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Affective and physiological correlates of the perception of unimodal and bimodal emotional stimuli

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Abstract

Background: Despite the multisensory nature of perception, previous research on emotions has been focused on unimodal emotional cues with visual stimuli. To the best of our knowledge, there is no evidence on the extent to which incongruent emotional cues from visual and auditory sensory channels affect pupil size. Aims: To investigate the effects of audiovisual emotional information perception on the physiological and affective response, but also to determine the impact of mismatched cues in emotional perception on these physiological indexes. **Method:** Pupil size, electrodermal activity and affective subjective responses were recorded while 30 participants were exposed to visual and auditory stimuli with varied emotional content in three different experimental conditions: pictures and sounds presented alone (unimodal), emotionally matched audio-visual stimuli (bimodal congruent) and emotionally mismatched audio-visual stimuli (bimodal incongruent). **Results:** The data revealed no effect of emotional incongruence on physiological and affective responses. On the other hand, pupil size covaried with skin conductance response (SCR), but the subjective experience was partially dissociated from autonomic responses. **Conclusion:** Emotional stimuli are able to trigger physiological responses regardless of valence, sensory modality or level of emotional congruence.

Keywords: Pupillary response, skin conductance response, bimodal stimuli, incongruence, eye tracking.

Resumen

Correlatos afectivos y fisiológicos de la percepción de estímulos emocionales unimodales y bimodales. **Antecedentes:** a pesar de la naturaleza multisensorial de la percepción, la investigación que se ha hecho hasta el momento sobre las emociones se ha centrado en las señales emocionales típicamente unimodales. Según nuestro conocimiento, no existen estudios previos sobre cómo las señales emocionales incongruentes pueden afectar el tamaño de la pupila. **Objetivos:** investigar los efectos de la percepción de la información emocional audiovisual incongruente sobre las respuestas de tipo fisiológico y afectivo. **Método:** el tamaño pupilar, la actividad electrodérmica y las respuestas subjetivas afectivas de 30 participantes fueron registradas mientras ellos veían y escuchaban estímulos con contenido emocional que fueron expuestos en tres condiciones experimentales diferentes: imágenes y sonidos presentados aisladamente (unimodal); estímulos audiovisuales emocionalmente coincidentes (congruente bimodal); y estímulos audiovisuales emocionalmente no coincidentes (incongruente bimodal). **Resultados:** el estudio no reveló un efecto de la incongruencia emocional sobre las respuestas fisiológicas y afectivas. De otra parte, se encontró que el tamaño pupilar presenta una covariación con la actividad dérmica. Sin embargo, la experiencia subjetiva se mostró parcialmente disociada de las respuestas autónomas. **Conclusión:** los estímulos emocionales tienen la capacidad de desencadenar reacciones fisiológicas, independientemente de la valencia, modalidad sensorial o nivel de congruencia.

Palabras clave: respuesta pupilar, respuesta de conductancia dérmica, estímulos bimodales, incongruencia, eye tracking.

As the human emotional system is founded on an appetitive and a defensive motivational system, emotional visual stimuli (e.g. pictures) can elicit distinctive and intense cortical and peripheral responses (e.g., Lang & Bradley, 2010) . Thus, and despite having been used less than pictures, auditory stimuli (e.g. sounds) can also elicit emotional responses (Cox, 2008). Despite the considerable evidence of the impact of unimodal emotional cues on autonomic responses, emotion recognition in humans emerges from a multimodal emotion processing ability (Borod et al., 2000). Recent investigation into multimodal emotional integration reveals that responses to an emotional stimulus in one modality can be influenced by the occurrence of a stimulus in another modality (Arriaga, Esteves, & Feddes, 2014). Due to divergence between visual and auditory systems, the weightings from each modality may not be equal regarding sensory integration (Espósito, 2009). In order to examine possible bias in the emotional integration process, several paradigms have been applied. (e.g., Ferrari, Mastria, & Bruno, 2014) Concerning unimodality, the pattern of self-report responses and physiological reactions elicited by emotional auditory stimuli is comparable to emotional visual stimuli (Lang & Bradley, 2010). In regard to multimodality, there is some contradictory evidence regarding sensory bias (see Shams & Kim, 2010). These contradictions

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may be due to stimulus properties and the type of experimental task (see Yang & Lin, 2013). Emotional bimodal perception has been usually studied by means of combined perception of emotions from these two modalities (e.g., Arriaga et al., 2014). Some findings suggest that incongruent audiovisual combinations are rated as less emotionally as other congruent combinations, however, there have been dissonant evidence (Gerdes et al., 2014). Recent studies suggest that the incongruence between audio visual channels may lead to a decreasing activation of the amygdala (e.g., Latinus, van Rullen, & Taylor, 2010). Curiously, and despite the fact that pupil response has been linked to the phasic activity of the *locus coeruleus* noradrenergic system (Gilzenrat, Nieuwenhuis, Marieke, & Cohen, 2010) and amygdala (Lang & Brandley, 2010), it is not a common measure (for exceptions see Arriaga et al., 2014; Hong, Walz, & Sajda, 2014) and there is still a need to understand how the pupil reacts during emotional bimodal integration. The main driver behind the choice of using pupil dilation is based on its current use for understanding emotional response (e.g., Rosa, 2015; Rosa, Esteves, & Arriaga, 2014, 2015). If emotional processing and pupil size variation were reliably associated with each other, then eye tracking would offer a non-intrusive way to investigate the impact of three different conditions on affective and physiological responses: the two unimodal ones, vision only and audio only, and their bimodal combination (incongruent vs congruent). Taking these prior studies into consideration, the aim of the present study is to analyze the subjective affective state and pupil size as a measure of autonomic activation when incongruent/congruent bimodal and unimodal stimuli are presented.

Method

Participants

The sample of this study consisted of 30 psychology students of the Universidade Lusófona de Humanidades e Tecnologias, in Lisbon. Of these, 50 % were male (n = 15). The average age of the sample was 21.90 years (SD= 2.69), ranging from 21 to 27 years old. All participants were Portuguese and reported normal medical history with no hearing or visual problems. Participants were treated in accordance with the American Psychological Association's ethical code (APA, 2010).

Instruments

The following sociodemographic information was collected: nationality, gender and age. Subjective affective measures, such as hedonic valence and arousal, were assessed by using the Self Manikin Assessment (SAM; Bradley & Lang, 1994). Trait and state anxiety were assessed through the trait version of the State Trait Anxiety Inventory (STAI; Spielberger 1989). The Beck Depression Inventory–II (BDI-II; Beck, Steer, & Brown, 1996), was applied to assess the severity of depressive symptomatology. Subjective fatigue assessment was measured with a Pichot's fatigue scale (Pichot & Brun, 1984). Anxiety, depression and fatigue levels were made in order to control a possible source of variation on results as these factors have been thought as confounding factors in literature on emotion (Rosa et al., 2014, 2015). Regarding the experimental stimuli, twenty images were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005), consisting of 10 positive (e.g. sports, erotica) and 10 negative (e.g., mutilated bodies, explosions). The IAPS catalog numbers used for pictures were following: (a) 4652, 4659, 4668, 4669, 4670, 4687, 8080, 8179, 8200, 8499 for the positive images and (b) 3005, 3015, 3069, 3168, 3170, 6563, 9410, 9635, 9921, 9940 for the negative images. All images were converted to grayscale 8-bit Joint Photographic Experts Group (JEPG) image file format and finally resized to 1280x 1024 resolution. Equivalent apparent luminance and contrast were found for negative and positive images, $t_{luminance}(18) = 0.289$, $p = .776$ and $t_{contrast}(18) = -1.199$, $p = .246$, respectively. The objective visual complexity of images was calculated based on three measurements: Canny edge detection method (Gaussian kernel radius = 2px; threshold 2.5 - 7.5px); perimeter detection; and JPEG compression file size in Kilobytes (Calvo & Lang, 2004; Donderi, 2006; Rosa, Gamito, Oliveira, Morais, Pavlovic, & Smyth, 2015). Both metrics revealed that positive and negative images presented similar visual complexity (see table 1). All analyses were made were using the software ImageJ 1.49 and JPEG compression was made via Photoshop CS6.

Furthermore, twenty acoustic stimuli from International Affective Digital Sounds (IADS; Bradley & Lang, 1999) 10 positive (e.g. laugh) and 10 negative (e.g. scream) with similar arousal were selected. The IADS catalog numbers used for acoustic stimuli were the following: (a) 110, 202, 216, 220, 226, 310, 352, 353, 415, 820 for the positive sounds and (b) 115, 261, 278, 286, 287, 290, 292, 706, 711, 730 for the negative sounds. These acoustic stimuli were converted into .wav file (frequency of 44.100*Hz*). RMS normalization to -16*db* (Full Scale) and pan-normalization of the left and right channels were made via WaveLab 6.0 Software. Images and sounds were equivalent in terms of normative rated arousal ($p>.05$). As expected, Subjects gave higher ratings of hedonic valence to positive stimuli ($M_{images} = 6.95$; $M_{sounds} = 5.90$) than to negative stimuli ($M_{images} = 1.67$; $M_{sounds} = 1.85$), $F(3,36) = 112.04$, $p<.001$. No differences of normative valence ratings were found between images and sounds from the same hedonic category (All $ps>.05$)

Experimental stimuli were presented through Superlab 4.0 presentation software and auditory stimuli were delivered via

Table 1
Comparison of mean for the three visual complexity parameters between positive and negative images

	Positive images (n = 10)		Negative images (n = 10)		t
Parameter	M	SD	M	SD	
Number of edges	593.60	374.24	1148.60	1009.44	1.63
Perimeter	117.79	30.53	101.01	28.05	-1.28
JPEG size in kB after compression	162732.60	24792.82	179678.30	52070.93	0.93

headphones to both of the participant's ears at a comfortable constant volume level. The presentation software ran in an Intel core2duo 6550 desktop computer, which was connected to a Tobii -T60 Eye Tracking System (Tobii Technology AB, Sweden) and integrated into a TFT 17" monitor.

The binocular pupil diameter (PD) was measured using the mentioned eye tracker at a sample rate of 60Hz with a bias error 0.5 of degrees' visual angle. SCR was measured using Biopac MP100 physiology measurement system (BIOPAC System, Inc., Santa Barbara, CA, USA) for analogical/digital conversion running the AcqKnowledge software (version 3.8.1) at a sample rate of 250 Hz. Chloride electrodes (Ag/AgCl), with an electrolytic paste based on sodium chloride (NaCl) were placed on the index and middle fingers (middle phalanxes) on participants' non-dominant hand. A 1-byte digital trigger was sent via parallel port from the PC running Superlab to the MP100 system.

Procedure

The experiment was carried out in a soundproof, constant low bright-room (42 Lux) during only one session. The participants were randomly assigned to three balanced experimental conditions via the online software Research Randomizer. The headphones were put on and the participants were instructed to remain as still as possible in order to keep a distance of 60cm from the center of the computer screen. In the unimodal condition, 10 participants were exposed to 40 unimodal stimuli (20 images and 20 sounds presented in an isolated and random fashion). The second group with 10 participants was exposed to 40 (20 × 2) congruent pairs of audiovisual stimuli (positive image-sound vs negative image-sound) and the last and third group with 10 participants that were exposed to 40 (20 × 2) incongruent pairs of audiovisual stimuli. No significant differences were found for anxiety, depression and fatigue levels assuring homogeneity across experimental groups (All *p*s>.05). Following two practice trials, a block of 40 stimuli (unimodal or bimodal), with a duration of 5000ms, were presented depending on the experimental condition. The inter stimulus interval (ISI) was 8000ms. ISI and background were presented on a gray color (Red-Green-Blue: 150, 150,150) to minimize differences in luminance during stimulus presentation. A fixation cross was presented at the centre of the screen for 500ms before stimulus onset. Right after each stimulus the participant had to rate her/his affective experience on two dimensions: valence and arousal on a nine-point (1-9) scale using the computer keyboard. In bimodal conditions, as a pair of stimuli was presented twice, participants were instructed to rate his/her affective experience in auditory or in the visual domain, one at the time. Skin conductance response (SCR) and pupil activity were simultaneously recorded during the whole the experiment. At the end, the participants were thanked, debriefed and dismissed.

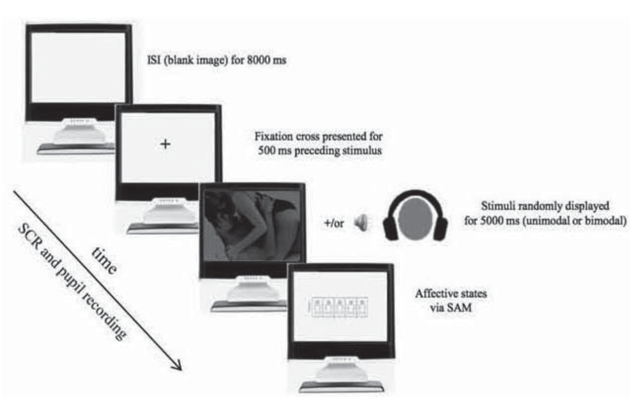

Figure 1. The time sequence of the experimental procedure. Note that this example picture was not among the experimental stimuli

Data analysis

Regarding pupil measurement, data reduction was performed as previously described by Rosa et al. (2014). Pupil data were smoothed using a 7-point moving and peak dilations were computed as described in detail by Rosa et al. (2015). SCR magnitude was calculated based on recommendation of Marcos and Redondo (2002). As the hedonic valence entered in the statistical model as within-subject factor, both physiological indexes were computed for each experimental condition as follows: unimodal [average response value for the 20x positive trials (sounds + images) and 20x negative trials (sounds + images)]; congruent bimodal (average response for the 20x positive congruent trials and for the 20x negative congruent trials) and incongruent bimodal [average response for the 20x incongruent trials with positive images (negative sound) and for the 20x incongruent trials with negative images(positive sound)]. All statistical analyses were performed using IBM SPSS Statistics 22.0 (SPSS Inc, USA) for Windows. Greenhouse-Geisser corrected degrees of freedom were used to report significant levels. Bonferroni correction was applied for pairwise comparisons and all tests of statistical significance were done at a 'p' value of .05.

Results

Physiological response

Results of a 2 (type of stimulus: positive vs negative) × 3 (experimental condition: unimodal vs congruent vs incongruent) mixed design MANOVA showed neither a main effect of hedonic valence, *Pillai's trace* = .048, $F(2, 26) = 0.66$, $p = .053$, nor a main effect of arousal experimental condition *Pillai's trace* = .764, $F(4, 52) = 1.83$, $p = .129$. No interaction effect experimental condition and hedonic valence was found. *Pillai's trace* = .116, $F(4, 52) = 0.83$, $p = .513$.

In the interest of exploring whether physiological indexes were affected differently by visual and auditory stimuli, an in-depth analysis in the unimodal condition was performed. The results of a 2 (hedonic valence: positive vs negative) × 2 (sensory channel: visual vs auditory) repeated measures MANOVA revealed neither a main effect of hedonic valence, *Pillai's trace* = .017, $F(2, 8) = 0.79$, $p = .483$, nor a main effect of sensory channel *Pillai's trace* = .313, $F(2, 8) = 1.82$, $p = .223$. No interaction effect between sensory channel and hedonic was found. *Pillai's trace* = .090, $F(2, 8) = 0.39$, $p = .687$. Figure 2 illustrates a similar pattern for pupil peak diameter and SCR. Therefore, in order to explore whether the pupil peak diameter covaries with SCR amplitude, a Spearman correlation (r_s) was performed. Confirming to our expectations, a significant correlation between pupil peak size and SCR amplitude was found, $r_s = .112$, $p = .004$, Nevertheless, and since there are some evidence of interaction of emotional auditory and emotional visual processing (Gerdes et al., 2014), the covariation between pupil peak SCR amplitude was deeper examined across the different experimental condition. The results showed that in unimodal condition, a significant correlation between pupil peak size and SCR amplitude was also found $r_s = .176$, $p = .018$.

However, in the congruent bimodal condition, a stronger correlation between pupil peak size and SCR amplitude was revealed $r_s = .346$, $p<.001$. Conversely and surprisingly, a significant negative correlation between pupil peak size and SCR amplitude was found for incongruent bimodal condition $r_s = -.245$, $p<.001$ (see figure 3).

Affective states

In order to analyze hedonic valence and arousal, two mixed design ANOVAs for each variable were performed, as these dimensions are commonly treated as independent factors.

The ANOVA for hedonic valence data showed a triple interaction effect of experimental condition, sensory channel and type of stimulus *Pillai's trace* = .363, $F(2, 27) = 7.07$, p = .002; $\eta^2_p = 0.36$. The triple interaction effect was decomposed into 2-way interaction effects via split-plot and simple effects were analyzed. Simple effect analyses revealed that, for negative unimodal stimuli, images were lower rated on valence ($M = 3.60$) than sounds ($M = 4.30$, $p = .002$; d=1.15). However, no differences were found in valence ratings between sounds and images for positive unimodal stimuli (all *ps*>.05). Similar results were found in negative congruent bimodal stimuli, presenting the participants higher ratings for sound's valence ($M = 5.30$) in comparison to image's valence ($M = 4.52$ $p = .003$; $d = 1.20$) for the same bimodal stimuli. Again, no differences in valence ratings between sounds and images were found for positive congruent bimodal stimuli (all *ps*>.05). Regarding incongruent bimodal stimuli, no differences in valence ratings between sounds and images were found (all *ps*>.05) (Figure 4).

Regarding arousal, a main effect of sensory channel was found, *Pillai's trace* = .640, $F(1, 26) = 6.29$, p = .001, $\eta^2_p = .0.35$, indicating that the images were rated as more arousing stimuli ($M = 5.11$) than sounds ($M = 4.46$, $p = .001$; d =1.19), regardless of type of stimulus. A main effect of experimental condition on rated arousal was also found $F(2, 26) = 4.02$, p = .030; $\eta^2_p = .0.24$.

Post-hoc tests revealed that congruent bimodal pictures higher were higher rated on arousal ($M = 5.40$) than the incongruent bimodal pictures ($M = 4.04$, $p = .030$; $d = 0.86$). Yet, no differences in arousal ratings between unimodal stimuli and bimodal stimuli were found (all *ps*>.05), as shown in Figure 5.

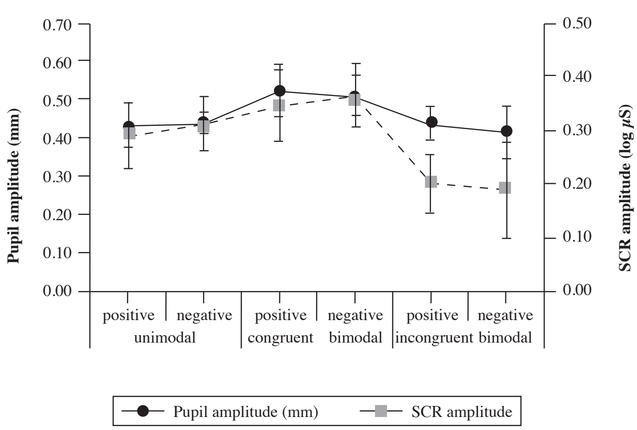

Figure 2. Pupil and SCR amplitude for positive and negative stimuli across experimental conditions. The error bars represent the standard error of the mean

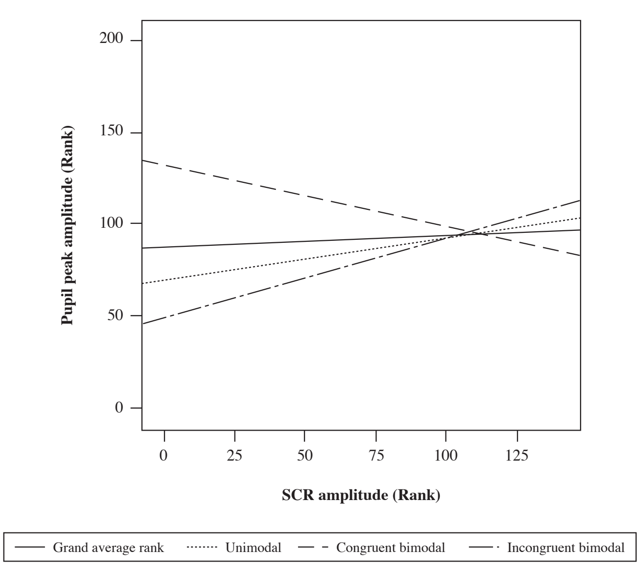

Figure 3. Spearman rank correlation between pupil peak size and SCR amplitude as function of experimental condition by type of stimulus

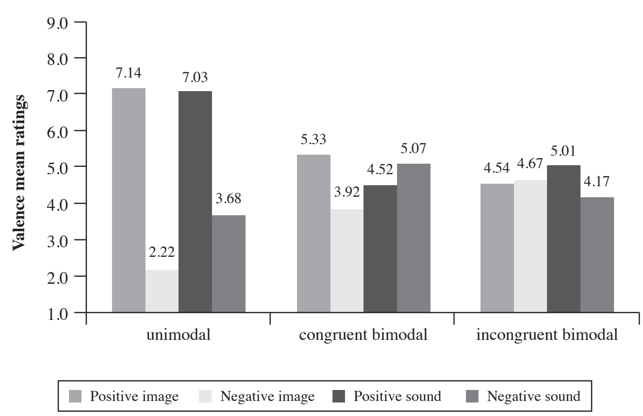

Figure 4. Valence mean ratings as a function of experimental condition, sensory channel and type of stimuli

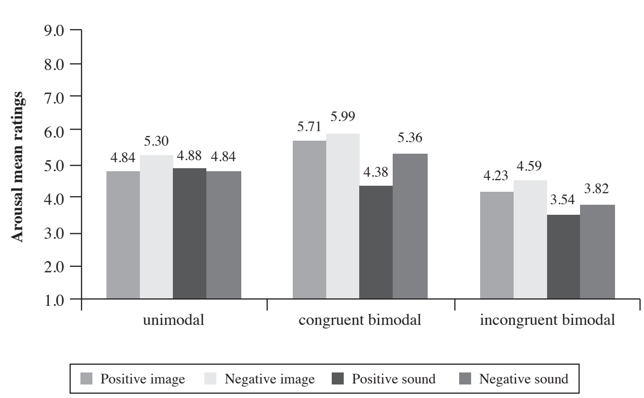

Figure 5. Arousal mean ratings as a function of experimental condition, sensory channel and type of stimuli

Discussion

The present study extended previous research on emotionally audiovisual pairings, as pictures were controlled for low-level features (visual complexity, apparent luminance and contrast) and both type of stimuli (images and sounds) were controlled for arousal. No differences in pupil size or SCR amplitude between positive and negative stimuli across experimental conditions were found. Our results suggest that pupil dilates when emotionally engaging stimuli are processed, regardless of valence or sensory modality (e.g., Rosa et al., 2015). This finding is consistent with recent empirical evidence showing identical cortical activity between emotional pictures and sounds (e.g., Scharpf, Wendt, Lotze, & Hamm, 2010). No differences were found in pupil size and SCR between unimodal and congruent bimodal pairs, which suggests that audiovisual interactions do not occur in a stronger form if the emotional congruent information is conveyed by both modalities. Surprisingly, contrary to our initial predictions, no effect of emotional incongruence was found, which supports the notion that multisensory integration of emotional cues is an automatic process and that autonomic responses can be triggered, despite the incongruence between audiovisual channels.

In addition, our results showed a covariation between pupil size and SCR, which is consistent with the premise that pupil size seems to reflect sympathetic nervous system activity linked to the emotional response. However, when the relation between pupil dilation and skin conductance was further examined across experimental conditions, the congruent bimodal condition was the only one to present a significant positive correlation. Remarkably, a significant negative correlation between pupil peak size and SCR amplitude was found in incongruent bimodal condition. The results might suggest parasympathetic activity eliciting a constriction due to mismatching information, as the electrodermal activity is only controlled by the sympathetic branch (Kreibig, Wilhelm, Roth, & Gross, 2007) . As the cortex has a direct influence on the pupil through direct projections to the parasympathetic Edinger-Westphal nucleus in the midbrain, a negative correlation between pupil size and SCR in the incongruent bimodal condition may be explained by a perceptual dilemma that mirrors top-down processes. With regards to affective responses, more pronounced hedonic valence was reported for negative sounds than negative images in unimodal and congruent bimodal conditions, reflecting a visual bias. This could be explained due to fact that negative sounds were perceived closer to neutral than negative. Despite this difference on the level of self-report hedonic valence, both types of stimuli (images and sounds) had a similar autonomic pattern response. In terms of arousal, it was surprising that as the subjective arousal was higher for images than sounds, even after they were controlled for arousal. It is also important to note that neither pupil size nor SCR corresponded to the scores on the subjective arousal scale. Furthermore, the perception of emotional arousal increases when matched information between sensory channels is presented. These results are in line with Cox (2008) that found that stimuli can be significantly perceived as more negative when accompanied by pictures that show matched information. Nevertheless, these results need to be interpreted with caution given the study's design and analysis. One limitation is related to the lack of a neutral condition for stimuli. Moreover, other form of mismatched information, which can be thought as a "disunity effect" (Vatakis & Spence, 2007), might have created a possible double additive effect on incongruent pairings. Finally, a potential caveat is that results are based on a small sample size that may increase Type II error in the statistical analyses. Future studies with larger samples would certainly give more statistical power to the results.

In conclusion, our results suggest that the perceived valence and arousal is affected by which particular information channel(s) is/are used to process emotional information and that the subjective experience is partially dissociated from autonomic responses. Moreover, the covariation of pupil size with SCR suggests, for emotional processing, that this mechanism may share some brain structures and thus reflecting autonomic activation (Lang & Bradley, 2010). Though pupillary activity is determined by emotional arousal, variations on pupil diameter might reflect other cognitive processes which should be taken into account and that cannot be estimated via SCR. In future, other physiological indexes sensitive to valence (e.g., Heart Rate Variability) could disentangle this issue (Kreibig et al., 2007). Another issue that is of great practical importance is to apply the eye tracking technique, as a non-intrusive measure, to clinical samples. The assessment of multimodal emotional processing could improve the understanding of several mental disorders such in anxiety (Rosa et al., 2014, 2015) and may provide a rich source of data for both researchers and clinicians.

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