Effects of Emotionally Charged Content Over Behavioral and Physiological Responses During Memory Encoding, Consolidation and Recognition

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ABSTRACT

The influence of arousal and the valence of audiovisual emotional stimuli over physiological measures during memory encoding, early consolidation and recall was investigated. An audiovisual test of emotional memory was applied to twenty-nine volunteers during the first session. A subsequent recognition task was applied during the second session ten days later. Physiological measures were registered continuously during both sessions. Emotional material induced higher levels of arousal, surprise, sadness and fear. Higher pulse frequency and higher skin conductance level were found during emotional scores evaluation stage compared to encoding phase for both emotional and neutral version of the test. Higher pulse frequency was found during the emotional score evaluation stage in the group exposed to the emotional content. Recall of emotional content produced higher pulse frequency and skin conductance level compared to neutral content recall. These results show that early consolidation and recall of emotional information are accompanied by dissimilar physiological responses that participate in the memory enhancement phenomenon.
KEY WORDS: autonomic nervous system; emotional memory; physiologic responses.

RESUMO

Neste trabalho investigamos a influência do nível de alertamento e a valência de estímulos emocionais audiovisuais sobre parâmetros fisiológicos durante a codificação, consolidação inicial e a evocação da memória. O teste audiovisual de memória emocional foi aplicado a vinte e nove voluntários durante uma primeira sessão e dez dias depois foi feito um teste de reconhecimento. Medidas fisiológicas foram registradas de forma contínua durante as duas sessões. O material emocional produziu níveis mais

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altos de alertamento, surpresa, tristeza e medo. Foram encontrados maiores níveis de freqüência de pulso e condutância da pele durante a avaliação do valor emocional em comparação à fase de codificação em ambas as versões – neutra e emocional – do teste. No grupo exposto ao conteúdo emocional foi encontrada uma maior freqüência de pulso durante a avaliação do valor emocional. A evocação do conteúdo emocional produziu maiores níveis de freqüência de pulso e condutância da pele em comparação à evocação do conteúdo neutro. Estes resultados mostram que a consolidação inicial e a evocação de informação emocional são acompanhadas de diferentes respostas fisiológicas que participam no fenômeno de facilitação da memória.

PALAVRAS-CHAVE: Sistema nervoso autônomo; memória emocional; respostas fisiológicas.

INTRODUCTION

Evidence from laboratory studies, as well as everyday common experience demonstrate the enhancing effect of emotion over memory, showing that memories associated with emotional stimuli are more resistant to decay over time than memories for comparable non-arousing stimuli[1-7].

Audiovisual remembering tasks are widely used and are considered an useful method to measure declarative memory by both recognition and recall[1,2,6]. It is also an ideal material due to the facility to manipulate some contents of interest (e.g. auditory emotional content) while keeping controlled some others characteristics (e.g. visual emotional content)

Both arousal and valence dimensions of the emotional stimuli have shown to influence the memory enhancing effect[8,9] and to modulate physiological patterns of activation[10,11]. Concerning valence properties, some studies have shown that different neural substrates are involved in memory processes for different valence categories[12-14], and that memory enhancing effect differs between valences[3,7,15]. Differences between genders in the neural substrates of emotional memory processing have also been evident[16-19]. However, only a few systematic studies have been conducted to elucidate interactions between gender and arousal or valences properties of the emotional stimuli.

Emotion is associated with physiological states elicited by the autonomic nervous system. These changes in the physiological activity allow subjects to deal better with situations presented in the environment. Psychophysiological studies demonstrated that emotionally charged stimuli elicit patterns of autonomic responses especially related to an augmented sympathetic nervous system activity[10,11]. Moreover, the physiological activity elicited by emotional stimuli is associated with a better memory for this stimuli[9,20,21] supporting the idea that these physiological responses are not only an epiphenomenon but rather a critical process in the emotion enhancing effect on memory[10].

According to Cahill[20], memory enhancement for emotionally arousing information is dependent of β-adrenergic activation during the encoding phase and the pharmacological blockade of this system impairs the memory enhancement effect of the emotional content while keeping the subjective emotional experience unaffected. Additionally, it has been found that this potentiation is dependent on central and peripheral β-adrenergic activity[10, 21-24], and it could be also mediated by stress hormones[25-28], demonstrating that encoding, consolidation and recall processes are modulated by autonomic activity and stress hormones.

Following this line of research, the aim of the present study was to investigate the effect of emotional arousal and valence on the memory enhancement phenomenon and their physiological manifestations during encoding, early consolidation and memory recall phases. A secondary objective was to evaluate the influence of gender on behavioral and physiological measures.

SUBJECTS AND METHODS

Experimental protocol was approved by the Institutional Ethical Committee of the Universidad Industrial de Santander, Bucaramanga, Colombia. Twenty nine healthy volunteers (14 males, 15 females, mean age: 20.93±0.99 years) recruited by announcement ads in the *campi* of two different universities (Universidad Industrial de Santander and Universidad Pontificia Bolivariana, Bucaramanga, Colombia) were included. Subjects with history of psychiatric or neurological illness, visual or acoustic impair, concurrent use of medication or substance abuse, were excluded. Written informed consent was obtained from all participants. They did not receive money or other incentive for their participation. Subjects were naïve about the aims of the study; however, after completing the protocol, researchers explained to them the real objectives of this work.

The procedure is schematically represented in Figure 1. A series of 11 slides accompanied by a narration were used as stimuli. It consists in the same material used by Cahill & McGaugh[1] and Frank & Tomaz[2]. A Spanish language version, validated for the Colombian population[6] was used. Slides 3, 7 and 8 were the same used by Cahill & McGaugh[1] in the original version. Slides 1, 2, 4, 5, 6, 9, 10 and 11 were new pictures. Characters and general quality of the pictures were kept as similar as possible to the originals. Each slide was presented for 10 seconds. Two different narrations could accompany these slides: Emotionally Neutral (Neutral) and Emotionally Arousing (Emotional), both of them narrated by the same person with an unemotional voice and with a similar grammatical construction in both versions. Narration starts with the slide presentation. Previous works with this test determined that narration could be divided into 3 phases; the second phase (slides 5-8) is the one where emotional content is presented to the emotional version group. A detailed description of each slide could be found in Frank & Tomaz[2].

Emotional score rating consisted in the subjective verbal quantification of the arousal level induced by the story. Subjects were asked to quantify the arousal level of either positive or negative emotions. This rating ranges from 0 (non arousal) to 10 (extremely arousal). A similar procedure was used for each of the basic emotions defined by Ekman[29]: Happiness, Sadness, Angry, Surprise, Disgust and Fear. The complete list of six items was read in a different random order for each participant. After a brief rest, physiological measures were stopped and the first session was finished (**Figure 1A**).

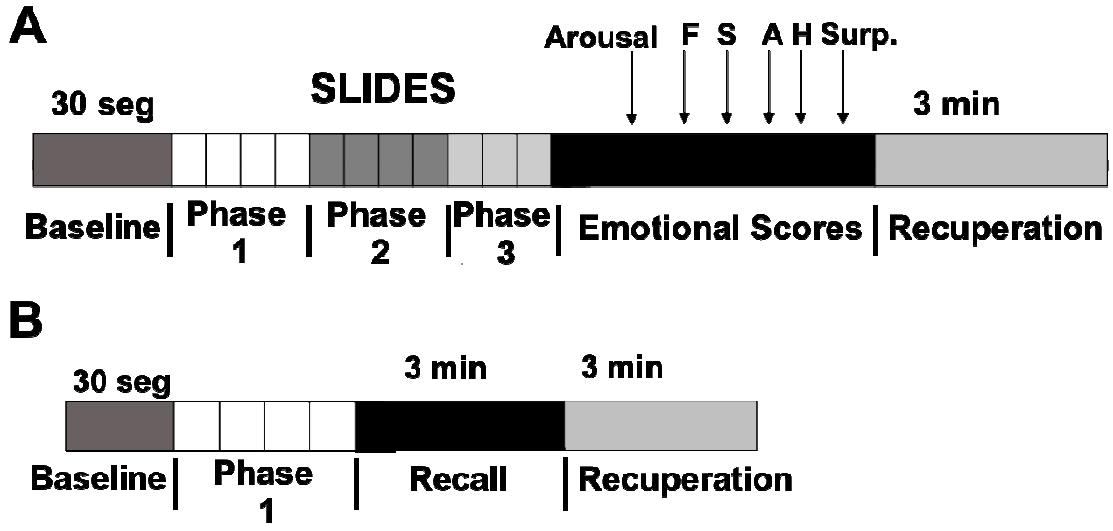

Figure 1. Schematic representation of the experimental procedure. Physiologic activity was continuously registered during both sessions. A: First session. B: Second session.

Ten days later, during the second session, the slides from Phase 1 were showed again to all subjects. After the slide projection, subjects were asked to recall in silence the continuation of the history they watched in the first session. After a brief rest, physiological recordings were finished and the recognition task was applied (**Figure 1B**). The questionnaire used to measure the recognition of information from the story was translated from the Portuguese version[2]. The instrument has a total of 64 questions with multiple choice options with 4 to 8 questions regarding either visual or verbal information from each slide. When participants declared that they did not recognize any option as the correct one, they were asked to point out the most likely answer.

Physiological measures of pulse frequency (PF), and skin conductance level (SCL) were done using a PhysioRecorder (Model 73000, Standard Type. Lafayette Instruments). Data from pulse were obtained by a pulse-oxymeter placed on the index finger of the non-dominant hand. Beat-to-beat latency was automatically transformed to instantaneous heart rate frequency. Skin conductance level was registered with two superficial auto-adherents Ag/AgCl electrodes (0.5 V, 0.79 cm^2) placed on thenar and hypothenar eminence of the non-dominant hand.

Slide presentation, narration and physiological measures were synchronized using Biofeedback 2000 software (Schuhfried, Mödling, Austria). Slides were projected to approximately 2 m from the subject and loudness for all narratives was kept similar.

RESULTS

The mean age of Neutral (N) and Emotional (E) groups was not different (N=21.83±2.18; E=20.36±0.48; Student t-test, p=0.483). Behavioral results were already published (see [30]). A brief summary is presented here.

As expected, E group showed a higher mean subjective score for Arousal ($p<0.001$), Surprise ($p=0.004$), Angry ($p=0,044$) Sadness ($p<0.001$) and Fear ($p=0.044$) when compared to N group.

The mean percentage of total correct answers in the recognition questionnaire was not different among subjects in either group versions of the story ($p=0.130$). No differences were found between groups when comparing the percentage of correct answers in Phase 1 (P1) and Phase 3 (P3). However, groups scores were statistically different ($p=0.050$) in Phase 2 (P2). Between-genders analyses demonstrated that females (F) achieved higher percentage of correct answers than males (M) for P1

(p=0.042) and P3 (p=0.030) and in Total (p=0.030).

For the first session, MANOVA showed no significant effects for Group and Sex or their interaction with the physiological measures, Fs(2, 22)<1.026, ps>0,374. There was a significant effect of Stage, F(10, 14)=14.458, p<0.001, and no significant effects of the Stage × Group, Stage × Sex, or Stage × Group × Sex interactions, Fs(10, 14)<1.186, ps>0,374. Univariate analyses for each physiological measure confirmed the previous results and found statistically significant differences due to Stage for PF, F(5, 115)=24.665, p<0.001, and SCL, F(5, 115)=19.777, p<0.001, (Figure 2 A & B). For PF, the multiple comparison procedure found significant differences between the emotional score rating stage (ES) and all the remaining first session's stages (ps<0.001). For SCL, differences were found when ES was compared to Baseline (BL), P1, P2 and P3 (ps<0.001), and when Recuperation (REC) was compared to BL, P2 and P3 (ps<0.01). MANOVA discarded a significant effect of the Stage × Group interaction over both dependent variables concomitantly. However, univariate analyses found a statistically significant effect of this interaction over PF, F(5, 115)=2.364, p=0.048). This effect was evidenced by a higher PF for E group compared to N group during ES stage (p=0.050) (**Figure 2 A**). Such effect was not found for SCL, F(5, 115)=0.621, p=0.578). There was also no significant effect of the Stage × Sex interaction in the univariate analyses, Fs(5, 115)<1.835, ps>0.111.

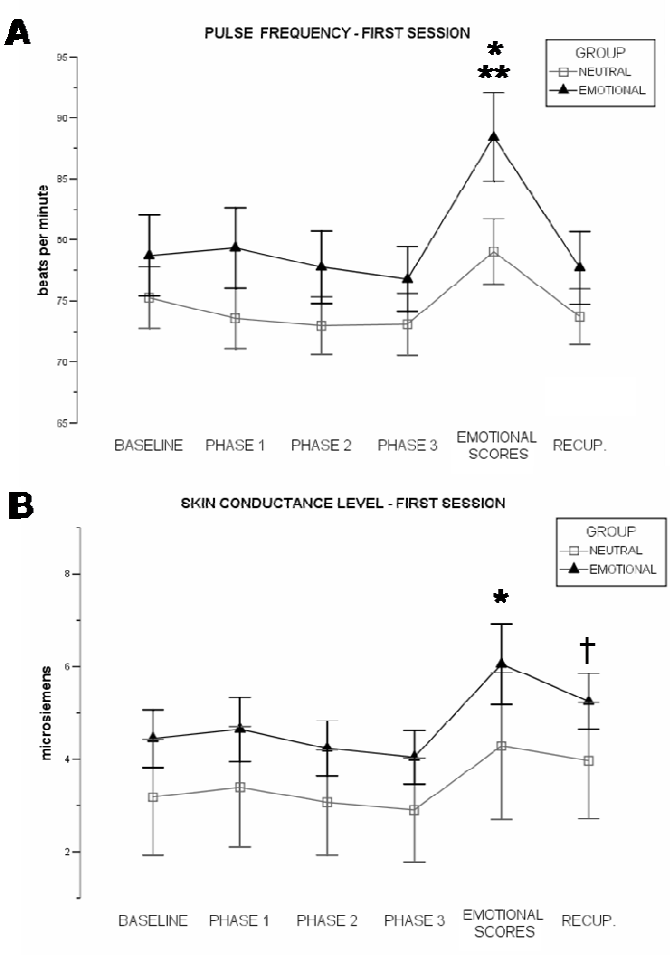

Figure 2. Mean ± SEM of the physiologic activity registered during the first session for Emotional and Neutral groups. A: Pulse frequency. B: Skin conductance level. *: p<0.05 between Emotional Scores stage and the remaining stages. †: p<0.05 between Emotional Scores stage and Baseline, Phase 2 and Phase 3 stages. **: p<0.05 between Emotional and Neutral groups within the Emotional Scores stage.

For the second session, MANOVA found a statistically significant effect of Group, F(2, 21)=2.667, p=0.047 (one-tailed), and a marginally significant effect of Sex, F(2, 21)=2.527, p=0.052 (one-tailed). The two factor interaction Group × Sex did not show a significant effect over PF and SCL, F(2, 21)=0.349, p=0.355 (one-tailed). Stage factor also exerted a significant effect, F(6, 17)=2.259, p=0.044 (one-tailed), whereas Stage × Group, Stage × Sex and Stage × Group × Sex interactions had no significant effect over the two dependent variables, Fs(6, 17)<1.653, ps>0.096 (one-tailed). Univariate analyses confirmed the previous results for Group, finding a statistically significant effect over SCL, F(1, 22)=3.558, p=0.037 (one-tailed), and a marginal effect over PF, F(1, 22)=2.788, p=0.055 (one-tailed). For both measures, E group showed a higher mean in comparison to N (**Figure 3 A & B**). Univariate analyses found a significant effect of Sex over SCL (Male>Female, F(1, 22)=5.151, p=0.033, and not over PF, F(1, 22)=0.004, p=0.949, (Data not shown). Stage factor showed a significant effect in the univariate analysis over PF, F(3, 66)=4.241, p=0.037, and SCL, F(3, 66)=3.911, p=0.049); even though no differences were found in the multiple comparisons procedure, a cubic trend was found for both measures, Fs(1, 22)>7.213, p<0.014. Such trend indicates a decrease-increase waveform for PF and an increase-decrease waveform for SCL (**Figure 3 A & B**).

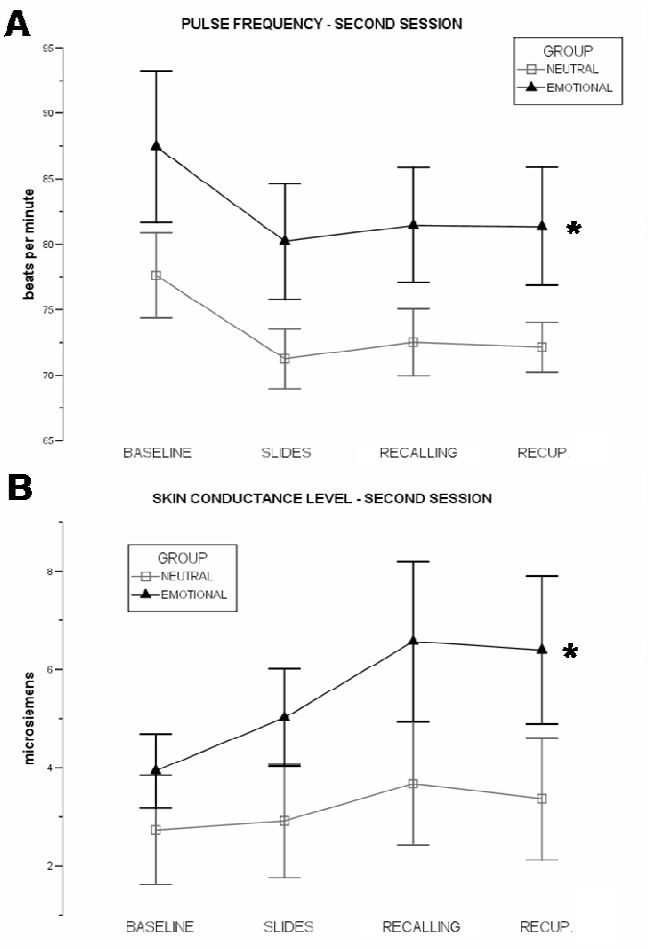

Figure 3. Mean ± SEM of the physiologic activity registered during the second session for Emotional and Neutral groups. A: Pulse frequency. B: Skin conductance level. * represent the statistically significant effect of the Group factor over both physiological measures (E > N).

Bivariate correlations among behavioral and physiological data were performed in the whole sample and in each subgroup. In the whole sample, percentage of correct answers for P1 was negatively correlated to the SCL during the third phase of the slide presentation in the first session, and to the SCL during the slide projection and recall phases in the second session, $r<-0,412$, $p<0,036$. Percentage of correct answers for P3 was positively correlated to SCL during the three phases of the slide presentation and to the ES phase in the first session, $r>0,460$, $p<0,020$.

DISCUSSION

Behavioral measures (emotional scores and percentage of correct answers in the recognition questionnaire) were published elsewhere[30]. In summary, they replicated the findings from previous works using the same stimuli[1,2,6]. As a new contribution, the stimuli used in this test were described within the frame of the basic emotions, as described by Ekman[29].

MANOVA demonstrated that Stage exerted a significant effect over PF and SCL, which showed an accentuated increase during the ES in the first session. This result demonstrated that the procedure of asking for a subjective evaluation induced, as expected, stress-related physiological responses[31-33]. SCL is a reliable index of the sympathetic activity level, not influenced by the parasympathetic nervous system activity; on the other hand, heart rate (and consequently the PF) is a physiological variable over the control of both subdivisions of the autonomic nervous system[33]. Remarkably, the univariate analyses showed a significant effect of the two-way interaction Stage × Group only over the PF, and not over SCL. There was a different PF for the Emotional and Neutral groups during the ES stage, while no differences were found for SCL. Changes in the parasympathetic activity has been related to several cognitive functions such as attention [32,34,35] and encoding of emotional stimuli [10,36]. Jointly, our results suggest that the subjective rating of the emotional content in this test induced a high PF by inhibiting parasympathetic activity over the heart. Within the frame of our work, this could be explained by a state of physiological activation induced by the exposition to emotional content during the ES stage in the E group. Alternatively, this difference in the PF response might be explained as an effect of the reverberation – or recall – of information, a prerequisite to perform the subjective Emotional Score evaluation. Remembrance of emotional content might elicit a higher PF response in comparison to the remembrance of non-emotional information.

The exposition to the slides and narrative did not induce the decrease-increase-decrease response of heart rate found during codification of emotional visual stimuli[10,36]. However, the properties of the stimuli differ, and we used the mean PF during each Phase of the test instead of the instantaneous heart rate for each slide.

During the second session Stage, Group and Sex exerted significant effects independently. Emotional group showed higher SCL and a tendency to a higher PF in comparison to Neutral group during the second session. Males showed a higher SCL than females during the second session. A lower SCL during the second session seems to be related to a better performance in the recognition questionnaire and is congruent with results from several studies evaluating the effect of stress over memory retrieval[28, 37-39].

Comparison of the physiological responses registered during the first and second session shows that the differences between groups and between genders were not the same in both sessions. This fact suggests that the physiological mechanisms involved in each group and gender during codification and initial consolidation, are not the same involved in memory retrieval.

Regarding physiological arousal and memory performance, discrepant results have been found demonstrating either an enhancing or impairing effect of stress hormones over memory perfor-mance[28, 39-41]. In addition to the well known

dose-dependent effect of physiological arousal over memory performance[42] and the different kind of protocols employed, we also suggest that the task's difficulty is another important factor that has not been considered in previous works. Correlation analyses in the whole sample demonstrated that physiological arousal level could either increase or decrease the recognition of emotionally neutral information. It enhanced the memory for information that showed a low recognition level (P3), and impaired the memory for information that was easily recognized by the participants (P1).

Wolf *et al*. studied the relationship between memory for a word list and plasmatic cortisol, and found a negative correlation between them[40]. Nevertheless, a following analysis within each gender found that this association was maintained only in the male group. In spite of the methodological differences, our results also suggest differences between genders in the memory processes as found in others works[16-18,43].

CONCLUSIONS

This work contributes to a better understanding of the memory enhancement phenomenon induced by the emotional content used in this test. Differences in the physiological activity between E and N groups were demonstrated in both sessions and suggest the participation of both subdivisions of the autonomous nervous system. Encoding and recalling processes were accompanied by different physiological responses. As showed by previous works, our results also suggest a differentiated processing of the emotional stimuli for each gender.

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