2021, Vol. 1, No. 1-2, pp. 114-155

Journal of Anomalous Experience and Cognition (JAEX)

Observer Dependent Biases of Quantum Randomness: Effect Stability and Replicability[1]

Moritz C. Dechamps*[a], Markus A. Maier*[a], and Markus Pflitsch[a] Michael Duggan
[a] Ludwig Maximilian University

Abstract. Quantum mechanics (QM) proposes that a quantum system measurement does not register a pre-existing reality but rather establishes reality from the superposition of potential states. Measurement reduces the quantum state according to a probability function, the Born rule, realizing one of the potential states. Consequently, a classical reality is observed. The strict randomness of the measurement outcome is well-documented (and theoretically predicted) and implies a strict indeterminacy in the physical world's fundamental constituents. Wolfgang Pauli, with Carl Gustav Jung, extended the QM framework to measurement outcomes that are meaningfully related to human observers, providing a psychophysical theory of quantum state reductions. The Pauli-Jung model (PJM) proposes the existence of observer influences on quantum measurement outcomes rooted in the observer's unconscious mind. The correlations between quantum state reductions and (un)conscious states of observers derived from the PJM and its mathematical reformulation within the model of pragmatic information (MPI) were empirically tested. In all studies, a subliminal priming paradigm was used to induce a biased likelihood for specific quantum measurement outcomes (i.e., a higher probability of positive picture presentations; Studies 1 and 2) or more pronounced oscillations of the evidence than expected by chance for such an effect (Studies 3 and 4). The replicability of these effects was also tested. Although Study 1 found strong initial evidence for such effects, later replications (Studies 2 to 4) showed no deviations from the Born rule. The results thus align with standard QM, arguing against the incompleteness of standard QM in psychophysical settings like those established in the studies. However, although no positive evidence exists for the PJM and the MPI, the data do not entirely falsify the model's validity.

Keywords: Micro-Pk, Mind-Matter Interaction, Pauli-Jung model, Model of Pragmatic Information, Subliminal Priming, Change of Evidence

1 Address correspondence to: Dr. Moritz Dechamps, Department of Psychology, Ludwig Maximilian University, Munich, Germany, moritz.dechamps@psy.lmu.de. * These authors contributed equally to the work.

https://doi.org/10.31156/jaex.23205

Highlights:

- An extension of quantum mechanics proposes observer influences of (un)conscious mental states on measurement outcomes.
- In a set of 4 studies with more than 12,000 participants in total, a subliminal priming paradigm was used to induce a biased likelihood for specific quantum measurement outcomes.
- Even though strong evidence for an observer influence effect was found initially, later replications failed to reproduce the finding.
- The results are discussed in light of the so-called 'decline effect' in psi research and a temporal analysis of the change of evidence over time is proposed.

The theoretical framework of quantum mechanics (QM) has provided a powerful scientific approach for the understanding of physical reality (Rosenblum & Kuttner, 2011). At its core, it highlights the prominent role of the measurement process in quantum state reduction. None of QM's predictions have been falsified and doubts regarding its completeness, first raised by Einstein (e.g. Einstein et al., 1935), have been ruled out by the theoretical work of Bell (1964) and empirical evidence provided by Aspect et al. (1982) and others since. QM holds that measurement of a quantum system does not register a pre-existing reality but rather creates reality from the quantum superposition of potential states—so-called quantum states. A measurement reduces the quantum states' superposition according to a probability function—the Born rule (Born, 1926)—realizing one of the potential states. Consequently, a classical reality is observed. The strict randomness of the measurement outcome and the question of what exactly constitutes a measurement are among QM's most profound enigmas. Some physicists in the early days of quantum theory (e.g. London & Bauer, 1939; Wigner in his early years, see Primas & Esfeld, 1997) and subsequently (e.g. Mensky, 2013; Stapp, 2007) have struggled with orthodox interpretations of the measurement problem and proposed that consciousness might play a crucial role in quantum state reduction. The research reported herein aimed to test the validity of this proposition by exploring the circumstances under which an observer's mental state might influence quantum state reductions.

We generally agree with mainstream QM interpretations that deny the role of consciousness-related quantum state collapse (e.g. Yu & Nikolić, 2011), but believe that this is only true insofar as the specific outcome of a measurement provides no personally relevant meaning to a conscious observer. This is usually the case for standard experiments in quantum physics. However, for rare experimental cases involving meaning we think that the observer's specific mental state will be correlated with the quantum measurement process, leading to a biased outcome. We thus argue for the incompleteness of QM in situations in which psychologically relevant information evolves from quantum state reductions and is individually observed or experienced. For all other circumstances, the validity and causal closure of QM remains intact. So, if it is posited that physical theories are not concerned with meaning in the above-mentioned scenario, QM can be considered complete. However, for situations in which meaning is attached to conscious observation of a quantum system's measurement outcomes, the observer's psychological state might need to be included as a biasing factor. This extended QM framework was initially proposed by Wolfgang Pauli and Carl Gustav Jung in a letter exchange between 1932 and 1958. Some propositions derived from this theory were tested experimentally in the studies presented here.

Any measurement device interacting with a quantum superposition will form a combined system following the fundamental rules of QM. This process is repeated for any additional measurements of the combined system, leading to a theoretically infinite chain of combined systems for which QM theory provides no ending point. To suggest a natural final step, von Neumann (1932) speculated that this chain must eventually end with the subjective perception of a human observer. In line with this, London and Bauer (1939) explicitly proposed that an observer's consciousness causes the collapse of the wave function. Wigner also strongly favored this idea and became an important proponent (Esfeld, 1999) but abandoned this view completely when faced with the problem of solipsism (Atmanspacher, 2004).

Although some scientists have pursued subsequent models that favored a role for consciousness (e.g. Mensky, 2013; Stapp, 2007), they remain a minority within the scientific community in which mainstream quantum physics considers this hypothesis to be empirically falsified. For example, Yu and Nikolić (2011) analyzed the validity of the consciousness-causes-collapse argument by referring to empirical data from experiments in which the collapse of the wave function is dissociated from the conscious observation of the outcome. In these studies, "which-path-information" was assessed in either idler photons or single atoms. Under such circumstances, the interference pattern was destroyed even if the actual status of the signal stimuli was not registered macroscopically (Dürr et al., 1998; Eichmann et al., 1993; Mandel, 1999; Zeilinger, 1999; Zou et al., 1991). Their conclusion was that if "which-path-information" is identifiable in principle, it constitutes a sufficient condition for the collapse of the wave function. Conscious observation or any other concrete registration of quantum states is thus not a necessary condition for state reduction. This rendered any strong versions of consciousness-only-causes-collapse models implausible. QM and quantum measurement work well even without conscious observation (but see Radin et al., 2016; Tremblay, 2019).

Nevertheless, some prominent physicists with a special interest in mind-matter relations have proposed ideas that include mental states in physical theories within a quantum theoretical framework. These approaches elaborate on dual-aspect monism, a philosophy of mind that states that the mental and physical realms evolve from an underlying common domain in which both form an undivided union. Bohm (2002) formulated a distinction between an explicate order that describes the classical world and an implicate order that refers to the world's quantum theoretical evolution. He related the disjunctive nature of mental and physical states to the explicate order, whereas in the implicate order this distinction vanishes "*with this deeper reality … [being] something beyond either mind or matter*" (Bohm 1990, cited in Atmanspacher, 2012, p. 99; see also Bohm & Hiley, 1993; Hiley, 2001). Similarly, d'Espagnat (1999, 2006) argued that the deepest level of reality—the 'Real'—is "*prior to mind-matter splitting*" (d'Espagnat, 2006, p. 454).

A more elaborate theory, although not mathematically formalized, was formulated by Pauli and Jung in a correspondence exchange between 1932 and 1958 (for a summary see Atmanspacher, 2014, 2020). In their view, at the deepest level of reality quantum states and unconscious knowledge of them constitute a union that Jung called the *unus mundus*. This level is ontic and thus not empirically accessible. Any transition from this level to a higher level represents an epistemic split upon which conscious knowledge and corresponding classical physical states appear. Within the mental realm, this process is expressed by a knowledge transition from unconscious (i.e., unknown) to conscious (i.e., known) mental states. This parallels the transition in the material domain from quantum to classical physical states during the measurement process. Because conscious observation and classical physical states both evolve from a common ground, a psychophysical correlation can be assumed.

Two types of psychophysical correlations between mind and matter are addressed by Pauli and Jung: First, structural correlations are proposed. They are persistent and reproducible owing to ordering factors located in the *unus mundus* (*archetypes* in Jung's terminology) and are evident in the parallelism of mind-brain activities described above. Second, induced correlations (ICs) are proposed: the psychophysically neutral domain of the *unus mundus* can be affected by mental activity causing certain changes in an individual's unconscious mind. These unconsciously activated mental states are also manifested as changes in their corresponding physical quantum states that exist in a superposition and are described by a wave function. Specifically, mental activation of certain unconscious states co-produces biased amplitudes of physical states of the wave function that represent the corresponding quantum reality. During the occurrence of an epistemic split, this will lead to the increased likelihood of a conscious experience of the previously activated unconscious state and the realization of its interrelated classical physical state. Thus, ICs of this nature predict local violations of the Born rule and of the indeterminacy principle of standard QM. Importantly, ICs are restricted to situations in which conscious observations of *meaningfully* related physical states occur during the measurement of a quantum system. Aware of the potential conflict with standard QM, Pauli emphasized the local—as opposed to generalized—nature of such effects. Those phenomena were labeled *synchronistic events* and were supposed to be evasive, occasional, and not (easily) reproducible (Pauli, 1952 in von Meyenn, 1996, pp. 634-35, cited in Atmanspacher, 2012, p. 114 and Atmanspacher, 2014, p. 254). Jung and Pauli's consideration of these mind-matter interactions as rare and unsystematically occurring special cases, even within a meaningful observation context, ensured that overall their theory was in line with the indeterminacy principle of QM. A downside of the unsystematic nature of ICs is that they should hardly be detectable empirically. This issue will be addressed in the paragraphs that follow.

A mathematically consistent formalization of the Pauli-Jung model (PJM) was recently provided by Atmanspacher and colleagues (Atmanspacher et al., 2006; Atmanspacher et al., 2002; Filk & Römer, 2011). In their generalized quantum theory (GQT), they referred to QM only in analogical form. Within GQT, mind-matter interactions are described as analogous to entanglement correlations. Entanglement involves acausal correlations based on the principle of complementarity. Accordingly, unconsciously induced mind-matter interactions are thought to vary unsystematically across time.

Consequently, Lucadou et al. (2007) formulated a set of axioms subsumed under the label *model of pragmatic information* (MPI) (see also Lucadou, 1995, 2015, 2019). In this model, novelty is defined as initial evidence for ICs and is complementary to the confirmation—that is, the replicability—of the effect. Thus, a first-hand empirical documentation of an IC should be followed by the effect's decline in a later replication attempt, leading to a reversed u-shaped curve of evidence for the effect across time. The MPI therefore predicts that any replication attempt with the same design will most likely result in a null finding. Thus, ICs would be, in principle, non-replicable and cannot be distinguished from chance effects in this way. To escape this scientific dead end, the MPI also proposes a replacement of the effect during replications. This phenomenon also occurs unsystematically and may manifest itself, for example, in the effect's shift toward the control condition or other experimental data that have been collected in addition to the main dependent variable. These anomalies may be detected in a correlational matrix that might reveal more significant correlations between multiple relevant variables than expected by chance. The matrix method was initially applied successfully (Lucadou, 2006), but recent attempts to replicate the matrix data with an independent experiment yielded null findings using the exact same data matrix but showed significant effects with a larger matrix that included more variables than those originally included (Walach et al., 2019).

The author of the MPI, Lucadou (2019), has provided a summary of all replication attempts using the matrix method and concluded that, given that some matrix replications failed, a degree of elusiveness is inherent in the empirical investigation of ICs and cannot be circumvented solely by switching to a higher level of testing, such as the matrix method. Regardless of the methods applied, exact replications will therefore most likely produce null findings. A potential way out of this maze might be to abandon attempts at exact replication and to proceed with conceptual replications. The less similar a replication design is to the original design, the more likely it is that the ICs will reappear. The problem with this proposition is that the "degree of similarity" necessary for a replication design to be potentially successful cannot be easily specified. Moreover, the MPI is very reserved in this respect and assigns this option only a low likelihood of success.

Taking a different route, some authors have recently challenged the MPI and the unsystematic nature of the ICs proposed therein. Maier and Dechamps (2018) slightly extended the MPI's theoretical framework, arguing that the decline does not necessarily lead to white noise (see also Dechamps & Maier, 2019; Maier et al., 2018). Based on their own empirical data, they proposed a non-random oscillating temporal pattern of effect change across time. The appearance of ICs in the data constitutes a local reduction of entropy, and with continuous data collection, the inevitable increase of global entropy leads to a vanishing of the original effect. Once this state is re-established, ICs with local violations of entropy can be set in again. Such entropic corrections may recur several times within a sufficiently lengthy data collection process, leading to a pattern of oscillation in the evidence for and against the effect. Thus, average quantum measurement outcomes in a given data set should obey the indeterminacy postulate and appear to be random (and, on the mean score level, obey the Born rule), but occasional deviations from randomness should display a periodic pattern (i.e., vary systematically across time).

Taken together, the central predictions with regard to the occurrence of ICs in a quantum measurement experiment derived from such a revised PJM are as follows: (a) Induced correlations during quantum measurement involving a conscious observer are established when the potential classical physical states are meaningfully related to the observer's unconscious state. The unconscious mind thus serves as an ordering factor. (b) Any activation of unconscious mental states should affect the likelihood of a conscious experience of this state and its corresponding physical manifestation after the epistemic split occurs. And (c) such effects should globally follow the indeterminacy principle and thus occur randomly when looking at the mean scores of the potential measurement outcomes but should follow a non-random, systematic pattern across time.

Testing the Existence of ICs Empirically

A large body of research has tested the existence of ICs during the last five decades (for an overview see Varvoglis & Bancel, 2015). This line of research is called micro-psychokinesis (micro-PK) and typically uses quantum-based random number generators. The studies conducted involved the participation of human observers and equipment that allowed the production of quantum-based outcomes, so-called quantum random number generators (qRNGs). A qRNG uses a quantum process to establish the superposition of two potential states, such as the decay or non-decay of an atom (Schmidt, 1974) or a photon taking one of two potential paths (Quantis qRNG). The specific quantum states were then translated into a consciously experienced event, such as the illumination of a lamp to the left or to the right in a circular display (Schmidt, 1970) or the presentation of a positive or negative picture on a computer screen in front of the participant (Maier et al., 2018). The volunteer's explicit or implicit task was to mentally influence the outcome. Hundreds of studies with different variations on observers' intentions and various outcome measures have been conducted and have yielded an impressive amount of data. A meta-analysis of these studies found an overall significant effect and thus evidence for observer-dependent variations in quantum randomness, that is, evidence for the existence of ICs (Bösch et al., 2006; Duggan & Tressoldi, in prep.; Radin & Nelson, 1989). However, it quickly became obvious that many micro-PK studies, including Schmidt's original work, could not be easily replicated (see Varvoglis & Bancel, 2015). This is exemplified by the PEAR benchmark study published by Jahn et al. (1997). The authors of this study employed a strict universalist approach, working with unselected participants, keeping the experimental environment constant, and following a strict predefined experimental protocol. This study took 12 years and included 91 participants with over 2.5 million trials altogether. They presented a qRNG-based random walk to the observers as a moving line on a computer screen, and the participants were instructed to mentally influence the walk upwards or downwards or to leave it unmoved. The results yielded a *Z*-score of 3.8 (difference between up and down conditions) at which the null hypothesis could

Journal of Anomalous Experience and Cognition (JAEX) 2021, Vol. 1, No. 1-2, pp. 114-155

be rejected. A pre-registered exact replication with 227 participants invited to three participating labs, however, yielded a non-significant *Z*-score of 0.6. Although different explanations may be offered as to why the replication failed—for example, insufficient study power due to an overestimation of the original effect (Varvoglis & Bancel, 2015)—proponents of the MPI interpret these findings as evidence of the unsystematic variation of the effect in later replications and thus the theoretically inherent decline of evidence for ICs (Lucadou et al., 2007).

Most studies completed in this area made no explicit reference to the PJM, which provides a set of circumstances for the occurrence of ICs. Hence, they did not simultaneously test the three predictions outlined above. In particular, the contribution of unconscious processes to the initiation of ICs has been widely ignored. This is not a major issue, since it was not the only theory to predict micro-PK effects, but to take the PJM seriously, it is necessary to study the participants' unconscious states and their variations in combination with qRNG outputs that correspond to these unconscious psychological states.

An exhaustive test of the PJM and its extension was recently provided by Maier et al. (2018) and Dechamps and Maier (2019). In some of their studies, they used smokers as participants and non-smokers as controls. Smokers were believed to have an (unconscious) need for smoking-relevant stimuli (such as cigarettes) that would be absent in non-smokers. All participants observed images depicting either smoking-relevant or neutral material. These were randomly chosen for each trial using a qRNG. Across three experiments, the authors applied Bayesian analysis and found that the evidence for a deviation from chance expectations in the smokers' sample was undecisive (while moderate evidence for a random behavior was found for the non-smokers). However, the effect varied non-randomly and periodically to a significant degree. A fast Fourier transform (FFT) analysis applied to the sequential Bayes factors (BFs) obtained from the smokers and non-smokers revealed that the number of significant amplitudes found within the smokers' data was significantly different from chance (the amplitudes of the resulting frequencies were found to exceed 95% of the corresponding amplitudes obtained from 10,000 simulated data sets. The latter were created without meaningful stimuli and without conscious observation during trial generation).

Additional analyses of the area under the BF curve and the highest BF reached also confirmed this data pattern. The non-smokers' temporal effect change was undistinguishable from the simulated data and thus from the chance variations. The smokers' unconscious mind set seemed to systematically correlate with the consciously observed output of the qRNG. Thus, the conscious experience and the physical display of smoking-related images matched the unconscious state of the observer from which both were supposed to emerge. This was the first promising test of the revised PJM, although, with regard to non-random variations of effect, admittedly on a post-hoc basis.

The data obtained from these studies were primarily based on a quasi-experimental design comparing smokers with non-smokers. In the studies presented here, an experimental manipulation of the unconscious state of the participants with a within-subject design was performed to conceptually replicate the above-described findings and to provide a more stringent test of the theory. Each participant performed 40 trials. During each trial, either a positive or a negative picture from a given set (e.g., aggressive dog vs. friendly dog) was chosen by a qRNG and presented to the participants for conscious observation. In each trial, before the picture presentation, a subliminal priming technique was applied. In the experimental condition, the positive outcome was subliminally primed, and thus an unconscious expectation toward the positive outcome was established. The effectiveness of positive (priming) stimuli to activate approach tendencies is well established in the literature (Phaf et al., 2014; Zech et al., 2020). In the neutral condition, a neutral mixture of both states was primed; that is, no preferred expectations were activated here.

Our predictions were as follows:

P1: Standard QM would assume that the outcome of a quantum measurement process as performed by an accurately working qRNG should be independent of any of the observers' states and should therefore be random, as expressed by the Born rule (i.e., 50% positive and 50% negative pictures), regardless of condition.

P2: A simpler model proposing the existence of ICs according to the PJM that ignores the elusive nature of these effects would predict strong evidence for more positive images than would be expected by chance in the experimental condition and smaller or null effects in the control condition. This prediction was our starting point in Study 1 and was also the pre-registered prediction in Study 2, which attempted to replicate Study 1.

P3: A more elaborate model proposing the existence of ICs according to PJM that assumes an oscillating pattern of evidence for the effect across time would predict a non-random fluctuation of the evidence for the effect (oscillating sequential BF) in the experimental condition and smaller or no oscillations in the control condition. This prediction became central over the course of Studies 1 and 2, when sequential testing (which is allowed in BF testing) provided some hints. This prediction should be replicable in an independent pre-registered Study 3.

P4: The MPI, a sophisticated elaboration of the PJM, would predict initial evidence for an effect following a decline of the effect over the course of a study (given high study power). Such a pattern or any other non-random oscillations should not be replicable in Study 3. The effect might reappear in a different pre-registered Study 4 when the degree of design similarity is low, that is, when a conceptual rather than a direct replication is performed.

We ran four studies to test these different predictions. In Study 1, we tested P1 and P2. In Study 2, we attempted to replicate Study 1, again testing P1 and P2, and explored P3 on a post-hoc basis. In Study 3, we tested P3 and P4 on an a priori basis. In Study 4, we tested P4. Studies 2, 3, and 4 were pre-registered. In sum, the starting point of this research was a test of P1 and P2 in Study 1 and 2. P3 and P4 were added to this research later after Study 2 and led to the predictions tested in Study 3 and 4. All studies reported in this article consisted of online experiments. Recruitment was performed using two polling agencies called Norstat and Kantar, together providing a representative pool of over 100,000 volunteers. Participants were invited from their professional subject pools via email. They were paid about 2 Euros for participating in one of the studies described here. Each participant could only participate once and was then deleted from the invitation list.

Study 1

Overview

In Study 1, we tested P1 and P2. Each participant ran 40 trials. During each trial, a positive or negative picture was chosen by a qRNG and presented on the screen for conscious observation of the result. In half of the trials, the corresponding positive picture was primed subliminally before the qRNG's choice, and in the other half neutral subliminal priming had been carried out in advance. Although no pre-registration was made, our prediction was that in the priming condition more positive images than expected by chance would be selected on average by the qRNG (see P2). This is the standard prediction in micro-Pk studies. Smaller or no effects should be found in the control condition. For both conditions planned one-sample Bayesian *t*-tests were performed to test the actual mean scores of positive pictures against chance expectation (50%) separately. Since a Bayesian approach was used, data collection continued until a pre-specified stopping criterion (BF > 10) for evidence for either the H0 or the H1 in the experimental condition had been reached. Since Bayesian testing allows for the confirmation of the H_0, P1 (no deviation from chance in the experimental condition) could be tested against P2 (deviation from chance in the experimental condition). No or smaller effects in the control condition—compared to strong evidence for an effect in the experimental condition—would support the role of unconscious activations of meaningful picture contents in producing ICs and therefore support the PJM's central assumption.

Participants

Study 1's sample consisted of German participants distributed throughout the country. Participant recruitment and data collection were organized by Norstat, a professional data collection company specializing in online surveys. The invitations to participate in the study were sent out by Norstat to a random selection of their participant pool daily via email, aiming for a completion rate of about 100 per day. Twenty-two percent of invited participants took part in the study, with a drop-out rate of 44%.

Participants gave their consent for participation in the study electronically by pressing an accept button prior to the experiment. They were also informed in general terms about the study and advised that participation was voluntary. Volunteers received a short, written explanation of the study's purpose after its completion. All data were coded, stored, and analyzed anonymously. The ethical board of the Department of Psychology at the LMU Munich and Norstat approved this procedure.

Statistical Approach and Data Collection

We used a Bayesian approach in this and all subsequent studies. Bayesian inference statistics allow for data accumulation (i.e., the addition of individuals' data until a specific stopping criterion has been met). A BF of 10 in the experimental condition indicating strong evidence for either H0 or H1 was defined as the stopping rule. For Study 1, an uninformed prior following a Cauchy distribution centered around 0 with an r = 0.1 was a priori chosen and used for the analyses (i.e. $\delta \sim$ Cauchy (0, 0.1)). This prior was based on an estimated effect size of Cohen's d = .1 and has previously been applied in our micro-Pk research (Maier et al., 2018).

We predicted more positive stimuli than expected by chance in the experimental condition and a smaller, possibly non-substantial effect in the same direction for the control condition. Consequently, we decided to use two separate one-sample Bayesian *t*-tests with a one-tailed approach for the analyses performed. Since data accumulation allows for repeated testing, the Bayesian *t*-tests for the experimental and the control conditions were performed on a regular basis (more or less weekly) with the respective actualized sample's mean scores. We used the statistical software JASP (Version 0.9; JASP Team, 2018) for the Bayesian analyses. The data collection took place between March 2018 and July 2018.

Sample Size

Although the stopping criterion of BF_{10} = 10 for Study 1 was reached several times in the experimental condition during data collection, these hits remained unnoticed, since for each analysis we added multiple data points, sometimes from several hundreds of participants collected on a weekly basis and the final BF at the end of a week always underscored the predefined threshold for a longer period. We thus continued data collection until the stopping criterion had been securely met. This was the case at *N* = 4,092 (demographic data available for 4,034 participants: 54.82% male, 45.18% female; mean age = 47.96, SD_{age} = 11.15) at the end of one week. We then stopped data collection in accordance with the Bayesian rules of analysis.

Materials

Experimental program

The study was run as an online experiment. All participants could participate from any location using their private computers and internet access. The experiment was executed using a dedicated webserver based in the university's computer center and displayed on the participants' web browsers. This was implemented using jsPsych (de Leeuw, 2015), a JavaScript library designed to run online behavioral experiments.

Stimuli

Positive and negative pictures were used as target stimuli with a mixture of them as prime stimuli. The target stimulus sets consisted of photographs obtained on Shutterstock, a provider of royalty-free stock images. The positive target stimuli comprised 20 photographs depicting pets, peaceful landscapes, and groups of happy-looking people. Negative target stimuli were 20 photographs depicting dangerous or attacking animals and other negative scenarios. These pictures were pre-selected by the two first authors of this paper, both experts in experimental emotion induction techniques using pictorial material. Stimulus selection was primarily based on independent valence estimations. Strongly negative and positive photographs were chosen based on the experts' ratings in case of mutual agreement. In addition, effort was made to create matched target pairs; that is, the content of each positive target picture was similar in content to a negative counterpart. These pairs of target pictures represented specific subjects (e.g., a dog) with either positive (e.g., a friendly dog) or negative (e.g., an aggressive dog) valence. The stimulus material was converted to black-and-white to balance out a general inequality with regard to the coloring of the positive and negative images.

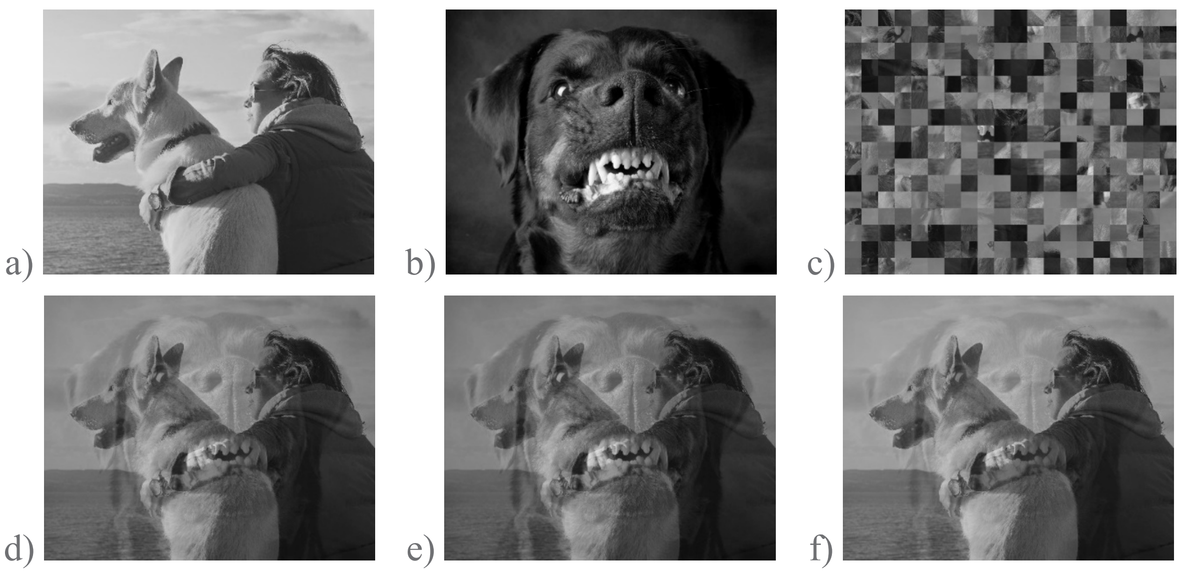

Fig 1. Sample stimuli**.** One trial consisted of a positive target picture (a) or a negative target picture (b), chosen by the qRNG. Beforehand, participants were primed with either an equal mixture of the two outcomes (d; neutral priming) or with a sequence of mixtures becoming more accentuated towards the positive target (d, e, and f; positive priming). Each prime was accompanied by a scrambled-up version of the 50/50 mixture that served as a mask (c).

From the target stimuli, two classes of priming stimuli were created: a neutral (control) and a positive priming (experimental) condition. For the neutral priming condition, each priming stimulus comprised an overlay of two matched target pictures. Those primes were constructed by coalescence between two matched targets into one final combined target. Each was designed in such a way that the positive and negative stimuli were both arranged with an equally strong appearance (50/50). Therefore, the prime represented a homogenous mixture of both matched target pictures. Since 20 matched target pairs existed, the resulting number of corresponding priming stimuli was 20. Homogeneous mixtures of both target pictures were considered to constitute neutral primes since such arrangements were assumed to reflect the superposed existence of both affective states in the *unus mundus* and would not activate any specific affective tendency above the other. Primes were accompanied by forward and backward masks comprising scrambled and indefinable versions of each prime. These masks preceding and following the primes were generated by dividing the priming image into a 20 x 16 block grid, and randomly shuffling these blocks in horizontal and vertical positions. For the resulting scrambled versions of the priming pictures the local image information remained the same, but the meaningful content of the image was destroyed. Using such scrambled versions of the original stimuli as masks optimizes the masking process and is a standard procedure in subliminal priming (e.g., Huang et al., 2019). Each priming stimulus was presented three times during a given trial before the target display. The latter was chosen randomly by a qRNG from the pair of targets from which the corresponding prime stimulus was created.

The positive priming condition used the same mixtures from the matched target pairs and the same presentation modes during the trial, but following the first perfect 50/50 mixture presentation, two slightly different priming images were displayed during each priming sequence in a given trial. The first prime was identical to the neutral priming condition and depicted both matched target stimuli equally (50/50). For the second prime presentation, however, the same matched target pair was used, but the positive share was more distinct (60/40) and in the third prime presentation even more so (70/30) (1). In this way, the positive picture became more dominant during the priming sequence and was expected to be more strongly activated in the perceiver's unconscious mind. This rather unusual positive priming procedure should within a trial mimic the evolution of a classical reality and its conscious perception out of the *unus mundus* under the biasing impact of an induced correlation. The assignment of positive or neutral priming to a trial was performed by a pseudo-RNG (pRNG). Following the priming sequence, the quantum-based RNG (qRNG) randomly selected one of the two target pictures from which the priming stimuli were created in a given trial (see fig 1 for sample stimuli and fig 2 for a schematic display of the procedure).

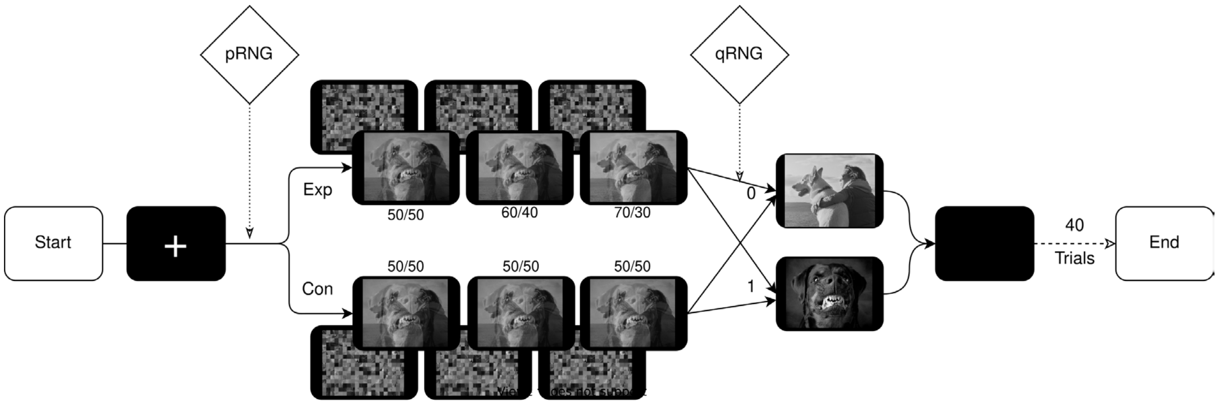

Fig 2. Schematic display of a trial. It represents the order of stimuli presentations for the positive priming condition (Pos: upper line) and for the neutral priming condition (Neu: lower line). A pseudoRNG (pRNG) was used to determine the order of positive and neutral priming trials. After masked priming with either increasingly positive primes in the positive priming condition (Pos: from 50/50 to 70/30) or neutral primes in the neutral priming condition (Neu: 50/50), the qRNG selected the corresponding target picture (attacking dog or friendly dog).

Generation of Quantum Randomness

During each trial after the priming sequence, a qRNG was used to determine whether a target stimulus from the positive or negative picture set was presented. To achieve this, a Quantis qRNG by idquantique was connected to the webserver. This device generates two equally likely superposed quantum states by sending photons through a semi-conductive mirror-like prism. Upon measurement, only one of the two states can be observed and is translated into either a 0 or a 1 bit. Using the random nature of quantum state reduction, a truly unpredictable result is generated. The qRNG passed all major validation tests of randomness, such as the DIEHARD and NIST test batteries, and is regarded as one of the most effective sources of randomness (Turiel, 2007). The device was connected directly to the server via USB and generated a random bit for each trial after completion of the priming sequence and immediately before the display of the target stimulus, therefore working without a buffer. Care was also taken to ensure that each participant received an individual bit.

Design

The study employed a within-subjects design with two conditions: a positive priming condition in which the positive pictures from respective matched target pairs predominantly served as prime stimuli and a neutral priming condition in which neutral mixtures from respective matched target pairs served as neutral prime stimuli.

Procedure

The invitation to participate in the study was issued via email by the polling company Norstat to their pool of professional clients. Participants were advised to ensure an undisturbed environment before commencing the survey. They were asked for some basic demographic information to ensure the inclusion criteria. They were then provided with a link, and by clicking on it they were subsequently taken to the experiment running on the university's webserver. After the participants were asked to activate their browser's full-screen mode, they were shown the written instructions for the task. Participants were advised that over the course of the experiments they would repeatedly see flickering visual stimuli as well as positive and negative images and that these stimuli should be passively watched. They were reminded that they could abort the experiment at any time. Prime and picture presentations began after the participants had acknowledged the instructions and had given their consent for participation.

Each participant viewed a total of 40 trials. For each individual, half of the 20 matched target pairs were randomly assigned to the positive priming condition and the other half to the neutral priming condition using a software randomizer (pseudo-RNG) at the beginning of the experiment. Each of the 20 target pairs was used twice in this setting, resulting in a total of 40 trials. Next, the pseudo-RNG was used to individually permutate the order in which the 40 trials were presented via sampling without replacement. During each trial, a fixation cross was first presented on the center of the screen (1200 ms) to direct participants' attention toward this location. Next, in the priming sequence, a mixture (neutral priming condition) or different mixtures (positive priming condition) of the two pictures that corresponded to the respective target pair of a given trial were used as prime stimuli. In the neutral priming condition, the 50/50 mixture prime stimulus was displayed three times for 55 ms each and each time was accompanied by a corresponding forward mask (110 ms) and a backward mask (110 ms) to ensure a subliminal presentation. Each prime stimulus had a specific masking stimulus that was a scrambled version of the original. In the positive priming condition, the presentation mode and times were the same as in the control, but the prime stimuli varied between a perfect mixture (50/50), a 60/40 mixture, and a 70/30 mixture of the positive/negative target pair used in a given trial. In each trial, after the priming sequence had been displayed, the qRNG was activated to provide an individual random bit that determined whether the positive or negative target stimulus from a given matched pair would be presented for 1000 ms. After this, a black inter-trial interval was presented for another 1200 ms, before the next trial started. The two dependent variables consisted of the mean number of positive pictures and therefore the number of 0 bits generated by the qRNG in the positive and neutral priming conditions.

Journal of Anomalous Experience and Cognition (JAEX) 2021, Vol. 1, No. 1-2, pp. 114-155

After they had completed the task, participants were asked to complete a short questionnaire. Stimulus-seeking behavior was assessed using a scale containing two statements (Bem et al., 2011): "I am easily bored" and "I often enjoy seeing movies I've seen before" (reverse scored). Additionally, a self-efficacy attitude measure related to general life outcome expectancies was assessed (6 items) (Maier et al., 2018), as well as the Life Orientation Test-Revised (LOT-R) (Scheier et al., 1994), which assesses generalized optimism and pessimism with three items each. We had no a priori hypothesis regarding these questionnaires and their relationship to any micro-Pk results. We used these measurements for purely exploratory reasons, and these results will be reported in a future publication.

Results

Two separate Bayesian one-sample *t*-tests (one-tailed) were performed to test whether the mean number of positive pictures was higher than expected by chance (P2) in the positive and neutral priming conditions. The expected mean score expected to occur by chance (P1) was 10 positive pictures (out of 20 possible) on average for each condition. For the positive priming condition, BF_{10} = 13.35, indicating strong evidence in support of H_1 (frequentist *t*-test for comparison: $t(4091) = 2.89$, $p = .002$) The mean score of positive pictures in this condition was $M = 10.10$ (SD = 2.27). For the neutral priming condition, BF_{01} = 4.19, indicating moderate evidence for H_0 ($t(4091) = 0.73$, $p = .23$). The mean score of positive pictures in this condition was $M = 10.03$ (SD = 2.26). Fig 3 shows the sequential Bayesian analyses for both *t*-tests separately for each condition. While the BF of the positive priming condition hit the pre-specified stopping rule of BF > 10, the BF of the neutral priming condition showed a linear trend for a null effect because the accumulated evidence increasingly supported the null hypothesis at least moderately.

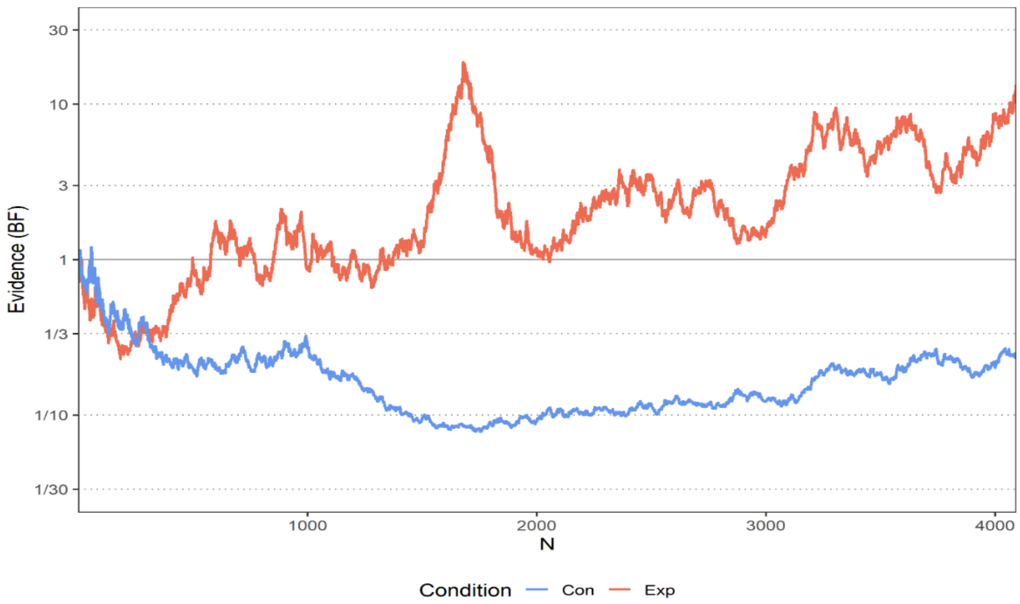

Fig 3. Sequential Bayes factors from study 1 for positive (red line) and neutral (blue line) priming conditions

Discussion

The results of Study 1 clearly matched our predictions. In the positive priming condition, strong evidence for the appearance of more positive pictures than expected by chance was found. Moreover, in line with our expectations, no substantial deviation from chance was observed in the neutral priming condition. This data pattern supports our proposition 2 (P2), according to which induced correlations (ICs) should be detectable when meaningfully—in this case, emotionally and approach-motivating—relevant outcomes (targets) are observed during quantum measurements obtained from a qRNG after unconscious activation by subliminal priming. Such deviations from chance expectation violate the Born rule (i.e. P1) and, according to Pauli and Jung, can be interpreted as ICs. The difference in the results between the positive and the neutral priming conditions suggests the central role of unconscious activations, since ICs seem to be limited to contextual circumstances in which unconscious activations precede quantum observation. The data are therefore in line with propositions derived from the PJM that emphasize the unconscious origin of such effects. The sample size, in addition to the high BF reached in the positive priming condition, indicates a robust effect. One limitation of the study, however, was that it was not pre-registered. Although the Bayesian prior and all procedural details were a priori determined by the researchers based on their earlier work (Maier et al., 2018) and data collection was delegated to a professional data collection agency, such extraordinary findings must be more rigorously processed. In addition, micro-Pk research is characterized by a considerable lack of successful replications (e.g. Dechamps & Maier, 2019; Jahn et al., 2000). The PJM classified ICs as spurious and perhaps even unsystematically varying across time. This idea was formalized in the MPI (e.g. Lucadou et al., 2007) that predicts a decline effect in later replication attempts. We therefore decided to replicate our findings precisely in a pre-registered study.

2021, Vol. 1, No. 1–2, pp. 114–155

Study 2

Overview

In Study 2, we performed an exact replication of Study 1 to test its replicability. Study 2 was pre-registered at the Open Science Framework (OSF) (https://osf.io/83efr). All predictions were the same as those in Study 1. Specifically, we expected a positive deviation in the mean score of positive pictures from chance in the positive priming condition and no or smaller deviations from chance in the neutral priming condition. This would fit the assumptions made in P2 and test it against P1. The latter would predict a clear null result, with no deviations from chance in either condition. At this point, we did not consider P3 or P4 to be persuasive alternative outcomes given the evidence found in Study 1.

A BF of 10 was again used as a stopping criterion. Since we had more precise information regarding the effect size, we decided to use an informed prior of δ ~ Cauchy (0.05, 0.05). This was the only deviation from the original protocol. Data were collected between September and October 2018.

Journal of Anomalous Experience and Cognition (JAEX)

Participants

Participant recruitment and data collection were again performed by Norstat and followed the same protocol as Study 1. Over the course of data collection, the sequential BF reached the predefined threshold for stopping at n = 937. Since the predicted effect was supposed to be very small, at this stage of data collection a lack of power could have been responsible for the strong evidence for the H0. In addition, we deemed this sample size to be too small compared to that used in Study 1and therefore decided to continue collecting data while closely monitoring the BF. The final sample size was N = 2,063, at which point we ceased recruiting (demographic data available for 2,021 participants: 56.16% male, 43.84% females; m_{age} = 57.37, SD = 15.07).

Materials, Design, and Procedures

All materials, study design, and procedures were identical to those used in Study 1.

Results

Two separate Bayesian one-sample *t*-tests (one-tailed) were performed to test whether the mean number of positive pictures was higher than expected by chance (P2) in the positive and neutral priming conditions. The mean score expected to occur by chance (P1) was 10 positive pictures (out of 20 possible) on average for each condition. For the positive priming condition, BF_{10} = 0.09 (BF_{01} = 11.31), indicating strong evidence in support of H_0 ($t(2062) = -0.79$, p = .78). The mean score of positive pictures in this condition was M = 9.96 (SD = 2.23). For the neutral priming condition, BF_{01} = 4.48, indicating moderate evidence for H_0 ($t(2062) = 0.32$, p = .38). The mean score of positive pictures in this condition was M = 10.02 (SD = 2.23). Fig. 4 shows the sequential Bayesian analyses for both t-tests separately for each condition. The sequential BFs of both conditions showed a linear trend for a null effect with the positive priming condition in particular.

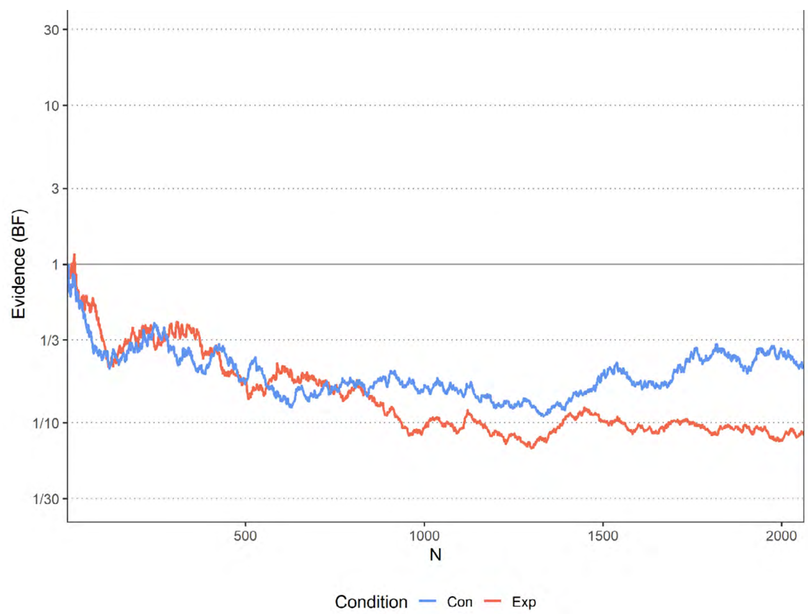

Fig 4. Sequential Bayes factors from study 2 for positive (red line) and neutral (blue line) priming conditions

Discussion

The results of Study 2 indicated that the pre-registered replication attempt failed. Contrary to our prediction, strong evidence was found for a null effect in the positive priming condition. Moderate evidence for the null hypothesis was also found for the neutral priming condition, similar to Study 1. These data support the argument that the original effect found was not replicable and may therefore have been a false positive. Although the Study 2 results could also be interpreted as a false negative, at this point, P1, which propagates the overall validity of the indeterminacy principle and the Born rule in any distributions of quantum measurement outcomes, seems to be the more valid assumption with respect to QM and the role that observation might play therein. P2 could not be confirmed in this replication.

Post-hoc Analyses of the Data from Studies 1 and 2 Combined

In the following sections, several post-hoc analyses that addressed the elusive nature of ICs as proposed by the PJM are reported. This idea was ignored in propositions P1 and P2 and was therefore not addressed a priori in Studies 1 and 2. The MPI, which formally describes the elusive nature of ICs, proposes a decline in the evidence for ICs after initial detection to conserve the indeterminacy principle of QM. In other words, only local deviations from the Born rule are assumed, and a strict temporal order of effect detection and subsequent disappearance is proposed. Building on this model, Maier and Dechamps (2018) argued that the change of a micro-PK effect across time might follow a systematic pattern that could be detected by corresponding temporal change analyses (see P3). They suggested testing the existence of ICs within the PJM in the form of systematically oscillating patterns of evidence for the effects across time. This should reveal itself in the combined data sets of Studies 1 and 2 as non-random oscillations of the evidence for the effect (oscillating sequential BF) in the positive priming condition and smaller or no oscillations in the neutral priming condition. Three methods, originally developed by Dechamps and Maier (2019), were used for the analysis of the present data to test non-systematic variations of the evidence for the effect as expressed by the sequential BF. We will describe each method in the following section and apply them in a purely post-hoc fashion to the combined sequential Bayesian evidence data sets from Studies 1 and 2 by keeping the data in the strict temporal order in which they were collected (Fig 5). We planned to replicate any results obtained by these analyses in a pre-registered Study 3.

Temporal Change Analyses

Three methods (see Dechamps & Maier, 2019) were applied to test the oscillations of the effects for data that combined the initial effect detection and replication attempt across time. To this end, we first concatenated the sequential Bayesian analysis scores of Studies 1 and 2 for the positive and the neutral priming conditions separately (Fig 5).

The time courses of the two sequential BFs were then analyzed using (a) an identification of the highest reach BF found within each of the two conditions at any time during the data collection compared with the highest BFs reached in 10,000 simulations of the data obtained from the same QRNG used in the original design (MaxBF analysis); (b) a test of the areas under the sequential BFs (energy of the curve). The sequential BF curve's energy indicates the general orientation toward the concurring hypotheses over the course of data aggregation. It is calculated as the area between the sequential BF curve obtained from each condition and the BF = 1 horizontal as baseline compared to areas obtained in the same fashion from 10,000 simulations (BF energy analysis); and (c) FFTs of the sequential BFs of each condition and the 10,000 simulations with a comparison of the amplitudes obtained. These three analyses test the non-random variation of the effect across time and provide a conservative test of non-random fluctuations. We wish to emphasize that these analyses were purely exploratory and were proposed here for testing during future confirmatory research in Study 3.

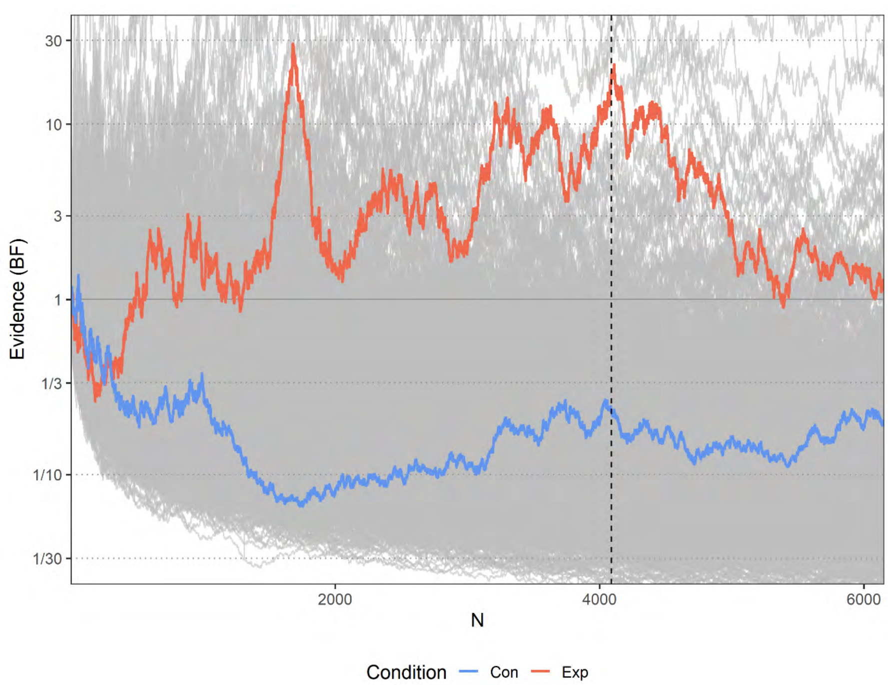

Fig 5. Combined sequential Bayes factors from studies 1 and 2 for the positive (red line) and neutral (blue line) priming. The gray lines indicate the sequential Bayes factors obtained from the 10,000 simulations. The dashed vertical line indicates the transition from Study 1 to Study 2.

Results

MaxBF Analysis

The MaxBF analysis performed on the sequential BF of the positive priming condition revealed that the highest BF reached in this data set was BF_{max} = 28.78 at n = 1,680. Only 2.72% of the simulations showed the same or a higher BF at any point within these data sets. For the neutral priming condition, a BF_{max} = 1.38 at n = 58 was found, which was surpassed by 63.16% of the BF_{max}s in the simulations.

BF Energy Analysis

The sequential BF curve's energy provides information about the evidence over the course of data aggregation. A positive score indicates that, on average, the energy is above the BF = 1 line (evidence points towards H1), and negative scores denote an energy overhang below the BF = 1 (evidence points towards H0) line. The BF energy analysis revealed that the positive priming condition's energy was 19,964.42, which was found to be surpassed by 1.37% of the simulations' energy. The neutral priming condition's energy was -5,033.84, which is surpassed by 60.81% of the simulations' energy. The mean energy of the simulations was -2,586.55 (SD=20724.52).

FFT Analysis

Third, the sequential BF curves for the positive priming condition, the neutral priming condition, and each of the 10,000 simulations was Fourier-transformed via an FFT. The FFT decomposes an empirical time course of data into its underlying frequencies and calculates their amplitudes. The resulting transform thus indicates the amplitudes of all frequencies (sample rate 1/N) that comprise the original curve. Since the transform is symmetric, only the first half is considered in the analysis, resulting in 3,078 tested frequencies. To test the FFT results from the experimental data and the control data against chance occurrence, all 3,078 amplitudes obtained from the FFT of the experimental data set were added up, creating a sum score of the amplitudes obtained from all tested frequencies of this set. This was also performed for the control data. In the same way, for each of the 10,000 simulations, the sum score of amplitudes was computed (see Maier et al., 2020). The latter provided a null distribution of amplitude sums. Earlier, a similar but less sophisticated test was used (Dechamps & Maier, 2019). The test used in the present analysis investigates the non-random oscillatory nature of the experimental and control time course data: the amplitude sum of the positive priming condition was 30.75, which was surpassed by 2.3% of simulations. The amplitude sum of the neutral priming condition was 1.34, which was surpassed by 75.39% of simulations. The mean amplitude of the simulation was M_{amp} = 6.95 (SD = 63.8).

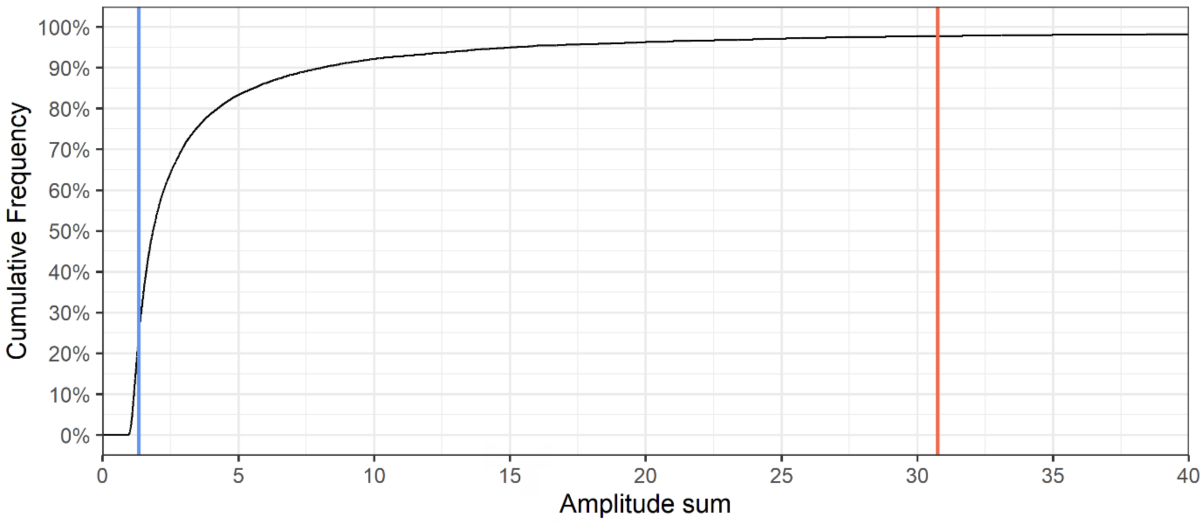

Fig 6. Cumulative frequency distribution. Amplitude sums of all 10,000 Fourier-transformed Monte Carlo simulations and values of the positive (red line) and neutral (blue line) priming conditions of studies 1 and 2 combined.

Discussion

The post-hoc analyses revealed significant deviations from chance occurrence in the positive priming condition and no deviations in the neutral priming condition in the three analyses employed. This aligns with P3, which proposes systematic non-random oscillations of IC effects across time. What looked like a false positive (Study 1) and a true negative (Study 2) given the failed replication may thus have been an effect of oscillation that mimicked such a pattern. The fact that only a few of the simulations (< 5%) displayed similar pronounced oscillatory effects across time may support the idea of systematic effect variations owing to the elusive nature of ICs, as proposed by P3. It has been argued that such oscillations were stable and can thus be replicated in an independent study (Dechamps & Maier, 2019), whereas the MPI predicts the impossibility of successful replications even at this or any other level of data accumulation (P4). Also, standard QM that denies the existence of ICs (P1) would not expect a successful replication of the data pattern described in the previous paragraphs. In any event, since these findings were obtained on a post-hoc basis only after an inspection of the data, it was necessary to confirm them in another study. This was the goal of the next study.

2021, Vol. 1, No. 1-2, pp. 114-155

Journal of Anomalous Experience and Cognition (JAEX)

Study 3

Overview

The study presented here was a pre-registered experiment to test P3. The pre-registration was stored at the OSF: https://osf.io/894cb. P3 is a more elaborate model than P2, which also proposes the existence of ICs according to PJM, but contrary to P2 it assumes a non-random oscillating pattern of evidence for the effect across time. Specifically, for the study reported herein, it predicted a non-random oscillation of the evidence for the effect (oscillating sequential BF) in the positive priming condition and smaller or no oscillations in the neutral priming condition replicating the post-hoc results. MPI with P4 would argue for the impossibility of successful direct replications that should also extend to oscillations of the kind proposed by P3. A successful replication of the post-hoc analyses' results—as attempted here—would provide some initial confirmatory evidence for P3 while invalidating P1, P2, and P4. It can thus be considered a test of one of the four propositions made. Because we designed Study 3 to confirm and replicate the results obtained in the post-hoc analyses of Studies 1 and 2, the goal was to collect data from an equal total number of participants. We thus aimed for a comparable sample size as a stopping criterion (N ≈ 6,000), as specified in the pre-registration.

The prediction derived from P3 was tested using the same three temporal analyses that were performed in the post-hoc analyses described above: for the positive priming and the neutral priming conditions, the maximal BF reached (maxBF analysis), the energy of the sequential BF (BF energy analysis), and the sum of amplitudes obtained from FFT analyses (FFT analysis) were computed and compared to 10,000 simulations of these conditions on which the same analyses were conducted and which served as null distributions.

Participants

Participant recruitment and data collection were again performed by Norstat and followed the same protocol as Studies 1 and 2. Because the German participant pool was exhausted at some point during data collection in Study 3, further invitations were distributed to Austrian panelists. Data collection began in October and ended in December 2019. It resulted in a final N = 6,099 (demographic data available for 6,047 participants: 50.42% males, 49.57% females; M_{age} = 51.25, SD_{age} = 14.44).

Materials, Design, and Procedures

All materials, study design, and procedures were identical to Studies 1 and 2.

Results

The data were analyzed only once, after the pre-specified number of participants was reached. Sequential Bayesian analyses based on one-sample Bayesian t-tests were performed for the positive priming condition, the neutral priming condition, and for data from each of the 10,000 simulations. The chance expectation for the number of positive pictures chosen by the qRNG in each condition was 10. Again, an informed prior of δ ~ Cauchy (0.05, 0.05) was used. These sequential BFs obtained were subsequently subjected to the three temporal change analyses to test for non-random oscillations within the positive priming and the neutral priming conditions compared to the oscillations found in the simulations' sequential BFs. The sequential BFs found in Study 3 can be seen in Fig 7.

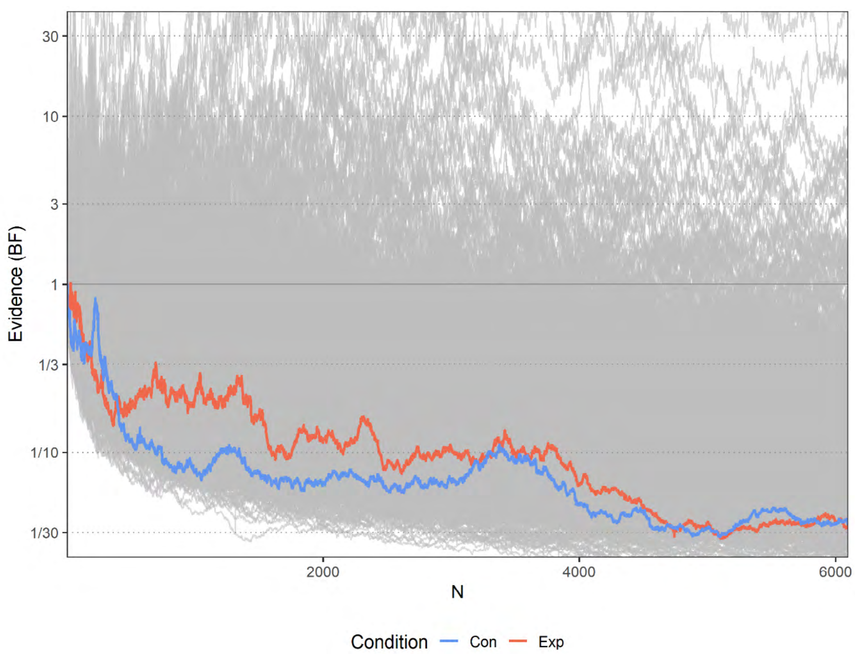

Fig 7. Sequential Bayes factors for the positive (red line) and neutral (blue line) priming conditions of study 3. The gray lines indicate the sequential Bayes factors obtained from the 10,000 simulations.

Although irrelevant to the hypotheses tested here, a final mean score of positive pictures of M = 10.00 (SD=2.24) in the positive priming condition and of M=10.01 (SD=2.23) in the neutral priming condition was found. T-tests revealed a BF_{01} = 11.44

($t(6098) = 0.05$, $p = .48$) and a $BF_{01} = 9.40$ ($t(6098) = 0.25$, $p = .40$) respectively. The temporal change analyses yielded the following results.

MaxBF Analysis

The MaxBF analysis performed on the sequential BF of the positive priming condition revealed that the highest reached BF found in this data set was $BF_{max} = 1.01$ at n = 28, and that 82.33% of the simulations showed the same or a higher BF at any point within these data sets. For the neutral priming condition, a $BF_{max} = 1.00$ at n = 1 was found, surpassed by 83.02% of the BF_{max}s found within the simulations.

BF Energy Analysis

The BF energy analysis revealed that the positive priming condition's energy was -4,841.63, surpassed by 54.24% of the simulations' energies. The neutral priming condition's energy was -5,255.64, surpassed by 76.01% of simulations' energies. The mean energy of the simulations was -2,547.43 (SD=20690.58).

FFT Analysis

Third, the sequential BF curves for the positive priming condition, the neutral priming condition, and the 10,000 simulations were each Fourier-transformed via an FFT and their amplitudes were summed up. The amplitude sum of the positive priming condition was 1.36, which was surpassed by 74.2% of the simulations' amplitude sums. The amplitude sum of the neutral priming condition was 1.09, which was surpassed by 95.23% of the simulations' amplitude sums. The mean amplitude sum of the simulations was $M_{amp} = 6.94$ (SD = 63.68).

Journal of Anomalous Experience and Cognition (JAEX) 2021, Vol. 1, No. 1-2, pp. 114-155

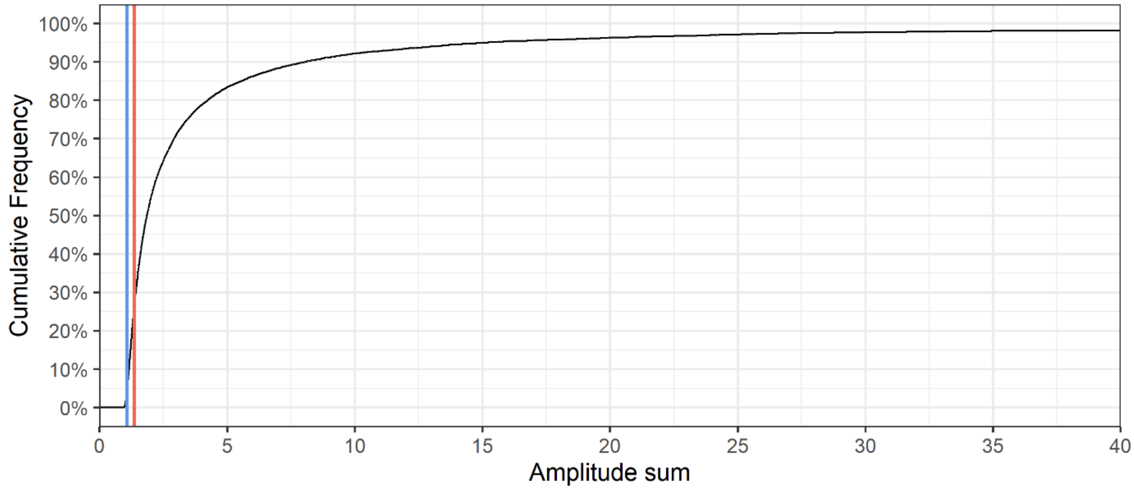

Fig 8. Cumulative frequency distribution of the simulations' amplitude sums and values of the positive priming condition (red line) and neutral priming condition (blue line) of Study 3.

Discussion

None of the three temporal change analyses revealed significant non-random oscillation of the sequential BF10 in the positive priming condition compared to the 10,000 simulations. Thus, the direct replication of the post-hoc analyses made across Studies 1 and 2 failed. No effects were found for the neutral priming condition either. This finding contradicts our predictions derived from P3, as made public in the pre-registration. The data did not support either P2, since the final BF01s for the final mean scores of positive pictures found in each of the two conditions were higher than or very close to 10, confirming a null finding.

Overall, the data obtained so far from three high-power studies clearly contradict the predictions derived from P2 and P3. For now, these two models are thus considered to be false assumptions concerning the appearance of ICs within the PJM. The only valid models that remain at this point are P1 and P4. P1 denies the existence of ICs and would argue that Study 1's results were false-positives due to the consistent lack of successful replications. P4 also remains unchallenged by the results obtained so far since it predicts an initial effect followed by a decline. The latter would reveal itself in unsuccessful replications of any non-random observation effects on qRNG outputs, even at the level of oscillations. Since after a first successful study, P1 and P4 made the same predictions for later replication attempts, a new study was designed focused on the difference between the two models.

Study 4

Overview

The difference between P1 and P4 is that whereas P1 would classify the presentation of more positive pictures than expected by chance in a qRNG-based task as observed in the unconscious priming condition in Study 1 as occasionally occurring false-positives, P4 considers them to be real effects produced by observers whose unconscious priming treatment initiated induced correlations (ICs) according to the PJM. However, the PJM considers them to be evasive, occasional, and not (easily) reproducible (see Atmanspacher, 2012, 2014) to meet the restrictions imposed by the indeterminacy principle of QM. A downside of ICs' unsystematic nature is that they should hardly be detectable empirically. Lucadou et al. (2007) formulated a set of axioms subsumed under the label "model of pragmatic information" (MPI) that formalized this central aspect of the PJM (see also Lucadou, 1995, 2015, 2019). In this model, novelty is defined as initial evidence for ICs and is complementary to confirmation, that is, replicability, of the effect. Thus, the appearance of an effect decline is proposed and any replication attempt with the same design will most likely result in a null finding. Thus, ICs are in principle non-replicable and thus cannot be distinguished from chance effects. Given these propositions, P1 and P4 could not decisively be tested against each other using a "direct replication" strategy, the standard scientific practice for identifying false-positives. Thus, an unorthodox path that the MPI explicitly suggests must be chosen: The MPI's authors propose to entirely skip exact replication attempts and proceed with conceptual replications. The less similar a replication design is to the original design, the more likely it is that the ICs might reappear. However, the necessary "degree of similarity" cannot be easily specified. Although the boundary conditions for a successful conceptual replication are only vaguely defined in the MPI, we decided to give this option a chance. We designed a new study in which the priming stimuli and the priming procedure deviated from the original design employed in Studies 1 to 3. Thus, a conceptual rather than a direct replication was performed. Admittedly, we were unsure as to whether these changes would induce a sufficient degree of dissimilarity between the original and new designs to work satisfactorily. Nevertheless, we predicted a reappearance of the effect in the experimental (positive priming) condition with a potentially later decline should enough data be provided. Specifically, we predicted in the pre-registration that at some point during data collection in the positive priming condition, the mean score of positive pictures would exceed chance expectation and that a Bayesian analysis (Bayesian one-sample *t*-test, one-tailed) would provide strong evidence ($BF_{10} > 10$) for this. Subsequently, the effect might decline, as proposed by the MPI. To test such an effect, the maxBF analysis described above was considered appropriate. This test would demonstrate the likelihood of such a finding under the null model. FFT analyses were also proposed to test the effect. Additionally, a BF energy analysis, as described above, was pre-registered as secondary analysis. Smaller effects of these kinds might also appear in the neutral priming condition. A significant maxBF test (with the maxBF10 in the positive priming condition being greater than or equal to 10), a significant FFT analysis and/or a significant BF energy analysis in the positive priming condition would support P4, whereas no significant effects would support P1. The experiment and our predictions were pre-registered at the OSF (https://osf.io/ckufx).

Participants

The analysis strategy was identical to Study 3 and focused primarily on the change of evidence tests performed on the sequential BFs produced by two Bayesian one-sample *t*-tests (one-tailed) applied to the raw data (mean of positive pictures) of the positive priming and the neutral priming conditions. Since we predicted a volatile effect, a fixed BF threshold could not be specified as a stopping criterion. Based on the positive results of Study 1, we therefore decided and pre-registered to aim for a sample size of about 4,000 participants. Data collection for Study 4 took place between February and March 2020 and was organized by Kantar, another data collection company providing a professional subject pool. Data collection was established with a protocol identical to that used in the previous studies. The data collection rate was about 100 participants per day. The final sample consisted of 3,996 participants (demographic data available of 3,951 participants: 48.04% males, 50.65% females, 1.32% other; M_{age} = 46.25, SD_{age} = 12.86). After reaching this number, data collection was discontinued and the data were analyzed.

Materials

An identical experimental setup to that used in the previous studies, including the generation of randomness, was implemented with two exceptions: a slightly different priming procedure and different stimuli for primes and targets were used to conduct a conceptual rather than direct replication of Studies 1 to 3.

Stimuli

As stimulus material, images depicting affective facial expressions were selected from the Pictures of Facial Affect (Ekman & Friesen, 1976), a database of photographs widely used in facial expression research. These 110 photographs show the faces of 14 different actors expressing different emotional states. Out of these, the pictures showing happiness, anger, and neutral states were selected, yielding 14 picture sets each containing three images. The principal investigators based on their expertise in emotion induction techniques decided, in addition to neutral faces, to focus on affective facial expressions that were most aversive (angry faces) and most appetitive (happy faces) to human observers. Scrambled versions were created from each neutral facial expression to serve as masks in the priming procedure. Subliminal processing of facial expressions has been shown to be effective (e.g., Smith, 2012; Whalen et al., 1998).

Design

A design similar to that used in the previous studies was employed. Participants were exposed to 20 experimental (positive priming) and 20 control (neutral priming) trials in random order. Conditions differed with respect to the prime content that was presented prior to the selection of the target stimulus. Masked neutral facial expressions were presented as primes in the neutral priming condition, and masked happy facial expressions served as primes in the positive priming condition as primes. In this way, subliminal activation of happy or neutral facial content was intended.

Procedure

Recruitment of participants for this study was organized by Kantar, a polling company, via email communication. Participants were invited to visit the study by clicking on a weblink in the invitation email. The study itself was run on an LMU webserver with access from individual web browsers. Participants were asked to enable their browser's full-screen mode, received a short instruction, and were asked to provide basic demographic details. A pseudo-RNG then determined the order of trials and conditions. First, the 40 trials were randomly assigned to either the positive (happy face priming) or neutral priming (neutral face priming) condition, resulting in 20 trials for each condition. Forty stimulus sets were then selected from the 14 available sets via sampling with replacement. This procedure was repeated for each individual. After the participants signaled that they were ready by pressing a button, picture presentation was initiated. Within each trial, a fixation cross was displayed for 1200 ms, followed by a forward mask (160 ms), a prime consisting of a neutral or happy facial expression (40 ms), and a backward mask (200 ms). The prime presentation was repeated three times in each trial using the identical prime. Neutral or happy primes, masks, and target faces were matched; that is, within a trial, they were derived from the same actor. A qRNG was then used to determine whether a happy ("0" bit) or angry facial expression ("1" bit) was displayed as target stimulus to the participant for 1000 ms. The next trial commenced following a black inter-trial interval of 1200 msec.

After the presentation of 40 trials, in which individuals were simply required to watch the stimuli presented on their screens, they were asked according to two overall ratings (1 "do not agree at all" to 7 "completely agree") whether they perceived the friendly faces as positive and the angry faces as negative. They were also presented with a single item asking to indicate whether they "have the feeling that [they] will succeed in everything today" using the same seven-point scale. Finally, they were thanked and linked back to the polling company for a short debriefing.

Results

The data were analyzed only once, after the pre-specified number of participants had been reached. Sequential Bayesian analyses based on one-sample Bayesian *t*-tests were performed for the positive priming condition, the neutral priming condition, and each of the 10,000 simulations' data. The chance expectation for the number of positive pictures chosen by the qRNG in each condition was 10. Again, as specified in the pre-registration, an informed prior of $\delta \sim$ Cauchy (0.05, 0.05) was used. These sequential BFs obtained from the positive priming and neutral priming conditions were subsequently submitted to primary (maxBF and FFT) and secondary (BFenergy) analyses and were compared to the oscillations found in the simulations' sequential BFs. The sequential BFs found in Study 4 are illustrated in Fig 9.

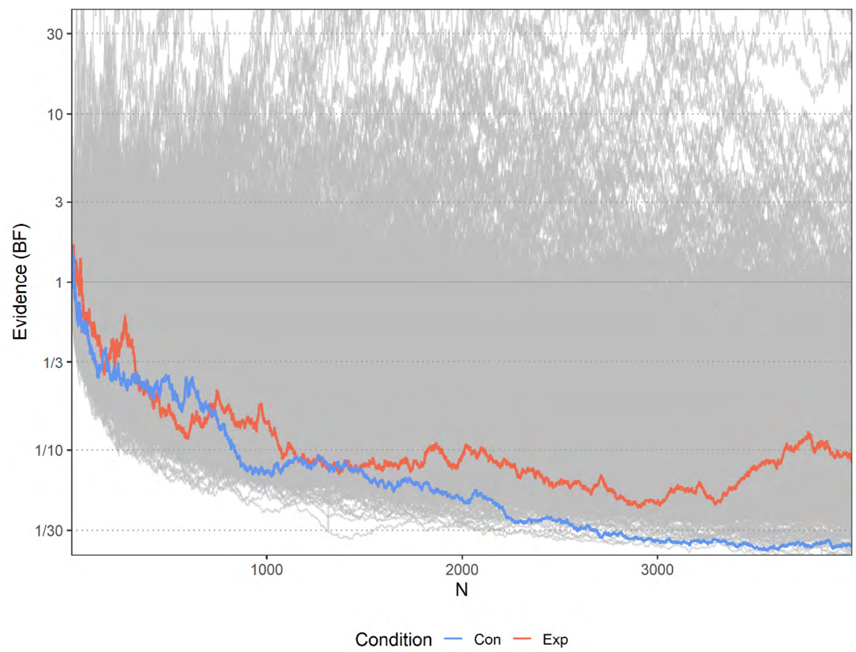

Fig 9. Sequential Bayes factors for the positive (red line) and neutral (blue line) priming condition of study 4. The gray lines indicate the sequential Bayes factors obtained from the 10,000 simulations.

Although not relevant to the hypotheses tested here, a final mean score of happy faces was M = 9.99 (SD=2.19) in the positive priming condition (final BF_{01} = 11.90; $t(3995) = -0.30$, p = .62) and M = 9.91 (SD=2.25) in the neutral priming condition (final BF_{01} = 36.70; $t(3995) = -2.42$, p = .99).

Primary Analyses

MaxBF Analysis

First, the MaxBF analysis performed on the sequential BF of the positive priming condition revealed that the highest reached BF found in this data set was BF_{max} = 1.65 at n = 11, and that 52.51% of the simulations showed the same or a higher BF at any point within these data sets. For the neutral priming condition, a BF_{max} = 1.56 at n = 5 was found, which was surpassed by 55.36% of the BF_{max}s found within the simulations.

FFT Analysis

Second, the sequential BF curves for the positive priming condition, the neutral priming condition, and the 10,000 simulations were each Fourier-transformed via an

Journal of Anomalous Experience and Cognition (JAEX)
2021, Vol. 1, No. 1-2, pp. 114-155

FFT and their amplitudes were summed up.. This was also performed for the control data and for each of the 10,000 simulations. The amplitude sum of the positive priming condition was 1.50, which was surpassed by 59.88% of the simulations' amplitude sums. The amplitude sum of the neutral priming condition was 1.33, which was surpassed by 69.82% of the simulations' amplitude sums. The mean amplitude sum of the simulations was M_{amp} = 6.43 (SD = 58.67).

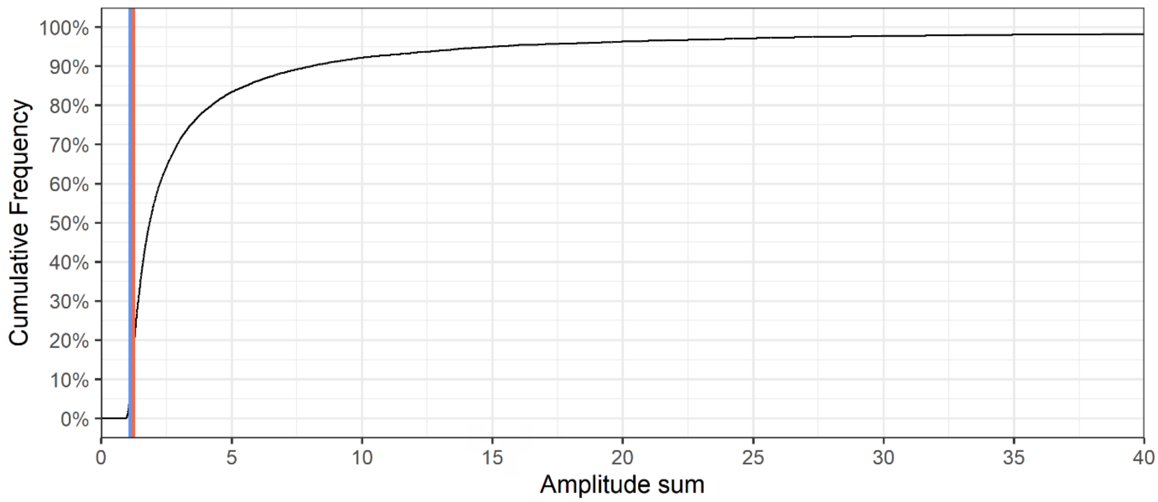

Fig 10. Cumulative frequency distribution. Simulations' amplitude sums and values of the positive priming condition (red line) and neutral priming condition (blue line) of Study 4.

Secondary Analyses

BF Energy Analysis

The BF energy analysis revealed that the positive priming condition's energy was -3,459.29, which was found to be surpassed by 87.56% of the simulations' energies. The neutral priming condition's energy was -3,609.59, which is surpassed by 97.27% of the simulations' energies. The mean energy of the simulations was *M* = -1,203.86 (SD=18635).

Discussion

Contrary to our prediction, none of the pre-registered primary analyses performed on the sequential BF_{10} in the positive priming condition revealed significant effects compared to the 10,000 simulations. The same pattern was found for the neutral priming condition. Neither the BFmax analyses nor the FFT analyses found any indication of the ICs' appearance in one of the two conditions. Rather, a clear null effect pattern was observed in the positive and neutral priming conditions, with both final BF_{01}s greater than 10. Similarly, no significant effects were found in the secondary analysis. The BF energy was not appreciably different from that of the simulations. The results clarify that the null hypothesis could not be rejected in any of the analyses performed. Thus, neither the results of Study 1, which originally showed strong evidence for the occurrence of ICs, nor the findings reported in the post-hoc analyses of Studies 1 and 2 combined, which showed pronounced oscillations of IC effects across time, could be replicated in this conceptual replication attempt. In sum, a first test of P4, which predicted a reappearance of the effect in one of the two ways described above, failed. The data, rather, support P1, which is based on standard QM and denies an active role for human observation in quantum measurement outcomes.

It would be premature to claim, based on these findings, that the MPI should be considered to have been falsified. The MPI predicts the reappearance of an IC effect if the original and the replication designs are dissimilar to a certain extent. One might therefore argue that, in the case of Study 4, a sufficiently high degree of dissimilarity was not reached. Additional studies that continuously vary the design similarities are needed to determine the validity of the MPI. Study 4 is the beginning of a program aimed at addressing this issue.

Given the results obtained in Study 4 with those reported in Studies 2 and 3, we can say that P1 passed all these tests successfully, whereas P4 still lacks positive confirmatory evidence in this set of studies. However, there is promising evidence for P4 in past micro-PK research (Bierman, 2001; Walach et al., 2019) and we expect additional confirmatory evidence to be found with future research. The data found here in our studies, however, require a conservative interpretation. Based on these results, it seems appropriate to favor P1 since it is based on an accepted and well-proven theoretical QM framework, despite the results of Study 1 that challenge (or rather extend) this view. The PJM and its formalized version, the MPI, would imply an extension of the standard QM that comes close to a paradigm shift. Such a shift can only be initiated with resounding confirming evidence, which, given the results of Study 4, has not been obtained. The main question for future research will be how such a confirmation might look, given the lack of replicability inherent in the PJM and MPI frameworks. All raw data and analyses scripts are available at https://osf.io/hgxt3/.

Journal of Anomalous Experience and Cognition (JAEX) 2021, Vol. 1, No. 1-2, pp. 114-155

General Discussion

This study aimed to test a set of propositions derived from a theory first presented by Pauli and Jung. According to this theory, which we refer to as the "Pauli-Jung model" (PJM), human observers can unconsciously influence the outcome of a quantum measurement when meaningfully relevant outputs are involved. Such observational effects were originally called "induced correlations" (ICs) and were supposed to manifest as entanglement correlations between observers' mental states and quantum outcomes. ICs were described as elusive and occurring unsystematically, therefore preventing violations of the indeterminacy principle of standard QM. The model of pragmatic information (MPI) (Lucadou, 1995, 2015, 2019; Lucadou et al., 2007) addressed this elusiveness and proposed that an initial empirical documentation of ICs would be followed by declines of effects in later direct replication attempts. This non-replicability theorem, formulated as a necessary condition, renders that theory unfalsifiable by scientific observations, since the same causal effect must occur under the same circumstances when tested empirically. The MPI emphasizes the acausal nature of entanglement correlations underlying ICs and suggests conceptual replications as an alternative testing strategy to ensure the minimum amount of falsifiability. In four studies, the propositions derived from the PJM/MPI and variations of these (some of which ignored the non-replicability theorem) were empirically tested (P2, P3, and P4) against the predictions derived from standard QM (P1).

An unconscious priming paradigm with human observers was used together with meaningfully loaded qRNG outcomes (i.e., pictures displaying affective contents (Studies 1 to 3)) or affective facial expressions (Study 4), to test these propositions in four experiments. Although, in line with P2, strong evidence for the existence of ICs—in terms of more positive pictures chosen by the qRNG than were expected by chance—was found in Study 1; this effect could not be replicated in subsequent studies. Rather, Studies 2 and 3—two direct replications—and Study 4, a conceptual replication, revealed strong evidence for a null effect. These data support P1, which propagates the ubiquitous validity of the indeterminacy principle and the Born rule. The same is true for P3, which proposes a replicable non-random oscillating data pattern in the priming condition, which could not be confirmed in Studies 3 or 4. On the one hand, this aligns with the assumption that Study 1 represents a false positive finding caused by failed direct replication attempts. On the other, this fits the non-replicability-theorem of the MPI (P4), which proposes a decline after an initial true-positive within a series of direct replications. The MPI's non-replicability theorem can arguably only be circumvented by conceptual replications (P4). Under such circumstances, ICs may reappear. However, a first test of P4 with Study 4, a conceptual replication of Study 1 did not support this proposition either. In sum, most findings except those from Study 1 are in line with the assumptions derived from standard QM, and no confirmatory evidence deriving from the MPI was found for P4.

Since the PJM, with its mind-matter unification approach, and the MPI, with its "limitations of replicability" issue, pose a severe challenge to mainstream theories concerning mind and matter as well as science as a whole, and since no confirmatory evidence could be provided from the studies presented here, some readers might favor standard QM over any extensions of this theory, such as PJM and MPI. There are some hints in the data and some theoretical considerations that motivate further exploration and testing of the propositions derived from the PJM and the MPI. We highlight these findings, including some theoretical arguments and their potential impact on the validity of both models, below.

First, if Study 1 is considered a false positive, then it would be particularly extraordinary. The results of Study 1 obtained in the positive priming condition revealed strong evidence for the effect, with a $BF_{10} > 13.35$ at a remarkable sample size of $n = 4{,}092$. Reaching such a BF with such a sample size makes a successful replication much more (13 times) likely than a failed replication. This argument is also supported by the time course analyses of the sequential BF obtained from the positive priming condition across Studies 1 and 2 combined (see post-hoc analyses reported at the end of Study 2 results section), which indicates an unusual time course of the sequential BF. We also calculated the probability of finding a BF of 10 or a higher given this sample size and found a $p < .004$ based on 10,000 simulations. Such a high *p*-value would make this result a highly unusual false positive. The MPI, which predicted both the effect and failed replications, addresses these results more successfully. Admittedly, Study 1 was not pre-registered and was therefore susceptible to questionable research practices (QRPs). However, this study was free of any obvious QRPs, with outsourced data collection and predefined analyses and methods that followed the exact procedural details reported in a similar micro-PK study (Maier et al., 2018). Additionally, although Bayesian analyses do allow for optional stopping, we ran more participants than necessary, since a BF of 10 was exceeded several times. That is, we did not stop when it was convenient for our hypothesis to do so but continued until the stopping criterion had been securely met.

Second, the MPI predicts a displacement of the effect in later replication attempts. This may include anomalies in the control condition (Lucadou, 2019). We found such an anomaly for the neutral priming control condition in both replication studies. In the secondary analyses, an amplitude sum lower than 95.23% of simulations was found in Study 3 and a BF energy of the sequential BF lower than 97.18% of the simulations was found in Study 4. This implies that the control data behaved more neutrally than expected by chance (i.e., followed an "ideal" null model), which is a typical displacement effect as proposed by the MPI.

Third, although no confirmatory evidence for the MPI was found in Study 4, one could argue that the design dissimilarity between Study 1 and Study 4 did not meet the criterion for a conceptual replication to work. Thus, further conceptual replications must be performed, varying the degree of similarity between the designs before the MPI could be considered falsified.

Speculating a bit more, if the MPI interpretation was correct, the question would arise at which level of observation did the micro-PK effect and its decline take place? Novelty and confirmation are less relevant for the participants being the primary observers, but rather for experimenters, data analyst, and the readers of the data report who will interpret the data in exactly these ways (novel and/or confirmative). That is, the MPI might primarily address the impact of second order observations and might therefore be considered a theory about experimenter-psi (epsi) and similar phenomena. Epsi has long been suspected of playing a role in micro-PK research (e.g. Kennedy & Taddonio, 1976) and the Bayesian testing approach in which the investigators repeatedly update their knowledge about the existence or absence of micro-PK by watching interim results would be a pretty likely scenario for epsi to occur. Although we favored the participants' observational impact in our theoretical framework, it is unclear at which level of observation a biasing impact on quantum randomness has occurred in case micro-PK and decline would be considered confirmed by the present data (cf. Rabeyron, 2020). Given these empirical and theoretical arguments, PJM and MPI merit further exploration, even though the actual data at this point support standard QM.

Author's contributions:

MCD designed the first study, co-designed studies 2 to 4, organized data collection and carried out the statistical analyses. MM co-designed studies 2 to 4 and drafted the first version of the manuscript. MP participated in the data collection and revised the manuscript. MD revised the manuscript.

References

Aspect, A., Dalibard, J., & Roger, G. (1982). Experimental test of Bell's inequalities using time-varying analyzers. *Physical Review Letters*, *49*(25), 1804–1807. Doi: 10.1103/PhysRevLett.49.1804

Atmanspacher, H. (2004). Quantum theory and consciousness: An overview with selected examples. *Discrete Dynamics in Nature and Society*, *2004*(1), 51–73. Doi: 10.1155/S102602260440106X

Atmanspacher, H. (2012). Dual-aspect monism à la Pauli and Jung. *Journal of Consciousness Studies*, *19*(9–10), 96–120. Doi: 10.1063/1.4773112

Atmanspacher, H. (2014). 20th century variants of dual-aspect thinking. *Mind and Matter*, *12*(2), 245–288.

Atmanspacher, H. (2020). The Pauli–Jung conjecture and its relatives: A formally augmented outline. *Open Philosophy*, *3*(1), 527–549. Doi: 10.1515/opphil-2020-0138

Atmanspacher, H., Filk, T., & Römer, H. (2006). Weak quantum theory: Formal framework and selected applications. *AIP Conference Proceedings*, *810*, 34–46. Doi: 10.1063/1.2158709

Atmanspacher, H., Römer, H., & Walach, H. (2002). Weak quantum theory: Complementarity and entanglement in physics and beyond. *Foundations of Physics*, *32*(3), 379–406. Doi: 10.1023/A:1014809312397

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, *1*(3), 195–200. Doi: 10.1103/PhysicsPhysiqueFizika.1.195

Bem, D. J., Utts, J., & Johnson, W. O. (2011). Must psychologists change the way they analyze their data? *Journal of Personality and Social Psychology*, *101*(4), 716–719. Doi: 10.1037/a0024777

Bierman, D. J. (2001). On the nature of anomalous phenomena: Another reality between the world of subjective consciousness and the objective world of physics? In P. van Loocke (Ed.), *The Physical Nature of Consciousness. Advances in Consciousness Research 29* (pp. 269–292). John Benjamins.

Bohm, D. (1990). A new theory of the relationship of mind and matter. *Philosophical Psychology*, *3*(2–3), 271–286. Doi: 10.1080/09515089008573004

Bohm, D. (2002). *Wholeness and the implicate order*. Psychology Press.

Bohm, D., & Hiley, B. J. (1995). *The undivided universe*: *An ontological interpretation of quantum theory*. Routledge.

Born, M. (1926). Zur Quantenmechanik der Stoßvorgänge [On the quantum mechanics of impact processes]. *Zeitschrift für Physik, 37(12), 836–867. Doi: 10.1007/BF01397477*

Bösch, H., Steinkamp, F., & Boller, E. (2006). Examining psychokinesis: The interaction of human intention with random number generators - A meta-analysis. *Psychological Bulletin*, *132*(4), 497–523. Doi: 10.1037/0033-2909.132.4.497

Dechamps, M., & Maier, M. (2019). How smokers change their world and how the world responds: Testing the oscillatory nature of micro-psychokinetic observer effects on addiction-related stimuli. *Journal of Scientific Exploration*, *33*(3), 406–434. Doi: 10.31275/2019/1513

de Leeuw, J. R. (2015). jsPsych: A JavaScript library for creating behavioral experiments in a web browser. *Behavior Research Methods*, *47*(1), 1–12. Doi: 10.3758/s13428-014-0458-y

d'Espagnat, B. (1999). *Conceptual foundations of quantum mechanics* (2nd ed.). CRC Press.

d'Espagnat, B. (2006). *On physics and philosophy*. Princeton University Press.

Duggan, M., & Tressoldi, P. (2021). *Human interaction with random number generators: A review of psychokinesis experiments 2006 - 2020*. [Unpublished manuscript].

Dürr, S., Nonn, T., & Rempe, G. (1998). Origin of quantum-mechanical complementarity probed by a-'which-way' experiment in an atom interferometer. *Nature*, *395*(6697), 33–37. Doi: 10.1038/25653

Eichmann, U., Bergquist, J. C., Bollinger, J. J., Gilligan, J. M., Itano, W. M., Wineland, D. J., & Raizen, M. G. (1993). Young's interference experiment with light scattered from two atoms. *Physical Review Letters*, *70*(16), 2359–2362. Doi: 10.1103/PhysRevLett.70.2359

Einstein, A., Podolsky, B., & Rosen, N. (1935). Can quantum-mechanical description of physical reality be considered complete? *Physical Review*, *47*(10), 777–780. Doi: 10.1103/PhysRev.47.777

Ekman, P., & Friesen, W. v. (1976). Measuring facial movement. *Environmental Psychology and Nonverbal Behavior*, *1*(1), 56–75. Doi: 10.1007/BF01115465

Esfeld, M. (1999). Wigner's view of physical reality. *Studies in History and Philosophy of Science Part B - Studies in History and Philosophy of Modern Physics*, *30*(1), 145–154. Doi: 10.1016/S1355-2198(98)00031-8

Filk, T., & Römer, H. (2011). Generalized quantum theory: Overview and latest developments. *Axiomathes*, *21*(2), 211–220. Doi: 10.1007/s10516-010-9136-6

Hiley, B. J. (2001). Non-commutative geometry, the Bohm interpretation and the mind-matter relationship. *AIP Conference Proceedings*. Doi: 10.1063/1.1388680

Huang, M., Sun, H., & Vaina, L. (2019). Visual attributes of subliminal priming images impact conscious perception of facial expressions. *Journal of Behavioral and Brain Science*, 9, 108–120. Doi: 10.4236/jbbs.2019.93009.

Jahn, R., Dunne, B., Bradish, G., Dobyns, Y., Lettieri, A., Nelson, R., Mischo, J., Boller, E., Bösch, H., Vaitl, D., Houtkooper, J., & Walter, B. (2000). Mind/machine interaction consortium: PortREG replication experiments. *Journal of Scientific Exploration*, *14*(4), 499–555.

Jahn, R. G., Dunne, B. J., Nelson, R. G., Dobyns, Y. H., & Bradish, G. J. (2007). Correlations of random binary sequences with pre-stated operator intention: A review of a 12-year program. *Explore: The Journal of Science and Healing*, *3*(3), 244–253. Doi: 10.1016/j.explore.2007.03.009

JASP Team. (2019). *JASP (Version 0.9) [Computer Software].*

Kennedy, J. E., & Taddonio, J. L. (1976). Experimenter effects in parapsychological research. *Journal of Parapsychology*, *40*(1), 1–33.

London, F., & Bauer, E. (1939). *La théorie de l'observation en mécanique quantique* [The theory of observation in quantum mechanics]. Hermann & Cie.

Lucadou, W. (1995). The model of pragmatic information (MPI). *European Journal of Parapsychology*, *11*, 58–75.

Lucadou, W. (2006). Self-organization of temporal structures: A possible solution for the intervention problem. *AIP Conference Proceedings*, *863*, 293–315. Doi: 10.1063/1.2388760

Lucadou, W. (2015). The correlation matrix method (CMM): A new light upon the repeatability problem in parapsychology. In *Paper for the 58th Annual Convention of the Parapsychological Association and the 39th SPR International Conference*. University of Greenwich.

Lucadou, W. (2019). Homeopathy and the action of meaning: A theoretical approach. *Journal of Scientific Exploration*, *33*(2), 213–254. Doi: 10.31275/2019.1343

Lucadou, W., Römer, H., & Walach, H. (2007). Synchronistic phenomena as entanglement correlations in generalized quantum theory. *Journal of Consciousness Studies*, *14*(4), 50–74.

Maier, M. A., Buechner, V. L., Dechamps, M. C., Pflitsch, M., Kurzrock, W., Tressoldi, P., Rabeyron, T., Cardeña, E., Marcusson-Clavertz, D., & Martsinkovskaja, T. (2020). A preregistered multi-lab replication of Maier et al. (2014, exp. 4) testing retroactive avoidance. *PLoS ONE*, *15*(8), Article e0238373. Doi: 10.1371/journal.pone.0238373

Maier, M. A., & Dechamps, M. C. (2018). Observer effects on quantum randomness: Testing micro-psychokinetic effects of smokers on addiction-related stimuli. *Journal of Scientific Exploration*, *32*(2), 265–297. Doi: 10.31275/2018.1250

Maier, M. A., Dechamps, M. C., & Pflitsch, M. (2018). Intentional observer effects on quantum randomness: A Bayesian analysis reveals evidence against micro-psychokinesis. *Frontiers in Psychology*, *9*, Article 379. Doi: 10.3389/fpsyg.2018.00379

Mandel, L. (1999). Quantum effects in one-photon and two-photon interference. *Reviews of Modern Physics*, *71*(2), 274–282. Doi: 10.1103/revmodphys.71.s274

Mensky, M. B. (2013). Everett interpretation and quantum concept of consciousness. *NeuroQuantology*, *11*(1), 85–96. Doi: 10.14704/nq.2013.11.1.635

Phaf, R. H., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: A meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in Psychology*, *5*, Article 378. Doi: 10.3389/fpsyg.2014.00378

Primas, H., & Esfeld, M. (1997). *A critical review of Wigner's work on the conceptual foundations of quantum theory*. http://philsci-archive.pitt.edu/1574/

Rabeyron, T. (2020). Why most research findings about psi are false: The replicability crisis, the psi paradox and the myth of Sisyphus. *Frontiers in Psychology*, *11*, Article 2468. Doi: 10.3389/fpsyg.2020.562992

Radin, D. I., & Nelson, R. D. (1989). Evidence for consciousness-related anomalies in random physical systems. *Foundations of Physics*, *19*(12), 1499–1514. Doi: 10.1007/BF00732509

Radin, D., Michel, L., & Delorme, A. (2016). Psychophysical modulation of fringe visibility in a distant double-slit optical system. *Physics Essays*, *29*(1), 14–22. Doi: 10.4006/0836-1398-29.1.014

Rosenblum, B., & Kuttner, F. (2011). *Quantum enigma: Physics encounters consciousness*. Oxford University Press.

Scheier, M. F., Carver, C. S., & Bridges, M. W. (1994). Distinguishing optimism from neuroticism (and trait anxiety, self-mastery, and self-esteem): A reevaluation of the life orientation test. *Journal of Personality and Social Psychology*, *67*(6), 1063–1078. Doi: 10.1037/0022-3514.67.6.1063

Schmidt, H. (1970). A pk test with electronic equipment. *Journal of Parapsychology*, *34*(3), 175–181.

Schmidt, H. (1974). Comparison of pk action on two different random number generators. *Journal of Parapsychology*, *38*(1), 47–55.

Smith M. L. (2012). Rapid processing of emotional expressions without conscious awareness. *Cerebral Cortex*, *22*(8), 1748–1760. Doi: 10.1093/cercor/bhr250

Stapp, H. P. (2011). *Mindful universe: Quantum mechanics and the participating observer*. Springer. Doi: 10.1007/978-3-642-18076-7

Tremblay, N. (2019). Independent re-analysis of alleged mind-matter interaction in double-slit experimental data. *PLoS ONE*, *14*(2), Article e0211511. Doi: 10.1371/journal.pone.0211511

Turiel, T. P. (2007). Quantum random bit generators. *American Statistician*, *61*(3), 255–259. Doi: 10.1198/000313007X223225

Varvoglis, M., & Bancel, P. A. (2015). Micro-psychokinesis. In E. Cardeña, J. Palmer, & D. Marcusson-Clavertz (Eds.), *Parapsychology: A handbook for the 21st century* (pp. 266–281). McFarland.

von Neumann, J. (1932). *Mathematische Grundlagen der Quantenmechanik [Mathematical foundations of quantum mechanics]. Julius Springer.*

Walach, H., Horan, M., Hinterberger, T., & von Lucadou, W. (2019). Evidence for anomalistic correlations between human behavior and a random event generator: Result of an independent replication of a micro-pk experiment. *Psychology of Consciousness: Theory Research, and Practice*, *7*(2), 173–188. Doi: 10.1037/CNS0000199

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *The Journal of Neuroscience*, *18*(1), 411–418. Doi: 10.1523/JNEUROSCI.18-01-00411.1998

Yu, S., & Nikolić, D. (2011). Quantum mechanics needs no consciousness. *Annalen der Physik, 523(11), 931–938. Doi: 10.1002/andp.201100078*

Zech, H. G., Rotteveel, M., van Dijk, W. W., & van Dillen, L. F. (2020). A mobile approach-avoidance task. *Behavior Research Methods*, *52*(5), 2085–2097. Doi: 10.3758/s13428-020-01379-3

Zeilinger, A. (1999). Experiment and the foundations of quantum physics. *Reviews of Modern Physics*, *71*(2), 288–297. Doi: 10.1103/revmodphys.71.s288

Zou, X. Y., Wang, L. J., & Mandel, L. (1991). Induced coherence and indistinguishability in optical interference. *Physical Review Letters*, *67*(3), 318–321. Doi: 10.1103/PhysRevLett.67.318