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Implicit learning of sequential bias in a guessing task: Failure to demonstrate effects of dopamine administration and paranormal belief ☆

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Abstract

Previous research suggests that implicit sequence learning (ISL) is superior for believers in the paranormal and individuals with increased cerebral dopamine. Thirty-five healthy participants performed feedback-guided anticipations of four arrow directions. A 100-trial random sequence preceded two 100-trial biased sequences in which visual targets (arrows) on trial t tended to be displaced 90° clockwise (CW) or counter-clockwise (CCW) from those on $t - 1$. ISL was defined as a positive change during the course of the biased run in the difference between pro-bias and counter-bias responses. It was hypothesized that this difference would be greater for believers in the paranormal than for skeptics, for those who received dopamine than for those who received placebo, and for believers who received dopamine than for the other groups. None of the hypotheses were supported by the data. It is suggested that a simple binary guessing task with a focus on prediction accuracy during early trials should be considered for future explorations.

Keywords: Implicit sequence learning; Response bias; Dopamine; Belief; Feedback

1. Introduction

With experience over time, people are increasingly able to make predictions about the outcome of future events. In everyday situations, many events follow one another on a probabilistic basis rather than according to a fully predictable scheme. It is thus by ‘‘intuitive statistics’’ that an individual uses previous experiences to decide about the likelihood of future events. The behavioral sciences have relied on variations of guessing

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behavior as paradigms to systematically study these inferential processes. Explicit probability learning, prediction tasks and the (implicit) learning of sequential constraints are among these paradigms (e.g., Bischoff-Grethe, Proper, Mao, Daniels, & Berns, 2000; Critchley, Mathias, & Dolan, 2001; Elliott, Rees, & Dolan, 1999; Hake & Hyman, 1953; Huettel, Mack, & McCarthy, 2002; Seidenberg, 1997). The latter two methodologies both require participants to make a decision about a current stimulus, and decision accuracies (and, in many studies, response latencies; e.g., Peigneux et al., 2000) are analyzed as a function of previous stimuli and previous decisions, respectively. Results from these studies demonstrated that humans exploit past experience with the statistical structure of stimulus sequences for successful inferences about future events. Importantly, the sources of this acquired knowledge remain concealed to the participants themselves, that is, they claim to ''just guess'' and remain unaware of any mediating information acquisition (Reber, 1993; Stadler & Frensch, 1998).

A number of investigations have illuminated the functional neuroanatomy underlying implicit sequence learning (ISL). Clinical studies have shown impaired ISL in patients suffering from degenerative disorders involving lesions of the basal ganglia, primarily Parkinson's disease (see Siegert, Taylor, Weatherall, & Abernethy, 2006; for overview), but also of other structures mediating the learning of motor sequences (Ackermann, Daum, Schugens, & Grodd, 1996; Doyon, Laforce, Bouchard, Gaudreau, & Roy, 1998). Work with healthy participants supports the view that ISL depends also on striatal functioning (Peigneux et al., 2000) as well as on functions of the prefrontal cortex (Huettel et al., 2002). The ventromedial prefrontal cortex might particularly be involved in the evaluation of the consequences of a behavioral response, as this part of the brain plays a crucial role in monitoring the violations of an expected pattern and thus appears to be the primary site of feedback evaluation (Huettel et al., 2002; see Ivry & Knight, 2002; for further references).

The striatal brain regions implicated in the process of sequence learning are strongly innervated by dopamine containing neurons (see Hikosaka, Takikawa, & Kawagoe, 2000 for overviews). Furthermore, predictive behavior in a feedback situation involves the brain's ''reward system'', since feedback about a correct prediction constitutes a reward and feedback about incorrect predictions a sort of punishment (Dehaene & Changeux, 2000; Elliott, Frith, & Dolan, 1997). Apart from the close link between dopamine and the reward system in animals and man (see Schultz, 2000; for an overview), it is the *anticipation of reward* (rather than the reward itself) that triggers dopamine release in subcortical pathways (Schultz, Dayan, & Montague, 1997; Spanagel & Weiss, 1999). Moreover, dopamine-containing cells in the monkey brain have been found to increase their firing rate before a highly probable, but not before a certain reward is provided (Schultz et al., 1997). Together, these findings indicate that dopamine is centrally involved in the predictive behavior of uncertain events; in simple terms, dopamine mediates guessing.

One implication of the increasing literature on ISL concerns a field of enquiry that is associated by some researchers as one with a revolutionary potential (e.g., Radin, 1997), and by others as a mere pseudoscience (e.g., Alcock, 1990). We are referring to parapsychology, which includes the study of extrasensory perception (ESP). It has been suggested (Gatlin, 1977; Brugger & Taylor, 2003) that above-chance guessing, interpreted by parapsychologists as ESP, might rather reflect the natural tendency of participants to exploit feedback information if the target sequences are not adequately random. Specifically, participants in a guessing task with trial-by-trial feedback learn to adjust their guesses to the biases contained in target sequences by the information provided in the feedback. Empirical evidence for this contention comes from research by Colwell, Schroder, and Sladen (2000). In their first experiment on the ''sense of being stared at'', participants who were either being stared at or not stared at by a remote observer completed a serial guessing task. Above chance scoring was found only in staring trials in which participants received immediate feedback of the correctness of each guess. However, subsequent testing for local regularities in the target sequences revealed more alternations between staring and non-staring trials than theoretically expected, that is, the sequence to be guessed contained a typical element of subjective randomness (Brugger, 1997). In a replication experiment using true random sequences, no differences in accuracy from mean chance expectation were obtained. The authors concluded that the improvement in accuracy during staring episodes was due to the detection and response to local structure (i.e., an under-representation of repeats) present in the target sequences, rather than to an increased ability to detect staring. In other words, the findings by Colwell et al. (2000) suggest that an increased accuracy for staring episodes was due to ISL rather than ESP.

However, it should be noted that this criticism does not apply to all successful ESP studies with trial-by-trial feedback. In at least two studies, the source for the targets was shown to be adequately random in comparable control tests (Honorton, 1987; Vassy, 1986). A thorough test of the target sequences themselves in the extensive precognition experiments of Schmidt (1969) showed them to be satisfactorily random (Palmer, 1996).

The studies by Colwell et al. (2000) mainly challenged the so-called ‘‘sheep–goat effect’’ (Schmeidler & McConnell, 1977), which states that believers (‘‘sheep’’) in ESP score higher in guessing tasks than skeptics (‘‘goats’’). This effect is one of the most robust findings within parapsychology (Lawrence, 1993; Palmer, 1971). However, contrary to the design of Colwell et al. (2000), the sheep–goat effect is based on studies that do not employ feedback about the accuracy of the guesses. The veridicality of the sheep–goat effect has also been challenged by suggesting that believers in the paranormal are more likely than skeptics to see patterns in stimulus conglomerations that are in fact purely random, such as photographs partially degraded by electronic noise (Blackmore & Moore, 1994) or two-dimensional random dot patterns (Brugger et al., 1993). In terms of signal detection theory (Tanner & Swets, 1954), this means that belief in the paranormal appears to be associated with a low response criterion. In fact, the higher than normal hit rate in sheep as compared to goats was mainly observed for ‘‘yes’’ but not ‘‘no’’ answers in the study by Colwell et al. (2000). The relevance of such data to ISL arises from the plausible although not demonstrated assumption that *attribution* of patterns to patternless stimulus sequences is positively associated with the implicit *detection* of those that are in fact contained in the sequences.

The data and theorizing discussed above suggest that both dopamine and belief in the paranormal could be associated with improved ISL. We tested this assumption in a guessing task with participants who were either strong believers in ESP or strong skeptics. In a double-blind procedure, half of the participants received levodopa (a precursor substance of dopamine regularly administered to patients with Parkinson's disease), and the other half received a placebo. Participants had to guess in which of four directions on a computer screen (up, down, right, and left) an arrow would point. Feedback was provided by presenting the arrow pointing in one of the four directions according to a predetermined sequence. Each participant performed 3 runs. Whereas the 1st run always had a random target sequence (and no ISL could thus take place), the 2nd and 3rd runs had sequences that contained experimenter-introduced target biases, one in the clockwise direction and the other in the counterclockwise direction.

We proposed 3 hypotheses for the experiment: (1) believers in ESP will show more evidence of ISL than skeptics, (2) individuals who received levodopa will show more evidence of ISL than those who received a placebo, and (3) improved ISL is particularly enhanced in believers in ESP who also received levodopa. This final hypothesis is based on findings from the psychiatric and psychopharmacological literature that psychotic-like and magical beliefs might underlie a higher than normal cerebral dopaminergic system (see Mohr, Landis, Sandor, Fathi, & Brugger, 2004; Mohr, Sandor, Landis, Fathi, & Brugger, 2005 for overviews).

2. Methods

2.1. Participants

Physically and mentally healthy right-handed males between 20 and 40 years of age were enrolled in the study. Individuals were recruited by flyers posted at the University of Zürich and bookstores or shops in the University district, by an advertisement in a local newspaper, and by a call to a local radio station. The recruiting material introduced the study as an ‘‘experiment in neuropsychology assessing the role of dopamine on cognitive functions’’. It mentioned that each participant may or may not receive dopamine and that in any case blood samples would be taken. An unspecified fee was announced as reimbursement. Critically, the material used to recruit believers in ESP listed as an inclusion criterion the phrase ‘‘*You do not only consider extrasensory perception a theoretical possibility but you think you are using your own paranormal abilities in everyday situations*’’ (without further justification of why this was a requirement). A standardized telephone interview excluded those persons with a personal or first-degree family history of neurological and psychiatric disease as well as serious learning disabilities and drug abuse (cf., Campbell, 2000). In view of the association of claimed paranormal abilities, especially ESP, and temporal lobe epilepsy (Neppe, 1983; Sadler & Rahey, 2004), occurrence of previous seizures was specifically inquired about (none was reported). Casual consumption of THC was not considered an abuse, provided that the time since last consumption was more than 2 months. Persons meeting all inclusion criteria were sent a brief information brochure (by regular mail) about the role of dopamine in the central nervous system, including potential side effects if it were taken at high doses. This brochure also described the task as one that required the prediction of a series of events presented on a computer screen. It also mentioned the requirement to fill in several questionnaires, as well as the approximate duration of the session (''one to two hours'') and the financial reimbursement (50 Swiss Francs, about 40 US Dollars).

After the final selection of 20 participants (''believers''), a new version of the flyer was posted at similar locations. It was identical to the first flyer, except that the passage referring to belief in the paranormal stated: ''*You have a skeptical attitude toward so-called 'paranormal' phenomena and do not generally believe in the existence of or have experienced extrasensory perceptions like telepathy, clairvoyance and precognition*''. Initial telephone interviews and information about the study were the same as described above. This solicitation yielded 20 ''skeptics'', who were matched to the believers with respect to age and educational background.

2.2. Questionnaires

Prior to the test session, participants were mailed copies of three questionnaires, which they completed and brought with them to the session. Handedness was assessed by a brief inventory developed by Chapman and Chapman (1987). Two questionnaires were used to assess participants' experiences of and attitude toward paranormal phenomena. The *Australian Sheep–Goat Scale* (ASGS) is an 18-item paranormal belief scale presented in a visual analog format (Thalbourne & Delin, 1993). This instrument (revised form; our translation) was considered especially relevant for this experiment as it assesses not only participants' *belief* in paranormal phenomena (specifically telepathy, clairvoyance, precognition and psychokinesis), but also their own relevant experiences. Each item is scored from 0 to 13, giving a possible range of 0–234. The *Magical Ideation* (MI) *Scale* is conceptualized as an indicator of schizotypy (Eckblad & Chapman, 1983; normative data in Garety & Wessely, 1994). Consisting of 30 true/false items, it requires participants to indicate their belief in a range of paranormal phenomena, including telepathy and precognition but also spanning the topics of extraterrestrial life and contacts with the deceased. Pronounced MI and analogous measures of schizotypy are reportedly associated with elevated scores on questionnaires assessing belief in supernatural or paranormal phenomena (Wolfradt & Straube, 1998), and with specific performance patterns in neuropsychological and electrophysiological tasks (e.g., Barnett & Corballis, 2002; Brugger & Graves, 1997a; Brugger & Graves, 1997b; Leonhard & Brugger, 1998; Mohr, Bracha, & Brugger, 2003; Pizzagalli, Lehmann, & Brugger, 2001; Taylor, Zäch, & Brugger, 2002; Tsakanikos, 2004; Weinstein & Graves, 2002).

2.3. Substance administration

Participants had been told not to consume any alcohol or medications for at least 24 h before testing, and to refrain from any food-intake between noon and the beginning of the experiment at 3:30 p.m. Compliance with these requests was 100% by self-report. After having provided informed consent, participants in the levodopa group were administered a dual-release formulation of 200 mg levodopa/50 mg benserazide (Madopar® DR, Roche Pharma AG, Reinach, Switzerland), with fast absorption during the first hour and sustained concentration levels thereafter (Gasser, Jorga, Crevoisier, Hovens, & van Giersbergen, 1999). Also following informed consent, participants in the placebo group received 1 tablet of Berocca® (Roche Pharma Switzerland), a multivitamin preparation containing Vitamin-B1, -B2, -B6, -B12, Nicotinamid, Pantothenic Acid, Biotin, Vitamin-C, Folic Acid, Calcium, Magnesium and Zinc. All participants consumed 200 ml water directly after substance administration. The experimenter left the room during intake of the substance. After 30 min and before the experiment started, a blood sample (about 5–7 ml) was collected. As soon as behavioral testing was completed (about 120 min after the first blood sample had been taken), a second sample was drawn. For further details on blood sampling and analysis, see Mohr et al. (2004).

2.4. Prediction task

2.4.1. General procedure

Participants were told that the computer would randomly select one of the four directions on each trial. They were required to predict the direction of the next arrow in the target sequence by pressing with the right hand one of four response keys, marked with an arrow for each direction and located on the right side of the computer keyboard (see Fig. 1). After participants' predictions, immediate feedback was provided by highlighting the computer-selected "correct" arrow for 2 s. Although prediction times were not limited, the spontaneity of each decision was emphasized. Whenever participants' guesses matched the computer's choice, the word "hit" overlaid the arrow; otherwise the German word "schade" (too bad) appeared. The experiment was controlled by "Superlab Pro 2.01" software.

2.4.2. Three independent guessing sequences

Each participant completed 3 runs with 100 guesses each. A different sequence of target directions was used for each run. The sequences were generated using a self-written computer algorithm and *Fortran* software. In all three target sequences, the four different arrow directions occurred equally often (25 times). In the 1st run, the distribution of the 25 targets was randomly permutated. The remaining two sequences followed a fixed bias, such that the direction of the arrow in trial t depended statistically on the direction of the arrow in trial $t-1$. Specifically, one of the biased sequences was characterized by a 90° clockwise rotation of consecutive arrow directions (CW), whereas the other was characterized by a 90° counterclockwise bias (CCW). The experimenter was outside the room during the completion of the test runs and thus could not give indications to the participants about the order and nature of the different target sequences.

Optimal values for the degree of bias in the biased sequences had been determined by a pilot study ($N = 12$) designed to guarantee (1) unawareness of the bias on a verbal level in most of the participants, and (2) the occurrence of implicit learning of the bias in a majority of the unaware participants. The pilot-study participants were not preselected for belief/disbelief in the paranormal. Following the psychophysical method of limits, the sequential biases (CW and CCW, respectively) were increased or decreased until performance of an individual participant revealed implicit but not explicit sequential learning. Immediately after receiving a random run followed by a biased run, participants were asked in an extensive open-ended interview about their guessing strategies, in order to determine whether they had been aware of any sequential bias and, if so, at what point during the run(s) they had noticed a pattern. The optimal values determined by this process were 46.5% of the trials in the pro-bias direction (for example, clockwise in the CW run) and 10.1% in the counter-bias direction. The two other alternatives each appeared an average of 21.7% of the time.

Participants were not informed about how many trials were in a run but just told that it would last approximately 7 min. Prior to the experiment, all participants received 10 "practice trials" (discarded from analysis) and were then left alone in the experimental room until all 3 runs had been completed. The 1st run was always the random run; the 2nd and 3rd runs were either CW or CCW, the order counterbalanced between participants. Immediately following the test session, participants were asked whether they believed they were given a placebo or levodopa. They were also asked extensively about their response strategies, such as whether they "discovered any 'system' in the presentation of arrows", or whether they used any particular guessing strategy.

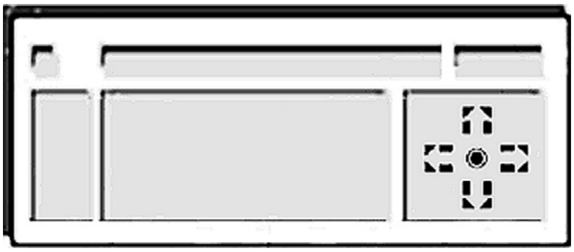

Fig. 1. Response keys on the computer keyboard.

3. Results

3.1. Sample

The post-experimental interview revealed that 4 participants explicitly recognized the sequential manipulation. Two were from the placebo group (1 believer, 1 skeptic) and 2 from the levodopa group (1 believer, 1 skeptic). Another participant (skeptic, placebo) ignored the instruction to respond spontaneously and without an obvious pattern. His responses were highly perseverative: 59.9% were repetitions of the same motor prediction as the feedback in the previous guess, a value more than two *SD*s above the group mean. These 5 participants were excluded from the analyses, reducing the final sample size to 35.

Believers scored higher than skeptics on both the ASGS, $M = 168.72$ vs. 38.00, $t(33) = 13.1$, $p < .001$ and the MI scale, $M = 19.94$ vs. 3.59, $t(33) = 15.1$, $p < .001$. The two groups did not differ with respect to age, $t(33) = 0.1$ or education, $t(33) = 1.74$.

The blood tests revealed no levodopa in the placebo group. In the levodopa group, the mean levodopa serum concentration was 159.8 ± 144.4 ng/ml for the first blood sample and 208.4 ± 106.7 ng/ml for the second blood sample, $t(16) = 1.04$. A similar number of participants had higher levodopa concentrations in the 1st ($n = 8$) and 2nd ($n = 10$) samples, $\chi^2(1, N = 18) = 2.22$. None of the participants reported remarkable side effects, and none could reliably guess whether they had received levodopa or a placebo.

3.2. Results of the guessing task[1]

For the two biased runs separately, the number of pro-bias and counter-bias predictions were calculated. For instance, predicting "DOWNWARD" after the previous target was "RIGHTWARD" was scored as a pro-bias guess in the CW run, but a counter-bias guess in the CCW run. The number of pro-bias minus the number of counter-bias predictions thus reflected participants' tendency to adjust the sequential structure of their guesses to that in the target sequence. Because the 1st trial of each run could not be scored (there is no prediction preceding the very first prediction), there were 99 total scored trials per run. Because learning implies an improvement of this relative pro-bias responding (rPBR) in response to the feedback, our ISL-relevant hypotheses were based on the change in rPBR during the course of the run, as represented by an accelerating exponential curve. For each run, a centered moving average of rPBR across trials was computed with a span of 5. The resulting 95 averages were then fit to exponential curves using the curve estimation routine in SPSS. The standardized beta-weights resulting from these analyses were the final measures of ISL.

To test the 3 hypotheses, the rPBR scores from the 2 biased runs were submitted to a mixed ANOVA, with belief, substance, and order of testing (CW–CCW, CCW–CW) as between-subject factors, and run as a repeated measure. The rPBR means for each run for each of the 4 cells defined by belief and substance are illustrated in Table 1.

The 1st hypothesis, that believers in the paranormal would demonstrate ISL more strongly than skeptics, was tested by the belief main effect. The mean rPBR score was .030 ($SD = .233$) for the 18 believers and −.065 ($SD = .213$) for the 17 skeptics. Although in the predicted direction, the difference between the 2 means was not significant, $F(1, 27) = 1.46$. Thus, Hypothesis 1 was not supported.

The 2nd hypothesis, that participants who received levodopa prior to testing would demonstrate ISL more strongly than participants who received a placebo, was tested by the substance main effect. The mean rPBR score was −.026 ($SD = .255$) for the 18 participants who received dopamine and −.006 ($SD = .197$) for the 17 who received placebo. The difference between the 2 means was in the opposite direction from that predicted and not significant, $F(1, 27) = 0.72$. Thus, Hypothesis 2 was not supported.

For the 3rd hypothesis it was predicted that ISL would be greater for believers who received levodopa than for the other groups. Confirmation of the hypothesis would be represented by a significant substance by belief interaction. This interaction did not attain significance, $F(1, 27) = 3.05$. The mean rPBR score for the 9

[1] All *p*-values reported in the paper are two-tailed.

Table 1
Mean standardized beta-weights for relative pro-bias responding (rPBR) for the run as a function of belief and substance

Group	Substance	rPBR (*SD*)—run 1	rPBR (*SD*)—run 2	*N*
Believers	Dopamine	−0.037 (0.324)	0.199 (0.401)	9
Believers	Placebo	−0.128 (0.246)	0.086 (0.291)	9
Skeptics	Dopamine	−0.069 (0.308)	−0.196 (0.366)	9
Skeptics	Placebo	−0.046 (0.348)	0.068 (0.254)	8

dopamine believers was .081 ($SD = .280$). Although in the predicted direction and the highest of the 4 cells, it was not significantly greater than 0, $t(8) = 0.87$. Thus, Hypothesis 3 was not supported.

None of the other interaction effects in the ANOVA were significant.

4. Discussion

By administration of a 4-choice guessing task with trial-by-trial feedback (cardinal directions of an arrow displayed on the computer screen) we investigated whether (1) belief in the paranormal, and (2) an increased cerebral dopamine concentration is related to enhanced ISL, and if so, if this would result in above chance guessing (Brugger & Taylor, 2003; Colwell et al., 2000; Gatlin, 1977). We predicted first that "believers" who are convinced that they use "paranormal abilities" in their everyday life would show a stronger tendency than "skeptics" to unconsciously adjust their guesses to the targets. Second, we predicted that a pharmacologically induced cerebral dopamine increase (levodopa administration) would result in enhanced ISL. This prediction was derived from previous pharmacological studies showing that dopamine boosts implicit learning (e.g., Breitenstein et al., 2004), that dopamine deficiencies impair ISL (Siegert et al., 2006), and also from the link between a cerebral hyperdopaminergia and the generation of paranormal, or rather psychotic-like thoughts (see Mohr et al., 2004; Mohr et al., 2005 for overviews). Third, we predicted that ISL would be particularly enhanced in believers who received levodopa, based on findings from the psychiatric and psychopharmacological literature that psychotic-like and magical beliefs might underlie a higher than normal cerebral dopaminergic system (see Mohr et al., 2004; Mohr et al., 2005, for overviews). None of these predictions were confirmed by the data.

Several reasons may exist for our failure to demonstrate effects of paranormal belief on ISL. First, it was recently shown that healthy participants' attitude towards the learning situation is critical to successful ISL (Fletcher et al., 2005). Specifically, participants who were informed that there was actually a pattern to be detected in the stimulation sequence performed worse than those led to believe they were merely guessing. In our experiment, all participants were told that the computer would randomly select the targets. It may be that believers conceived the prediction task as a test of skill (note that they were selected on the basis of their claimed ability to successfully predict events in everyday life). On the other hand, for the skeptics, it was a mere guessing task. Thus, the "benefit of not trying" (from the title of Fletcher et al.'s study, cited above) may have favored skeptics' ISL and cancelled out any advantage on the part of the believers. Similar effects were described by Snodgrass and Shevrin (2006), who even demonstrated significant inhibition of ISL (i.e., below-chance guessing) in certain conditions of active pattern seeking. Little is known about interactions between skill vs. chance orientations on guessing performance in ISL paradigms, and even less on their possible modification by dopamine.

To summarize, investigations of individual differences in the susceptibility to ISL will be of increasing importance (Norman, Price, & Duff, 2006), and the modification of such susceptibility, whether instructional or pharmacological, is of considerable clinical interest. In future studies testing the relationship between paranormal belief, ISL, and dopamine, it may be indispensable to control for an individual participant's skill/chance orientation to the experimental task. Also, it may be profitable to use a longer stimulus sequence (see, e.g., Breitenstein et al., 2004; whose sequences comprised more than 100 trials, or Peigneux et al., 2000; who presented 12 blocks of more than 400 trials each). On the other hand, a recent study of artificial grammar learning revealed that dopamine depletion manifested itself in an impairment of feedback susceptibility specifically during early phases of a task (Smith & McDowall, 2006). Keeping in mind the successful paradigm used by Colwell et al. (2000), a simple binary guessing task with a focus on prediction accuracy during early trials is strongly recommended for future explorations.

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