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Citation: AIP Conference Proceedings **1841**, 030005 (2017); doi: 10.1063/1.4982776
View online: https://doi.org/10.1063/1.4982776
View Table of Contents: http://aip.scitation.org/toc/apc/1841/1
Published by the American Institute of Physics

Empirical Retrocausality: Testing Physics Hypotheses With Parapsychological Experiments

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Abstract. In 2011, Daryl Bem published a report of nine parapsychological experiments showing evidence of retrocausal information transfer. Earlier in 2016, the team of Bem, Tressoldi, Rabeyron, and Duggan published the results of a meta-analysis containing 81 independent replications of the original Bem experiments (total of 90 with the originals).[1] This much larger database continues to show positive results of generally comparable effect size, thus demonstrating that the effects claimed by Bem can be replicated by independent researchers and greatly strengthening the case for empirically observed retrocausation. Earlier (2011) work by this author showed how a modification of one of Bem's original experiments could be used to test the mechanism implicitly proposed by Echeverria, Klinkhammer, and Thorne to explain how retrocausal phenomena can exist without any risk of self-contradictory event sequences (time paradoxes). In light of the new publication and new evidence, the current work generalizes the previous analysis which was restricted to only one of Bem's experimental genres (precognitive approach and avoidance). The current analysis shows how minor modifications can be made in Bem's other experimental genres of retroactive priming, retroactive habituation, and retroactive facilitation of recall to test the EKT anti-paradox mechanism. If the EKT hypothesis is correct, the modified experiments, while continuing to show replicable retrocausal phenomena, will also show a characteristic pattern of distortion in the statistics of the random selections used to drive the experiments.

INTRODUCTION

For many years retrocausation was summarily rejected in physics, to such an extent that demonstrating the mere possibility of retrocausal effects resulting from a postulated phenomenon was considered a sufficient argument to prove the nonexistence of that phenomenon.[2] In more recent years retrocausation has become more acceptable, with some prominent physicists explicitly invoking it in theoretical constructs.[3][4] In 1991 a publication by Echeverria, Klinkhammer, and Thorne (EKT) demonstrated that one of the strongest arguments against retrocausation, the possibility of so-called "time paradoxes" or self-canceling event sequences, was invalid.[5] They did this by performing a rigorous analysis of a traversible wormhole pair so configured as to allow objects to physically travel into their own pasts, and demonstrating that any attempt to create a paradoxical, self-cancelling event sequence would instead lead to a slightly different sequence which was self-consistent.

Although the EKT analysis strictly applied only to the traversible wormholes predicted by General Relativity, there were obvious and plausible generalizations to any situation containing retrocausal effects. In 2011 Daryl Bem of Cornell published a report of several experiments demonstrating retrocausal effects in time-reversed versions of standard psychological experiments.[6] In the same year the current author published a demonstration of how to modify one of Bem's experiments to test the hypothesis that the same phenomena analyzed by EKT could be generalized to a broader range of retrocausal phenomena.[7]

Earlier in 2016, Bem and several colleagues published a meta-analysis of independent replications of Bem's original experiments, expanding by an order of magnitude the number of experimental observations of retrocausal effects.[1] The current analysis, inspired by this publication, will demonstrate how the remaining genres of these experiments can be used to test the existence of the general EKT phenomenon.

Quantum Retrocausation III
AIP Conf. Proc. 1841, 030005-1–030005-12; doi: 10.1063/1.4982776
Published by AIP Publishing. 978-0-7354-1511-9/$30.00

REVIEW OF PAST RESULTS

Since this work is an extension of fairly complicated results presented in earlier publications, it seems advisable to start with a review of the relevant past material.

Terminology

The term *time paradox* is reserved in this analysis for an event or a sequence of events which prevents itself from occurring, and which therefore happens if and only if it does not happen. It should be obvious that such an event or sequence necessarily involves a retrocausal step, since in ordinary causation an event can have no influence on its pre-existing causes. The archetypal case would be a suicidal time traveler who enters the past in order to kill his younger self, thereby preventing himself from taking the time trip. The term paradox is sometimes mistakenly applied to *closed causal loops*, in which an event retrocausally becomes (one of) the factors that causes it. The archetypal case here would be the arrival of a set of blueprints for a time machine, leading someone to construct the machine according to the plans and send the blueprints back to the time when they were in fact received. It should again be obvious that while a closed causal loop may be counterintuitive, it does not involve any element of self-contradiction and therefore cannot be considered a paradox.

The *bilking paradox* is a frequently used label for a special case of time paradox. An event which is known to be a retrocausal effect of a future cause is observed. Some agent then proceeds to prevent the future cause from occurring, thereby "bilking" the observed event of its cause. It differs from a basic time paradox only in that the contradiction involves interaction with outside forces rather than being innate to the retrocausal event itself.

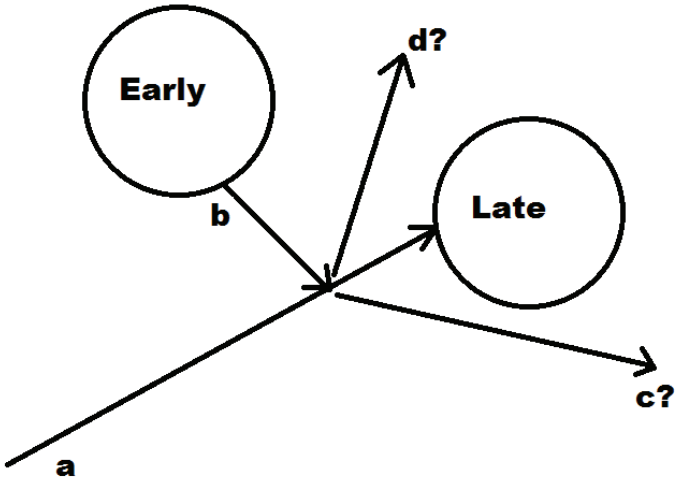

FIGURE 1. An attempt at creating paradox. A projectile is fired along course (a) into the *late mouth* of a wormhole (the mouth that connects to later times than the other, *early* mouth). Its course and speed are such that, before entering the late mouth, it emerges from the early mouth along course (b), which will bring it to a collision with its prior self. After the elastic collision both instances of the projectile are on courses ((c) and (d)) which never enter the wormhole, which is inconsistent with the fact that instance (b) must have entered the wormhole in order to have emerged from it: hence, a paradox.

The *EKT analysis* is a rigorous demonstration of the impossibility of inducing paradox in a spacetime containing traversible wormholes allowing closed timelike trajectories. It can be taken as a established result applying to such wormholes, if they exist. The *EKT effect* is a hypothetical extension of this analysis presuming that, in situations which are much too complicated for comparably rigorous physical analysis, similar mechanisms must come into play to prevent time paradoxes from occurring.

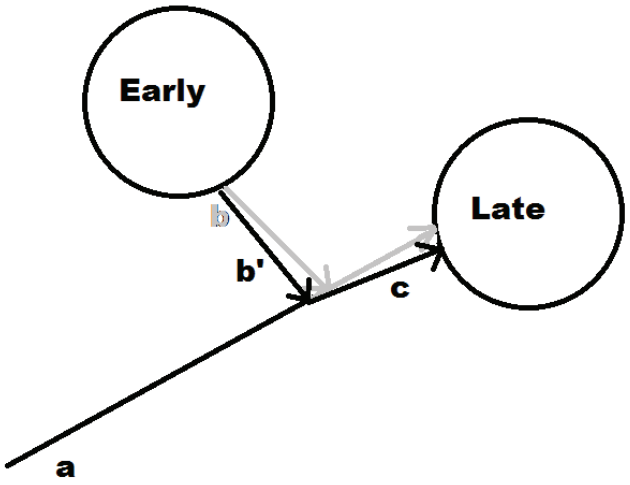

FIGURE 2. Resolution of the paradox. The projectile is fired along course (a) exactly as in Figure 1, but it does not emerge on the course (b) that would be computed from its initial trajectory alone. It is observed to emerge on a slightly different course (b') which leads it to a grazing collision with its prior instance, deflecting itself onto course (c) which will cause it to emerge on the observed course (b'). This sequence of events is self-consistent. The paradoxical course is shown in gray.

The term *valence* is frequently used in discussing psychological stimuli. The valence of a stimulus (a picture, a word, a sound) is the positive or negative emotional impact it has on the person experiencing it. Pleasant, enjoyable stimuli have positive valence; distressing or unpleasant stimuli have negative valence. Psychological experiments frequently rely on a large library of images that have been calibrated for reliable valence across a diverse population of viewers.[8] It should be noted that some measure of controversy, completely irrelevant to the actual merits of such experiments, derives from the fact that many of the positive-valence images are erotic (and frequently, to avoid unnecessary contrasts, all such images chosen for a particular experiment will be). To avoid stoking such pointless disputes, the current analysis will note in passing that most positive-valence images are erotic and refer to them in discussions simply as having positive valence.

Avoiding paradox in a spacetime containing traversible wormholes

The EKT analysis can be briefly summarized as shown in Figure 1 and 2. The terms "late mouth" and "early mouth" require some explanation. If the wormhole is time-traversing, the two mouths have experienced different amounts of proper time since the wormhole's construction. Since the interior of the wormhole shares a single time reference, this means that an observer inside the wormhole, looking out through the two mouths at clocks showing time references for the external universe, will see different times through the two mouths. The mouth which connects to earlier times in the external universe is the early mouth, the other is the late mouth. An object which enters the wormhole through the late mouth, and traverses it rather than lingering to sightsee in the "throat" connecting the two mouths, will emerge at the earlier time that the early mouth connects to, and thus travels into its own past as seen by external observers.

Part of EKT's extensive analysis is the demonstration that for any paradoxical trajectories as shown in Figure 1, there is always at least one non-paradoxical trajectory derivable from it with slight changes, as shown in Figure 2.

Avoiding paradox in an experiment containing retrocausal communications

Although the EKT analysis is limited to time travel via traversible wormholes, the basic concept seems readily generalizable. It seems intuitively obvious that any possible event sequence leading to a time paradox has closely related sequences that are not paradoxical. The type of exact physical analysis performed by EKT is not generally feasible

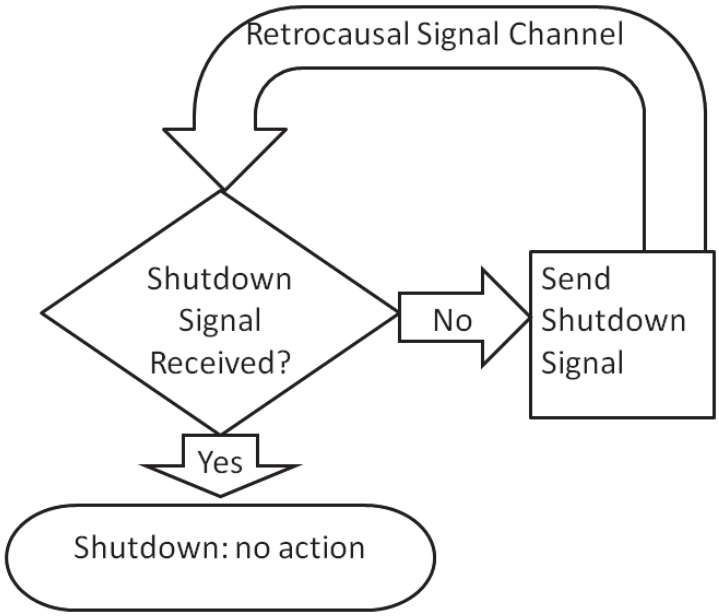

FIGURE 3. A self-canceling system requiring only signaling to the past rather than physical travel. A system including a retro-causal information channel is set up so that at some predesignated time it sends a shutdown signal to itself in the past. If all components function as shown in the schematic, the operation is a paradox: it shuts down if and only if it does not shut down.(Figure taken from [7],p. 241)

for more complex systems; indeed, EKT themselves restricted their analysis to ballistic trajectories in the vicinity of wormholes precisely to avoid the problem of having to present an exact physical model of such complex entities as human agents reacting to observed events.

As a first step in considering a generalized EKT effect, let us conduct a *gedankenexperiment* in which the retrocausal phenomenon is not an instrument for physical travel, but simply a communication channel. Let us also follow EKT in setting up a situation which requires no human intervention to produce a paradox, once the initial conditions are established.

Posit that we have a computer with a communication channel that allows it to send messages into its own past, which necessarily entails that it can receive messages from its own future. Set a program running that will monitor received messages and will shut down the computer if a message ”STOP” is received. Set a second program running that will, at 10AM on a particular day, send the message ”STOP” to 9AM on that day. Presuming no human intervention after the initial setup, this is a paradox; if the computer receives the message at 9AM, it will shut down, and therefore will not send the message. But if it does not send the message, it will not receive the message and will not shut down. The message is sent if and only if it is not sent.

Although a digital computer is vastly more complex than a ballistic projectile, we may ask whether this hypothetical event sequence has the qualitative property of allowing closely similar but non-paradoxical sequences. The answer is surely “yes,” because complex instruments are never perfectly reliable. The communication device may mistake line noise for a particular signal, therefore triggering a shutdown even though no signal was sent. (Note that this error need not occur at the planned moment for the shutdown signal to have been received – any time before

10AM will do.) The communication device may suffer a breakdown, transmitting the signal in garbled form that is not recognized as the shutdown trigger, or failing to transmit it at all. The computer itself may receive no signal and then suffer a power failure, disk crash, or other mechanical fault before the signal was due to be sent, therefore never sending the signal.

It may be argued that modern equipment is highly reliable and that the various failure modes discussed here are extremely improbable. However, since a paradoxical event is inconsistent with its own existence, it *cannot* occur under any circumstances. It should be noted that this statement requires no assumptions regarding the underlying quantum ontology. Even if some version of the many-worlds interpretation is true, so that different event sequences can occur in different branches of reality, a paradoxical event sequence by hypothesis occupies a single branch. This is because the retrocausal effect, whatever it may be, is stipulated to carry objects or information into the originator's *own* past, not the hypothetical past of some other reality branch. We may speculate that a full quantum-mechanical sum-over-histories evaluation of such a sequence (impossible at this time due to the complexity of the systems) would show that the amplitude of the paradoxical history must be exactly zero, so that quantum amplitude and hence probability will be distributed over the remaining histories, however improbable they would seem under normal circumstances. To paraphrase the fictional Sherlock Holmes, once paradox eliminates the impossible, whatever remains, however improbable, must occur.

Parapsychological experiments and low-reliability communication channels

Various phenomena indicating retrocausal information flow have been reported in a great number of parapsychological experiments. The genres of interest for the current analysis may be described as *precognition* and *presentiment*, denoting respectively conscious and unconscious knowledge of future events. Experiments in these genres typically involve allowing participants to make conscious choices, or measuring unconcscious physiological responses, which can be shown to correlate with later events; said later events are determined by a random number generator or other unpredictable source so as to preclude the correlation being due to participant knowledge of relevant causal factors.

In 2011 Daryl Bem published the results of an array of nine related experiments involving retrocausal versions of four well-established psychological effects.[6] These were:

- **Approach and avoidance**, in which organisms preferentially make choices that have received positive reinforcement, and avoid choices that have received negative reinforcement. In the retrocausal version, a human participant makes a choice between two alternatives and receives positive, negative, or neutral reinforcement after the choice has been made.
- **Priming.** In conventional priming experiments human participants are asked to judge, as quickly as possible, whether an image presented to them is pleasant or unpleasant. Before the presentation and judgment, the participant is presented with a brief glimpse of a priming word which has either positive or negative associations (e.g. "pretty" or "vile"). It is well established that participants arrive at their decisions more quickly if the priming word is *congruent* with the image (has valence of the same type, both positive or both negative), and more slowly if the priming word is *incongruent* with the image. In the retrocausal version, the priming word is presented after the image is presented and judged.
- **Habituation.** The intensity of response to any stimulus declines over time; upon repeated exposures to the same stimulus, whether positive or negative, a participant's response diminishes. This means that positive-valence stimuli will be less well-liked with repeated exposure, while negative-valence stimuli will be less disliked. In the retrocausal habituation experiment, two pictures chosen for valence as nearly matched as possible (not only both positive or both negative, but both positive or negative to the same degree) are presented and the participant indicates their preference. Afterward, one of the two photographs is randomly selected to to be shown rapidly to the participant several times. If habituation occurs, the participant is expected to choose the habituation target more often for unpleasant pairs (since the habituation will make it less unpleasant), while choosing the nontarget more often for pleasant pairs (since its effect has not been diluted by habituation).
- **Facilitation of recall** is another well-established effect in which practicing a set of items makes them easier to remember. In a typical recall-facilitation experiment, the participant will be presented with a list of words and then take a memory test in which they try to recall as many of those words as possible. For the facilitation aspect, the participant practices by reviewing a randomly-chosen subset of the words before the presentation and the memory test. In the retrocausal version, the practice is performed after the memory test rather than before.

It should be borne in mind that the conventional versions of each of these experiments demonstrate well-established effects in cognitive psychology. Bem's publication reported that they continued to demonstrate these effects when time-reversed. It should also be noted that, while Bem's experiments involve no physiological monitoring, they rely entirely on unconscious rather than conscious reactions to future conditions. They are therefore properly describable as studies of presentiment, rather than studies of precognition, despite the lack of physiological monitoring.

An important point for subsequent consideration is that, to the extent that positive results in such a parapsychological experiment point to the existence of a retrocausal information channel, it is one with a fairly low reliability. For example, in Bem's original approach/avoidance experiment, participants chose the option that would be rewarded with a positive-valence image 53.1% of the time, rather than the 50% expected by chance for a binary choice.[6]

Partial bilking and an empirical test for the EKT mechanism

Unfortunately, attempting to bilk a presentiment experiment is at face value a self-defeating proposition. This is the case even if presentiment were much more effective than seen in any controlled experiment. Imagine a completely reliable precognitive who could state in advance, with 100% accuracy, whether a randomly chosen playing card which would be shown to her in five seconds would be red or black. Let this accuracy be established to any desired level of confidence. Now modify the experiment so that the card presenter, be it an experimenter or a machine, always shows a black card when the precognitive says "red", and always shows a red card when the precognitive says "black". If the precognitive's talent is a genuinely reliable perception of the future, it is possible that she may be unable to say anything, because as soon as she opens her mouth to start saying one of the options the future, and hence her perception, changes to the opposite case. At best, the revised experiment has a 100% failure rate, which reveals nothing about the nature of either time or precognition because it is built into the experiment.

Close analysis of the Bem approach-avoidance experiment showed that it contained a venue for testing the generalized EKT effect through partial bilking. In Bem's original version, while the participant only made a single binary choice, there were two binary variables in the presentation. There were two positions (right or left) in which an image could appear, and two types of images (positive or neutral) which might be shown. The participant's option was to choose the image position; if correct, he or she would then see the image (and be rewarded if it was a positive image), while choosing the wrong position would reveal a picture of a blank brick wall. As noted above, prediction rates were higher than expected by chance for positive images only; neutral images were predicted with chance accuracy.

The fact that neutral images were predicted with chance accuracy meant that this particular Bem experiment offered a less destructive venue for bilking: presenting a neutral image did not guarantee a wrong result (0% prediction rate), it simply turned off the retrocausal channel (50% prediction rate). To quote the author's 2011 publication on the topic:

> "...if the experiment involves a probabilistic alternative between bilked and non-bilked pathways, EKT predicts that the paradoxical portion of the bilked pathway (the probability corresponding to self-cancellation by transmission of the bilked signal) will vanish and be redistributed among non-paradoxical alternatives."[7]

This probabilistic alternative was achieved by introducing another binary decision invisible to the human participant. For each trial, a preferred direction would be chosen at random (and not revealed to the participant in any way). If the participant chose the preferred direction, the experiment would proceed normally; if the participant chose the non-preferred direction, *and* the trial had been scheduled to use a positive image, the retrocausal channel would be turned off by presenting a neutral image instead. For convenience of later analysis, the position randomizer that actually placed the image was recast as randomly generating 1 or 0 to place the trial in the preferred or non-preferred direction, respectively. A detailed analysis of conditional probabilities, in the trials scheduled for positive targets, leads to the following conclusions:

1. If the partial bilking is not activated, the introduction of a preferred direction is an "invisible" addition to the protocol which will have no effect on the experiment; it is merely an additional step in the random selection of the target. The prediction accuracy of the participant will remain some value $P > 1/2$.
2. Since the participant's prediction is made without knowledge of the preferred direction, and the preferred direction is not part of the feedback to the participant, the prediction will match the preferred direction half the time.

3. In the half of positive-target trials where the prediction is for the preferred direction, the prediction accuracy P implies that a fraction P of the targets match the predicted direction, and hence the preferred direction.
4. In the half of positive-target trials where the prediction is against the preferred direction, the prediction accuracy P implies that a fraction P of the targets match the predicted direction, whence a fraction $1-P$ are in the preferred direction.
5. Overall the fraction of targets placed in the preferred direction (the fraction of trials in which the position randomizer generates 1) is
$$\left(\frac{1}{2}\right)P + \left(\frac{1}{2}\right)(1-P) = \frac{1}{2}, \tag{1}$$
as expected.
6. If we now turn on the partial bilking, so that all predictions not in the preferred direction are bilked by switching the positive image for a neutral image, the following changes occur:
7. Conclusion (2) still holds since the participant's only feedback is the placement direction, not the preferred direction.
8. Conclusion (3) still holds since predictions in the preferred direction are not bilked.
9. Conclusion (4) does not hold since bilking shuts off the retrocausal channel and the prediction accuracy drops to 1/2.
10. The overall fraction of 1 values from the placement randomizer is now
$$\left(\frac{1}{2}\right)P + \left(\frac{1}{2}\right)\left(\frac{1}{2}\right) = \frac{P}{2} + \frac{1}{4} = \frac{1}{2} + \frac{(P-1/2)}{2}. \tag{2}$$

This analysis leads to the conclusion that turning on partial bilking changes the statistics of the placement randomizer. The change is a signature of the EKT effect because the prediction-dependent shutdown of the retrocausal channel makes it paradoxical for the retrocausal signal to carry the information that prevents it from being sent. The population of accurate predictions in the non-preferred direction, which produce the $1-P$ preferred placement rate that would balance the statistics of the placement randomizer, are prevented from occuring by the EKT effect and replaced by a possible and consistent population with a 1/2 placement rate. We may further conclude that the distortion in the placement randomizer's statistics will have the properties of a sampling bias, since the EKT effect is eliminating a biased subset of the randomizer's output.

This concludes the review of previous results. The rest of this paper will extend the EKT analysis from the approach/avoidance experiment to the other genres. One extension is so trivial that it does not merit its own section. The analysis above deals with the retroactive approach/avoidance genre, but it deals solely with an approach-based experiment, in which participants either receive positive reinforcement or no reinforcement. The modification and the EKT analysis is exactly identical for an avoidance experiment in which participants succeed in staying away from negative-valence images, except that the "prediction" probability $P < 1/2$ instead of $P > 1/2$.

OVERVIEW OF 2016 META-ANALYSIS

Before advancing to the construction of EKT tests for other genres, it seems advisable to review the newly published results. Bem's original nine experiments as published in 2011 reported a composite $Z = 6.66$, with an effect size of 0.22. Statistically significant effects were found in every genre investigated.[6] Against this standard, the 2016 meta-analysis of 90 experiments (including the original 9) might be thought disappointing at first glance, since the aggregate across all experiments only attains $Z = 6.33$ with an effect size of 0.09.[1] First, it should be noted that the meta-analysis uses Hedges' g statistic as a uniform measure of effect size across disparate experiments, which was not the calculation in the original paper. Second, while the replications as a whole clearly have a smaller effect size than the original experiments, they are highly significant in their own right: the 69 independent replications have $g = 0.06$, $Z = 4.16$. (The reason there are 69 independent replications instead of 90 - 9 = 81 is because of additional experiments by Bem and the inclusion of experiments that tested the same hypotheses but were not designed as replications.)

Experimental results by genre are also reported in the meta-analysis.

- **Precognitive detection of reinforcement:** 14 experiments, $g = 0.14$, $Z = 4.22$.
- **Precognitive avoidance of negative stimuli:** 8 experiments, $g = 0.09$, $Z = 3.10$.
- **Retroactive priming:** 15 experiments, $g = 0.11$, $Z = 2.85$.

- **Retroactive habituation:** 20 experiments, $g = 0.08$, $Z = 3.50$.
- **Retroactive facilitation of recall:** 27 experiments, $g = 0.04$, $Z = 1.66$

In addition to these 84 experiments, the meta-analysis reports two genres that do not seem to be in Bem's initial experiment set: "Retroactive practice," which is not clearly explained in the text, had four experiments, and "Retroactive facilitation of practice on text reading speed" had two. As these are small databases with protocols not discussed in detail in the meta-analysis, they shall not be discussed further here.

It is notable that while Bem's original experiments showed success in all four genres (precognitive detection of reinforcement and precognitive avoidance of negative stimuli are in the same approach/avoidance genre), the meta-analysis finds no significant effect for retroactive facilitation of recall. While post-hoc explanations must always be evaluated with caution, some of the meta-analysis authors' own words may be instructive here:

> "... 12 of the 27 attempted replications of Bem's retroactive facilitation of recall experiment were modified replications. The 15 exact replications of that protocol yielded an overall effect size of 0.08, but the 12 modified replications yielded a null effect size (−0.00)."[1]

The authors also noted that, because of much larger numbers of participants, the modified experiments (especially seven in which sessions were conducted online, enabling much larger participant pools while sacrificing controlled laboratory conditions) have a stronger impact on the effect-size calculation than the simple count of experiments would suggest.

For purposes of the current analysis we may note that *exact* replications of Bem's facilitation of recall protocol yielded an effect size comparable to those of the other experimental genres. Since it is at least plausible that this protocol shows retrocausal effect under appropriate conditions, it will be included in the discussion of extending the EKT testing methods that follows. An additional reason for regarding this genre as particularly interesting is also noted in the meta-analysis. Unlike the other genres in which retrocausal effects are elicited on a time scale of seconds or milliseconds, the facilitation of recall experiment takes minutes (their protocol description indicates a total time span as long as $14\frac{1}{2}$ minutes to complete the three phases of presentation, recall test, and retroactive practice). As psychologists the authors find this interesting primarily because of the difference between "fast-thinking" and "slow-thinking" cognitive phenomena which has recently been receiving considerable attention in cognitive psychology. As a physicist, the current author finds this difference interesting because it examines retrocausal effects over a much longer time interval than the other genres.

EXTENSION: TESTING EKT WITH RETROACTIVE FACILITATION OF RECALL

In the retroactive facilitation of recall experiment, participants are first shown a list of common nouns (48 of them in Bem's original design), one at a time, on a computer screen. They are then administered a "surprise" recall test in which they are asked to type out as many of the words as they can remember. After the recall test is concluded, a random process selects half of the words for a practice session and the participant rehearses those words in a series of practice exercises. The retrocausal effect, predicted and sometimes observed, is that the words used in the retroactive practice session are recalled at a higher rate than words not practiced.

There is a surprising degree of isomorphism between this experiment and the approach/avoidance genre. Each individual word on the presentation list is either remembered, or not, a binary alternative (although unlike the approach/avoidance situation we do not know a prior probability for this condition, and there is no particular reason to suspect that this unknown probability is anywhere close to 1/2.) The word recalled is either in the presentation list (the retrocausal-channel case) or not (the no-retrocausal-channel case). The apparent retrocausal effect is a higher proportion of recalled words from the practice list rather than the no-practice list, corresponding to the higher proportion of correct predictions for positive-valence targets.

Given these similarities, it would seem natural to suggest that the key feature for testing the EKT effect, adding a probabilistically invoked bilking pathway, can also be achieved in a structurally similar way. The experiment can randomly designate half of the words as preferred words, using a separate randomization process from that used to select a practice word. In the non-bilked form of the experiment the status of a word as preferred has no effect and can be ignored. To turn on probabilistic bilking, we add a rule to the selection process. If a word appeared in the recall test, is on the list of practice words, and is not part of the preferred set, the practice is bilked by removing the word from the practice set. To maintain the 50% practice rate that is part of the experimental experience, some other word not originally slated for practice must be subsituted into for the practice set.

The structure of the experiment does create an important difference here. In the approach/avoidance experiment, the retrocausal information channel is driven by the content of the image (high positive or negative valence is perceived retrocausally), so that substituting a neutral valence picture shuts down retrocausal communication. In this experiment it is apparently the fact of practice, rather than the content of the words practiced, that drives the retrocausal effect. Scheduling a replacement word for the practice list has two possible effects. It could be a different word that was recalled successfully, in which case the experiment is not actually bilked; instead, two words that were successfully recalled, one with practice and one without, have swapped categories, making no change to the overall statistics. Alternatively, if the replacement word was not recalled, the experiment is not only shutting down the retrocausal signal for a recalled word, but additionally making an attempt to activate a retrocausal signal that is known in advance to have failed. This suggests that the most sensitive detection of an EKT effect will be achieved by monitoring the random choice of the replacement word that is moved from the unpracticed list to the practiced list. If the EKT effect is generally applicable, the random choices should be biased towards words that were recalled but not originally on the list.

Mathematical Analysis

The starting point for analyzing the experiment is that out of N presentation words, a fraction p_r is recalled in the recall test. The presentation words consist of two equal subpopulations N_p of practiced words and N_u of unpracticed words, such that $N_p + N_u = N$, and $N_p = N_u = N/2$. Of the total number Np_r of recalled words, a number Np_p come from the practiced set and Np_u come from the unpracticed set; $p_p + p_u = p_r$. The retrocausal effect is that $p_p > p_u$. It follows that one can define

$$P = \frac{p_p}{p_r} = \frac{p_p}{p_p + p_u} \tag{3}$$

where P is the "prediction accuracy", the fraction of recalled words coming from the practice set. In a sense, the successful recall of a word constitutes a prediction that that word is in the practice set, and P gives the accuracy of the prediction; note that by construction, if the data are consistent with retrocausal effects then $P > 1/2$.

Now let us consider the statistics of the partially bilked experiment. The experiment for words assigned to the preferred list is entirely identical to the unbilked experiment and we would expect, absent other factors, that it should reproduce the statistics of p_p and p_u for the standard experiment. The statistics seen in this subset can be used both to continue to test for retrocausal effects and as a control to verify that this more complex experiment has not disrupted the participants' ability to experience presentiment.

For the bilked side of the experiment, the expected signature of EKT is that the replacement word for the practice list is more likely to be a word that was recalled but was not originally on that list. By the hypotheses leading up to Equation 3, the fraction of unpracticed recalled words should be p_u, and the fraction of unpracticed unrecalled words $1 - p_u$. Therefore the detection of an EKT bias consists in finding that the fraction of replacement words drawn from the recalled set should be larger than p_u. A quantitative assessment of how much larger has been intractable as of this writing.

EXTENSION: TESTING EKT WITH RETROACTIVE HABITUATION

Retroactive habituation, like facilitation of recall, appears to have many features isomorphic to approach/avoidance. The participant makes a binary choice between two pictures. After that choice, one of the two is selected for a habituation presentation in which it is repeatedly shown to the participant in subliminal flashes[1]. Again, the participant's choice can be seen as a retrocausal "prediction" of whether the chosen image will be used for habituation, with the difference that when the two pictures are attractive the participant is expected to choose the nontarget, while with unpleasant pictures the participant is expected to choose the target. The existence of the retrocausal information channel, however, is apparently driven by a process performed with the target, rather than by the content of the target, as was also seen in retroactive facilitation of recall. This makes it impossible to apply the partial bilking process as it operates in the approach/avoidance experiment while leaving the participant's experience completely unchanged. The approach that seems to most nearly produce the conditions of the partial bilking analysis for approach/avoidance is to apply the extra condition of a preferred choice and so forth, and then bilk the prediction by simply not providing any habituation stimulus at all. This once again stops retrocausal information flow by turning it off at the source. The quantitative analysis for the partially-bilked experiment then follows unaltered from that for the approach/avoidance

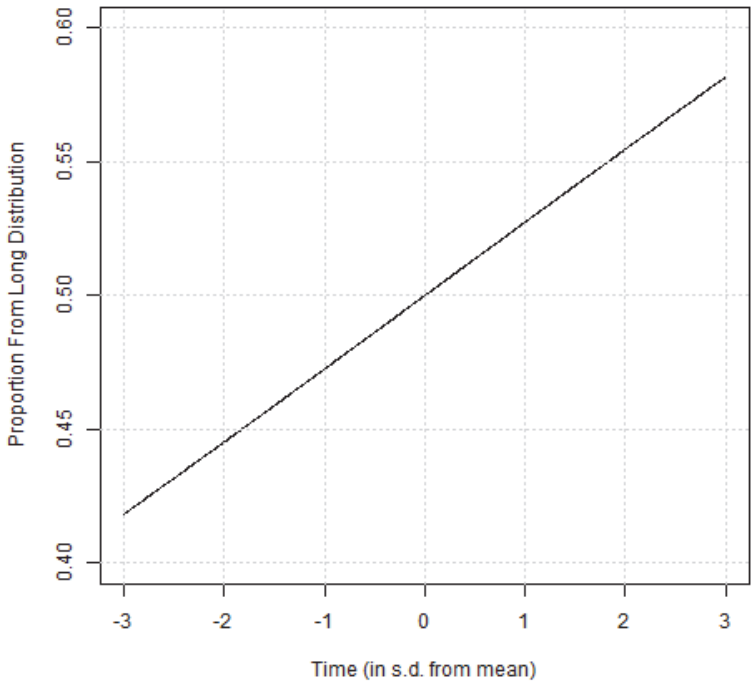

FIGURE 4. Retroactive priming. Proportional contribution to response time distribution coming from the long-biased component. Time axis is normalized to overall mean and scaled in standard deviations of the distribution.

experiments leading to the conclusion that Equation 2 describes the distorted behavior of the random generator governing the choice of the habituation target. This presumes, however, that a substantive change in the protocol – that some trials are not followed by any habituation exposures – will not disrupt the retrocausal effect for the experiment as a whole. While it seems reasonable to expect that this should be the case, the fact that modest changes in protocol reported for some experiments in [1] seem to have resulted in replication failures should be taken as a cautionary note.

EXTENSION: TESTING EKT WITH RETROACTIVE PRIMING

The retroactive priming experiment has been reserved for last because it displays the most extreme differences from the approach/avoidance experiment initially analyzed. In this experiment, the participant is shown a picture and is asked to evaluate it as attractive or unattractive, as quickly as possible. The experimental measure is not the participant's decision, but how long he or she takes to make the decision. After the decision is recorded the participant is given a priming stimulus (or "prime"). A congruent prime has the same type of valence as the picture, either both positive or both negative. An incongruent prime has the opposite valence. The result observed in conventional priming experiments, and now also seen in retroactive priming, is that participants make their decisions more quickly when the prime is congruent to the picture, and more slowly when the prime is incongruent.

This experiment is different from the others in almost every feature. The participant's only choice is irrelevant to the measure of retrocausal effect. The measure that is affected by retrocausal influence is a continuous variable; Bem *et. al.* do not report on the distribution in detail, although Bem's original 2011 publication mentions that it is skewed and that extreme values of slow response are excluded as outliers. From the reported effect size we can infer that the difference between the means of the two distributions is about one-tenth of the standard deviation. Hence there is no clear distinction for whether a trial is associated with congruent or incongruent priming, only a higher probability that the prime will be congruent for short response times, and a higher probability of an incongruent prime for long

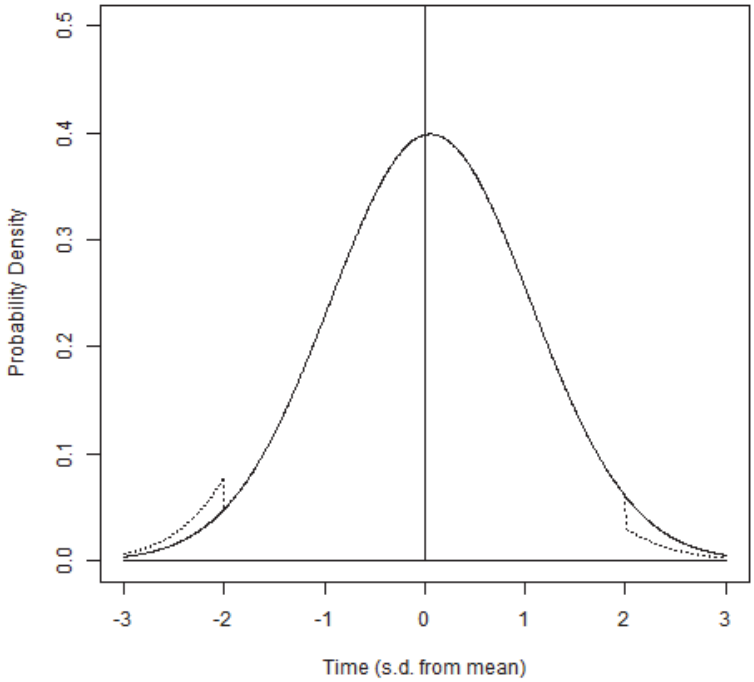

FIGURE 5. Retroactive priming. Post-bilking distribution for incongruent priming (long response times). The solid line shows the unbilked distribution; note that its peak is slightly to the right of the $t = 0$ line, indicating its mean shift toward longer response times. The dotted line, which overlies the solid line for much of the figure, shows the distribution after bilking has been applied. Bilking ratio $R = 0.5$, bilking threshold $b = 2.0$.

ones. To put it another way, the distribution of response times depends on whether the prime will be congruent or not, but since the two distributions overlap there is no definitive way to identify a particular observation as belonging to one distribution or the other. Figure 4 illustrates the proportion of the overall response time distribution coming from the component associated with longer times, under the false assumption that the distribution is normal; even at ±3 standard deviations from the mean, only modest confidence about the source of a particular observation is possible.

It is not clear that this experiment can even invoke the EKT effect, since the probabilistic nature of the fundamental measurement seems to prevent clear-cut identification of any particular sequence of experimental events as paradoxical. If, however, it is possible to engage the effect, the partial bilking algorithm described below seems to offer a route for doing so.

Let the software bilk a fraction R of all trials that are more than b standard deviations away from the overall response-time mean, in the predicted direction for the experiment. This would mean short response times for a trial about to be given a congruent prime, or long response times for a trial about to be given an incongruent prime. The bilking consists simply of reversing the prime given. Figure 5 illustrates the resulting distribution of response times for incongruent primes with the parameters $R = 0.5$, $b = 2.0$. It once again assumes the distribution is normal, which is known to be false but is convenient for qualitative illustrations. Although this bilking procedure reverses the primes for the most extreme values with the strongest contributions to the mean shift, the fact that it operates only in the extreme tails means that it need not dilute the observed effect to any disastrous extent. A rough estimate of the loss of effect size can be made by calculating yet again from a normal distribution; even though this is known not to be the distribution of response times, the real value should not be extremely far from the estimate for any distribution that retains well-defined moments. The effect size is reduced by the proportional factor

$$1 - RF\left(\frac{\epsilon}{2} - b\right), \tag{4}$$

where the terms R and b are the bilking rate and threshold as defined above, ϵ is the effect size, and $F(z)$ is the cumulative normal probability distribution. For the specific parameters of interest here — $b = 2$ and $R = 0.5$ for our example, $\epsilon = 0.11$ for the observed value — the effect size will be reduced to 0.987 of its unbilked value. Even if using the erroneous normal distribution for this model throws off the calculation by a factor of five, this is not so large a loss of efffect as to make the experiment impractical.

All of the above has assumed that the EKT effect does not apply. The fact that the privileged knowledge of the experimental apparatus enables it to bilk only trials that are known to have outcomes consistent with the choice of priming provides the greatest possible opportunity to trigger a paradox. If this happens and the EKT effect comes into play, the effect is straightforward: Fewer than the expected fraction of trials will be bilked, because some of the bilked outcomes will be erased from history by the EKT effect. Of all of these experiments, however, this must be considered the least likely to invoke an EKT effect, due to the lack of a clear-cut identification of any given outcome as consistent or paradoxical.

CONCLUSIONS AND SUMMARY

The 2011 work of Bem has been replicated, and a meta-analysis of 81 new experiments, including 69 completely independent replications, confirms the existence of retrocausal effects. Retrocausal effects of any kind seem at face value to risk a possibility of time paradoxes. The EKT analysis of traversible wormholes rigorously demonstrated that there is no risk of time paradox arising from the trajectories of particles in the presence of time-displaced traversible wormholes. The EKT effect is a speculative generalization that similar mechanisms of avoiding paradox will come into play for any situation involving retrocausality. It has now been demonstrated that all of the experimental genres used in the Bem replication meta-analysis can be modified to detect the signature of the EKT effect, if it is active in experiments that have been modified in an attempt to induce paradox. This implies that there is a wide variety of options for using parapsychological experiments to test whether the EKT effect operates in real-world retrocausal situations. While this may be of minor practical importance, a demonstration that the generalized EKT effect is real would mean that physics already contains a built-in safeguard that prevents time paradox even in situations containing arbitrary forms of retrocausation. This in turn would mean that one of the strongest criticisms used to attack claims of retrocausal phenomena can safely be dismissed.

ACKNOWLEDGMENTS

This work would have been impossible without the groundbreaking research of Daryl Bem, and would not have been motivated without the meta-analysis published by Bem, Tressoldi, Rabeyron, and Duggan.

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