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Quantum nature of consciousness – Double slit diffraction experiment in medicine

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ABSTRACT

The essence of our hypothesis is quantum properties of conscious processes as well as the possibility to measure changes in conscious attention by using quantum double-slit experiment. We supposed that the act of observing in state of focused attention cause a wave function collapse in double-slit diffraction. In order to test the hypothesis, 26 participants took part in the study divided into physical and physiological parts of the experiment. The purpose of the physical system was to reproduce the brain quantum process via hypothesized quantum entanglement. The physical part consisted of a red laser source, neutral density filter, double-slit diaphragm, and linear couple charged camera, while the physiological part of the experiment was significant for the physiological quantifying state of attention. Physiological data were collected by using 29 channel electrophysiological unit with 21 channel electroencephalograph. The study had control and experimental group according to dependent variables measured in the physical part of the experiment. The data in the experimental group were collected over ten studies (sessions). Results obtained in hypothesis testing showed significant increases in corpuscular properties of the electromagnetic wave as well as significant quantum entanglement between the brain and external double-slit quantum system. Our results also offer insight into the connection between the chaotic dynamic of the electroencephalographic signals and uncertainty in the physical system due to focused attention effect. We also hypothesized that the state of concentrated attention was highest during the first several seconds. The last hypothesis considered possible backward time referral effect of cognitive evoked potential p300.

Medical hypothesis

The first hypothesis proposes the possibility that consciousness is a quantum process, as well as the possibility that the double-slit physical system reflected brain quantum behavior. According to our experiment, quantum entanglement is the underlying mechanism of psychophysical interaction between the brain quantum system in the state of concentrated attention and the electromagnetic wave in double-slit diffraction, which can be used to detect changes in human attention. In other words, this implicated that quantum entanglement is a mechanism by which decoherence of neuronal superposition, as the possible quantum source of consciousness and focused attention, induce wave function collapse or particle-like behavior in an external quantum system, which can be proved by measuring quantum variables in double-slit diffraction.

The second hypothesis states that focused attention is highest during the first several seconds.

The third hypothesis denotes the possibility that the reduction of the uncertainty and consequently wave properties in the physical system is reversely associated with the entropy of the EEG signal during an increased information acquisition in the state of concentrated attention.

The fourth hypothesis concerns the possibility that a backward time referral effect can modulate the consciousness process via cognitive p300 potential.

Introduction

The intensity with which attention is applied to a particular task is

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accompanied by a high arousal state of consciousness. Possible inherent quantum properties, consciousness, and conscious related attention showed through interaction with the external physical system. Double slit diffraction experiment was carried out by Thomas Young in which two light rays pass through the two slits making diffraction pattern on the screen. This was a classical double-slit experiment which demonstrated the wave nature of the light. At the point of the two slits light interfere making famous diffraction patterns [1,2]. The quantum double-slit experiment was originally outlined by Richard Feynman in the form of the thought experiment. Richard Feynman said that the double-slit diffraction experiment is the most beautiful experiment ever made [3]. Electromagnetic wave function collapse denotes that the superposition of eigenstates suddenly collapse by choosing a particular eigenstate after observer took part in the experiment. There is a possibility that brain functions obey the quantum process of superposition and entanglement. Decoherence of superposition state possibly give rise to consciousness and could prove via quantum entanglement with an external quantum system. Observer effect can be explained in terms of acquiring as more information (expressed by entropy) as possible about external physical system provides better precision with which participant or detector determines the particle's position in the double-slit system, which correlates with more particle-like behavior of the electromagnetic wave, or in other words, with lower uncertainty and interference.

The previous study performed by Dean Radin and coauthors postulated that attention had a significant influence on interference [4–6]. We examined the consciousness interactions with five parameters of the external physical system in a relaxed attention state, concentrated state of attention during a long period and concentrated state of attention during a short period in the cognitive evoked potential registration procedure.

Hypothesis testing

The experimental procedure was divided into the physical and physiological set-up.

Participants

Participants included in the experiment were 26 healthy adults. Participants in an informed consent form had to be signed by themselves to take part in the experiment.

Participants took part in three experimental groups: concentrated attention group, relaxed attention group and group for evaluating cognitive evoked potential effect on the double-slit system, which was divided into three subgroups according to time point at which data was recorded: 100 ms (E100), 300 ms (E300) and 1000 ms (E1000).

Measurements

Groups were formed according to measurements in the physical part of the system and were divided into control and experimental groups. Results from the control group were obtained by recording the 1170 double-slit diffraction pattern per session over 45 s during all 10 studies (sessions) without any participant presents in the experimental environment. The experiment with a concentrated attention group was performed with 26 participants in the state of concentrated attention, which underwent every second recording of diffraction pattern during 10 sessions, each of 45 s duration. Participants were previously informed to concentrate their attention on the voice command. Relaxed attention group included participants in the state of close eyes and relaxed mental state under the same condition as previously was described for concentrated attention group. In the group with cognitive evoked potential p300 registration, 45 double-slit diffraction patterns were extracted only if they have met the condition that they are associated with meaningful sound stimulus presentation to the participant, in each of 10 sessions for each subgroup (E100, E300 and E1000). Participants were instructed to focus their attention as quickly as possible inside the time range of one second when a meaningful stimulus was presenting.

The physical set-up of the experiment

Physical part of experiment includes: Laser (Red Didactic Laser LD1, wavelength of 635 nm, power 1 mW), neutral density filter (Thorlabs absorptive NDF optical density 3, transmission 0.1%) and the second neutral density filter with optical density 2 (Thorlabs NDF density 2, transmission 1%), double-slit diaphragm (3B Scientific, slit width 100 µm and distance of 500 µm between the slits), optical rail (Thorlabs dovetail optical rail). The distance between the double-slit diaphragm and the camera was 25 cm. In order to get optimal results, the laser was held in the active state for 15 min before the start of the experiment, temperature and light were unchangeable. All electric devices except those involved in the experiment were not in the room with double-slit experimental devices [7,8]. The intensity of diffraction recorded by the camera was expressed on a scale from zero to one, while the diffraction envelope consisted of interference maxima and minima. Integration time in Thorlabs camera was set on the value of 100 ms, while all data were collected by using time-sequential scan (one scan per second) for control, concentrated and relaxed attention group in contrast to fast sequential recording (ten scans per second) performed in a group with a cognitive evoked potential acquisition. Participants were 2 m away from the optical system.

The physiological set-up of the experiment

The physiological set-up consisted of electrophysiological units Neuron-Spectrum-4/epm (29-channel multifunctional digital EEG system for neurophysiological study). Electrode montage respected 10–21 system with adequate EEG cap, and average electrode as a reference electrode for monopolar registration protocol [9,10]. During EEG registration high pass filter was set to 0.5 Hz, low pass filter to 35 Hz, notch filter was on, sensitivity was set up to 10 µV/mm, the sample rate was 500 Hz, electrode impedance was in range 4–10 kΩ. Elicitation of cognitive evoked potential p300 was achieved through an experimental oddball paradigm in which potential p300 was recorded during procedure with auditory stimulus presentation which included meaningful stimulus intensity of 100 dB, frequency of 1500 Hz, duration of 1000 ms and stimulus probability of 30% as well as participant exposure to nonmeaningful auditory stimulus frequency of 1000 Hz, intensity of 80 dB and duration of 1000 ms. The recording was made with a sample rate of 1000 Hz, a low pass filter was set up to 75 Hz, while a high pass filter was set up to 0.5 Hz, sweep speed was 50 ms, curve scale was 50 µV. Electroencephalogram recording was synchronized with recording in the physical part of the experiment.

Preprocessing data

Dependent variables

To achieve condition of variable independency, we were linearly detrended data prior to statistical analysis. Phase was unwrap to remove sudden jumps [4].

Distinguishability. Distinguishability (corpuscularity) was calculated as:

$$V^2 + P^2 \leq 1 \quad (1)$$

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (2)$$

V stands for visibility, P is corpuscularity and denote particle properties, I_{max} and I_{min} are maximum and minimum of the second-order interference fringe. This duality relation, first used by Englert-Greenberger-Yasin, is a quantitative formulation of Bohr's complementarity principle [11].

Entanglement. Degree of entanglement was calculated according to the next equation:

$$D = -\frac{1+V}{2}Log\frac{1+V}{2} - \frac{1-V}{2}Log\frac{1-V}{2}, \quad (3)$$

where D is the degree of entanglement between the photons in double-slit, as well as between the brain and photons according to our assumption, V is visibility.

Heisenberg uncertainty. Heisenberg uncertainty was calculated by multiplying the standard deviation of impulse and position of the first three peaks of interference in a double-slit diffraction pattern [12,13]. The equation for uncertainty:

$$\Delta P \times \Delta X \geqslant \frac{h}{4\pi}, \quad (4)$$

ΔP is impulse uncertainty, while ΔX represents the uncertainty of peak position.

Impulse uncertainty was calculated as:

$$\Delta P = \frac{h}{\lambda}\sin\Theta, \quad (5)$$

where h is Planck constant ($6.62 \times 10^{-34} JS$), λ is wavelength (635 nm), θ is angle of maximum interference fringe. Uncertainty was expressed as calculated value*ħ ($\hbar = 1.054 * 10^{-34}$ JS). It is of interest to emphasize that ħ is h/2π.

Interference. This variable represents the value of interference in a double-slit diffraction envelope, calculated after data was processed by using FFT (fast Fourier transformation) and logarithmic transformation. The position of the second peak on the frequency domain of the power spectrum density plot represents the magnitude of interference in decibels (dB).

A/B. A/B represents the ratio of the electric field intensity at the position of each of two slits of the double-slit diaphragm [4]. This ratio was calculated by fitting a basic equation for double-slit diffraction intensity with parameters used in our experimental study. Equation used for this calculation is:

$$I = A^2\left(\frac{asin\beta_1}{r_1\beta_1}\right)^2 + B^2\left(\frac{asin\beta_2}{r_1\beta_1}\right)^2 + 2AB\frac{a^2sin\beta_1 sin\beta_2}{r_1 r_2\beta_1\beta_2}\cos\frac{2\pi}{\lambda}(r_2 - r_1) + I_{DC}, \quad (6)$$

where $\beta_1 = \frac{\pi a x_1}{\lambda\sqrt{D^2 + x_1^2}}$, the same equation was used for β_2, $x_1 = x - \frac{1}{2}(a+d)$, $x_2 = x + \frac{1}{2}(a+d)$, x is the central maximum position, a is the slit width, d is distance between the slits, I_{DC} is background light intensity. Parameters used for fitting procedure in our study were (a = 100 µm, d = 500 µm, L = 25 cm, λ = 635 nm).

Independent variables

Independent variables measured in the study have used to quantify the state of human attention.

Correlation dimension 2, Lyapunov exponent, and Entropy. These parameters were calculated by using data recorded at FP1, FP2, F3, and F4 derivation during the first four seconds in concentrated and relaxed attention group, while in cognitive evoked potential registration group we used data recorded during first four meaningful stimuli. These variables in prosaic meaning represent nonlinear properties of the attention [14–16]. Correlation dimension 2 was calculated after the hyperdimensional sphere of adequate embedding dimension and radius was created, followed by calculation of the fraction data within that sphere for various value of the radius, and plot is made as log of this fraction of data versus the log of the radius. Correlation dimension 2 was then calculated as the slope of the cumulative curve and require flat plateau to be correctly calculated. Lyapunov exponent is a measure of the rate at which nearby trajectories in phase space diverge. Chaotic data have positive Lyapunov exponent. Entropy is a measure of the disorder of the system and represents sum of the positive Lyapunov exponents.

Software

All data in physical and physiological part of experiment were processed by using Chaos Data Analyzer (The Professional version 2.2 (c) 2012 by J.C.Sprott) academic software, Dataplore (v.2.2–2 (c)), Matlab (R2015b), Neuron-Spectrum EEG and EP Digital Neurophysiological System Software, Version 1.6.10.16 from 11.5.2017 (64-bit), Splicco software version 4.3.0.

Statistical analysis

Distribution was assessed by using the Shapiro-Wilk statistical test. Taking into account the fact that all variables are stochastically independent due to data preprocessing for further analysis, all variables in all cases was compared to the control group by using the Mann-Whitney U test. Z score obtained by this test (Z(v)) for each variable separately, was transformed in composite Z score (Z(c)) by using Z score for phase (Z(ph)) according to the next equation:

$$Z(c) = \frac{(Z(v) + Z(ph))}{\sqrt{2}} \quad (7)$$

Stouffer Z(s) score for a given variable during all sessions (N) was obtained by combining the composite Z score according to the next equation:

$$Z(s) = \sum_{i=1}^{N}\frac{Z(c)_i}{\sqrt{N}} \quad (8)$$

Finally, to decrease artificial effects on the measured variable, as well as false-positive results arising from the statistical oscillation in measured variables from trial to trial, Stouffer Z score was compared with circular block nonparametric bootstrap test results. This computations procedure which was performed involves sampling with replacement to construct randomly permuted artificial data vector for all groups in order to generate a samples of Z(v), Z(c) and finally Stouffer Z score with (µ) mean and (sd) standard deviation by using 1000 iteration during all 10 sessions [4,7]. This new score is expressed according to the next equation:

$$Z = \frac{Z_{(s)-\mu}}{sd} \quad (9)$$

For this Z score, we found the corresponding p value. Effect size (es) was calculated as Z/√N, where N is the number of studies (sessions). In order to evaluate the effects of conscious attention during the first few seconds, we compared time series of dependent variables from the control group with lagged time series of the same dependent variables from the experimental group, in other words, the time series were shifted by one before we made the above mentioned statistical comparisons. Physiological variables, expressed as mean ± standard deviation, were compared by using the Friedman test for repeated measures. Dependent variables values expressed as overall or total sessions mean ± standard deviation. Statistical significance was declared if p value was < 0.05. All data were analyzed by using IBM SPSS Statistics Version 23 and Matlab (R2015b) software.

Results

Results of the physiological part of the experiment

The results of measuring the dynamic properties of conscious processes have shown significant changes in deterministic chaos features.

Table 1
Parameters of deterministic chaos measured in a relaxed and concentrated attention group, as well as in evoked potential registration group, in four EEG derivations. Values expressed as mean ± standard deviation, while a, b and ns represent the existence of a difference between the relaxed attention group and other groups. [a]p < 0.05, [b]p < 0.01, [ns]nonsignificant.

Derivations	Groups	Parameters		
		CD2	Entropy	Lyapunov exponent
FP1	relaxed	2.68 ± 0.27	0.37 ± 0.05	0.29 ± 0.08
	concentrated	2.72 ± 0.11[a]	0.40 ± 0.05[a]	0.31 ± 0.07 [ns]
	evoked	2.66 ± 0.22 [ns]	0.39 ± 0.04 [ns]	0.29 ± 0.05 [ns]
FP2	relaxed	2.63 ± 0.16	0.36 ± 0.04	0.28 ± 0.07
	concentrated	2.78 ± 0.11[b]	0.42 ± 0.05[b]	0.31 ± 0.08 [ns]
	evoked	2.72 ± 0.17[a]	0.41 ± 0.06[b]	0.30 ± 0.07 [ns]
F3	relaxed	2.68 ± 0.09	0.38 ± 0.03	0.33 ± 0.05
	concentrated	2.74 ± 0.08[a]	0.40 ± 0.04 [ns]	0.34 ± 0.06 [ns]
	evoked	2.73 ± 0.14 [ns]	0.39 ± 0.03 [ns]	0.32 ± 0.04 [ns]
F4	relaxed	2.69 ± 0.09	0.37 ± 0.03	0.32 ± 0.04
	concentrated	2.78 ± 0.07[b]	0.43 ± 0.04[b]	0.35 ± 0.05[a]
	evoked	2.75 ± 0.12[a]	0.40 ± 0.04[b]	0.33 ± 0.05 [ns]

Correlation dimension 2 was significantly increased in concentrated compared to relaxed attention group in all derivations, while in evoked potential registration group correlation dimension 2 was significantly increased in FP2 and F4 derivations. Lyapunov exponent was significantly increased in concentrated compared to the relaxed attention group in F4 derivation, but Lyapunov exponent values were non-significantly changed in evoked potential registration group. Entropy was significantly increased in focused attention group in FP1, FP2 and F4 derivations, while in evoked potential registration group entropy was significantly increased in FP2 and F4 derivations, which is shown in Table 1.

Results of the physical part of the experiment

Table 2 showed the values of variables in control and experimental groups with corresponding p values, while Table 3 showed the Z score and effect size of the same dependent variables in experimental groups. Distinguishability (corpuscularity) increased from 0.293 ± 0.045 in control group to 0.308 ± 0.054 in concentrated attention group with p = 0.01 and es = −0.80. In the same manner, entanglement was increased significantly in the concentrated attention group (0.106 ± 0.025 vs. 0.116 ± 0.031, p < 0.01, es = −0.83). Uncertainty decreased significantly (p < 0.01, es = −0.96) as well as interference and A/B ratio (p < 0.01, es = −0.90) in concentrated attention group compare to control group. In relaxed attention group the increase of the distinguishability was not statistically significant (0.293 ± 0.045 vs. 0.301 ± 0.048, p = 0.08, es = −0.54) as was the case with entanglement (0.106 ± 0.025 vs. 0.111 ± 0.028, p = 0.06, es = −0.59). We noticed a slight but insignificant decreases of interference (21.96 ± 0.056 vs. 21.63 ± 0.218, p = 0.07, es = −0.57), while uncertainty increased significantly (1.165 ± 0.244 vs. 1.209 ± 0.263, p < 0.01, es = −0.93). A/B ratio was decreased compared to the control group without reaching any significance (0.893 ± 0.001 vs. 0.857 ± 0.013, p = 0.05, es = −0.61). In E100, E300 and E1000 subgroups distinguishability and entanglement increased significantly, while uncertainty, interference and A/B ratio was decreased significantly. In Fig. 1 have shown Z scores for five quantum related variables after data was lagged for the first 11 s in a concentrated attention group. In addition, Z scores of corpuscularity, entanglement, uncertainty, interference, and A/B ratio were the largest 3 s after the participants started to concentrate their attention, indicated that concentration is highest during this period.

Table 2
Variables measured in control vs. experimental groups. All values expressed as mean ± standard deviation, while a, b and c represent the existence of a difference between the control group and the measurements in experimental groups. [a]*P* < 0.05, [b]*P* < 0.01, [c]*P*: not significant.

Variables	Groups	Results
Corpuscularity	Control	0.293 ± 0.045
	Concentrated	0.308 ± 0.054[a]
	Relaxed	0.301 ± 0.048[c]
	E100	0.301 ± 0.044[a]
	E300	0.306 ± 0.049[b]
	E1000	0.315 ± 0.045[b]
Entanglement	Control	0.106 ± 0.025
	Concentrated	0.116 ± 0.031[b]
	Relaxed	0.111 ± 0.028[c]
	E100	0.112 ± 0.025[a]
	E300	0.114 ± 0.028[b]
	E1000	0.120 ± 0.026[b]
Uncertainty (*h)	Control	1.165 ± 0.244
	Concentrated	1.122 ± 0.267[b]
	Relaxed	1.209 ± 0.263[b]
	E100	1.143 ± 0.260[a]
	E300	1.133 ± 0.261[b]
	E1000	1.127 ± 0.259[b]
Interference (dB)	Control	21.96 ± 0.056
	Concentrated	20.51 ± 0.116[b]
	Relaxed	21.63 ± 0.218[c]
	E100	21.20 ± 0.443[a]
	E300	20.53 ± 0.393[b]
	E1000	20.53 ± 0.270[b]
A/B ratio	Control	0.893 ± 0.001
	Concentrated	0.831 ± 0.009[b]
	Relaxed	0.857 ± 0.013[c]
	E100	0.839 ± 0.018[a]
	E300	0.840 ± 0.018[a]
	E1000	0.837 ± 0.013[a]

Discussion

In our study we have shown that the presence of the subject in a state of high concentrated attention had an influence on wave-particle duality of the electromagnetic wave, attenuating visibility (wave properties) significantly and consequently increases corpuscularity, except for the relax group, in all groups compared to control. This fact means that the laser wave function collapsed in the interactive field of focused attention [17]. In a way that relates to statistics, corpuscularity derived from Greenberg Yasin relation (Eq. (1)) was insignificantly increased in relaxed attention group (p = 0.08, es = −0.54). Increases in particle properties concomitantly increase and “which way information” in double slit experiment according to Bohr's complementarity principle [18]. Entanglement for two-particle is given by the Schmidt decomposition. Quantum entanglement between photons as well as between subjects who took part in experiment and

Table 3
Z score and effect size of dependent variables in corresponding experimental groups.

Parameters	Statistics	Groups				
		Relaxed	Concentrated	E100	E300	E1000
Corpuscularity	z score	−1.73	−2.55	−2.09	−2.79	−3.09
	effect size	−0.54	−0.80	−0.66	−0.88	−0.97
Entanglement	z score	−1.87	−2.64	−2.03	−2.60	−2.99
	effect size	−0.59	−0.83	−0.64	−0.82	−0.94
Uncertainty	z score	−2.95	−3.05	−2.87	−2.49	−3.06
	effect size	−0.93	−0.96	−0.90	−0.78	−0.96
Interference	z score	−1.82	−2.84	−2.28	−2.71	−2.82
	effect size	−0.57	−0.90	−0.72	−0.86	−0.89
A/B ratio	z score	−1.95	−2.86	−1.97	−2.23	−2.37
	effect size	−0.61	−0.90	−0.62	−0.70	−0.75

electromagnetic wave arrives from ingenious Hardy analysis which showed that a two particles entangled state will have a maximum probability of (5√5-11)/2, or 9%, what could be expressed by using golden mean (ϕ) as ϕ^5 [19,20]. The degree of entanglement has a reversal relation to the visibility with a maximum value equal to Ln2 in case of zero visibility. In contrary to a relaxed attention group, in all other experimental groups, we have noticed a significant increase in the degree of quantum entanglement in chain consisted of participants and photons in the double-slit. These results emphasize the possibility that a state of high focalization of consciousness concomitantly is reflected in the physical system due to quantum entanglement. In particular, supposed decoherence of neuronal superposition in state of focused attention favored particle like behavior of photons, implicated quantum nature of consciousness. We supposed that the degree of entanglement revealed not only the connection between photons, already between the brain and the double-slit quantum system. In addition, we can conclude that photons are in a state of quantum coupling, while brain quantum system and photons which took part in double-slit diffraction are in a state of quantum entanglement. It is of particular interest to emphasize significantly reduced Heisenberg uncertainty principle in all groups, except for the relaxed attention group, implying reduced wave properties as well as increases of information about photon position. Interference is essential to formed maxima and minima under the diffraction envelope and can be expressed as:

$$I = I_0 cos^2\left(\frac{\pi d \sin\Theta}{\lambda}\right).$$

Interference values, which, except for relaxed attention group, were significantly decreased in all experimental groups, provide strong evidence about a consciousness-related reduction of wave properties of the laser light. We also found that electric field ratio for each of two slits, calculated by fitting Eq. (6) with parameters used in this study (a = 100 μm, d = 500 μm, L = 25 cm, ʎ = 635 nm), differ significantly in all experimental groups compare to control, except for the relaxed attention group where it didn't reach significance (p = 0.05, es = −0.61). The results of our study have shown that the described experiment concept can be used to detect changes in attention, for example, this can be used to precisely distinguish the state of relaxed attention from the state of focused attention. All variables, which are closely linked with consciousness-related quantum effects on the electromagnetic wave, have shown very steep decreases of Z score during the first 3 s in concentrated attention group, highlighting the fact that highest degree of attention is soon after participants received voice command to concentrate their attention. Parameters of deterministic chaos (entropy, correlation dimension 2 and Lyapunov exponent), which was used for EEG analysis, were calculated from data measured in four derivations. Entropy was increased significantly in concentrated compared to relaxed attention group in FP1 (0.37 ± 0.05 vs 0.40 ± 0.05, $p < 0.05$), FP2 (0.36 ± 0.04 vs 0.42 ± 0.05, $p < 0.01$) and F4 derivations (0.37 ± 0.03 vs 0.43 ± 0.04, $p < 0.01$), while nonsignificantly increment was measured in F3 derivation. In evoked potential registration group entropy was increased in all derivations, with significant difference in FP2 (0.37 ± 0.05 vs 0.41 ± 0.06, $p < 0.01$) and F4 derivations (0.37 ± 0.03 vs 0.40 ± 0.04, $p < 0.01$). Correlation dimension 2 was increased significantly in all derivations in concentrated vs relaxed attention group, while Lyapunov exponent was increased significantly in F4 derivation (0.32 ± 0.04 vs 0.35 ± 0.05, $p < 0.05$) and nonsignificantly in FP1, FP2, and F3 derivations, indicated increases of chaotic pattern of behavior sensitive to initial conditions in the state of highly concentrated attention. In evoked potential registration group correlation dimension 2 was increased significantly in FP2 and F4 derivations, as opposed to F3 derivation where it was nonsignificantly increased and FP1 derivation where it was nonsignificantly decreased. Lyapunov exponent was nonsignificantly increased in FP2, F3 and F4 derivations with exception of FP1 derivation where we noticed non-significant decrement in evoked potential registration group. We noticed the inverse relationship between the increased entropy of the EEG signal and the reduction of the uncertainty of the physical signal. In particular, the reduction of uncertainty and subsequent collapse of the wave function can be attributed to participants gaining maximal information about a double-slit experiment in the state of focused attention which corresponds to accentuated chaotic behavior of the EEG signal. In this sense then, if entropy increases, in the same manner, the average rate at which the information is produced by the observer (participant) will be larger, producing a reduction of uncertainty and more particle-like behavior of the electromagnetic wave. Of great interest is the fact that collapse of the wave function, concomitantly with significant increase in particle properties (corpuscularity: p = 0.03, es = −0.66; interference:

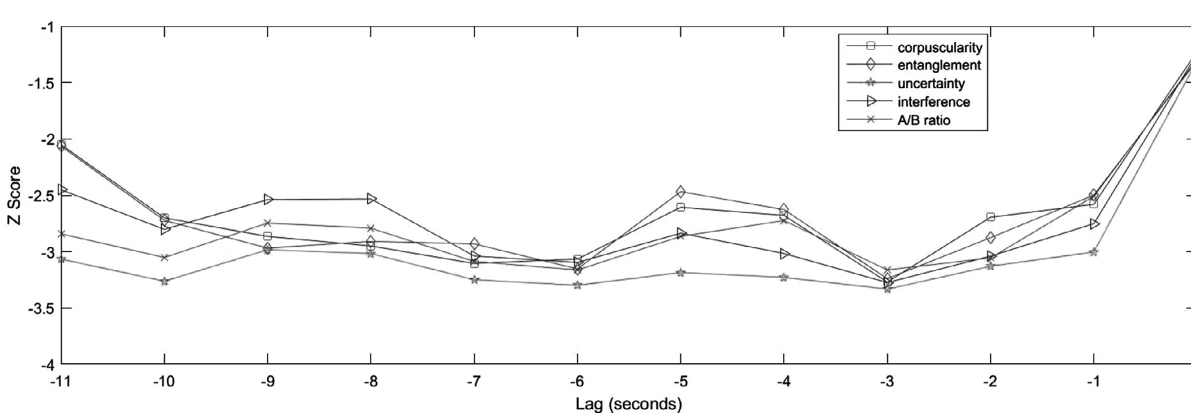

Fig. 1. Z score in the concentrated attention group calculated by using Eq. (9). Data was lagged for the period of the first 11 s after participants concentrated their attention.

$p = 0.02$, $es = -0.72$; A/B ratio: $p = 0.04$, $es = -0.62$;), occurred during the first 100 ms in evoked potential subgroup (E100), indicating possibility of backward time referral effect of cognitive potential p300 on measured variables, what is very similar to Libet's theory [21]. According to Libet's results, consciousness appears during the first 100 ms in comparison with the long latency of brain potentials. The important evidence is the brain potentials are necessary for consciousness to arise. This temporal misordering is crucial to claim that there is a possibility that cognitive p300 in our experiment showed a backward time referral effect during the first 100 ms through interaction with a neuronal quantum system. Taking into account the fact that physical and brain quantum systems were entangled, this effect should have an impact on double-slit diffraction, as our results concerning dependent variables in the E100 subgroup have shown.

Results published by professor Radin and coauthors in the study contributed by the 21 participants showed that the z score of interference magnitude and phase was largest ($z = -5.16$) with data lagged 3 s, as was the case in our experiment. Similarly, the same investigators observed the significant changes in Z score concerning the electric field ratio ($z = 4.38$) in concentration vs. relax condition, exactly what we observed in our study. The outstanding results obtained in the mentioned study proved for the first time the role of a conscious observer in the quantum double-slit experiment. A similar study which was performed by Guerrer included 127 participants [22]. The results of this study revealed a statistically significant difference between the measurements in intention versus the relax conditions ($p = 1.89 \times 10^{-10}$), supporting the existence of a not mapped form of interactions between participants and a physical system. With respect to the results of the previous experiments, we highlight the changes in absolute values of five variables calculated in our study with corresponding Z scores (corpuscularity, the magnitude of interference, quantum entanglement, Heisenberg uncertainty, and electric field ratio) which was shown in Tables 2 and 3. Concerning these values, our study showed an increase in the corpuscular properties of the electromagnetic wave after an observer took part in our experiment in a state of highly concentrated attention. Another novelty in our experiment compared to previous studies is the analysis of the quantum entanglement. The results obtained in our experiment clearly showed statistically significant quantum entanglement between the brain and the double-slit system, which is only possible if the brain is a quantum system. In addition, we found significant changes regarding the aforementioned variables, not only in task with a very long attention span (during 45 s), already in the task with cognitive evoked potential recording. Performing the procedure with cognitive evoked potential we wanted to show the changes in quantum variables over a very short period of time when consciousness arises, according to well established period of 300 ms (latency of p300 potential which is elicited in many consciousness processes) as well as 100 ms (according to Libet's theory). The peculiarity of our experiment is that we also included the entropy analysis of the EEG signal to show that observer effect, which collapses wave functions into the particle, is inevitably related to the amount of conscious information which is the same as measurement accuracy. In other words, by using the entropy, we have proved that the observer influence on the double-slit system can be due to the brain quantum system and not just a consequence of measurements performed by the physical detector, as it was previously thought. Our results regarding the quantum entanglement and entropy of the EEG signal can be the unknown form of interaction between the participants and the physical system in Guerrer's experiment beautifully denotes as Maxwell’s demon kind of interaction [22]. Very dedicated investigators of consciousness, such as Penrose and Hameroff, considered the quantum theory as the process through which the consciousness could arise, suggested a fine quantum process in microtubule as a source of consciousness [23].

Conclusion

Our experiment confirmed that attention affects electromagnetic wave causing wave function collapse. In other words, results of our study have shown that attention affects the manifestation of the particle-like behavior of electromagnetic waves. We tried to demonstrate this effect by using variables closely related to the wave-particle properties of the light. Heisenberg uncertainty principle, distinguishability, quantum entanglement, as well as interference and electric field ratio were significantly changed, with the exception of relaxed attention group, in all experimental groups compared to control group, implicated that attention or consciousness is a quantum process with possibility to be entangled with an electromagnetic wave. Quantum entanglement, confirmed by previously mentioned results in our study, also implicated the possibility that quantum superposition and collapse could be inside brain mechanisms that give rise to consciousness. We have concluded that if the entropy of the EEG signal and therefore, the amount of information and the accuracy of the measurement are greater, the wave properties of the electromagnetic wave are less.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2019.109382.

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