Article

Testing the Consciousness Causing Collapse Interpretation of Quantum Mechanics Using Subliminal Primes Derived from Random Fluctuations in Radioactive Decay

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Abstract

Stimulus primes derived directly from patterns in a local source of radioactive decay were flashed on a screen for a duration of time too brief to be consciously experienced. The primes were immediately followed by a presentation of a stimulus symbol that human participants were asked to rapidly respond to. According to the Consciousness Causes Collapse Interpretation of Quantum Mechanics (CCC), because the primes had not yet been exposed to conscious observation, they should continue to exist in a state of superposition based on the radioactive decay from which they were derived. It was hypothesized that if the CCC interpretation were correct, a prime produced in this way should not yield the standard effect on subsequent response times as it would in a control condition in which observation had deliberately occurred beforehand. This hypothesis was supported. The standard effect on response times was found in the observed condition but not in the unobserved condition. The current findings support the CCC interpretation of quantum mechanics.

Keywords: Consciousness, quantum mechanics, wave function, collapse, subliminal prime, test, superposition, observation.

1. Introduction

To make sense of experimental results researchers have postulated different interpretations of quantum mechanics. In the standard orthodoxy, often referred to as the Copenhagen Interpretation, particles exist in a state of superposition, a collection of all possible states described by Schrodinger's wave function, until the act of measurement, at which time the superposition collapses into only one of these possible states. The Copenhagen Interpretation is silent on what actually constitutes an act of measurement or on how or why it collapses the wave function. Unsatisfied with this lack of clarity, other interpretations have emerged that contest the reality of the superposition. For example, the Many Worlds interpretation (Everett, 1957) holds instead that the universe bifurcates every time a measurement is taken on a quantum system, that all the possibilities are actually realized. Other interpretations maintain that nonlocal hidden variables are determining the results of each measurement (Bohm, 1980), or that the collapse of the wave function is a random yet objective process (Ghirardi, Rimini, & Weber, 1986).

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Perhaps the most fantastic interpretation of quantum mechanics is the augmentation to the Copenhagen interpretation suggested by John von Neumann (1932) and Eugene Wigner (1961). This interpretation holds that there is no clear physical end to the superposition, that the mathematics allows for the collapse of the wave function to be placed anywhere on the causal chain from the physical measurement device all the way to the experimenter's subjective perception. In other words, when a particle in superposition interacts with a physical measuring device, it is reasonable to conclude that both the particle under consideration along with the physical measuring device itself are existing in a state of superposition until they are observed by the experimenter. What reason is there to conclude that macrophysical objects persist objectively in time while microphysical objects exist only in superposition? The only clear place to draw the line of collapse is at the point where a physical system interacts with consciousness, something that is outside of the physical reality that is governed by quantum mechanics. This has subsequently become known as the Consciousness Causes Collapse (CCC) interpretation.

In the years since its inception, the CCC interpretation has been further developed by researchers in a variety of disciplines, some using it to make a case for interactional dualism (Beck & Eccles, 1998; Schwartz & Begley, 2002; Stapp, 2003), while others have used it to argue for monistic idealism (Lanza & Berman, 2009). However, the interpretation remains unpopular. A recent poll among working physicists, mathematicians, and philosophers found that only six percent of the respondents thought that the observer had a role in collapsing the wave function (Schlosshauer, Koer, & Zeilinger, 2013). Many consider the CCC interpretation to be unparsimonious and unscientific because it adds nonphysical elements into physics (e.g., Stenger, 1993), furthermore most scientists and philosophers would consider consciousness to be itself entirely a physical process (e.g., Dennett, 1991; Levine, 2001), although this view has been contested by others (e.g., Chalmers, 1995; Nagel, 1974). Nevertheless, interest in the CCC interpretation persists into the present day by researchers who continue to argue that it remains a viable way to interpret quantum mechanics (Chalmers & McQueen, 2021, Kent, 2021).

Although work on the CCC interpretation has been largely conceptual, there have been proposals on how the problem could be resolved empirically. For example, Sebastián & Okón (2016) proposed an experimental paradigm where a physical measuring device is set to measure a particular property of a quantum system at an appointed time in the future and then sealed from conscious view. After the time in which the measuring device was to have taken its reading, they argue that it may be possible for a measurement of a different property of the system to be taken that can determine whether or not the first property continues to remain in a state of superposition. If that superposition were found to persist, they argue, it would provide support for the CCC interpretation. While this route may ultimately be a way to resolve the issue, the specifics of the experimental procedure have yet to be defined in such a way that an experiment can be performed.

Putting the CCC interpretation to an empirical test may require methods that are not limited to those of experimental physics. An interdisciplinary approach that utilizes existing methods in experimental psychology can provide the needed angle. Psychological researchers have developed paradigms that directly pertain to the border of conscious versus unconscious information processing, and have developed objective measures of their effects. The well-established research paradigm of subliminal priming provides a place to start.

In cognitive psychology the term *priming* refers to an effect where exposure to one stimulus influences a person's response to another stimulus. For example, a positive word such as “happy” is recognized and responded to faster after the word “joy” as compared to a negative word such as “sadness” or “death”. The word “up” is responded to faster following a prime such as “high” or “top” as opposed to “bottom” or “low”. Psychologists have been exploiting these reliable reaction time effects for decades as a multipurpose research tool. In recent years, these methods have even been used to prime subjects subliminally (Dehaene et al, 1998; Greenwald et al, 2003; Kouider & Dehaene, 2009). In such research, subjects are flashed a prime (such as a word or a symbol) on a computer screen for a length of time that is just underneath the duration that can be consciously experienced (about 50 milliseconds).

Despite subjects reporting to not be aware of seeing the prime, they demonstrated shorter reaction times responding to stimulus that is congruent with the prime than to incongruent stimulus. Their brains processed the meaning of the prime and began to react to it even though they were not aware of it. The prime was processed unconsciously. Utilizing this apparent ability for humans to process information unconsciously, and for that information processing to be objectively measured through its effects on response time, the CCC interpretation of quantum mechanics can be put to an experimental test. Specifically, this study aimed to create an interaction between a quantum phenomenon and a physical measuring device, and then to subsequently assess whether the phenomenon continued to be in a state of superposition before the data gathered from that physical measuring device had any interaction with consciousness. By looking unconsciously, we should be able to see the superposition without collapsing it.

2. Hypotheses

A sequence of stimulus primes will be derived directly from quantum events without any contact from a conscious observer. According to the CCC interpretation, these primes, having not yet been exposed to conscious observation, will have yet to collapse into an exact state. These primes, still in a state of superposition, will be paired with stimulus items that the participants will be asked to rapidly respond to. The participants' response times will be measured. This experimental condition will henceforth be referred to as the *unobserved condition*.

The primes in the control condition will be prepared identically to the experimental condition, with the exception that the experimenter will view these primes on the computer screen prior to the participant's engagement in the response time task. This will henceforth be referred to as the *observed condition.*

A prime in a state of superposition should not have an effect on response time as it will be simultaneously both congruent and incongruent with the stimulus. Therefore, it is hypothesized that if the CCC interpretation of quantum mechanics is correct the stimulus primes will not have the expected effect on reaction time (reducing it when congruent and increasing it when incongruent) in the unobserved condition as they will in the observed condition.

3. Methods

(1) Stimulus Response Task

The stimulus items were drawn randomly from the set of whole numbers 1-9, where each stimulus item consisted of a single digit. The primes were similarly drawn from the set of whole numbers 1-9, where each prime was also a single digit. Upon viewing the stimulus items the subjects were asked to give an oral response as quickly as possible to each number indicating whether the number was odd or even, by actually saying the words "odd" or "even" into the laptop microphone. The time it took for the participants to respond with their answer was measured automatically by the computer program to an accuracy of 1 millisecond.

For each trial, participants were asked to respond to a set of 80 stimulus items. During the trials the program proceeded automatically through the items with a 1.5 second interval in between each item. Each item began with a forward mask, a nonsense series of symbols that remained on the screen for a duration of 167 milliseconds. This was immediately followed by a prime that remained on the screen for 50.1 milliseconds. The prime was followed by a backwards mask (a different series of nonsense symbols) that remained on the screen for a duration of 33.4 milliseconds, followed by the presentation of the stimulus symbol, which remained visible for a duration of 1,200 milliseconds or until the participant responded by speaking the words "odd" or "even". The interval between the presentation of the stimulus and the participant's verbal response was recorded in the program along with the response itself. The stimulus symbols consisting of the numbers 1-9 were randomly assigned by a deterministic function within the computer program.

Because of the set up just described, sometimes odd numbered stimulus items followed odd numbered primes, and sometimes even numbered stimulus items followed even numbered primes. In these cases, the primes were labeled as being *congruent* with the stimulus items. However, in other cases, odd numbered stimulus items followed even numbered primes and even numbered stimulus items followed odd numbered primes. In these cases, the primes were labeled as being *incongruent* with the stimulus items.

(2) Preparation of the Primes

A Geiger counter was used to measure radioactive decay from a small sample of uranium ore during a series of four second intervals of time. Using Arduino software and related circuitry the number of Geiger counter clicks obtained during each four second interval was automatically transformed into a series of digital values that were fed into a laptop computer. The Geiger counter, uranium ore, the laptop, and the related circuitry were placed within a sound insulated container for the duration of time in which data from the radioactive decay was being taken (about 10 minutes). The room that housed the experimental apparatus was not occupied by any other human or animal, nor was anyone else on the floor of the lab during the time when the data was taken. To further ensure that the sound of the Geiger counter clicks were not coming into contact with any type of consciousness, loud music was played in the room to drown out any sound that escaped the container.

After each 10-minute data gathering period, the experimenter reentered the room and removed the laptop to a second room. The experimenter had covered the screen of the laptop with a wooden clipboard so that the contents of the screen could not be seen. The experimenter used keystrokes to unlock the computer, and then using the copy function transferred the Geiger counter data (about 150 digits) out of the Arduino program interface and closed the program.

The experimenter then removed the screen covering and opened up the response time program (Inquisit 6 Software). The experimenter then scrolled down to the section in the code where the numerical data from the Geiger counter clicks needed to be inserted. It is at this point where the only procedural difference between the two conditions was implemented. When inserting the primes for the unobserved condition, the experimenter covered the screen and pasted in the Geiger counter data using keystroke functions, thus never having had any conscious experience with the number sequence generated from the radioactive decay. However, when pasting in the prime sequence in the observed condition, the experimenter did not cover the screen and simply looked at the list of numbers for a few seconds after pasting them in the code. Once the primes were inserted in the code for both the observed and the unobserved conditions the program was set for the participants. The experimenter carried the laptop into a third room where the participant was waiting. The laptop was put in front of the participant who initiated the start of the stimulus presentations with a mouse click.

(3) *Correspondence of the Primes*

The program code had been set up in such a way so that the frequency of Geiger counter clicks pasted in the code became associated with a different whole number prime 1-9. There were eleven different sets of these correspondences. The correspondence set that was used was also determined by a blind cut and paste from the Geiger counter data. By basing both the sequence of primes and their correspondence directly on the Geiger counter data, a situation was created where two collapses needed to occur before the exact nature of each prime could be determined. This was done for the purpose of preventing against possible quantum backfilling in the unobserved condition, whereupon their eventual collapse during the data analysis items with a larger response time would be more likely to pull incongruent primes and items with shorter response times would be more likely to pull congruent primes. It was thought that the significant increase in complexity of the possible outcomes within the superposition that this would entail would work to prevent retroactive backfilling from being able to occur.

(4) Participants

Two different participants were used to produce response time data. Each participant was administered a series of six trials containing 80 items, for a total of 12 trials overall. Each of the trials consisted of 40 items from the observed condition and 40 items from the unobserved condition. The participants alternated the condition they started with each trial to control for order effects. The participants generated 464 responses in the observed condition and 464 responses in the unobserved condition. A total of 16 items in the observed condition and 16 items in the unobserved condition were spoiled due to either microphone sensitivity that resulted in those items being rapidly skipped before the participants could respond to them, or due to items with frequency values higher than 11 Geiger counter clicks, which resulted in no prime being generated. When asked following the data collection, neither of the participants reported to be able to discern the primes. One participant was removed from the study after their first trial upon reporting to be able to see the prime on some of the items.

4. Results

The participants responded to 928 items overall (464 in the observed condition and 464 in the unobserved condition). The participants responded incorrectly to only seven items (four in the observed condition and three in the unobserved condition). The response time measurements for each item that was incorrectly responded to was changed to the upper timeout limit of 1,200 milliseconds.

Although the primes used in the observed condition and the unobserved condition were both derived directly from the same source, the frequency of radioactive decay, comparisons were still made to ensure their equivalency. The primes in both conditions had a range of 1-9. The primes in the observed condition (M = 5.00, SD = 2.58) and in the unobserved condition (M = 5.04, SD = 2.48) had equivalent means and standard deviations.

Table 1. *Response Time Means and Standard Deviations Across Primes and Conditions*

	Observed Condition			Unobserved Condition		
	N	M	SD	N	M	SD
Congruent Prime	227	652.31*	128.40	231	675.95(ns)	138.52
Incongruent Prime	237	689.71	124.47	233	684.49	119.85

*p<.001, ns: non-significant

Table 1 presents participant response times across experimental conditions. Independent-samples t-tests were used to analyze the differences. The stimulus primes affected participant response time in the observed condition but not in the unobserved condition. In the observed condition participants responded faster to items preceded by congruent primes than they did to items preceded by incongruent primes (t = -3.19, p <.001). In the unobserved condition, participant response times to items preceded by congruent primes were statistically equivalent to those preceded by incongruent primes (t = -0.71, p = 0.239).

5. Discussion

All of the stimulus primes used in this study were determined by frequency patterns in a local source of radioactive decay. These primes were found to affect participant response times only if they were subject to prior conscious observation. Within the observed condition, significantly shorter response times were obtained on items paired with congruent primes than those paired with incongruent primes. However, within the unobserved condition (where conscious observation had been withheld) the response times between items with congruent and incongruent primes were statistically equivalent. This result indicates that the wave functions determining the primes in the unobserved condition were still in a state of superposition when the participants responded to the stimulus items. Otherwise, if they had already collapsed into definite states, they should have had the same effect on participants' response times as they did in the observed condition.

This result supports the CCC interpretation of quantum mechanics, which holds that the act of conscious observation brings about the collapse of the wave function, rather than the interaction of the quantum phenomena with a physical measuring device. If it were the case that the physical measuring device alone collapsed the wave function, the radioactive decay would have collapsed into a series of definite states upon its initial interaction with the Geiger counter, and whether the experimenter later viewed the values on a computer screen would not have altered the effect the primes had on reaction time. But this was not the case. The primes only worked once they were observed by the experimenter. Given this result, we are left with little option other than to conclude that it was the experimenter's conscious observation that played the critical role in causing the wave functions to collapse.

Replication of these results would be necessary before more confidence can be held in this conclusion. It is true, although it would be unlikely considering the obtained p values, that the results obtained here may be an artifact of statistical chance. To assess this likelihood, it is tempting to focus solely on the significant result in the observed condition. One may suppose that the significant differences between the congruent and incongruent primes within the observed condition are merely the result of a statistical anomaly. However, the effect demonstrated here, where subliminal primes congruent with a given stimulus reduce the average response time to that stimulus, has been replicated many times (e.g., Dehaene et al, 1998; Greenwald et al, 2003; Kouider & Dehaene, 2009). The striking result in the present study, rather, is the null finding in the unobserved condition. It is the chance of type 2 error (not finding a significant effect when one exists) that deserves the focus. In other words, not only was the insignificant finding in the unobserved condition at odds with the observed condition within the same study containing all its inherent shared variables (notwithstanding the experimental manipulation), but this insignificant finding is also at odds with previous studies in subliminal priming.

The participant's response modality in the present study, being verbal and abstract instead of being a keystroke, is of critical importance. Previous pilot studies of the current experimental paradigm were conducted where stimulus primes created large effects in the unobserved condition. The difference between the design of these studies and the present research is that the current response modality is both verbal and abstract, rather than purely directional. If the response task is contrived in a way such that the participant is required to hit the "A" or the "L" key depending on which way a directional symbol such as "<" or ">" is pointing, and the primes also consist of those directional symbols, then it was thought the prime alone was producing a *directional response impulse* that was being consciously experienced by the participants.

In other words, it was thought that the primes produced a directional impulse in participants that started them leaning one way or another, to the right or the left depending on the direction of the symbol "<" or ">". This impulse, this feeling of needing to go to the right or the left, was presumably collapsing the wave function, and preventing the realization of an actual unobserved condition. This was corrected in the current study. By changing the items and the primes to numbers, directionality was eliminated in the visual stimuli, and by requiring the participants to produce a verbal and abstract label (oddness and evenness are abstractions) directionality was also eliminated in the responses.

6. Conclusion

The purpose of this experiment was to use the methodology of subliminal priming to test the consciousness causes collapse interpretation of quantum mechanics. The findings obtained support this interpretation. The outcome suggests that the act of conscious observation may play a critical role in quantum mechanics, and, by extension, physical reality. Replications of this investigation will be necessary to establish more confidence in the outcome obtained.

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