Emotion Induction through Virtual Avatars and its Impact on Reasoning: Evidence from Autonomous Nervous System Measurements and Cognitive Assessment

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Summary

Many studies have shown the impact of emotion on cognition (Damasio 1995; Phelps 2004), however these influences remain ambiguous. The contradictions may be explained by a lack of experimental control but also by the existence of complex cross-influences between the dorsolateral prefrontal cortex, a major substratum of the executive functions (EFs) and the ventromedial prefrontal cortex, an area strongly connected to the limbic system (Simpson 2001a).

This work aims at gaining a more precise view of the links between emotion and EFs thanks to an experimental protocol that uses Virtual Reality (avatars) for a controlled emotional conditioning, measurements of the autonomous nervous system (ANS) as evidence of the emotional variations and a neuropsychological test battery for the detection of EFs variations, especially reasoning. The battery's major tasks consist in deductive reasoning and reasoning in dynamic situations.

The experimental data show that positive conditioning leads to a performance decrease (in agreement with Phillips et al. (2002a)), together with physiological variations (cardiac and pupillary activity). Moreover negative conditioning leads to ineffective actions: more actions (Dynamic task), more quickly (Deductive task) with no performance variation. These results may have applications in neuropsychology, for the assessment and the rehabilitation of patients (Mateer et al. 2005) and in neuroergonomics in the field of complex working situations where emotions may cause accidents (e.g. potential source of air crashes, Dehais et al. 2003).

Keywords: *Neuroergonomics, Neuropsychology, Emotional Avatars, Executive Functions, Autonomous Nervous System Measurement*

Introduction

The field of cognitive neurosciences has massively neglected emotions during the second half of the 20th century, until the rediscovery of the Gage's case (Damasio et al. 1994). Since, many studies have shown the impact of the emotion on cognition, for example memorizing (Phelps 2004) or logical reasoning (Blanchette and Richards 2003; Houdé et al. 2000).

Paul Ekman (1984) has established a list of six primary emotions: anger, disgust, fear, joy, sorrow and surprise. More recent researches tend to consider emotion through three major components: the subjective experience, physiological responses and behavioural expressions (Scherer 2000), and two dimensions: valence and activation. While the dimension of valence refers to the qualitative aspect of emotion, the dimension of activation concerns its intensity. Valence and activation received a significant number of experimental validations, in particular through works highlighting their associations with various physiological indicators (Bradley et al. 1996; Lane et al. 1997). The cerebral structures that are currently identified as being involved in emotional processes represent, beyond the limbic system (Maclean 1952), a vast cortico-subcortical loop (in particular prefrontal). Lesions in this system generate emotional disorders. For example, lesions in the amygdala can impair both the acquisition and the expression of fear (Ledoux and Muller 1997; Adolphs 2003) and lesions in the orbitofrontal cortex lead to a desinhibition pattern including unacceptable social behaviour, compulsive gambling, excessive alcohol etc. (Bechara et al. 1997). Such symptoms are also found in patients with bilateral lesions of the ventromedial prefrontal cortex (VMPC), in spite of an otherwise largely preserved intellectual ability.

Three physiological parameters are classically recorded as emotional markers: the Skin Conductance Response (SCR), the cardiac activity and the pupillometry.

The SCR represents electrical variations linked with the eccrine sweat glands activity that reflects the excitation of the ANS. The amplitude of the SCR is considered to be insensitive to the emotional valence (Codispoti et.al. 2001; Greenwald et al. 1989). In fact, the SCR variations may reflect the emotional activation as well as a particular attention processing. Moreover, the SCR is influenced by various factors such as temperature or food.

Cardiac measurements may reflect emotion since the heart is innerved by the two branches of the ANS (Venables 1991) that perform a complex regulation. The heart rate depends on the relative influences of these two branches. It does not have a linear behaviour regarding to the emotional activation and it is influenced by the emotional valence (Lang et al. 2000). The systolic pressure is defined as the peak pressure in the arteries during the cardiac cycle; the diastolic pressure is the lowest pressure (at the resting phase of the cardiac cycle). These pressures change in response to stress or emotion. Sinha and co-workers (1992), show that the systolic pressure and the heart rate increase during fear and anger. However, other studies demonstrate that the blood pressure can increase in both presence of positive and negative stimuli (Cacioppo et al. 1993; Warner and Strowman 1994).

Pupillometry also reflects the activity of the two branches of the ANS and thus gives clues on the emotional state or the mental workload (Hytintk et al. 1995). Links between pupillary diameter and emotional status are not yet clearly established. Pupil size may vary on a continuum according to emotional valence: an extreme dilatation for pleasant stimuli and an extreme contraction for aversive stimuli (Hess 1972). They may also reflect the emotional activation, the diameter evolving linearily according to the activation (Janisse 1974). More recently, Partal and co-workers (2000) showed that the pupillary diameter was significantly larger during and after negative stimuli than after positive ones.

While VMPC lesions cause emotional impairement, lesions of the dorsolateral prefrontal cortex (DLPC) are associated with EFs disorders. EFs refer to the processes that underlie flexible goal-directed behaviour, e.g. dominant responses inhibiting, goal creating and maintaining, action sequencing, decision-making (Burgess et al. 1998). EFs were initially inspired by the central executive in the working memory model (Baddeley 1986) and were introduced in neuropsychology by the notion of “dysexecutive syndrome”. The concept of “frontal lobe functions” a long time synonymous of EFs is today unjustified (Baddeley et al. 1997; Mayes and Daum 1997), since patients with non prefrontal lesions may have a dysexecutive syndrome (Godefroy et al. 1992; Kramer et al. 2002) and neuroimaging studies in healthy subjects have shown, for example, that the cingular cortex is involved, in addition to the dorsolateral prefrontal area, in the shifting task (Kondo et al. 2004).

After Damasio’s seminal studies (Damasio et al. 1994, Damasio 2001) showing the influence of emotion on decision-making and putting forward the somatic markers hypothesis, many other researches have suggested the existence of reciprocal influences between emotion and cognition. However, the nature of these links remains ambiguous: positive emotion can play a facilitating or a disturbing role (Philips et al. 2002a) and negative emotion may improve (Van Strien et al. 1995) or degrade (Hogan 2003) cognitive processes. These contradictions may have three main explanations. Firstly, the nature of the conditioning is not totally controlled in terms of valence and activation. Secondly, no real evidence of an emotional state variation, for example through ANS measurement, is provided (Turnbull et al. 2005). Thirdly, the nature of the cross-influences between the DLPC, a major substratum of the executive functions, and the VMPC, belonging to the “emotional cerebral system”, is very complex (Simpson 2001b) and may explain apparently contradictory emotional effects on cognition (Simpson 2001a).

Our goal is to disentangle the relationships between emotion and EFs in a first step, by tackling the experimental methodological problems, which are the emotional conditioning control and the verification of the effectiveness of the emotional stimulation, and in a second step, by getting a better insight of the links between the two prefrontal subsystems. The work presented hereafter is a contribution to the first step and aims at assessing, during a well controlled experimental protocol, the effect of emotion on EFs.

The three components of the experimental protocol are the emotional conditioning through virtual avatars, the measurement of the ANS activity through cardiac activity and pupil size measurements, and a test battery for executive functions, focusing on reasoning. Virtual reality allows flexibility and precision in emotional stimulation. Facial expressions of the virtual avatars can be controlled thanks to numerical values, and allow quantifying both the valence and the intensity of the emotional stimuli. In a similar way, oral expression (prosody, intensity…) can be parameterized. Although SCR is widely used in studies on emotion, its insensivity to the valence of emotion and its dependency on non emotional, non controllable parameters constitute major drawbacks that prevent its use our experiment. The test battery addresses two aspects of reasoning: logical reasoning, which is the core of high-level cognition, and reasoning in dynamic situations, which has proven to involve massively executive functions (Camus 2003).

Our work is based on three hypothesis: 1)Virtual avatars constitute really emotional stimuli, and this can be ascertained through ANS (pupillometric and cardiac) measurements; 2) There is an influence of emotion on EFs, i.e. the administration of the emotional avatars should modify the behavioural performance and the reaction times at the test battery; 3) The impact of the avatars on the cognitive performance is due more to an emotional effect than to attentional interferences. This assumption is tested thanks to the administration of emotionally neutral avatars.

Methods

Participants

Healthy subjects (n = 12) were recruited by local advertisement. Inclusion criteria were: young (18-30 years old), male, native French speakers, right-handed, under or postgraduates. We excluded subjects with sensorial deficits, history of mental retardation, neurological/psychiatric disorders, emotional disorders or any substances capable of affecting central nervous system. All subjects received complete information on the study's goal and experimental conditions and signed an informed consent. Subjects were split in two groups: 6 subjects received emotional conditioning during the deductive task, and the other 6 during the dynamic one.

Executive Function Tests Battery

To reach our goals, we have selected 3 neuropsychological tasks: a dynamic reasoning task involving in particular planning and working memory abilities, a task involving deductive reasoning and a task aiming at checking the homogeneity, in terms of visuomotor abilities, of the 2 experimental groups.

The dynamic reasoning task (EARTH © INSERM, Pastor 2000) assesses reasoning under temporal pressure and involves several other EFs: planning abilities, working memory, decision-making, self-monitoring.... The objective is to control a network of tanks and pipes (figure 1) where water flows by gravity, according to the laws of hydraulics. The capacities of the top and bottom tanks are equal to the total amount of water running in the network. At the beginning of the task, all tanks, except the top one, are empty. The instruction is "to fill the bottom tank as quick as possible by acting on on/off valves and avoid as much as possible overflowing the intermediate tanks". The performance measures were the percentage of water loss, the task total duration and 5 strategy variables: the number of actions on valves and 4 variables measuring risk taking at the aperture and closure of valves.

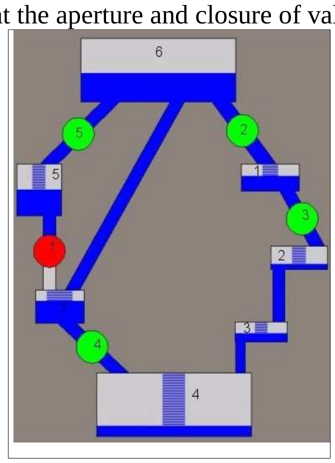

Figure 1: the dynamic task

The deductive reasoning task is inspired form Natsopoulos and co-workers (1997). Current research underlines the fact that normal adults do not spontaneously apply the principles of logic (Evans 2003), but that learning under positive emotional conditioning can improve deduction (Houdé et al. 2000). The goal of the task is to solve syllogisms by choosing, among three suggested solutions, the one that allows concluding logically. Syllogisms (figure 2) are based on a logical argument in which one proposition (the conclusion) is inferred from a rule and another proposition (the premise). We used the four existing forms of syllogisms: "modus ponendo ponens", "modus tollendo tollens", "fallacies of the affirming the consequent" and "fallacies of denying the antecedent". The syllogisms' sentences varied in terms of length and semantics. The purpose was to avoid contextual effects which could help or perturb the deduction and thus, to force a purely logical reasoning. Each participant had to solve 24 randomly displayed syllogisms. The measurements were the percentage of correct answers and the mean reaction times for correct and incorrect answers.

- If Gao Xingjian has written "The storm", then Gao Xingjian is not a good writer.
- Gao Xingjian has not written "The storm"
1) I cannot say anything on his writing abilities
2) Gao Xingjian is not a good writer
3) Gao Xingjian is a good writer

Figure 2: a syllogism example

The target-hitting task assesses visual attention and psychomotor skills. The subject had to click as quickly as possible on a target that appeared successively at random positions on the screen. The measurement was a velocity index. Emotion conditioning was not administered during the task that was only intended to check visuomotor homogeneity of our groups.

Emotional avatars

Participants were emotionally conditioned with three different valences of emotions (positive, negative and neutral) by avatars developed with Poser 6.0 (© Curious Labs). Avatars' brightness (moderate in order not to bias the pupil size measurements) and sex (male, for a weakened interaction with the participants' emotional status (Ku et al. 2005)) were controlled. Avatars expressed their emotion with facial expressions (figure 3) and speech prosody. Their comments were always semantically neutral. The different emotional types were positive (joy), negative (anger) and neutral. Each commentary, although semantically neutral, had interpretations in the 3 emotional valences. In order to be the most realistic possible, facial expressions, gestures, comments and labial movements of the avatars were copied on a non-professional actor, who previously played the scenes. Preliminary tests allowed us to select the avatars for which emotions were correctly recognised by at least 95% of the subjects.

During the dynamic task, the avatars appeared at critical moments at the periphery of the screen. During the deductive task, avatars were displayed in full screen between two stimuli. The avatars were presented four times with the same valence of emotion during a same task to maintain a homogeneous emotional state. Although the avatars' comments had no link with the subjects' performance, the facial expressions and the prosody of the speech were strong enough to make the subject think that the avatars were judging his performance. The administration of the emotional valences was counterbalanced among the subjects and among the tasks to avoid order effects.

Figure 3: illustration of 2 different emotions: joy and anger

Procedure

All the participants carried out two different blocks of tasks (figure 4). In the first block (in white), each subject performed the three tasks (dynamic task, deductive task and target hitting task), with no emotional conditioning. In the second block (in grey), each group carried out a task, which is performed three times according to the 3 available emotions: for the first group of subjects this "tested task" is the dynamic one, for the second group of subjects this is the deductive one. For example, subject 1, who belonged to the group conditioned during the deductive task, performed this task without emotion (control task), then the target hitting task and finally the dynamic task (white bloc). Finally, the subject carries out three times the deductive task with positive, negative and neutral conditioning (in grey). To cope with learning effect, all the tasks are counterbalanced and the control task (deductive or dynamic task according to the group) is always at the same distance of the tested task, separated by the two others tasks.

The total test battery performing lasted approximately one hour. The experimentation took place in a calm office within the Centre for Clinical Investigation (Toulouse, France). Each subject specified his age, laterality and confirmed the absence of medication or other disorders, and then the neuropsychological tests battery described below was administered.

S1	*S2*	*S3*	*S4*	*S5*	*S6*
De	De	De	De	De	De
T	T	T	Dy	Dy	Dy
Dy	Dy	Dy	T	T	T
De +	De +	De -	De -	De 0	De 0
De -	De 0	De 0	De +	De -	De +
De 0	De -	De +	De 0	De +	De -
S7	*S8*	*S9*	*S10*	*S11*	*S12*
Dy	Dy	Dy	Dy	Dy	Dy
T	T	T	De	De	De
De	De	De	T	T	T
Dy +	Dy +	Dy -	Dy -	Dy 0	Dy 0
Dy -	Dy 0	Dy 0	Dy +	Dy -	Dy +
Dy 0	Dy -	Dy +	Dy 0	Dy +	Dy -

Figure 4: experimental design
Si = subject number i, De = deductive task, Dy = dynamic task, T = target-hitting task. +, -, 0 are respectively positive, negative and neutral emotional valences

The different tasks were performed on a Sony Vaio PCG-GRT816M notebook. Subjects used the mouse or the Cedrus (Model RB-730) response pad to accomplish the task.

ANS measurements

The subject was comfortably installed during 4 or 5 minutes so that the physiological parameters came back to a rest state. Indeed, hospital environment and experimental situation may create a stress that bias ANS measurements. A headphone was placed on the ears of the subjects for a better isolation from disturbing noises. Moreover, the headphone transmitted the auditory modality (commentaries of the avatars). Cardiac and pupillometric measurements were started at the launching time of the first task.

Concretely, pupillometric measurements were collected thanks to the iView X RED eyetracker (SensoMotoric Instruments, Teltow, Germany). The main interest of this type of oculometer (remote camera) is that it is non-invasive, which allows a more ecological situation.

The cardiac parameters were recorded with a Finapres sensor plugged to an electrocardiogram (Ohmeda 2300). The Finapress is a non-invasive continuous blood pressure monitor, based on the vascular unloading technique. The Finapress sensor was placed on the middle finger of the left hand and recorded the heart rate and the blood pressure. All physiological measurements were synchronized with the tasks thanks to triggers.

In practice, establishing mean physiological values for a group of subjects for an entire task is meaningless because of inter-individual variability. We use Delta values (difference between working and resting states) for measuring the ANS.

Statistics

Non-parametric statistical tests were used: paired comparison analyses were performed with Friedman Anova and Wilcoxon tests, unpaired comparison analyses were performed with the Mann-Whitney U test.

Behavioural results

Target-hitting and control tasks

The velocity index in the target-hitting task, the performance and the strategy variables of the control dynamic task as well as the performance and reaction times in the control deductive task showed no difference between the "deductive task" group and the "dynamic task" group.

Attentional vs. emotional effects

The results showed no effect, whether in the dynamic task or in the deductive task, of the presentation of neutral avatars on the task performance compared to the performance in the control task (no avatar presentation). The effects described hereafter cannot therefore be due to an increased involvement of attention due to the avatars' sudden comments.

Dynamic task, emotional effects

We found significant differences concerning the number of actions (openings and closings) on valves (figure 5), between the three emotional conditions (Friedman $p = 0.03$). In particular, there were more actions on valves during the negative condition than during the positive one (Wilcoxon $p = 0.02$).

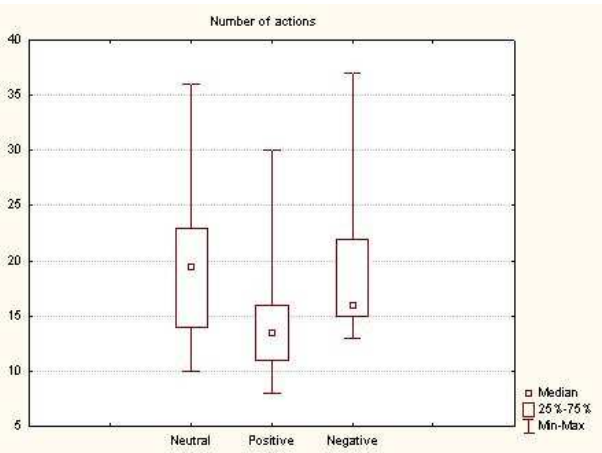

Figure 5: number of actions during dynamic task according to emotional valences

Deductive task, emotional effects

The incorrect response times differed (figure 6) between the 4 conditions, the 3 emotional conditioning, plus the control task (Friedman $p = 0.05$).

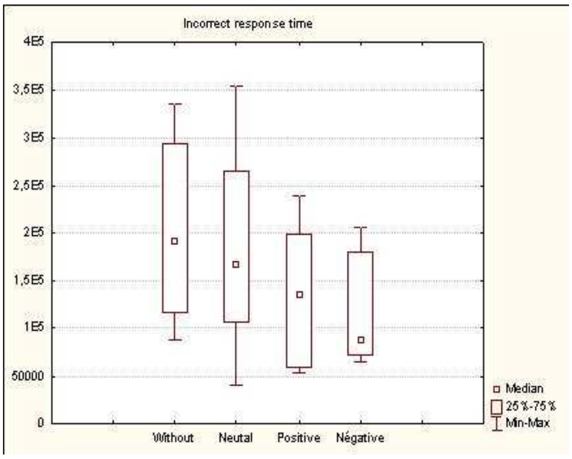

Figure 6: response time in the deductive task according to emotional conditions

More precisely, results showed a reduction of incorrect response times during the negative condition compared to the one without emotion (Wilcoxon $p = 0.04$).

Additionally, the percentage of correct answers tend to be different (figure 7) among the different emotional conditions (near threshold: Friedman $p = 0.06$). A significant degradation of the appropriate answers in positive emotional condition appeared, when compared to the other ones (Wilcoxon: $p = 0.04$ for neutral and $p = 0.06$ for negative emotion).

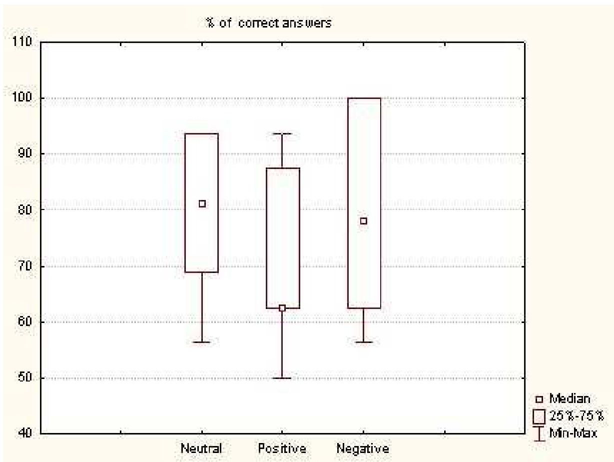

Figure 7: percentage of correct answers in the deductive task according to the emotional conditions

ANS results

Attentional vs. emotional effects

The results showed no effect, whether in the dynamic task or in the deductive task, of the presentation of neutral avatars on the ANS parameters during the task performance compared to the baseline values. The effects described hereafter cannot therefore be due to an increased involvement of attention due to the avatars' sudden comments.

Dynamic task, emotional effects

The results showed no effect of the avatar presentation on the different cardiac parameters or the pupil diameter during the task performance.

Deductive task, emotional effects

The mean Delta systolic pressure differed (figure 8) globally among the 3 emotional conditions (Friedman p = 0.01). Precisely, there was a trend of the Delta systolic pressure to be higher during the positive condition than during the negative one (Wilcoxon p = 0.06).

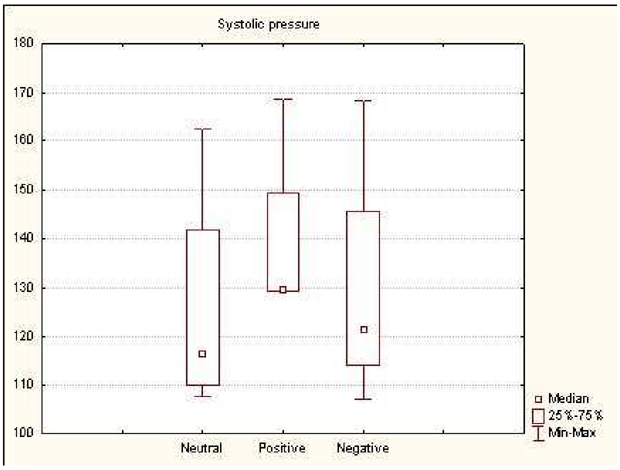

Figure 8: delta systolic pressure in the deductive task according to emotional conditions

The Delta pupillary diameter did not vary (figure 9) significantly among the 3 emotional valences, although there was a trend of the Delta diameter to be larger in the positive condition than in the negative one (Wilcoxon p = 0.07).

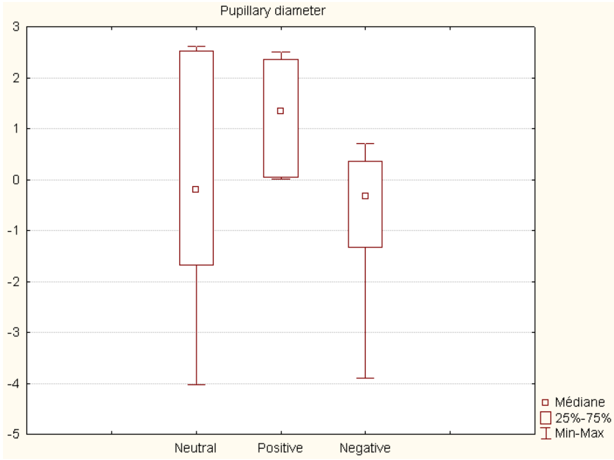

Figure 9: delta pupillary diameter among the 3 emotions during the deductive task

Inside the positive condition, the mean pupillary diameter (figure 10) increased globally during the avatar presentation in comparison to the rest state (Friedman p < 0.01). This increase was produced by the display of the two first avatars (Wilcoxon p = 0.02 in both cases). The mean pupillary diameter came back progressively to the baseline value with the presentation of the two other avatars, during the second part of the task.

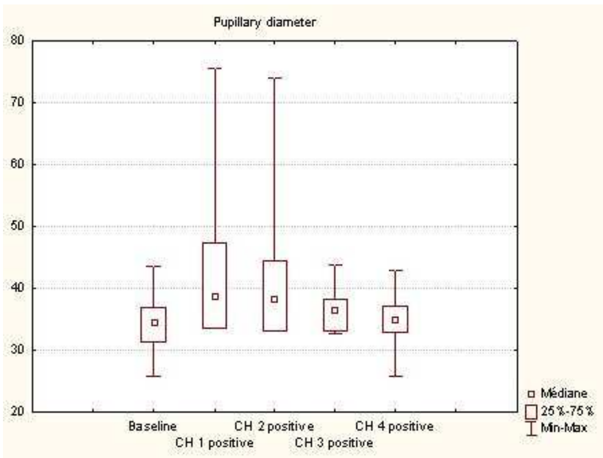

Figure 10: mean pupillary diameter evolution during the baseline and among the 4 avatars in deductive task

Discussion

Subjects' basic characteristics

The target-hitting task showed that the two groups of subjects had similar visuomotor abilities. Moreover, no group effect existed concerning executive functions since the performances were similar in the two groups for the dynamic and deductive tasks.

Hypotheses

Our first hypothesis said that the administration of the avatars should provoke changes in the ANS states, especially pupillometric and cardiac variations proving emotional effects of the stimulation. The results partially corresponded to our hypothesis, since this was only the case during the deductive task.

Our second hypothesis stipulated that administration of avatars should lead to qualitative and quantitative modifications of the performance in the tasks involving EFs. Our results showed under every emotional condition, the effect of emotions during both dynamic and deductive tasks. For the deductive task, negative emotion created a decrease of the response times of correct and incorrect answers and positive emotion depleted the percentage of good answers. For the dynamic task, the subjects modified their strategies: the number of actions on the valves was higher during the negative condition.

According to our third hypothesis, the impact of the avatars is only emotional, and not simply due to attentional interferences. The analysis showed that the presentation of the emotionally neutral avatars did not generate behavioural or physiological variations. Thus, no attentional bias could explain variations observed during positive and negative emotions.

Deductive reasoning abilities

The average school level was particularly high, with scientific background that could possibly influence the performance in deductive reasoning. According to Braine (1990), there is a universal human logic or "natural logic" defined as a set of very simple automated inference rules that are considered universal and independent of the education level. Nevertheless, education influences a secondary level of reasoning that requires complex analytical reasoning abilities. Thus, we expected that the subjects' scientific background that could have biased the results in the deductive task, (requiring the secondary level of reasoning). In fact, the percentage of "irrational" behaviour remained quite important, with approximately an average of 25% of erroneous answers during the control condition (without emotion). These results, in agreement with the literature confirmed the lack of natural competence of humans in pure logical reasoning. Moreover, it is interesting to note that the subjects of the deductive task group did not improve their percentages of good answers in spite of the fact that they perform 4 times the deductive task.

Emotional effects on behaviour

The dynamic task group were not affected by the emotions concerning global performances such as total task duration or loss of water, but were rather affected in their strategies. The negative emotion generated a significant increase of number of actions on valves (openings and closings). The apparition of the angry character had probably led the subjects to be anxious, and to adopt a "microscopic management" of the flow. Planning abilities seem therefore less effective under the reprimand. These results are in agreements with Hogan (2003) who observes a fall of the performances in a divided attention task under the influence of an important level of anxiety.

Concerning the effects of the emotions on the performances in the deductive task, we observed a reduction of correct and incorrect response times during the negative condition but without any improvement of good answers. These results are interpretable as a useless increase of risk taking. Indeed, this is in agreement with a study by Bechara and co-workers (2000), where VMPC patients, in spite of a good comprehension of the task, selected "risky cards", leading them to an important final loss. The participants under a negative emotion behave like VMPC patients, myopic to the consequences of their risked behaviours, answering as quickly as possible.

Another interesting result concerns the percentage of good answers: the analysis showed a lower rate of good answers during the positive emotional conditioning. These data are in agreements with Phillips (2002b) who reports a fall of the performances, during positive emotion, in the "Tower of London" task.

The old Yerkes-Dodson law (1908) probably holds an important truth: it is essential to consider the activation or valence of the emotion according to the nature of the cognitive activity. This theory indicates that high-level cognitive tasks require moderate emotional arousal to reach the best performances. On the contrary, more automated tasks, requiring only energy and motivation, should be better performed during a strong emotion. This theory is compatible with studies of Simpson (2001a,b) and is in agreement with the systemic description of the cross-modulation between the DLPC and the VMPC.

Emotional effects on cardiac activity

In agreement with Prkachin (1999), the effects mainly occurred on the systolic blood pressure. The deductive task under positive emotional conditioning showed a higher mean systolic blood pressure compared to the other conditions. These cardiac variations are compatible with behavioural results. Indeed, lower results, in terms of percentages of correct answers were obtained for the deductive task during the positive emotional conditioning.

We were not able to find ANS modifications during the dynamic task. The dissociation between performances (strategies modifications) and measurements of the ANS (no variations) for the dynamic task may be explained by the following hypotheses. Firstly, the dynamic task generated a high stress: the mean systolic blood pressure monitored for the dynamic control task was 134.8 mmHg whereas it was of 124.6 mmHg during the deductive control task. This increase of systolic pressure due to the sole effect of the task had probably masked the emotional effects of the avatars. In addition, the strong involving of EFs due to this task could have decreased the emotional effect of the avatars, a kind of inverted effect of the DLPC on the VMPC. The mood behaviour model (Gendolla and Krüsken 2001), which states that hard tasks are less affected by emotion, is compatible with this hypothesis. Secondly, another possible explanation refers to the increase of the number of actions during the negative emotion that can be considered as a mean to cope with stress, thus reducing ANS modifications (Gianakos 2000). Finally, whereas avatars were presented in full screen during the deductive task, they appeared in small at the periphery of the screen during the dynamic task. This choice has been taken not to generate visual interferences (not to hide the water level in the tanks) or operational (not to hide the valves). It is probable that the selected size is insufficient for the facial expressions to be clearly perceived. The emotional effect on strategies is probably explained by the sole auditory modality.

Emotional effects on pupillometrics

There is no significant difference among the emotional conditions by considering Delta values. However, positive emotional stimulations within the deductive task were associated with an increase of the mean pupillary diameter, in particular during the first avatar and the second avatar. After that, pupillary diameter came back to its baseline state, as if an emotional habituation to avatars occurred. The increase of pupillary diameter during the two first avatars is coherent with the fall of performances during the positive emotional condition in the deductive task. Hess (1972) suggested that large dilations occur during pleasant emotional stimuli and Janisse (1974) during stimuli with high level of activation, independently of their valences. The fact that we observed larger dilations during positive conditions could be in favour of the Hess' hypothesis as well as in favour of the Janisse's one. The positive emotion could have a stronger effect on the pupil's diameter than the negative condition, but the intrinsic activation of the positive condition could have been highest.

Emotional profiles

In Damasio experiments, the failures observed during the IGT are correlated with weaker RED reactions, and are interpreted as an unavailability of the somatic markers. Some weaker RED activities were found also in healthy subjects. Thus, it is probable that we are not all equal from the point of view of our sensitivity or our emotional regulation abilities. It would have been probably very interesting to take into account the emotional profiles of our subjects thanks to questionnaires.

Conclusion

The results showed the links between emotion and cognition under specific conditions. We observed that effects of emotional stimuli on cognitive performances occurred in parallel with modifications of physiological indicators, thus attesting the efficiency of virtual avatars to induce emotional states. In addition, these variations were not only attentional artefacts because "neutral" avatars did not generate behavioural or ANS modifications. However, we did not find a substantial effect during all emotional conditions: behavioural and ANS variations mainly appeared during the positive condition. Moreover, behavioural modifications mainly consisted in strategy changes, such as the reduction of the response times for the deductive task or the increase of the number of actions in the dynamic task. Modifications of global performances appeared during the deductive task, with a fall of correct answers in positive emotional condition. The small size of our groups may have limited some results to tendencies and the several repetitions of avatars during the experiment and the fact that verbal contents remain constant may have induced a habituation effect.

According to Ku and co-workers (2005), the virtual avatars are very efficient in the reproduction of the facial expressions but their ability to transmit and provoke an emotional state may remain limited. However, this technique provides a very flexible and precise manipulation of emotion with a high fine-tuning of valence and intensity of facial expressions, gesture and prosody. Solutions should be found very soon to increase the avatars effect on mood states, by improving the "sense of presence" in virtual reality, (Lee 2004).

Analysing the effects of emotion on cognition may lead to applications in Neuropsychology. For example, it could help the assessment and the rehabilitation of patients (Mateer et al. 2005) suffering neurological pathologies where the emotional impairment and the dysexecutive syndrome are closely entangled, such as during the early stages of the Alzheimer's disease. Emotion effects is also interesting for Neuroergonomics and Human Machine Interaction (HMI) in the field of complex working situations where emotion may causes accident (e.g. potential source of air crashes, Dehais et al. 2003). In this context, emotionally and cognitively relevant HMI may provide promising solutions.

Acknowledgements

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