UNCONSCIOUS EMOTIONAL INFORMATION PROCESSING: THEORETICAL CONSEQUENCES AND PRACTICAL APPLICATIONS

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Abstract: The nature of unconscious human emotional information processing remains a great mystery. On the one hand, classical models view human conscious emotional information processing as computation among the brain's neurons but fail to address its enigmatic features. On the other hand, quantum processes (superposition of states, nonlocality, and entanglement) also remain mysterious, yet are being harnessed in revolutionary information technologies like quantum computation, quantum cryptography, and quantum teleportation. In this paper, a behavioral- and two neuroimaging studies will be discussed that suggest a special role for unconscious emotional information processing in human interaction with other objects. Since this is a new research field; we are only beginning to understand quantum information processing in the human brain (Hameroff, 2006; Van den Noort and Bosch, 2006). This research is important since it could have important theoretical consequences in the way we understand physics and information processing in the brain. Moreover, it could lead to new information technologies and applications. For instance, it might give new insights on human consumer behavior (Dijksterhuis, 2004; Dijksterhuis, Bos, Nordgren, and Van Baaren, 2006a; 2006b), and lead to new commercial strategies for multinationals.

1 QUANTUM INFORMATION THEORY

From the beginning of quantum mechanics, the concept of measurement and the possible role of consciousness in the solution to the measurement problem have been important topics (e.g. Wigner, 1962). Despite of these unsolved issues (Penrose, 2005), quantum theory has further developed. At the quantum level (e.g. atomic and subatomic scales), the laws of physics differ strangely from our everyday "classical" world (Van den Noort, Hugdahl, and Bosch, 2005b).

Quantum theory describes the bizarre properties of matter and energy at near-atomic scales. Quantum particles (1) can interconnect nonlocally and correlate instantaneously over distance (quantum entanglement, long-range dipole correlations), (2) can unify into single entities (quantum coherence, condensation), and furthermore (3) can behave as waves and exist in two or more states or locations simultaneously (quantum superposition). When superpositioned particles are measured or observed, they immediately reduce to single, definite states or locations, known as quantum state reduction or "collapse of the wave function." Superposition and quantum state reduction are used in quantum computers in which information (e.g. bits of 1 or 0) may be temporarily represented as quantum information (e.g. quantum bits, or qubits, of both 1 and 0), which reduces to classical information as output (Hameroff, 2006; Woolf and Hameroff, 2001).

According to some scientists, all quantum properties can be applied to the seemingly inexplicable features of consciousness. First, quantum coherence (e.g. Bose-Einstein condensation) is a possible physical basis for

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'binding' or unity of consciousness (Marshall, 1989). Second, non-local entanglements (e.g. 'Einstein-Podolsky-Rosen correlations') serve as a potential basis for associative memory and non-local emotional interpersonal connection. Third, quantum superposition of information provides a basis for preconscious and subconscious processes, dreams and altered states. Finally, the transition from preconscious processes to consciousness involves quantum state reduction/wave function collapse in the brain (Penrose, 1994; Stapp, 1993).

In the Orchestrated Objective Reduction (Orch OR) model, quantum computation occurs in microtubules within the brain's neurons. Microtubules are polymers of the protein tubulin which, in the Orch OR model, transiently exist in quantum superposition of two or more conformational states. Following periods of preconscious quantum computation (e.g. on the order of tens to hundreds of milliseconds) tubulin superpositions reduce or 'self-collapse' at an objective threshold due to a quantum gravity mechanism proposed by Penrose (1994). Microtubule-associated protein (MAP-2) connections provide input during classical phases. Each Orch OR quantum computation determines classical output states of tubulin, which govern neurophysiological events, such as initiating spikes at the axon hillock, regulating synaptic strengths, forming new MAP-2 attachment sites and gap-junction connections, and establishing starting conditions for the next conscious event (Hameroff, 1998; Hameroff and Penrose, 1996; Penrose and Hameroff, 1995).

However, most cognitive- and neuroscientists are skeptical and there is an interesting discussion going on between physicists and cognitive neuroscientists (Van den Noort and Bosch, 2006). How can presumably delicate quantum states operate macroscopically at warm brain temperatures (Tegmark, 2000)? How could the human brain process information in a non-linear way? This appears to be in huge contrast to our experiences in daily life, in which time is experienced as being completely linear (Van den Noort et al., 2005b)!

In this paper, data of a behavioral study and two neuroimaging studies on the processing of positive and negative emotional pictures will be presented that support the quantum information theory of unconscious human emotional information processing. Before discussing this more into detail, we would like to briefly discuss some of the main findings on human emotional information processing.

2 HUMAN EMOTIONAL INFORMATION PROCESSING

From cognitive neuroscience it is known that emotional stimuli are first processed via an automatically engaged neural mechanism, which occurs outside conscious awareness. This mechanism, which was proven in neuroimaging studies, operates in conjunction with a slower and more comprehensive process that allows a detailed evaluation of the potentially harmful stimulus (LeDoux, 1996). Event-related potential (ERP) data revealed a double dissociation for the conscious versus unconscious perception of negative stimuli. In the unconscious condition, responses to the perception of negative stimuli were enhanced relative to neutral for the N2 "excitatory" component (a negative potential at +/-200 milliseconds), which is thought to represent orienting and automatic aspects of information processing. By contrast, conscious perception of negative stimuli was associated with relatively enhanced responses for the late P3 "inhibitory" component (a positive potential at +/-300 milliseconds), implicated in the integration of emotional processes (Liddell, Williams, Rathjen, Shevrin, and Gordon, 2004). From recent functional Magnetic Resonance Imaging (fMRI) studies, it is known that unconscious processing of fear may occur via a direct rostral-ventral amygdala pathway; whereas elaboration of consciously attended signals of fear may rely on higher-order processing within a dorsal cortico-amygdala pathway (e.g. Williams et al., 2006).

Previous social cognition studies have shown that a great deal of human emotional information processing is rooted in unconscious processes (Bargh, Chaiken, Raymond, and Hymes, 1996; Van den Noort, 2003). During the last two decades, several behavioral studies were conducted in this field. These studies, for example, have shown that humans pick up the emotional content of facial expressions outside conscious awareness (e.g. Murphy and Zajonc, 1993; Niedenthal, 1990). Other studies have shown that humans evaluate objects (as for example "good" or "bad") at an unconscious level (e.g. Bargh, Chaiken, Govender, and Pratto, 1992; Bargh et al., 1996; Chen and Bargh, 1999). As a result, this has far reaching behavioral consequences since our unconscious evaluation, for instance, influences our consumer behavior (Van den Noort, 2003).

There are two main theories on where emotional information is processed in the brain (Hellige, 1993). The right hemisphere theory (Borod, Kent, Koff, Martin, and Alpert, 1988) posits that the right hemisphere is dominant over the left hemisphere for all emotional information.

The valence theory, on the other hand, states that hemispheric asymmetry for expression and perception of emotions depends on emotional valence; the right hemisphere is dominant for negative emotional information and the left hemisphere is dominant for positive emotional information (Lee, Loring, Dahl, and Meador, 1993).

In our behavioral study, the focus will be on how humans process positive and negative emotional pictures. According to the right hemisphere theory (Borod et al., 1988), all attitudes are processed better and faster in the right hemisphere. This would result in the hypothesis that all emotional pictures are processed better and faster when they are presented in the left visual field (and processed in the right hemisphere). Whereas according to the valence theory (Lee et al., 1993), the right hemisphere is dominant for negative attitudes and the left hemisphere is dominant for positive attitudes. In line with the valence theory, the hypothesis would be that the negative emotional pictures are processed better and faster when they are presented in the left visual field and the positive pictures are processed better and faster when they are presented in the right visual field. In addition, we are interested in the question if the results are the same at different presentation times (e.g. subliminal, supraliminal, and completely conscious)?

2.1 Behavioral Study

2.1.1 Participants

Thirty-five students from the University of Bergen (Norway) participated in this study following written informed consent according to institutional guidelines. There were 15 males and 20 females with an average age of 23 years and they were all native speakers of Norwegian. An honorarium was given for participation.

2.1.2 Experimental Design

A 3 (Presentation time: 10ms, 120ms, 1000ms) x 3 (Visual field: left, right, center) x 2 (Valence: positive vs. negative) x 2 (Response button: positive-left/negative-right vs. positive-right/negative-left), within subject design was used (with the last factor as a between subjects factor).

2.1.3 Procedure

All participants were instructed to sit calmly behind a computer screen. All participants were positioned at a distance of 60 cm from the computer screen (see Hellige and Yamauchi, 1999). A divided visual field technique (Barton, Goodglass, and Shai, 1965; Nicholls, Wood, and Hayes, 2001) was used and, as a result, the pictures were presented in the right- and left visual field and at the center of the screen. The emotional pictures were presented at different presentation times (10ms, 120ms, 1000ms). There were sixty emotional pictures (30 positive and 30 negative). The pictures were taken from the International Affective Picture System (Ito, Cacioppo, and Lang, 1998) and from the internet. There were no significant differences in size and brightness between the 30 positive and 30 negative pictures. The participants task was to evaluate the pictures as positive or negative by pressing the ‘positive’ and the ‘negative’ button as soon as possible and the location of the ‘positive’ and ‘negative’ button (left vs. right) was varied between participants. Both the responses and the reaction times were measured.

After the experiment, all participants were asked if they knew the goal of the experiment after which they received feedback about the experiment.

2.1.4 Results

A 3 (Presentation-time: 10ms, 120ms, 1000ms) x 3 (Visual field: left, right, center) x 2 (Valence: positive vs. negative) x 2 (Response button: positive-left/negative-right vs. positive-right/negative-left), within subject multivariate analysis of variance (MANOVA) was conducted (with the last factor as a between subjects factor).

As can be seen in Table 1, at a presentation time of 120ms, the negative emotional pictures were processed significantly better and faster when they were presented in the left visual field ($p < .05$) and the positive pictures were processed significantly better and faster when they were presented in the right visual field ($p < .05$). At the conscious- and at the subliminal level, the opposite pattern was found. At these presentation times, evidence in favor of the right hemisphere theory was found only for the positive pictures. The positive pictures that were presented in the left visual field were processed significantly better and faster than when they were presented in the right visual field.

Table 1: Mean reaction time for the positive and negative pictures; specified for visual field (left vs. right) and presentation time (1000ms, 120ms, 10ms).

	Duration	Left	Right
Positive	1000ms	614ad	686ae
Negative	1000ms	759ad	612ae
Positive	120ms	769bd	661ae
Negative	120ms	993bd	1040be
Positive	10ms	1154cd	1320ce
Negative	10ms	1374cd	1292ce

*Note: Means (across rows and colons) with different subscripts are significantly different ($p < .05$).

2.1.5 Discussion

In the behavioral study, at a presentation time of 120ms, evidence in favor of the valence theory (Lee et al., 1993) was found. The negative emotional pictures were processed significantly better and faster when they were presented in the left visual field and the positive pictures were processed significantly better and faster when they were presented in the right visual field. At the conscious- and at the subliminal level, evidence in favor of the right hemisphere theory (Borod et al., 1988) was found only for the positive pictures.

The conclusion can be drawn that unconscious emotional information processing happens all the time and could have direct behavioral consequences (Van den Noort, 2003). Until now, these unconscious processes remain a great mystery. Although we are beginning to understand some of the mechanisms behind unconscious emotional information processing, a lot remains unanswered. For example, do humans process emotional information at the unconscious level in exactly the same way as at the conscious level; and what are the implications for human object (e.g. computers, other humans etc.) interaction? Moreover, could unconscious emotional information processing perhaps be the missing link between quantum information theory and conscious human emotional information processing (Van den Noort et al., 2005b)? In order to illustrate the way in which humans process unconscious emotional stimuli in the brain, two neuroimaging studies (Bierman and Scholte, 2002; McCraty, Atkinson, and Bradley, 2004) will be discussed.

3 NEUROIMAGING STUDIES

3.1 ERP Study

3.1.1 Methodology

McCraty et al. (2004) conducted an ERP-study on unconscious emotional information processing. Twenty-six adult participants, 11 males, 15 females participated in the study. Each participant was fitted with an EEG electrode cap according to the International 10-20 system. An additional electrode for recording the electrooculogram (EOG) was placed above the right eye to monitor eye blinks and movement. Data editing was blind to stimulus category (calm or emotional targets). Data processing and statistical analysis used DADISP, MATLAB and SPSS.

3.1.2 Results

Results for the group as a whole showed a significant difference in ERPs in the prestimulus period for future calm versus emotional pictures at both FP1 (left frontopolar; $t_{sum} = -28.82$, $p < .05$) and FP2 (right frontopolar; $t_{sum} = -27.27$, $p < .05$) EEG sites. The ERPs for a future emotional stimulus were more negative, with the point of maximum negativity occurring slightly before that of the ERPs for the future calm pictures. In addition, there was a positive shift with a steep slope observed approximately 4 seconds before the emotional stimuli. In both locations, this positive shift in the emotional trial ERP occurred approximately a second before the shift occurred in the calm trial ERPs. There was a significant t_{sum} difference between the prestimulus ERPs for calm versus emotional trials at midline EEG site Pz ($t_{\mathrm{sum}} = -13.24$, $p < .05$). Because of the significant findings at FP1 and FP2, an additional RPA of the EOG channel was conducted, which revealed that eye movement artifacts did not contribute to this result (McCraty et al., 2004; Van den Noort, Bosch, and Hugdahl, 2005a).

3.2 fMRI Study

3.2.1 Methodology

Bierman and Scholte (2002) examined the neural substrates of unconscious emotional information processing with fMRI. In the experiment, a 1.5 Tesla Siemens system was used. Ten participants (6 male, 4 female) entered the study. The task instruction was given outside of the scanner. First, an MPRAGE high resolution scan that lasted for about 20 minutes was made of every participant. Then, a position localizer scan of about 2 minutes was conducted after which the experimental task of about 13 minutes was presented. The participants were instructed to relax while passively looking at the pictures that were randomly presented by a computer connected to a video projector onto a screen. The participants were able to watch the screen by looking at a mirror inside the scanner. They were requested to try to forget any emotional material right after exposure finished so that the next presentation would be influenced as little as possible by the previous one. The stimulus material consisted of a picture pool of 36 emotional (18 erotic, 18 violent) and 48 neutral stimuli (e.g. Ito et al., 1998; Laan, Everaerd, Bellen, and Hanewald, 1994). For each stimulus presentation, the stimulus condition was determined randomly with a priori chance of 2 neutral versus 1 emotional. Each stimulus sequence started with the 4.2 second presentation of a fixation point during which the anticipation was measured. After the exposure of the stimulus picture, which also lasted 4.2 seconds, there was a period of 8.4 seconds during which the participant was supposed to recover from the stimulus presentation. Data were analyzed using Brainvoyager. The main hypothesis of the study was, whether non-linear differences in BOLD signal could be found (Bierman and Scholte, 2002).

3.2.2 Results

The poststimulus results showed whole visual cortex activation, which could be expected because visual stimuli were used. Interestingly, all regions of interest resulting from the contrast analysis, showed a response for all stimuli (including the calm pictures). An exception to this was the subcortical region close to the amygdala. Only the emotional pictures showed a response there. The fact that erotic stimuli have impact on the BOLD signal from the amygdala is in line with results from Everitt (1990), who found dramatic change in sexual behavior after lesion of the amygdala in rats. Moreover, the amygdala plays an important role in most brain-referenced theories of emotion (e.g. Cacioppo, Gardner, and Berntson, 1999; Davidson, Scherer, and Goldsmith, 2003; Gallagher and Chiba, 1996; LeDoux, 1996; Zajonc, 1998).

The analysis of the prestimulus phase showed larger anticipatory activation preceding emotional stimuli compared to neutral stimuli in the right amygdala and in the caudate nucleus. For the male participants, as can be seen in Figure 1, this appeared before the erotic stimuli while for the female participants both erotic and violent stimuli produced this prestimulus effect (Bierman and Scholte, 2002; Van den Noort, 2003; 2004b).

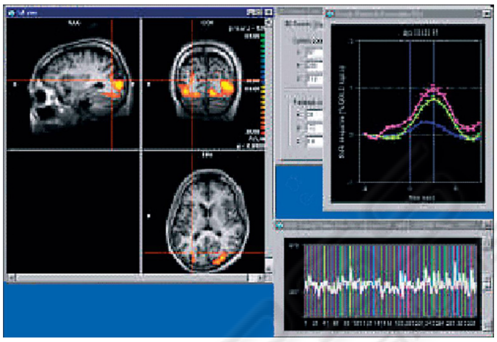

Figure 1: Results from an fMRI experiment. There is a significant difference in the prestimulus phase between highly emotional (pink curve) and neutral stimuli (blue curve) 4 seconds before stimulus presentation (Bierman and Scholte, 2002).

4 DISCUSSION

In this paper, data of a behavioral study and two neuroimaging studies on the processing of positive and negative emotional pictures was presented that support the quantum information theory of unconscious human emotional information processing. Evidence for unconscious non-linear human information processing was found, however, more research on this topic is needed; particularly on the direct human computer emotional interaction (Van den Noort, 2004c).

So far, we do know from studies with random generators, for example, that non-linear information-processing is possible up to longer time distances (Van den Noort, 2004a). In these studies, evidence for consciousness-related anomalies in random physical systems was found (Radin and Nelson, 1987). Before, during, and after powerful engaging events, the measurement system was affected. This was, for instance, the case before, during, and after the September 11 attacks. Significant trends in the data were found that could normally not be expected in the data produced by random generators. This research field might have important future applications. When it is combined with the existing technology, it could lead to a better prediction of coming major events like terrorist attacks and earthquakes (Van den Noort, 2003).

However, one should be critical with these data since alternative explanations, like methodological problems with the random generators, cannot be completely excluded (Van den Noort, 2004a). In addition, it is unknown whether non-linear information processing as observed in random generator data is the same mechanism underlying biological organisms. Therefore, more (brain) research in the direct human computer emotional interaction is needed.

Finally, research on human unconscious information processing could give important new insights on human consumer behavior (Dijksterhuis, 2004; Dijksterhuis et al., 2006a; 2006b); and as a result may lead to new commercial strategies on how multinationals could further improve their sales. An influential study on unconscious information processing and human consumer behavior was recently published by Dijksterhuis et al. (2006a). In four studies on consumer choice, both in the laboratory as well as among actual shoppers, they found that purchases of complex products were viewed more favorably when decisions had been made in the absence of attentive deliberation. Contrary to conventional wisdom and previous studies on consumer behavior (e.g. Bettman, Luce, and Payne, 1998; Kahneman, 2003), it is not always advantageous to engage in thorough conscious deliberation before choosing.

In future research, it would be interesting to replicate the ERP study in the MRI scanner. Combined recording could give us more direct information on the exact time-window and location of the brain activation (Eichele et al., 2005).

Moreover, it would be interesting to test the existence of non-linear information processing by using other experimental paradigms like the gambling paradigm (Bechara, Damasio, Damasio, and Anderson, 1994; Bechara, Damasio, Tranel, and Damasio, 1997). In this paradigm, skin conductance is measured just before participants take a winning or losing card from one of four randomized decks of cards. These decks are designed in such a manner that they are advantageous in the long run. This paradigm can be used to examine if participants' physiology reflects learned, unconscious knowledge about the decks before the participants are consciously aware that the decks are biased (Bechara and Damasio, 2002; Bechara, Dolan, and Hindes, 2002).

It is obvious, that if the neuroimaging results could be repeated with other methodological paradigms as well; this would highly support the hypothesis of non-linear information processing in the human brain. Therefore, it is important to exclude all methodological issues that could otherwise explain this phenomenon. With respect to this, replication studies with other methodological paradigms will be necessary.

5 CONCLUSIONS

The results that were presented in this paper might surprise scientists, who have a more conservative view on quantum physics and cognitive neuroscience. In the conventional approach, it has been generally accepted that the brain can be modelled, according to the principles of classical physics, as a neural network (e.g. Hopfield, 1982; 1994; Khanna, 1990). However, physical effects in the functioning of the nervous system that lie outside the realm of classical physics suggest that these models are over simplified (Hagan, Hameroff, and Tuszyński, 2000).

It is obvious that we are only beginning to understand quantum information processing in the human brain and more research is definitely needed (Penrose, 2005; Van den Noort and Bosch, 2006). This new research field is important since it could have important theoretical and practical implications:

1) First of all, it could have important theoretical consequences in the way we understand physics and information processing in the brain (Hameroff, 1998; 2006). Perhaps it is time to redefine nature and describe it not in particles, molecules, waves etc., but as a very large *information processor*, of which human beings are only a small part (Van den Noort et al., 2005b)?

2) Moreover, this research field could give new explanations on how the brain may give rise to conscious experience (Greenfield, 1995; 2000).

3) Finally, it could lead to important new information technologies and applications that could have a huge impact on our future daily life (Greenfield, 2003; 2006).

To conclude, unconscious (emotional) information processing plays an important role in human functioning (e.g. Chartrand, Van Baaren, and Bargh, 2006; Chen and Bargh, 1999; Dijksterhuis and Nordgren, 2006). This research field is particularly important since it will give important new insights in the way that humans interact with other objects (e.g. computers, other humans etc.). Moreover, it could create direct applications as well, for instance, it could lead to new and better commercial strategies for multinationals.

"No doubt there is only one world, the true nature of which we do not even glimpse at present."
– Roger Penrose

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