—9]. Perhaps these same areas are activated during conscious random number generation as number manipulation may be involved in some way. However, since the produced numbers seem to be truly random it is likely that they are not produced by arithmetical operations, as is the case for computer algorithms. Other brain regions involved in memory, mathematics and language production (e.g., Broca's area) might also be reasonably expected to be activated. The occipital lobe may also be involved in this type of task [10], and it is interesting to note that subjects tended fix their gaze at a certain object during sessions.

It is also noteworthy that subjects did not find the task of generating random numbers difficult. Most subjects reported that they ''did not have to think about what [they were] doing''. Numbers seemed to be generated effortlessly, even towards the end of sessions. The reason for the cessation of sessions was usually boredom and not fatigue or mental stress. Also, at the rate numbers subjects chose to generate numbers it seems unlikely that they were ''filtering'' or verifying that the numbers were random before verbalization. Perhaps this is important, and if subjects had ''filtered'' numbers before dictation the results may have been different. In fact, after their session, two subjects expressed concern that there was a pattern in their generated numbers and that they likely were not random (after analysis the numbers generated by these subjects was indistinguishable from the those of the other subjects). These subjects denied having such thoughts during the session, but perhaps if they had the results would have been affected. The effect of worrying about producing truly random numbers while doing so is an issue unique to humans.

If humans can generate truly random numbers, one might ask if this ability is uniquely human. For instance, artificial neural networks might be expected to be capable of producing truly random numbers if they are accurate models of the human brain. Random number generation is a potential test of purportedly intelligent machines. It will be interesting to see if connectionist networks or parallel distributed processing models, which claim to operate in ways analogous to the brain, are able to produce truly random numbers.

The fact that humans can produce random numbers also raises important questions related to decision making and free will. It is possible that humans use the same neural machinery to generate random numbers as they do to make ''difficult'' decisions for which each alternative is very similar. If these decisions are made randomly by an unconscious mechanism then responsibility and agency must be questioned. It is also possible that patients suffering from certain neurological deficits are unable to consciously generate random numbers. For example, schizophrenia patients may be less able to generate random number sequences because they are ''distracted'' by external stimuli. Random number generation tests may thus be a useful diagnostic tool or index of impairment. Also, if certain people have impaired random generators they may also have impaired, or at least different, decision-making capabilities. This finding would have profound implications in questions of agency, free will and criminal responsibility.

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