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Entropy and Information Transmission in Causation and Retrocausation

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"How wonderful that we have met with a paradox. Now we have some hope of making progress."
–Niels Bohr

Abstract. Although experimental evidence for retrocausation exists, there are clearly subtleties to the phenomenon. The bilking paradox, in which one intervenes to eliminate a subsequent cause after a preceding effect has occurred, appears on the surface to show that retrocausation is logically impossible. In a previous paper, the second law of thermodynamics was invoked to show that the entropy in each process of a psi interaction (presentience, telepathy, remote perception, and psychokinesis) cannot decrease, prohibiting psi processes in which signals condense from background fluctuations. Here it is shown, perhaps contrary to one's intuition, that reversible processes cannot be influenced through retrocausation, but irreversible processes can. The increase in thermodynamic entropy in irreversible processes – which are generally described by Newtonian mechanics but not Lagrangian dynamics and Hamilton's Principle – is required for causation. Thermodynamically reversible processes cannot be causal and hence also cannot be retrocausal. The role of entropy in psi interactions is extended by using the bilking paradox to consider information transmission in retroactive psychokinesis (PK). PK efficiency, η_{PK}, is defined. A prediction of the analysis is that $\eta_{PK} \leq H/H_0$, where H is the information uncertainty or entropy in the retro-PK agent's knowledge of the event that is to be influenced retrocausally. The information entropy can provide the necessary ingredient for non-reversibility, and hence retrocausation. Noise and bandwidth limitations in the communication to the agent of the outcome of the event increase the maximum PK efficiency. Avoidance of the bilking paradox does not bar a subject from using the premonition of an event to prevent it from occurring. The necessity for large information entropy, which is the expected value of the surprisal, is likely to be essential for any successful PK process, not just retro-PK processes. Hence uncertainty in the communication process appears to be a necessary component of retrocausation in particular, and of PK in general.

Keywords: causality, retrocausality, backwards causation, entropy, communications, information, surprisal, bilking, paradox, noise, psychokinesis, retro-psychokinesis, psi
PACS: 65.40.Gr, 89.70.+c, 05.40.Ca, 89.20.-a

INTRODUCTION

The common notion of retrocausation is that it should function just like forward causation but temporally reversed. Since there is no evidence for this sort of effect the whole concept is often deemed to be nonsense. In fact there is evidence[1] for retrocausation, but the phenomenon appears to be more subtle than the apparently clear-cut functioning of forward causation.

Yesterday the winner of a lottery was chosen using a random process. Today you decide that you would like to be that winner, and using retroactive psychokinesis (retro-PK) you make it so. Is this possible in principle? If so, how can this be accomplished without creating some sort of logical paradox? Using entropy considerations and this paradox as constraints, I develop a description of the conditions under which retrocausation may be feasible.

The goal here is not to explain the mechanism of retrocausation, nor to prove that it occurs (evidence in support of its existence may be found elsewhere). Rather, the goal is to set out the necessary conditions for retrocausation within the limits of accepted physics and logic, and to provide a quantitative model for these conditions. Once such a model is shown to be valid, an explanation for the mechanism may be developed.

In the following section I introduce the general bilking paradox, and review previous work dealing with the entropy of each local process in a psi interaction (presentience, telepathy, remote perception, and psychokinesis). The section following that makes use of the total entropy of the processes to decide whether there has been any causation, either in normal or retrograde time. Finally, I use the bilking paradox and the entropy in the information transmitted across time to provide quantitative constraints on retrocausation.

BACKGROUND

The Bilking Paradox

A commonly mentioned paradox of retrocausality is the grandfather paradox, in which one travels backwards in time to kill one's grandfather when he was a boy. At that point one's existence is paradoxical. Besides being overly vicious there is no evidence that one can do such a thing, and so to pose a retrocausation paradox in this form is not useful.

On the other hand, there is evidence that one can *influence* random events that have already occurred.[1] In one example H. Schmidt demonstrated a retro-PK effect using stereo headphones connected to a tape recorder.[2] The tape had previously been recorded with the output from a random noise source that produced clicks in the left or right track. Schmidt found that a person wearing the headphones could use intention to affect whether the clicks were audible dominantly in the left or the right headphone, even though the clicks had been recorded previously. A meta-analysis of 26 retro-PK studies found high statistical significance supporting the existence of retro-PK.[3] Therefore presenting the issue as one of influencing a previously occurring random event poses the paradox in a useful form.

The paradox is often stated in terms of bilking, which was originally used to show that retrocausation is logically impossible.[4] If an event *A* is caused by a subsequent event *B*, then once *A* has occurred it should be possible to intervene and block *B* from occurring. If this blocking could be accomplished, then event *A* would be bilked out of its cause and could not, in fact, be caused by *B*. Hence the paradox.

Numerous ways out of the paradox have been suggested, starting with Dummett,[5] who proposed that it would be impossible to test whether *A* precedes *B* because doing so would affect *A*. Although Dummett did not invoke quantum mechanics, his argument fits well with the uncertainty principle and the effects of measurements in quantum mechanics. If the mechanisms of psi are based on quantum mechanics – and this has not been proven – then Dummett's approach would resolve the paradox for microscopic psi phenomena. More recently a method based upon the meaning of the information has been developed in an attempt to explain the paradox.[6] The approach developed in the current paper does not rely on the retrocausal effects occurring at a quantum level, and rather than involving the meaning of the information it makes use of more quantifiable information and entropy involved in the processes.

Entropy of Each Process in Psi Interactions

In a previous article,[7] I first considered the constraints imposed by the second law of thermodynamics upon each process in a psi interaction. In normal forward-going time, causal processes are consistent with the non-decreasing entropy over time dictated by the second law. The entropy of a receiver in a process can decrease as long as there is a concomitant compensating increase in the entropy of the agent. The entropy of the combined agent-receiver system never decreases.

In a retrocausal process, however, things are not so simple. If the receiver's entropy were to decrease, followed temporally by a compensating increase in the agent, there would be an interval of time during which the net entropy of the agent-receiver system decreased, shown as a temporal entropy gap in Figure 1. This is inconsistent with the second law in forward-going time.[8]

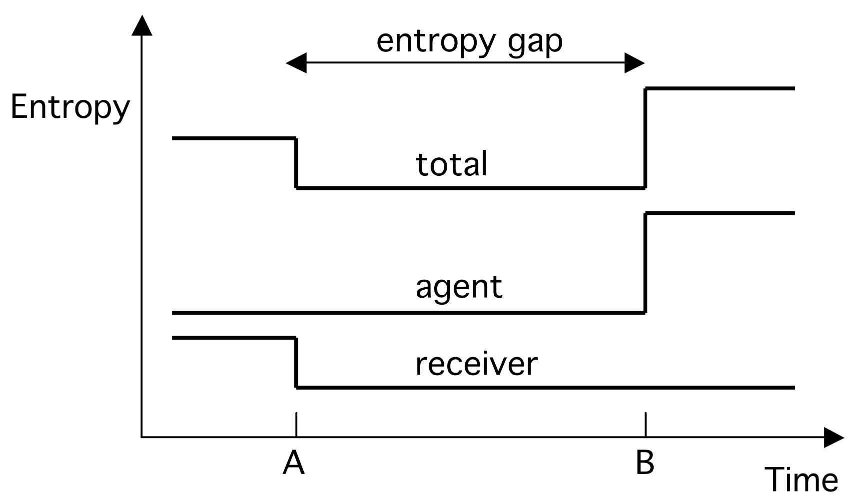

FIGURE 1. Formation of a temporal entropy gap in a retrocausal process. Here the entropy of the agent increases at time B and the entropy of the receiver decreases by a smaller amount at time A. Because A precedes B, there exists a period of time during which the total entropy of the system consisting of the agent and the receiver decreases. Because this would violate the second law of thermodynamics in forward-going time, the net entropy of a receiver cannot be decreased in a retrocausal process.

To maintain consistency with currently accepted thermodynamics, I proposed that the entropy of a receiver cannot be decreased by an advanced signal. Because a wide range of psi experiments have shown similar effect sizes no matter whether the agent acts before, simultaneously with, or after the receiver, I extended the proposition to state the entropy of a receiver cannot be decreased through a psi process independent of the temporal ordering of events. Finally, I noted that in psi interactions it is often ambiguous as to which party is the agent and which is the receiver. For example, presentience experiments often appear to have psychokinesis components, and vice versa. Therefore I extended the proposition to state the entropy of neither an agent nor a receiver can be decreased through a psi interaction.

Psi interactions composed of psi processes that are consistent with the second law of thermodynamics include the following classes and examples (references to the examples are given in reference 7):

- Human ⇔ Human Psi.
  Although living beings might produce some localized decreases in entropy, the net effect of physiological processes is to increase entropy.
  - Telepathy
  - Remote healing
- Human ⇔ Electronic Random-Event-Generator Psi.
  Processing and amplification of electronic signals requires an overall increase in entropy even though the effect of psi on the random triggers may be organizing.
  - PK of random-number-generator outputs
  - Presentience of electronically generated signals and images
- Human ⇔ Non-Electronic Inanimate System Psi.
  Again in this class of experiments psi influence may decrease the entropy to a level below what it would have been in the absence of psi, but still the overall process involves an increase in entropy, and so the second law is not violated.
  - PK influence on a random mechanical cascade
  - PK influence on the rate of decay of a pendulum
- Inanimate System ⇔ Inanimate-System Psi.
  It is not clear at this point whether we may legitimately call this psi, but some processes in inanimate systems share characteristics with psi. For example, the double-slit experiment found in most quantum mechanics texts is sometimes described in terms of delayed-choice. Single particles passing through the slits seem to sense in advance whether to sample both slits, which are open, or pass entirely through one because the other is blocked.

One could argue that in some if not all of these four classes of interaction, the psi serves to decrease the entropy of the receiver. If so, how could the second law of thermodynamics be observed? Although the psi interaction may decrease the entropy of the receiver to a level below what it would have been in the absence of psi,[9] the process also involves the generation of excess entropy. The sum of a possible reduction in entropy resulting from the psi interaction and a larger excess entropy leaves the process with an net increase in entropy.

Psi process that would violate the second law generally involve inanimate systems. Examples of these forbidden processes include the following (references to the examples are given in reference 7):

- Converging ripples in a pond. A stone falling into a pond causes concentric ripples to emanate from the point of entry. The temporal reversal of this process would be for concentric ripples to converge and meet an entering stone, an inanimate version of retro-PK in which the falling stone causes the advanced, converging ripples to form. The converging ripples would form from random surface fluctuations, and would represent a net reduction in entropy.
- An advanced signal pulse. A source emits a normal pulse, and after a transit time the normal pulse arrives at the detector and is registered. An advanced pulse would emanate at a distance and arrive at the source just as it was emitting. It would pass the detector a transit time *before* the source emitted the pulse. The advanced pulse would represent a reduction in entropy of background fluctuations, and therefore could not form.
- Advanced observation of astronomical events. As in the case of an advanced signal pulse, an astronomical event such as a solar prominence would be observable a transit time (8.3 minutes) before as well as after the event took place on the Sun. And as in the case of the signal pulse, the advanced wave could not form.

CONSTRAINTS ON RETROCAUSATION

Three types of entropy are analyzed. The previous section dealt with the *entropy of each local process* in a psi interaction. It was shown that the net entropy of each local process cannot decrease. In this section the development of the constraints imposed by entropy on psi interactions is extended in two ways. First the *entropy of the total processes* is used to decide whether there has been any causation, either in normal or retrograde time. Then the *entropy in the information transmitted across time from one local process to another* is used to provide quantitative constraints on retrocausation.

Entropy and Causality

At first glance it might appear that physically reversible processes are susceptible to retrocausation and irreversible process are not. In this section I explore the concept of causality in reversible and irreversible processes. The results are different from what one might expect.

A thermodynamically reversible process is one in which no new entropy is created. An example of such a process is the collision of a white billiard ball with a stationary red ball on a frictionless table. To make the analysis simple, suppose that the collision is head-on so that after it the white ball comes to a standstill. Let us examine this reversible process from three different perspectives and consider which ball is the causal agent.

Case R1. A stationary observer sees the red ball as being at rest until it is acted upon by the white ball moving towards it. Hence the white ball appears to be the causal agent.

Case R2. Here the observer is in an inertial reference frame moving with the initial motion of the white ball on the frictionless table. To begin with, the red ball and the billiard table appear to be moving. The observer sees the white ball as being at rest until it is acted upon by the red ball moving towards it. Hence the red ball appears to be the causal agent.

Case R3. We know that if the R1 collision is filmed and played back in reverse, it appears to obey all physical laws. In retrograde time a stationary observer sees the white ball as being at rest until it is acted upon by the red ball moving towards it. Hence the red ball appears to be the causal agent.

In these three different views of the same reversible process, the apparent causal agent varies. It is arbitrary as to whether the white ball or the red ball is designated as the causal agent. More accurately, neither is the causal agent and a reversible process itself is not causal.[10]

In contrast, the production of entropy results in an irreversible process. An example of such a process is the frictional heating of the sole of a shoe as it slides to a stop on a floor. Let us examine this irreversible process from three different perspectives and consider whether the causal agent appears to vary.

Case Ir1. A stationary observer sees the shoe as moving until it is slowed by friction, which produces heat and entropy. It appears that the motion of the shoe is the cause of the heat.

Case Ir2. Here the observer moves along with the shoe. This is not a legitimate inertial reference frame because the shoe is decelerating. Therefore this attempt to see the shoe as being acted upon and so not the causal agent does not work.

Case Ir3. Here the motion of the shoe is filmed and played back in reverse to see if the heat can be seen to cause the shoe to move. Viewed in retrograde time, this process is unphysical, as it would require a reduction in entropy over time. As in Case Ir2, this attempt to see the shoe being acted upon and therefore not the causal agent does not work.

In these three attempts at different perspectives of the same irreversible process, the apparent causal agent cannot be made to vary. It is clear that the motion of the shoe causes the heating. There is no reference frame in which one might attribute the shoe's motion to the heat from its sole. From this example it may be seen that for an irreversible process, there is a clear assignment of cause. Irreversible processes are causal.

To examine this distinction from a different perspective, consider Lagrangian dynamics. Classical laws of motion obey Newton's laws, which relate cause (force) and effect (acceleration). Newton's laws apply to both reversible and irreversible processes.

Motion of bodies may also be described using Lagrangian dynamics and Hamilton's Principle[11] (from which one may derive the principle of least action).

According to this principle, the path chosen by a dynamical system is the one that minimizes the time integral of the difference between the kinetic energy and the potential energy. While Newton's formulation emphasizes cause and effect, Hamilton's Principle is a non-causal description:[12]

> According to Hamilton's Principle... the motion of a body may be considered to result from the attempt of Nature to achieve a certain *purpose*, namely, to minimize the time integral of the difference between the kinetic and potential energies.

Rather than stating that the white ball causes the red ball to move, a purpose-oriented statement would be that the white ball and the red ball each moves so as to minimize the specified integral. Significantly, Hamilton's Principle does not apply to irreversible processes,[13] whereas Newton's formulation applies to both reversible and irreversible processes. This is consistent with the proposal that in reversible processes the assignment of cause is arbitrary and inappropriate, while irreversible processes are undeniably causal.

A process in which all the energy is converted to heat is purely causal. Processes in which some of the energy is converted to heat and some to another non-entropic energy form include both causal (entropy producing) and non-causal (reversible) components. A process in which no entropy and heat is produced (e.g., the billiard table example) is non-causal. Such processes may be viewed as being predetermined, and described by correlations, interdependencies, or purpose.

For the same reason that a process with no entropy gain cannot be causal, it certainly cannot be retrocausal. Therefore reversible and hence non-entropy producing processes are not retrocausal, and we cannot expect to influence them using retro-PK. In the process there must be some randomness, which is associated with entropy production, for it to be susceptible to retro-PK.

Retro-Psychokinesis Efficiency and Information Entropy

Returning to the retrocausation example posed in the Introduction, let us find a simple way out of the bilking paradox. Yesterday the winning numbers in a lottery were determined by a random process. Today you decide that you would like to be the winner of that lottery. You apply intention to the lottery to influence the outcome so that yours are the winning numbers. You are the retrocausal agent, using retro-PK that is evoked by your intention. If you know the outcome of yesterday's lottery, changing that outcome today would create a paradox, a conflict between what you know has occurred and the current reality of what has occurred. On the other hand, if you do not know the outcome of yesterday's lottery before applying your intention to it, no paradox exists.

Note that it is not necessary to consider the knowledge that others have of yesterday's outcome if you have not been informed of their knowledge. The outcome that others knew of will simply be the one that exists in response to your intention. If you were informed of others' knowledge before applying intention to yesterday's lottery, there would be a paradox because of your knowledge.

The two knowledge extremes have now been covered, that in which you have complete knowledge of yesterday's outcome and that in which you have no knowledge. The next step is to consider the case in which you have partial knowledge of yesterday's outcome. For example, suppose you heard some of the digits of the winning number on the radio but not all, and those digits that you did hear correspond to your lottery ticket number. The uncertainty in your knowledge may be specified quantitatively using information theory.

This uncertainty is expressed in terms of the surprise produced at learning that a particular outcome has occurred. If a particular outcome has a low probability, then the surprise will be large. It is expressed in terms of the surprisal,[14] $\log_2[1/p(A_n)]$, where $p(A_n)$ is the probability for the occurrence of a particular outcome A_n. (The term surprisal seems particularly appropriate in the context of psi phenomena.)

The uncertainty in the information is the information entropy, *H*. It is the average surprisal, which is the weighted sum (expected value) of all possible outcomes:[15]

$$H(A) = \sum_{i=1}^{n} p(A_i)\log_2\left(\frac{1}{p(A_i)}\right). \tag{1}$$

For a small value of *H* one would have a moderate degree of certainty of being the winner, and for a large value of *H* one would be very surprised to learn of being the winner.

The concept of information entropy may be applied to retrocausation by expressing retro-PK in quantifiable terms. As a measure of the efficiency of intention to evoke a particular PK outcome, I define a PK efficiency, η_{PK}, where

$$\eta_{PK} = \frac{p_{PK}(A_n)}{I_{intention}(A_n)}. \tag{2}$$

Here $p_{PK}(A_n)$ is the probability that the intended outcome A_n occurs. The meaning of p_{PK} is clear if the outcome is binary (yes/no). For outcomes that are qualitative rather than binary one may define an appropriate measure of the quality of the outcome compared to that which was intended. The $I_{\text{intention}}$ is a measure of the intensity of intention, which is beyond the scope of this paper to define precisely. Although Eq. (2) has been developed in the context of retro-PK, it may just as well be applied to PK that is not time reversed.

One's ability to affect yesterday's outcome today must be limited to the uncertainty in one's knowledge of that outcome today. Therefore

$$\eta_{PK} \le \frac{H(A)}{H_0(A)} \tag{3}$$

where H_0 is the maximum information entropy that can occur in the process. Other factors besides the information entropy can limit the η_{PK}, and therefore Eq. (3) is an inequality. In the lottery example H_0 would correspond to knowing none of the winning number digits. When the knowledge uncertainty is at its maximum, the maximum possible η_{PK} is 1. The possible retro-PK effect size increases as the information uncertainty or entropy increases, as shown in Figure 2. The bilking paradox disappears as long as Eq. (3) is adhered to.

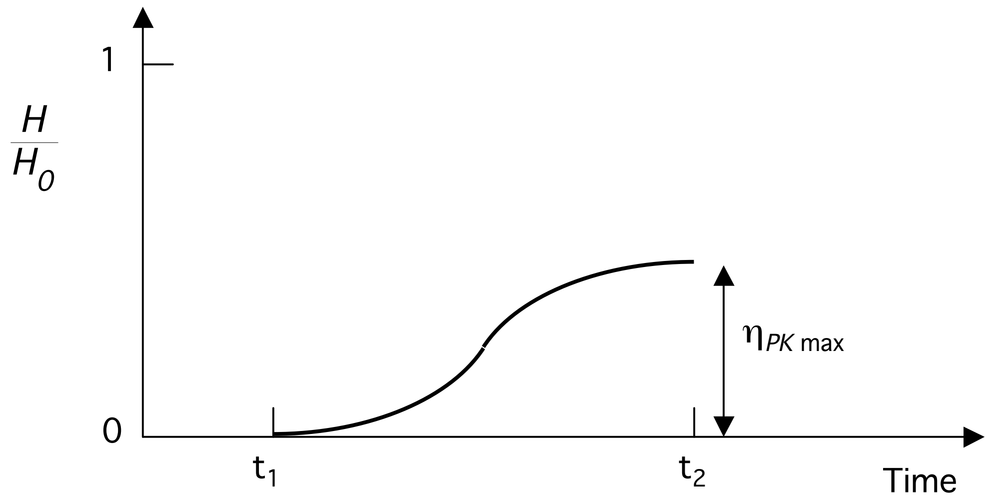

FIGURE 2. Maximum psychokinesis efficiency, $\eta_{PK\,\max}$, resulting from information uncertainty. The relative information entropy of an event occurring at time t_1, H/H_0, decreases as information of the event is transmitted to a receiver. This receiver acts as an agent at time t_2 to retrocausally influence the event that had occurred at time t_1. The maximum influence that the receiver/agent can exert, represented as $\eta_{PK\,\max}$, is limited to the normalized magnitude of the information entropy generated.

Increasing the noise in the communication process reduces the data rate and hence increases the information entropy at the receiver. The Shannon-Hartley theorem gives the communication channel capacity (C) as a function of the signal-to-noise ratio (S/N):[15]

$$C = BW \times \log_2\left(1 + \frac{S}{N}\right) \tag{4}$$

where BW is the bandwidth of the channel. Thus a number of factors can contribute to information entropy:

1. A large noise power at any point in the communication reduces the signal-to-noise ratio and increases the information entropy;
2. A limited channel bandwidth contributes to the entropy;
3. Incomplete information from the source results in entropy at the information receiver (who is also the PK agent);
4. Errors in the signal detection at the receiver (the PK agent) serve to increase the information entropy.

All of these factors increase the entropy and thereby allow for greater PK efficiencies.

To avoid any misconceptions, it is worthwhile clarifying what types of noise can and cannot increase the information entropy and hence improve the PK efficiency. Any noise that limits the receiver's knowledge of the outcome increases the entropy. Noise in the source process that determines the outcome (e.g., the random number generator producing the winning lottery numbers) does *not* increase the information entropy because it does not limit the receiver's knowledge of the outcome once it has been determined. There can be other reasons that a noisy, highly random (i.e., entropy producing) source is more susceptible to PK than a quiet one, such as those outlined in the Background section, but in the cases of these other reasons the improvement is not due to entropy resulting from the information transmission.

DISCUSSION

Based upon the above analysis we are led to a conclusion that may be counterintuitive initially: reversible processes are not susceptible to retrocausal influence, but irreversible processes are. This is because reversible interactions are non-causal, but in an irreversible interaction the entropy production that produces the irreversibility allows for the distinction between cause and effect.

Another constraint imposed by entropy, described in the Background section and in an earlier paper,[7] is that the net entropy change in each part of a psi interaction must be non-negative. If this is not the case an entropy gap appears, shown in Figure 1.

A third limitation on retrocausation imposed by entropy is a function of the uncertainty introduced by the transmission of information from one part of a psi interaction to another. As described by Eq. (3), for retro-PK to be possible there must some degree of uncertainty and hence information entropy in the agent's knowledge of the outcome. If there were not, the process would be open to the bilking paradox. The greater the entropy in the information received by the agent, the more efficient his or her PK can be, as shown in Figure 2. Although information entropy is not the same as thermodynamic entropy, they are intimately related. Just as information entropy provides a resolution to the paradox of Maxwell's demon in thermodynamics,[16] it also provides a resolution to the bilking paradox. As the thermodynamic entropy of a system increases so too does its information entropy.

The consequence is that efficient retro-PK and hence retrocausation requires an imperfect communication process. In our lottery example, the communication system includes of the process of transmitting the information to the agent, and the agent's receiving and registering mechanism. The system includes non-entropy-producing, noiseless processes as well as processes that produce entropy. For example, the lottery winner information may be carried with perfect fidelity from the random number generator to the person who will announce it over the radio. This part of the process cannot contribute to the maximum PK efficiency. It is the entropy-producing parts of the process that allow for retro-PK.

For the case in which the entire communication process has perfect fidelity and no noise, there will be no entropy production and no possibility of retrocausation. Aside from the need to avoid the possibility of bilking, such a process could not be susceptible to retrocausation because it is reversible (no new entropy creation) and hence non-causal, as shown earlier; a non-causal process may be viewed as being predetermined and not susceptible to retro-PK.

It is attractive to think about psi processes as functioning by correlation, along the lines of quantum entanglement.[17, 18] However, processes that are purely correlated cannot include retrocausal influence for two reasons. The first is that in correlation there is no causation – one cannot identify a causal agent – and hence there can be no retrocausation either. There could be only the illusion of causation and retrocausation. The second reason is that pure correlation would open up the processes to the bilking paradox because of the absence of entropy creation in communication among the correlated elements. Correlation could not give rise to retrocausal phenomena unless it includes a means to increase entropy, but in such a case one could argue that the interaction is no longer purely correlational.

It is routinely observed that psi phenomena are independent of the temporal order of stimulus and response,[19] and therefore the underlying mechanisms are most likely order-independent. For this reason it is tempting to generalize the conclusions that are presented here for retro-PK to forward PK, in which intention is applied to a future outcome, and also to simultaneous PK, in which intention is applied to an outcome that unfolds at the same times as the PK is applied. Assuming such a generalization is justified, then uncertainty in the communication process is required in forward, simultaneous, and retrograde PK processes. It is not only the knowledge that the agent receives before applying PK intention that is important, but also the information gained in response to the application. In particular, greater, more quantitative knowledge of the PK consequences detracts from the PK efficiency. This is consistent with the finding of decreased psi effects as the subjects' descriptions of their observations are forced into more objective and quantitative formats.[20] It is usually believed that feedback improves psi performance.[21] Perhaps this is not the case in reality, and performance is improved with additional noise in the communication system, at least with respect to the agent's knowledge of the direct consequences of his or her PK intention.[22]

The question arises as to whether the bilking paradox concept and the limitations it creates apply to presentiment. The experiment of Spottiswoode and May[23] provides a good example of presentiment. In it, a galvanic-skin-response signal in a subject was measured in advance of a loud horn sounding. There was measurable increase in that advanced signal when that galvanic skin response was averaged over many trials. Could the advanced galvanic skin response be used as a trigger to disable the horn, so that the subject's presentiment of the sound were bilked? It might appear that this would be a paradox, because the subject would then experience presentiment of an event that never occurs. If this were a genuine bilking paradox, the per-trial effect size, as opposed the effect size averaged over many trials, would always have to be so small that there would be insufficient signal for a disabling trigger. This situation of a presentiment response being sufficiently large to disable the horn is not, however, a paradox, and the concepts developed in the current paper do not predict a limit to the per-trial presentiment signal size. The reason is that the presentiment of an event is not direct knowledge of that event. If the presentiment turns out to be incorrect, then reality is not called into question and there is no true paradox. If presentiment has a biological function in helping one prevent a dangerous event from occurring, it would be less valuable if one could not have sufficient advanced information to be able to prevent that event from occurring.

For a model to be useful, it must be predictive and quantitatively testable. Otherwise it falls into the category of opinion.[24] The predictions of the current model are embodied by Eqs. (2) and (3). PK efficiency should increase as the information entropy of the agent's knowledge increases, and if this model is correct the measured maximum PK efficiency should conform to the predictions. When an experiment gives a null result it is natural to think about improving the measurement sensitivity and signal-to-noise ratio to obtain the desired outcome. However, with psi experiments often the experimenter should do just the opposite: decrease the signal-to-noise ratio. A noisy communication increases the information entropy and enhances the potential magnitude of a PK effect.

The analysis that I have presented has been consistent with currently accepted physics and information theory. I believe it prudent to work within this framework to understand psi phenomena unless and until it becomes clear that we must extend currently accepted physics concepts. Within this framework, the analysis is necessarily mechanistic and reductionist. A holistic approach, for example, von Lucadou's Model of Pragmatic Information,[25] may be successful in describing conditions for psi. That model deals with meaning, which operates on a different level from mechanistic models, and von Lucadou specifically states that psi cannot be treated as a classical signal. Only as we achieve a greater measure of success in modeling psi phenomena in the future, will it become evident whether there is, in fact, a contradiction between the holistic and mechanistic approaches. Quite possibly they deal instead with the operation of psi on different and complementary levels, just as any form of communication operates on both physical and semantic levels.

CONCLUSIONS

- Based on an earlier analysis,[7] the net entropy of each participant in a psi interaction cannot decrease.
- Causation and retrocausation require irreversibility and entropy creation.
- In a retrocausal process, the retro-psychokinesis efficiency is limited as described the relation $\eta_{PK} \le H / H_0$, where H is the entropy in the information about the event that is transmitted to the agent who intends to influence it.
- Because psi phenomena appear to be independent of the temporal order of events, not only retro-psychokinesis but all psychokinesis processes are likely subject to the above relation.
- Psychokinesis experiments are expected to provide larger effect sizes as the signal-to-noise ratio is *decreased*.
- Feedback in psychokinesis experiments may decrease the effect size.
- The bilking paradox does not preclude one's using presentiment of an impending event to prevent that event from occurring.

ACKNOWLEDGMENTS

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9. As developed in discussion with M. Ibison.
10. If one finds it difficult to agree that a reversible process is not causal, one might consider how cause and effect could be distinguished in a reversible process besides temporally.
11. Described in most texts on classical mechanics, such as J. B. Marion, *Classical Dynamics of Particles and Systems, Second Edition*, New York: Academic Press, 1970, Ch. 7.
12. Ibid., p. 212.
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19. For example, R. G. Jahn, , B. J. Dunne, R. D. Nelson, Y. H. Dobyns, and G. J. Bradish, "Correlations of random binary sequences with pre-stated operator intention: a review of a 12-year program," *J. of Scientific Exploration,* **11**, 345-367 (1997).
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22. There is some evidence for decreased PK effect size with feedback, but it is not statistically significant. See p. 384 in Y. H. Dobyns, B. J., Dunne, R. G. Jahn, and R. D. Nelson, "The megaREG experiment: replication and interpretation," *J. Scientific Exploration*, **18**, 369-397 (2004).
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24. "Without data your conclusion is just another opinion." Note taped to the door of one of my graduate students.
25. W. v. Lucadou, "The model of pragmatic information (MPI)," *European J. Parapsychology*, **11**, 58-75 (1995).