



Psychophysical Effects on an Interference Pattern in a Double-Slit Optical System: An Exploratory Analysis of Variance^{1,2}

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Abstract: *Objective:* A two-year online experiment tested the hypothesis that focused human attention alternatively directed toward or away from a double-slit optical system would affect the interference pattern in a predictable, unidirectional fashion. A control condition was employed by having a web server periodically simulate a human observer. *Method:* Based on the results of an independent reanalysis of these data and the outcome of an independent conceptual replication, we revisited the original directional hypothesis to explore the possibility that mind-wandering and other distractions might have caused attention or intention to unpredictably fluctuate. That in turn might have caused the hypothesized psychophysical influence to be more readily detected as a bidirectional effect (i. e., a shift in variance) rather than as unidirectional effect (a shift in mean). To test this idea, we developed a variance-based analysis using data collected during the first year of the experiment and applied it to data from the second year. *Results:* The first year's data showed that experimental sessions conducted by humans resulted in significant variance differences as compared to control sessions conducted by a computer, $z = 4.16$, $p = .00002$. The same analysis applied to the second year's data resulted in $z = 3.14$, $p = .0008$. Examination of environmental and apparatus variables indicated that those factors were not responsible for the observed changes in variance. *Conclusion:* The results suggest that a variance analysis may be more sensitive to psychophysical effects in this type of experiment.

Keywords: mind-matter interaction, collapse of the wavefunction, double-slit interference

Highlights

- Mind-matter interaction experiments testing how intention influences physical systems often use hypotheses evaluated by mean-shift or unidirectional metrics.
- This approach may not be optimal because of the unavoidable effects of mind-wandering and other distractions.
- Because attention and intention can fluctuate moment to moment, use of a variance or equivalent bidirectional metric may be a more robust way to evaluate an effect.

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- This approach was used in a reanalysis of previously recorded data in an online mind-matter experiment, resulting in a statistically clearer outcome.

Questions about the role of consciousness in the physical world have been debated by philosophers for millennia (Erich, 1999). Similar questions were posed by scientific pioneers. For example, in 1627, Sir Francis Bacon published *Sylva Sylvarum*, one of the first written works that helped to establish empirical research at the foundations of science (Bacon, 1639). Before Bacon, those seeking reliable answers to questions about the nature of Nature would have been advised to consult Aristotle (Wörner, 2001).

In *Sylva Sylvarum*, Bacon proposed that empiricism could be applied to many topics, including the study of mental intention, which he called the “force of imagination.” To do this, one would use objects that, in Bacon’s words, “have the lightest and easiest motions ... [such as] the motions of shuffling of cards, or casting of dice....” (Bell, 1964). His proposal about tossing dice presaged future studies of mind-matter interaction by some three hundred years (Radin, 2006; Radin & Ferrari, 1991).

Today, Bacon’s musings about the force of imagination can be found in a new form. As physicist Richard Feynman famously put it, it resides in “the heart of quantum mechanics” (Feynman et al., 1965). Feynman was referring to the fact that a quantum object behaves differently when it is observed than when it is not observed. This “quantum measurement problem” appears to violate the common-sense assumption that physical reality does not depend on observation (Myrvold, 2018). In the vernacular, it is reasonable to assume that the moon is still there even when you are not looking at it, but that everyday truism may not hold when dealing with the world at the quantum scale (Leggett, 1998; Josephson, 2002).

The measurement problem was discussed and debated by many of the founders of quantum theory, including Bohr, de Broglie, Heisenberg, Schrödinger, Eddington, Jor-

dan, Pauli, Planck, Jeans, London, Wigner, and Bohm (Rosenblum & Kuttner, 2006). All were concerned about the epistemological and ontological challenges presented by quantum theory. Some, like Jordan, Schrödinger, von Neumann, and Bohm specifically proposed that some aspect of consciousness was responsible for the behavior of physical reality (Radin et al., 2012). Those proposals did not imply the philosophical position of idealism, whereby the physical world is said to emerge from consciousness, but rather that mind interacts with matter and that such interactions are instrumental in the unfolding of the physical world. This is in alignment with the philosophy of dual-aspect monism (Atmanspacher & Rickles, 2022).

For example, consider this statement from Jordan: “Observations not only disturb what is to be measured, they produce it. We compel [the electron] to assume a definite position. We ourselves produce the results of measurement” (Marin, 2009, p. 818). Some might object that this quote is taken out of context or misrepresents Jordan’s position, but that is unlikely because Jordan was explicitly interested in mind-matter interaction as evidenced by an article he published in the *Journal of Parapsychology* entitled “Reflections on parapsychology, psychoanalysis, and atomic physics” (Jordan, 1951), and by an article on a related theme that he later published in the *International Journal of Parapsychology* (Jordan, 1960).

In a similar vein, Schrödinger wrote: “It is then quite clear that a measurement of x affects not only (as is always said) p [x ’s momentum], but also x itself. You have not found a particle at K ’ [x ’s definite position], you have produced one there! ... Before the second measurement, it is ubiquitous in the cloud (it is not a particle at all)” (Schrödinger, 1995, p. 106). And again, “ ... [t]he observer is never entirely replaced by instruments; for if he were, he could obviously obtain no knowledge whatsoever Many helpful devices can facilitate his work ... But they must be read! The observer’s senses have to step in eventually. The most careful record, when not inspected, tells us nothing” (Schrödinger, 1992, p 162).

John von Neumann used the term “psychophysical” to refer to mind-matter interactions in his proposal that the chain of possible interactions that occur between physical entities during the measurement process must at some point be “cut,” thereby converting quantum potentials into classical actuals, and that this would occur only when knowledge of the measurement was registered by the observer’s mind (von Neumann, 1955).

David Bohm too was interested in the mind-matter relation, as reflected by an invited talk he gave to the American Society for Psychical Research, later published in its journal, on “A new theory of the relationship of mind and matter” (Bohm, 1986). In that talk he said:

One may then ask: what is the relationship of [mind and matter]? The answer that I want to propose here is that there are no two processes. Rather, I would suggest that both [mind and matter] are essentially the same. This means that that which we experience as mind, in its movement through various levels of subtlety, will in a natural way ultimately reach the level of the wavefunction and of the “dance” of the particles. There is no unbridgeable gap or barrier between any of these levels (Bohm, 1986, p. 113).

Related themes can be found in the writings of Wheeler, Stapp, Penrose, and other contemporary physicists. While this concept is not the leading consensus among most physicists today, neither is it a trivial minority. For example, in 2016, a survey was conducted among physicists interested in foundational questions about quantum mechanics (Sivaram & Nielsen, 2016). One of the questions was: “In your opinion [do you think] the observer (a) is a complex quantum system, (b) should play no fundamental role whatsoever, (c) plays a fundamental role in the application of the formalism, but plays no distinguished physical role, or (d) plays a distinguished physical role.” Of the 150 respondents, 22% selected option (d). This suggests that a sizeable minority of physicists today agree that the formation of physical reality involves some sort of mind-matter interaction.

Despite the historical and continuing scientific interest in the mind-matter relationship, few physicists today are empirically exploring this topic. Perhaps this is because of the siloed nature of academic disciplines, which constrains the range of topics accepted as relevant. But this is not to say that there are no pertinent results reported in the peer-reviewed literature. Many physical targets have been used to explore the “force of imagination,” including cell cultures (Radin, Taft & Yount, 2004), plants (Shiah et al., 2017), variations in human mood (Shiah & Radin, 2013) and human physiology (Schmidt et al., 2004), and also in nonliving systems such as water (Radin et al., 2020; Schwartz et al., 2015), tossed dice (Radin & Ferrari, 1991), truly random number generators (Bosch et al., 2006; Radin et al., 2006; Radin & Nelson, 1989), and interference patterns generated by optical systems (Guerrer, 2019; Ibison & Jeffers, 1998; Radin et al., 2012, 2013, 2015, 2016, 2021). Overall, these studies suggest that small magnitude but statistically significant effects can be independently observed and replicated in controlled experiments (Cardeña, 2015, 2018).

That said, these effects are not trivial to reproduce because the task at hand is not simply a physics experiment, but one that involves poorly understood interactions between mind and matter. Conducting these studies thus also requires careful consideration of psychological factors like motivation, belief, and expectation, cognitive factors like the ability to maintain tightly focused attention, and also a host of potential unconscious influences (Carpenter, 2015).

When seeking to detect small magnitude effects, it is necessary to obtain adequate statistical power. To help achieve this, we conducted an online experiment where the psychophysical target was a double-slit optical system (Radin et al., 2016). That experiment was part of a series of studies using similar apparatus (Radin et al., 2021), which were deemed uniquely suitable for studying mind-matter interaction effects because an optical interferometer provides several pathways by which an influence might occur. One involves influencing components of the apparatus itself, including the laser power, the ori-



entation of the beam, the camera electronics, the path of individual photons, and so on. Another is that if one could gain knowledge about which of the two slits the photons passed through (i.e., so-called “which-path” information), then the wave-like nature of the interference would shift into a particle-like diffraction pattern in proportion to the accuracy of the knowledge gained. In either case, attention- or intention-associated effects might alter the interference pattern in detectable ways.

The present reanalysis of the previously published experiment was motivated by four factors. The first was an independent double-slit replication reported by Guerrer (2019). In a series of pilot tests, he reported confirmation of the directional hypothesis that consciousness would “collapse” the interference pattern. However, in follow-up formal studies, there was no evidence for a directional effect using the planned analysis, but post-hoc he found a significant bidirectional effect.

The second motivation was a reanalysis of the data gathered in this online study by Tremblay (2019). In his first published analysis, he confirmed that a significant effect was observed in one year of a two-year dataset. In a later correction, he found that a data trimming method we had used to remove outliers inadvertently inflated the p-values (Tremblay, 2021), which had been previously noted by Walleczek & von Stillfried (2019). We should note that we had also reported results with data that were not trimmed, and that outcome remained statistically significant, so the shortcoming in our outlier rejection procedure did not change the interpretation of the results (Radin et al., 2016, p. 20). Based on his analysis, Tremblay concluded in his latter paper that, “We observe, as in [the 2019 article] shifts in fringe visibility in the direction expected by the mind-matter interaction hypothesis. However, these shifts are not deemed significant ($p > 0.05$). Our re-analysis concludes that this particular dataset does not contain evidence of mind-matter interaction” (Tremblay, 2021, p.1).



The third motivation was a reanalysis of another experiment we had conducted (and which was also critiqued by Walleczek & von Stillfried (2019)), in which we found a highly significant difference in variance of data collected in experimental sessions as compared to data collected in time- and protocol-matched control sessions (Radin et al., 2021).

The fourth motivation was a reconsideration of potential unconscious factors involved in these kinds of experiments (Carpenter, 2004, 2005, 2015; Eisenbud, 1983). Conscious attention and intentions can be distorted or overridden by unconscious undercurrents, leading to experimental results called “psi-missing” (statistically significant results opposite to the intended results), decline effects, and other oddities that tend to reduce or otherwise confound predicted outcomes (Kennedy, 2003).

Given these ideas, we revised our original directional hypothesis and instead postulated that psychophysical effects in this kind of experiment might be more easily detectable as a bidirectional effect. To explore this possibility, we developed an analytical approach that assumed that mind-matter influences are unstable because of mind-wandering and other distractions (Brandmeyer & Delorme, 2020; Schooler et al., 2011; Zwarun & Hall, 2014). To do this, we compared differences in variance between the two attentional conditions in sessions conducted by humans, as compared to the same differences in control sessions conducted by a computer.

Method

Details about the apparatus, methods, and procedures used in this experiment are described in a previous publication (Radin et al., 2016). For convenience, they are briefly repeated here. The new analytical approach is described in more detail later in this section.

Apparatus

The double-slit apparatus consisted of five key components: (1) 5 mW linearly polarized HeNe laser (Melles-Griot Model 25 LHP 151-249, 632.8 nm, Melles-Griot, Albuquerque, NM, USA), (2) two 10% transmission neutral density filters (Rolyn Optics, Covina, CA), (3) a double-slit slide with 10 μm slit widths separated by 200 μm (Lenox Laser, Glen Arm, MD, USA), (4) a 3000 pixel CCD line camera (Thorlabs Model LC1-USB, Newton, NJ, USA), and (5) a Melles-Griot regulated power supply, rated at $\pm 2\%$ power drift per hour.

The camera was located 16 cm from the slits, and light intensity was integrated for 40 ms. The optical apparatus was housed inside a sealed aluminum housing painted matte black inside and out, and the laser and camera were powered on continuously. The optical system was located on an equipment rack near the web server in the laboratory of the Institute of Noetic Sciences.

The experiment was controlled by a Windows XP computer running a web server program written in Matlab (version 2009b, MathWorks, Natick, MA, USA) and augmented with Thorlabs software libraries. The web server captured interference patterns from the camera at approximately 16 frames per second, and every fourth camera frame was recorded for offline analysis and simultaneously uploaded to a cloud storage system.

Procedures

Anyone with internet access was allowed to participate in this experiment. After navigating to the experiment's website and agreeing to the informed consent, they were invited to shift their attention toward or away from the optical system according to voice instructions that would announce the beginning of attentional epoch. The spoken phrase "now please concentrate" indicated a focus-toward epoch, and the phrase "now you may relax" indicated a withdrawal of focus epoch.

The concentrate epochs were uniformly 30 s in length. These were counterbalanced with relax epochs, each of which was randomly varied from 30 to 35 s in length. The ran-

dom length relax epochs were used to help decouple the concentrate epochs from potential periodicities that might arise in the interference pattern due to periodic ambient environment factors or cycles in laser power. Each test session consisted of a series of 21 alternating epochs, starting with relax, for a total length of approximately 11 minutes.

A participant who wished to start an experimental session clicked a button on their browser. If the optical system was being used at that time, either by another person or by the web server acting as a "robot" or control user, a message would inform the person to come back in a few minutes. If the system was available, the experiment would begin.

During concentrate epochs a line graph was drawn on the browser to provide the user with real-time feedback about the nature of the interference pattern. No line was drawn during relax epochs. In 2013, the direction that the line moved was programmed such that if the wave-like interference pattern shifted toward a particle-like diffraction pattern, then the line went up. In 2014, the feedback was inadvertently reversed, such that the line went up as the interference pattern became more wave-like. For more details about the feedback, see the original article (Radin et al., 2016).

Hypothesis

The general hypothesis tested by this reanalysis was that consciousness directed toward a double-slit optical system would cause changes in the interference pattern. These changes would sometimes reflect the intentions of the participants, but at other times and in unpredictable ways other outcomes may arise. Thus, the specific hypothesis explored here predicted that the absolute difference in variance between the concentrate and relax conditions would be larger in sessions observed by humans, as compared to the same metric when observed by a computer ("robot" participants).

The analytical method described in the next section was developed first on data collected during the calendar year 2013. Then the same analysis was applied to the data

from 2014. After those two analyses was performed, all data were combined to further investigate the hypothesized effect.

Analysis

Figure 1 (top) shows the interference pattern observed by the line camera, averaged over 2,400 images collected in one session. Figure 1 (bottom) shows the log of the real portion of the Fourier transform associated with that pattern, from wavenumbers 1 through 60. The peak at wavenumber 42 is associated with the double-slit (DS) component of the interference pattern, and it is the metric of interest (henceforth referred to as “DS power”).

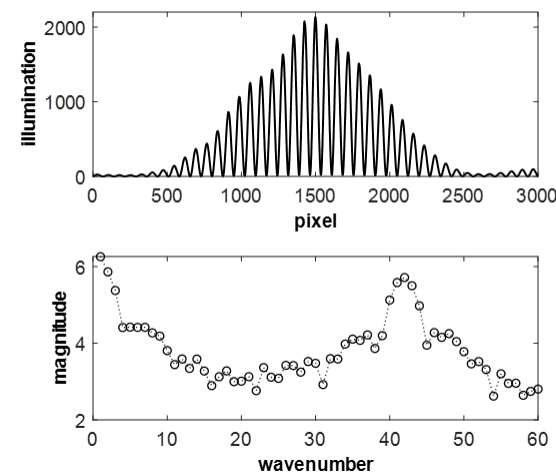


Figure 1

(top) Interference Pattern Averaged Over 2,400 Line Camera Images in One Session (bottom) Mean Log of the Real Component of the Fourier Transform of these Images for Wavenumbers 1 through 60

Figure 2 (top) plots DS power over the course of a typical 11-minute session. Fluctuations in that signal are expected because interferometers are exquisitely sensitive to variations in ambient temperature and vibration. Such variations add noise to the measurements of interest, thus to provide a more stable metric a simple method was devised to transform the raw DS power into the values shown in Figure 2 (bottom).

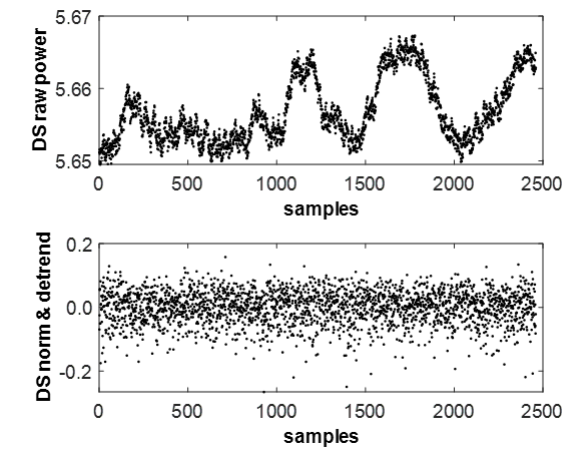


Figure 2

(top): Variations in DS Power over One Session. (bottom): DS Power After Normalizing the Spectrum from Wavenumbers 1 to 60 in each Camera Frame, and then Separately Detrending each of the 60 Wavenumbers

To achieve this transformation, for each frame collected in each session we:

- 1) Determined the log power spectrum of the interference pattern wavenumbers 1 through 60 (as in Figure 1, bottom).

- 2) Normalized the spectrum associated with each camera frame using a z-score transform to retain the spectrum’s shape without regard to its absolute baseline amplitude.

Then, across all camera frames within each session, we:

- 3) Calculated the difference between wavenumbers 1 and 42 in each frame. The former is associated with the baseline illumination level, and the latter with the peak DS power. The difference between these two values provides a way to measure changes in DS power with respect to the baseline (call this difference Δ).

- 4) Linearly detrended Δ to remove potential drifts over the course of each session.

5) Determined the absolute difference between the variance of all Δ samples in the concentrate condition, versus the variance of all Δ samples in the relax condition (call this value $|\Delta v|$).

6) Randomly permuted the order of the Δ values produced in step 4 to form a scrambled array for all human sessions, and separately for all robot sessions (using the Matlab function `randperm`).

7) Recalculated $|\Delta v|$ as in step 5, and then repeated this process 1000 times.

8) Calculated $z = (x - \mu) / \sigma$, where x was the original $|\Delta v|$, and μ and σ were the mean and standard deviations of the randomly scrambled $|\Delta v|$ values, respectively.

Now, across sessions, we:

9) Formed an array of the z scores produced in step 8 for all sessions involving human observers (call this array, $z_{|\Delta|H}$), and then formed a separate array for all sessions involving robots, $z_{|\Delta|R}$).

10) Combined the $z_{|\Delta|H}$ scores as a Stouffer Z to form a single score associated with human observers, and the same for the $z_{|\Delta|R}$ scores (Stouffer et al., 1949). This step requires the $|\Delta|$ scores to be independent, which was confirmed as shown in Figure 3.

11) Used a Wilcoxon rank sum test to compare the medians of the distribution of $z_{|\Delta|H}$ versus $z_{|\Delta|R}$ (a t -test could have been used, but the nonparametric test is more conservative).

12) Finally, lagged the original attentional condition assignments from 0 to 5 seconds to account for the time it takes to switch attention between two conditions. The optimal time shift was determined empirically for the 2013 dataset, and then the same parameter was used in analyzing the 2014 dataset. The reason that a lag analysis is important is that if the observed effect is really due to shifts in attention, then there should be a

lag in the results because the mind cannot “switch gears” instantaneously.

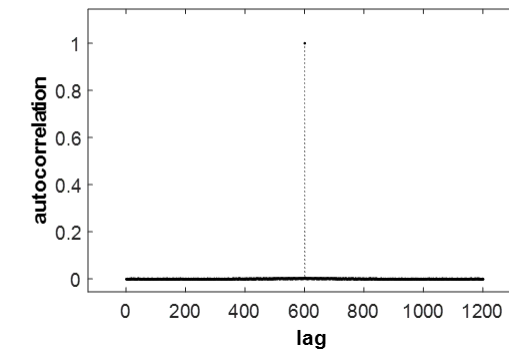


Figure 3

Autocorrelation \pm 600 Samples (Matlab function `xcorr`), Averaged over 500 Sessions, Indicating that the $|\Delta v|$ Samples Were Independent of each Other

Results

Sessions

Over the calendar year 2013, a total of 4,008 sessions were recorded. Of those, 1,256 were completed by humans and 2,312 by robots, where “completed” means that the data in a session were collected during a full run of 21 alternating attentional epochs. Those sessions were readily identified because the web server marked such sessions as “finished.” For the remaining 440 sessions, the server marked the session as “crashed” and were not analyzed. Crashed sessions could happen because the participant quit the web browser before the session ended, or because transmission of data from the optical system to the server was interrupted for unknown reasons.

During 2014, a total of 5,798 sessions were recorded, of which 1,569 were completed human sessions, 3,157 were completed robot sessions, and 1,072 were crashed sessions. Combined over both years there were 2,825 human and 5,469 robot sessions, for a total of

8,294 sessions. Details about the participants and their locations can be found in an earlier publication (Radin et al., 2016).

Analysis of Variance

Figure 4 shows the results of the Stouffer Z scores associated with human (shown as circles) and robot sessions (shown as diamonds), separately for the 2013 and 2014 data, with lags from 0 to 5 seconds (steps 10 and 12, above). After applying a False Discovery Rate (FDR) adjustment with $\alpha = .002$, the 2013 data resulted in six significant deviations for human sessions (red circles in Figure 3) and no significant deviations for robot sessions. Incidentally, this alpha was selected to help narrow down the most significant outcomes. Otherwise, if a more common alpha of $p < .05$ were used, nearly all of the comparisons would have been considered significant.

The peak deviation in 2013 was at a time lag of 1.25 seconds and was associated with $z = 4.16$, $p = .00002$. The same analysis applied separately to the 2014 data resulted in three significant deviations in human sessions (green dots), and again no significant deviations in robot sessions. The 2014 value at the 2013 peak of 1.25 seconds was associated with $z = 3.14$, $p = .0008$, replicating the 2013 results.

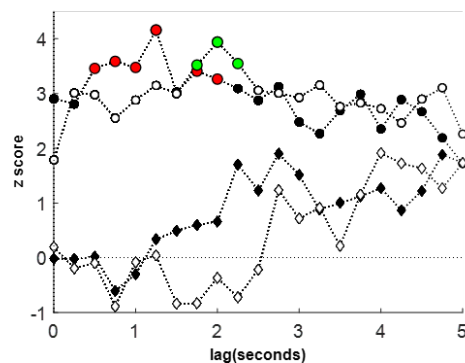


Figure 4

Z Scores for $z|\Delta|$ for Human and Robot Sessions (Black Circles and Diamonds, Respectively), Likewise for 2014 Sessions (White Circles and Diamonds)

We may note here that in our original study the maximum lag was observed at +9 seconds (Radin et al., 2016). Why the maximum lag in this analysis occurred at 1.25 seconds is unknown but it may be related to differences between the original and the present methods of analysis. In addition, previous experiments of this sort conducted in our laboratory found lags of 3 or 4 seconds (e.g., Radin et al., 2012). Establishing why these lag lengths differ with alternative analytical methods requires further study, although notice that even at zero lag the results in the present analysis remain significant (assuming FDR adjustment is not required if one considers only that one comparison).

Figure 5 shows the Wilcoxon rank sum results comparing the medians of the $z|\Delta|_H$ and $z|\Delta|_R$ scores (analysis step 11, above). After FDR adjustment with $\alpha = .025$, the 2013 data (black dots) showed three significant deviations (red dots) with lags ranging from 0.75 to 1.25 seconds. The same analysis applied to the 2014 data (white dots) showed three significant deviations (green dots), with lags from 1.25 to 1.75 seconds. The 2013 peak at 1.25 seconds was associated with $z = 3.21$ ($p = .0007$), and the 2014 peak at the same lag was $z = 2.71$ ($p = .003$).

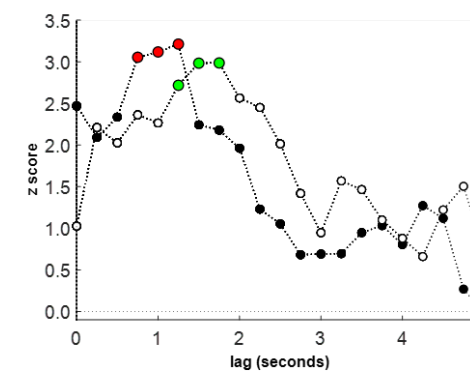


Figure 5

Wilcoxon Comparison of $z|\Delta|$ Human vs. Robot Sessions for 2013 Data (Black Dots) and 2014 Data (White Dots)

Figure 6 shows the Stouffer Z scores for all human and robot sessions combined across both years. After FDR adjustment at $\alpha = 10^{-6}$, the combined data showed two significant deviations for human sessions (red circles) and no deviations for robot sessions (with the latter more liberally tested with FDR, $p = .05$). The peak value for the human sessions at a lag of 1.5 seconds was $z = 5.57$ ($p = 1.3 \times 10^{-8}$). Figure 7 shows the Wilcoxon rank sum comparison between the human and robot data, indicating three significant deviations with FDR, $p = .002$. The peak value at 1.5 seconds in that case was $z = 3.79$ ($p = .00008$).

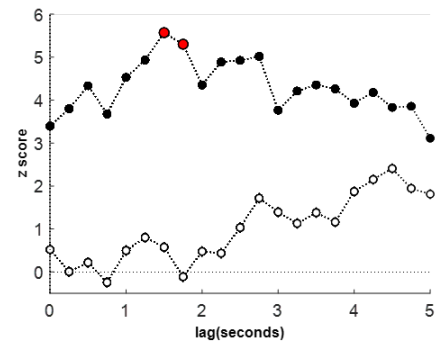


Figure 6

Z Scores for $z|\Delta|$ in all Human (Black Circles) and for all Robot (White Circles) Sessions, for all Data Combined Across Two Years

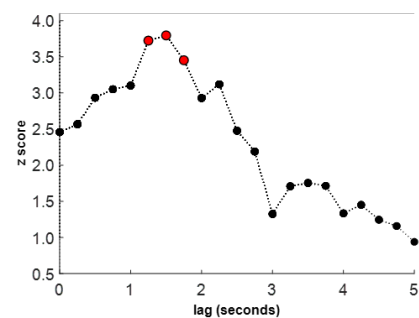


Figure 7

Wilcoxon Comparison of the Medians of $z|\Delta|$ for all Human vs. Robot Sessions Across all Data Combined

Time of Day Comparison

Considering all data across both years, Figure 8 compares effect sizes and 95% confidence intervals during the day (6 AM to 6 PM, Pacific Time), when laboratory staff were generally within a few meters of the optical apparatus, versus in the evening (before 6 AM or after 6 PM), when no one was present. The results show similar peak effect sizes at the same lags in both time periods. This argues against the possibility that the results were due to the presence of people in the lab, which may have introduced environmental artifacts like vibration or changes in ambient temperature.

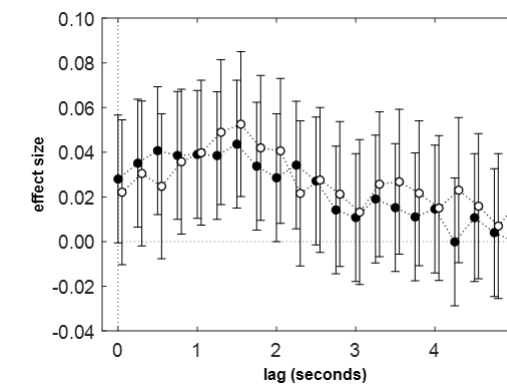


Figure 8

Effect Size \pm 95% Confidence Intervals Based on a Wilcoxon Comparison of Medians Between $z|\Delta|$ for all Human vs. Robot Data Collected During the Day (White Circles) Versus the Evening (black Circles). The Peak Effects for both Datasets Occurred at a Lag of 1.5 Seconds

Other Environmental Factors

We assumed that the robot sessions were ideal controls to compare against human sessions, and that the use of a detrended, differential metric reduced the possibility that variations in laser power or environmental influences might have given rise to spurious differences between the human and robot sessions. Neither the optical system nor the computer collecting camera data from that system “knew” if data were being served

to a distant human or a robot, and there were no indications on the apparatus or computer that might have revealed if it was idling or currently serving data. This “silent operation” was by design to prevent laboratory staff from being aware of, and thus inadvertently influencing, the on-going status of the experiment.

To check if these assumptions were correct, we explored if the results might have been due to a correlation between laser power and the $z|\Delta|$ metric, or to a non-uniform distribution of human and robot sessions. To do this we first examined the mean illumination level recorded by the line camera in each session in chronological order. Figure 9 shows that illumination declined over the course of the two-year experiment. This decline occurred for two reasons: Progressive reduction in laser power output (the laser was powered on continuously for two years), and accumulated misalignments of the laser beam in the apparatus due to ambient vibrations and/or variations in ambient temperature, the latter associated mostly with heating and cooling the lab as the seasons changed.

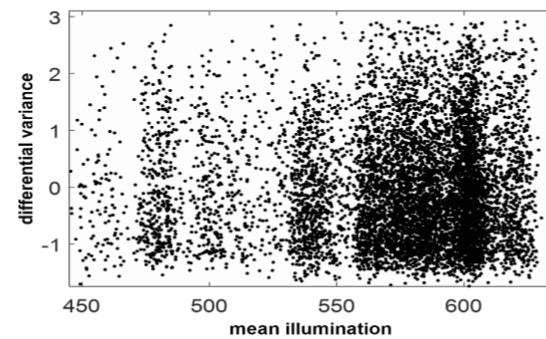


Figure 9

Mean Line Camera Illumination Level (in Arbitrary Units Returned by the Camera Software), Across all Sessions in Chronological Order

Figure 10 shows $z|\Delta|$ values obtained in all sessions in chronological order, with human sessions as black circles and robot sessions as red circles. This shows that there were periods when human trials were run with few or no interspersed robot trials. Figure 11 shows that despite the drop in illumination and the nonuniform distribution of human and

robot trials, the correlation between $z|\Delta|$ (lagged 1.5 seconds) and the illumination level was not significant ($r = .015$, $p = .18$).

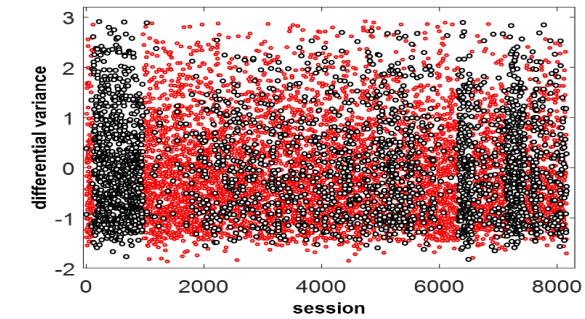


Figure 10

Distribution of all $z|\Delta|$ for all Human (Black Dots) and Robot Sessions (Red Dots), in Chronological Order

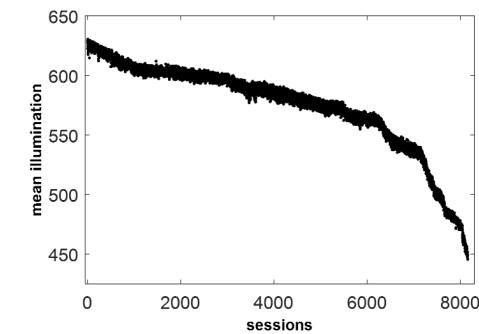


Figure 11

Relation Between Mean Illumination Level and $z|\Delta|$

Although no relation was found between the illumination level or distribution of the type of session, a Kolmogorov–Smirnov comparison of the distributions of human versus robot $z|\Delta|$ values resulted in $p = 3 \times 10^{-6}$ (Matlab function `kstest2`; see Figure 12), and a Wilcoxon rank sum comparison of the medians of those distributions resulted in $p = 3 \times 10^{-5}$. This again showed that the double-slit interference pattern differed when humans were observing the system as compared to when robots were observing.

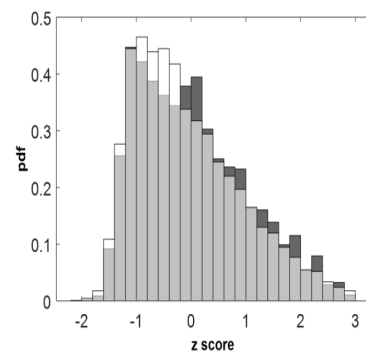


Figure 12

Histogram of $z|\Delta|$ for all Human (Black Bars) vs. Robot Sessions (White Bars). Notice the Constrained Variance in the Latter

Discussion

Tremblay's (2021) conclusion after reanalyzing the data from this experiment was: "this particular dataset does not contain evidence of mind-matter interaction...." That conclusion was justified based on the original hypothesis that focused attention would unidirectionally collapse the wavefunction in accordance with the observer's attention and/or intention. Incidentally, it is noteworthy that his conclusion was also extremely conservative because Tremblay's analytical method required Holm-Bonferroni adjustment for hundreds of statistical tests. By contrast, the present analysis only required a few adjustments.

If the original hypothesis were correct then such an effect would be best detected as a shift in the mean of a suitable metric. However, given the results observed in the present analysis, in Guerrer's replication attempt (Guerrer, 2019), and similar variance effects observed in another laboratory experiment we conducted (Radin et al., 2021), we suspected that a unidirectional hypothesis may not be the most sensitive way to detect the hypothesized effect. Instead, because of internal and external distractions (i.e., mind-wandering, phone calls, multitasking, etc.), a more suitable hypothesis may be bidirectional. This may be an especially important consideration when dealing with online par-

ticipants who are not selected for potential talent, or meditation experience, or other skills that require expertise in maintaining focused attention. It is also possible that even in those who can maintain tightly focused attention than their intentions may unavoidably wax and wane, akin perhaps to punctuated moments or "quanta" of consciousness.

The possibility that assumptions of the statistical tests used in this analysis were violated was avoided by using nonparametric methods, and also by demonstrating that the $|\Delta|$ values used to characterize the results in each session were independent of each other. Potential biases due to data selection were avoided by evaluating all completed sessions, and possible biases that might have arisen by adjusting analytical parameters to fit the data were addressed by first developing a method that was applied to the 2013 data, and then applying the same method to the 2014 data.

The primary limitation in this reanalysis is that it is unknown if the same analytical approach could successfully detect results in a similarly designed experiment. Only future replications can answer that question. However, the results so far suggest that revising the original hypothesis from directional to bidirectional reverses Tremblay's conclusion, suggesting instead the presence of a psychophysical interaction effect in an online double-slit experiment.

Data Availability: All data used in this study are available from <https://osf.io/ywktp/>. Matlab scripts for the analyses presented in this paper are available on request from the first author.

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**Psychophysikalische Effekte auf ein Interferenzmuster in einem optischen Doppelspaltsystem:
Eine explorative Varianzanalyse**

Dean Radin

Arnaud Delorme

Zusammenfassung: Zielsetzung: In einem zweijährigen Online-Experiment wurde die Hypothese getestet, dass die fokussierte menschliche Aufmerksamkeit, die abwechselnd auf ein optisches Doppelspaltsystem gerichtet ist oder sich von diesem entfernt, das Interferenzmuster in einer vorhersagbaren, unidirektionalen Weise beeinflussen würde. Als Kontrollbedingung wurde ein Webserver eingesetzt, der periodisch einen menschlichen Beobachter simulierte. Methode: Auf der Grundlage der Ergebnisse einer unabhängigen Reanalyse dieser Daten und der Ergebnisse einer unabhängigen konzeptionellen Replikation haben wir die ursprüngliche Richtungshypothese revidiert, um die Möglichkeit zu prüfen, dass das Herumwandern der Gedanken und andere Ablenkungen die Aufmerksamkeit und die Intention nicht vorhersagbar fluktuieren lässt. Dies wiederum könnte dazu geführt haben, dass der hypothetische psychophysische Einfluss eher als bidirektionaler Effekt (d.h. eine Verschiebung der Varianz) denn als unidirektionaler Effekt (eine Verschiebung des Mittelwerts) nachgewiesen werden kann. Methode: Um diese Idee zu testen, entwickelten wir eine varianzbasierte Analyse anhand der Daten, die im ersten Jahr des Experiments erhoben wurden, und wandten sie dann auf die Daten des zweiten Jahres an. Ergebnisse: Die Daten aus dem ersten Jahr zeigten, dass von Menschen durchgeführte Experimentalsitzungen zu signifikanten Varianzunterschieden im Vergleich zu den von einem Computer durchgeführten Kontrollsitzen führten, $z = 4,16, p = ,00002$. Die gleiche Analyse für die Daten des zweiten Jahres ergab ein $z = 3,14, p = ,0008$. Die Untersuchung der Umgebungs- und Gerätevariablen ergab, dass diese Faktoren nicht für die beobachteten Varianzveränderungen verantwortlich waren. Schlussfolgerung: Die Ergebnisse deuten darauf hin, dass eine Varianzanalyse bei Experimenten dieser Art empfindlicher auf psychophysische Effekte reagieren könnte.

Eberhard Bauer

**Efeitos Psicofísicos em um Padrão de Interferência em um Sistema Óptico de Fenda Dupla:
Uma Análise Exploratória de Variância**

Dean Radin

Arnaud Delorme

Resumo: Objetivo: Um experimento on-line de dois anos testou a hipótese de que a atenção humana focalizada alternativamente direcionada para um sistema óptico de dupla fenda afetaria o padrão de interferência de forma previsível e unidirecional. Uma condição de controle foi empregada ao ter um servidor web periodicamente simulando um observador humano. Método: Com base nos resultados de uma reanálise independente destes dados e no resultado de uma replicação conceitual independente, revisitamos a hipótese direcional original para explorar a possibilidade de que o vaguear da mente e outras distrações possam ter causado uma oscilação imprevisível da atenção ou da intenção. Isso, por sua vez, poderia ter ocasionado que a influência psicofísica hipotética fosse mais facilmente detectada como um efeito bidirecional (ou seja, uma mudança na variância) do que como um efeito unidirecional (uma mudança na média). Método: Para testar esta ideia, desenvolvemos uma análise baseada em variância usando dados coletados durante o primeiro ano do experimento, e depois a aplicamos aos dados do segundo ano. Resultados: Os dados do primeiro ano mostraram que as sessões experimentais realizadas por humanos

resultaram em diferenças significativas de variância em comparação com as sessões de controle realizadas por computador, $z = 4,16, p = ,00002$. A mesma análise aplicada aos dados do segundo ano resultou em $z = 3,14, p = ,0008$. O exame das variáveis ambientais e dos aparelhos indicou que esses fatores não eram responsáveis pelas mudanças observadas na variância. Conclusão: Os resultados sugerem que uma análise de variância pode ser mais sensível aos efeitos psicofísicos neste tipo de experimento.

Antônio Lima

**Efectos Psicofísicos en un Patrón de Interferencia en un Sistema Óptico deoble rendija:
Un Análisis Exploratorio de Varianza**

Dean Radin

Arnaud Delorme

Resumen: Objetivo: Un experimento en la red de dos años de duración puso a prueba la hipótesis de que la atención humana enfocada, dirigida alternativamente hacia o aparte de un sistema óptico de doble rendija, afecta el patrón de interferencia de forma predecible y unidireccional. Se empleó una condición de control haciendo que un servidor de la red simulara periódicamente a un observador humano. Método: Basándonos en los resultados de un nuevo análisis independiente de estos datos y el resultado de una réplica conceptual independiente, revisamos la hipótesis direccional original para explorar la posibilidad de que el vagabundo de la mente y otras distracciones pudieran haber causado que la atención o la intención fluctuasen de forma impredecible. Esto, a su vez, podría haber causado que la influencia psicofísica hipotetizada se detectara más fácilmente como un efecto bidireccional (es decir, un cambio en la varianza) en lugar de un efecto unidireccional (un cambio en la media). Método: Para evaluar esta idea, desarrollamos un análisis basado en la varianza utilizando los datos recogidos durante el primer año del experimento y luego aplicamos el mismo método a los datos del segundo año. Resultados: Los datos del primer año mostraron que las sesiones experimentales llevadas a cabo por humanos dieron lugar a diferencias de varianza significativas en comparación con las sesiones de control llevadas a cabo por un ordenador, $z = 4,16, p = ,00002$. El mismo análisis aplicado a los datos del segundo año dio como resultado $z = 3,14, p = ,0008$. Un examen de variables ambientales y del aparato indicó que esos factores no fueron responsables de los cambios observados en la varianza. Conclusión: Los resultados sugieren que un análisis de varianza puede ser más sensible a los efectos psicofísicos en este tipo de experimentos.

Etzel Cardeña