Understanding the Unconscious Brain: Evidence for Non-Linear Information Processing

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Abstract

Neuroimaging techniques have made breakthroughs in the field of conscious emotional processing possible. However, people process most emotional information at an unconscious level and this influences our daily life (Van den Noort, 2003). These unconscious processes still remain a great mystery. What are the limits of unconscious information processing? Neuroimaging- and skin conductance studies will be discussed to answer this question.

Keywords: unconscious; emotions; information processing; non-linear; consciousness.

Unconscious Information Processing

Emotions are the very center of human mental life. Emotions are those processes, which "establish, maintain, change, or terminate the relation between the person and the environment on matters of significance to the person" (Campos et al., 1994).

In the late seventies, the cognitive approach to emotion was more or less the only approach. This started to change with the publication of the paper *"Feeling and Thinking: Preferences Need No Inferences"* by Robert Zajonc (1980). He argued, on the basis of logic and clever experiments, that emotion can exist before and without cognition.

Much of contemporary psychology has come to recognize that a great deal of human emotional functioning is rooted in unconscious processes. During the last two decades, a lot of studies were conducted in this field. These studies, for example, showed that humans pick up the emotional content of facial expressions outside conscious awareness and intent to influence perceptions of the target individual (Baldwin, Carrell & Lopez, 1990; Murphy & Zajonc, 1993; Niedenthal, 1990; Niedenthal & Cantor, 1986). Other studies showed that humans evaluate objects (as for example "good" or "bad") at an unconscious level (Bargh et al., 1992; Bargh et al., 1996).

In the famous experiment by Chen and Bargh (1999) half of the participants were instructed to push a lever away from them if the presented stimulus word was evaluated as positive (incongruent). They were also instructed to pull the lever toward them if the stimulus word was negatively evaluated (incongruent). The other half of the participants received the opposite instructions. As can be seen in the first row of Table 1, people were significantly faster to respond to positive words when they were pulling the lever (congruent) than pushing the lever (incongruent), and faster to respond to negative words when they were pushing (congruent) rather than pulling the lever (incongruent).

In a second experiment, the conscious goal to evaluate the stimuli was removed, half the participants had to push and half had to pull the lever as quickly as possible when the word appeared, in a straight reaction-time task. As can be seen in the second row of Table 1, those pushing the lever were faster for negative (congruent) than for positive stimuli (incongruent), and those pulling the lever were faster for positive (congruent) than for negative (incongruent) stimuli, even though in the second experiment no evaluation was asked.

Table 1: Mean reaction time by congruency.

Congruent	Incongruent
1683a	1950b
679a	688b

Current theories of emotion suggest that stimuli are first processed via an automatically engaged neural mechanism, which occurs outside conscious awareness. This mechanism operates in conjunction with a slower and more comprehensive process that allows a detailed evaluation of the potentially harmful stimulus (LeDoux, 1996; Liddell et al., 2004).

The conclusion can be drawn that unconscious emotional processing happens all the time and has direct behavioral consequences. Until now, these unconscious processes remain a great mystery. What are the limits of unconscious information processing? (Van den Noort, 2004a)

Non-Linear Information Processing

To answer this question, data will be presented from several skin conductance- and neuroimaging (fMRI and ERP) studies.

Skin conductance studies

Skin conductance is a frequently used measurement technique in research on emotions. Skin conductance is an electrical measurement of the minute amounts of sweat being produced by the skin. It indicates changes in the autonomic nervous system, which in turn indicate emotional changes (Oatley & Jenkins, 1996).

In psychophysiological research on emotions, "emotional" or "calm" stimuli are presented to participants while psychophysiological measures are continuously monitored. The calm pictures include, for example, pastoral scenes and neutral household objects, and the emotional pictures include, for example, erotic and violent scenes (Radin, 1997). The dependent variable in all these studies is the post-stimulus response.

Interestingly, Radin (1997) found that the baseline level of skin conductance preceding highly emotional stimuli was higher than the baseline level preceding calm stimuli. He used a computer to randomly select and present target photos from a pool of digitized photographs. In this experiment, as discussed before, the calm pictures included pastoral scenes and neutral household objects, and the emotional pictures included erotic and violent scenes. In these prestimulus studies, the presentation of emotional and neutral stimuli was randomized with replacement so that each trial was completely independent of the previous ones. Four different experiments were conducted in which 31 participants were involved and 1060 target photos were presented. The results, as can be seen in Figure 1, showed an expecting orienting response after the target photo was displayed. Moreover, there was a significant prestimulus effect that peaked with a four standard error difference in physiological measures between extreme and calm targets, one second before the target photo was displayed.

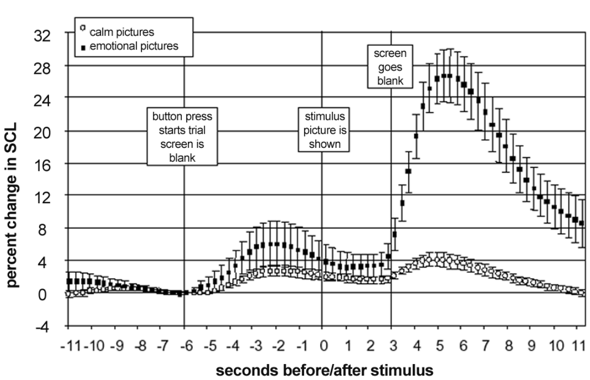

Figure 1: Results from a skin conductance experiment. The baseline level of skin conductance preceding highly emotional stimuli was significantly higher than the baseline level preceding calm stimuli (Radin 1997).

In replication studies, the same general results were found. Again, the baseline level of skin conductance preceding highly emotional stimuli was higher than the baseline level preceding calm stimuli (Van den Noort, 2003).

Interestingly, non-linear information processing was not only found in experiments by using visual material, but also in a study by using auditory stimuli. In this experiment, stimulus type was determined just before presentation by a true random generator. 125 participants heard 20 stimuli per session with a 50% chance of an auditory stimulus or a silent control. The dependent variable was the proportions of 3-second epochs prior to audio and control stimuli in which a skin conductance response, that is a minimum in skin conductance followed by a maximum, occurred. A significant effect was found (N = 125, Z-score (Z) = 3.27), effect size (ES) = 0.09 +/- 0.03, $p < .006$) (Van den Noort, 2004b).

FMRI study

Bierman and Scholte examined the neural substrates of anticipation in conjunction with fMRI (Bierman & Scholte, 2002; Van den Noort, 2003). A comparison of erotic and violent material in the earlier studies suggested that there might be different time courses for these different types of emotions.

In the experiment, a 1.5 Tesla Siemens system was used. Ten participants (6 male, 4 female) entered the study. Each participant first got an MPRAGE high resolution scan which lasted for about 20 minutes. The task instruction was given outside of the scanner. 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 scan. 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. The neutral and violent stimuli were taken from the International Affective Picture System (Ito, Cacioppo & Lang, 1998) while the erotic material was taken from a previous study on sexuality by Laan (Laan et al., 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 a prestimulus difference in BOLD signal could be found (Van den Noort, 2003).

The poststimulus results showed whole visual cortex activation, which could be expected because visual stimuli were used. Interestingly, all the 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. Both erotic and violent 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 (Cacioppo, Gardner & Berntson, 1999; Damasio, 1994; Davidson, Scherer & Goldsmith, 2003; Gallagher & Chiba, 1996; Gray & McNaughton, 1996; LeDoux, 1996; Zajonc, 1998).

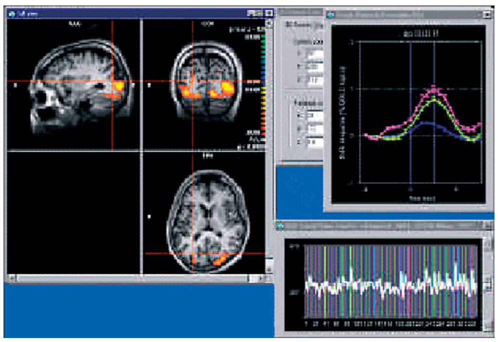

Figure 2: Results from an fMRI experiment. There is a significant difference in the prestimulus phase between highly emotional (pink curve) and neutral stimuli (blue curve) 4 seconds before stimulus presentation.

The analysis of the prestimulus phase showed a significant prestimulus effect that was widely distributed over many brain regions, including hippocampus, pallidus, amygdala, and caudate nucleus. Most brain regions did not show striking differences in anticipation before emotional and neutral stimuli. However, larger anticipatory activation preceding emotional stimuli compared to neutral stimuli was found in the right amygdala and in the caudate nucleus. For the male participants, as can be seen in Figure 2, this appeared before the erotic stimuli while for the female both erotic and violent stimuli produced this prestimulus effect (Van den Noort, 2003).

ERP study

The same experimental set-up as in the skin conductance and in the fMRI-studies was used for the ERP study (McCraty et al., 2004). 26 adult participants, 11 males, 15 females, participated in the experiment. 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. 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 (Van den Noort, 2004b).

Discussion

In this paper, data was presented that suggest the existence of non-linear human information processing, however, more research on this topic is needed.

In future research it would be interesting to replicate the ERP study in the fMRI scanner. Combined recording could give us more direct information on the exact time-window and location of the brain activation. In addition, the same experimental set-up can be used in an experiment with simultaneous fMRI and skin conductance recording (Williams et al., 2000; Williams et al., 2001). The great advantage of simultaneous fMRI and skin conductance recording, is that it could give us more insights in the exact interplay between brain activation and skin conductance response.

Moreover, it would be interesting to test the existence of non-linear information processing by using other experimental paradigms like the gambling paradigm (Bechara et al., 1994; Bechara et al., 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. The goal of the study is to examine if participants' physiology, reflects learned, unconscious knowledge about the decks before the participants are consciously aware that the decks are biased (Bechara & Damasio, 2002; Bechara, Dolan & Hindes, 2002).

It is obvious, that if the skin conductance- and neuroimaging results can 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 perhaps explain this phenomenon. With respect to this, replication studies with other methodological paradigms can be very helpful.

General Discussion

Given the effect of non-linear information processing, the question arises as to what functions it serves. A possible consequence of non-linear information is to predispose the individual's behavior toward positive objects and away from negative ones when the conscious mind is otherwise occupied (Van den Noort, 2004c). In other words, it might be an old evolutionary mechanism that humans share with other species. Humans slowly ascended from lower life forms to what we are today (Darwin, 1871). Therefore, if unconscious non-linear information processing is an old evolutionary mechanism, then other species should have this same mechanism.

So far, little scientific research on animal non-linear information processing has been done. At the elementary level of biologic organization, cellular structures appear to have immediate knowledge of remote actions in the system, thereby enabling the emergence of spontaneous long-range cooperative organization in bio-molecules and membranes (Hameroff, 1987), in dendritic networks of cortical neurons (Shepherd et al., 1985), and in colonies of single-celled organisms such as bacteria (BenJacob et al., 2000). At the level of multicellular organisms, a prestimulus response has been experimentally demonstrated in earthworms (Wildey, 2001). However, more scientific research on higher levels of life is definitely needed (Van den Noort, 2004b). These future studies on animals can perhaps explain the observations that were done directly after the large Asia earthquake last year? According to Wildlife officials in Sri Lanka, thousands of people perished in the quake and tidal wave catastrophe, but strange enough, almost no dead animals were found on the island nation (Bedi, 2004).

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