

Affective reactions to acoustic stimuli

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Abstract

Emotional reactions to naturally occurring sounds (e.g., screams, erotica, bombs, etc.) were investigated in two studies. In Experiment 1, subjects rated the pleasure and arousal elicited when listening to each of 60 sounds, followed by an incidental free recall task. The shape of the two-dimensional affective space defined by the mean ratings for each sound was similar to that previously obtained for pictures, and, like memory for pictures, free recall was highest for emotionally arousing stimuli. In Experiment 2, autonomic and facial electromyographic (EMG) activity were recorded while a new group of subjects listened to the same set of sounds; the startle reflex was measured using visual probes. Listening to unpleasant sounds resulted in larger startle reflexes, more corrugator EMG activity, and larger heart rate deceleration compared with listening to pleasant sounds. Electrodermal reactions were larger for emotionally arousing than for neutral materials. Taken together, the data suggest that acoustic cues activate the appetitive and defensive motivational circuits underlying emotional expression in ways similar to pictures.

Descriptors: Emotion, Sounds, Memory, Startle reflex, Autonomic, Facial EMG

In the laboratory, as in life, emotional reactions can be evoked by stimuli in different sensory modalities. Over the past 10 years, we have studied in detail the physiological, self-report, and behavioral reactions associated with processing emotional pictures (e.g., Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993; see Bradley & Lang, in press, for an overview). When people look at affective pictures, reliable patterns of physiological change are found in somatic, visceral, and central systems that vary significantly with reports of affective valence and arousal. When viewing unpleasant pictures, for example, there is clear cardiac deceleration, a large skin conductance response, increases in corrugator (frown) electromyogram (EMG), a larger scalp-recorded positivity, and potentiation of the startle reflex. In the studies reported here, we explored affective reactions to naturally occurring acoustic stimuli. The experimental design paralleled that used in studies of affective picture viewing. If the pattern of reactivity found previously when looking at affective pictures is duplicated when listening to affective sounds, the thesis that these responses reflect activation of a common emotional system is supported. Finding different patterns of reactivity would suggest modality-specific modulation. Thus, the goal was to determine if emotional sounds produce physiological patterns that covary with affect similar to those observed when people look at pictures.

Investigations of reactions to affective sounds are relatively few. Although a soundtrack is sometimes part of the stimulus when film is used to investigate emotional response (e.g., Gross & Levenson, 1993, 1995), its elaboration by visual input makes it difficult to isolate effects arising specifically from affective features of acoustic stimulation. Studies investigating physiological responses to affective sounds alone have tended to rely on small sets of stimuli. For example, in studies of cardiac reactivity, Gang and Teft (1975) used a single sound (high-speed dental engine) and Pallmeyer, Blanchard, and Kolb (1986) used a 30-s segment of combat noises. Using a somewhat larger stimulus set, Meyers and Smith (1987) presented two positive sounds (woman laughing, baby coo), two neutral sounds (tones), and two negative sounds (woman crying, woman screaming) in an investigation of hemispheric asymmetry. Use of small stimulus sets is probably due, in part, to the technical difficulties once involved in manipulating and controlling acoustic stimuli using analog media such as tape. With the advent of digitized storage and computer software for editing and manipulating digitized data, experimental control of acoustic stimuli is now feasible. For instance, Fabiani, Kazmerski, and Cycowicz (1996) developed a large battery of brief (400 ms), seemingly neutral, acoustic stimuli for investigating novelty effects in the event-related potential oddball paradigm. We have also taken advantage of digitized technology in devising and testing a set of acoustic stimuli that vary in pleasure and arousal.

The sound stimuli used here were selected to engage a broad range of emotional responses, varying systematically in affective valence and arousal. In this sense, they are comparable to a previously studied set of picture stimuli (i.e., International Affective Picture System, Lang, Bradley, & Cuthbert, 1999). In Experiment 1, each of 60 different sounds was rated by subjects on the dimensions of pleasure, arousal, and dominance, using the Self-Assessment Manikin (SAM), an affective rating system devised by Lang (1980). Use of this rating method stems from classical analy-

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ses of aesthetic perception (Berlyne, 1971; Wundt, 1902) and multivariate research on affective language, which have found that the principal variance in emotional meaning is explained by two factors: pleasure and arousal (Mehrabian & Russell, 1974; Osgood, Suci, & Tannenbaum, 1957; Smith & Ellsworth, 1985).

The goal of Experiment 1 was to compare the two-dimensional distribution of pleasure and arousal ratings for sound stimuli with the distributions previously obtained for picture stimuli. Figure 1 illustrates the boomerang-shaped distribution of affective space for pictures, with two arms that extend from a common calm, non-affective base toward either a high-arousal pleasant or a high-arousal unpleasant quadrant. This organization is consistent with an underlying bimotivational structure, involving two systems of appetitive and defensive motivation that each vary along a dimension of intensity or arousal. Assuming these basic appetitive and defensive motivational systems underlie all emotional experience, we expected that sound stimuli would show a similar distribution in the two-dimensional affective space defined by pleasure and arousal.

After the rating phase, an incidental free recall task was conducted in which the subject was asked to write down a brief description of each sound that could be remembered. When remembering emotional pictures, memory is generally better for materials rated as highly arousing, regardless of whether they are pleasant or unpleasant (e.g., Bradley, Greenwald, Petry, & Lang,

1992). Assuming that emotional arousal generally facilitates memory performance, we predicted that we would also obtain better memory performance for highly arousing sounds in the current study.

In Experiment 2, heart rate, skin conductance, facial EMG (corrugator and zygomatic), and the startle blink reflex were measured while subjects listened to and then rated affective sounds. One goal of this study was to assess physiological reactions as they vary when listening to pleasant, neutral, and unpleasant sounds, as defined by a priori groupings on the valence dimension. In the picture perception paradigm, corrugator EMG activity, startle blink magnitude, and heart rate changes differ when viewing unpleasant versus pleasant pictures, whereas skin conductance and orbicularis oculi EMG activity are greater for emotional pictures of either valence, compared with neutral stimuli. A second goal was to assess the covariation between individual subjects' reports of pleasure and arousal and their physiological responses. In a number of previous studies using picture stimuli (e.g., Greenwald et al., 1989; Lang et al., 1993), specific physiological responses show large correlations with changes in either reports of pleasure and arousal. For instance, facial EMG activity and the startle blink covary with ratings of valence, and skin conductance responses covary linearly with rated arousal.

Whether similar patterns will be obtained for sounds depends on the extent to which the dynamic nature of acoustic stimuli and

International Affective Picture System (1999)

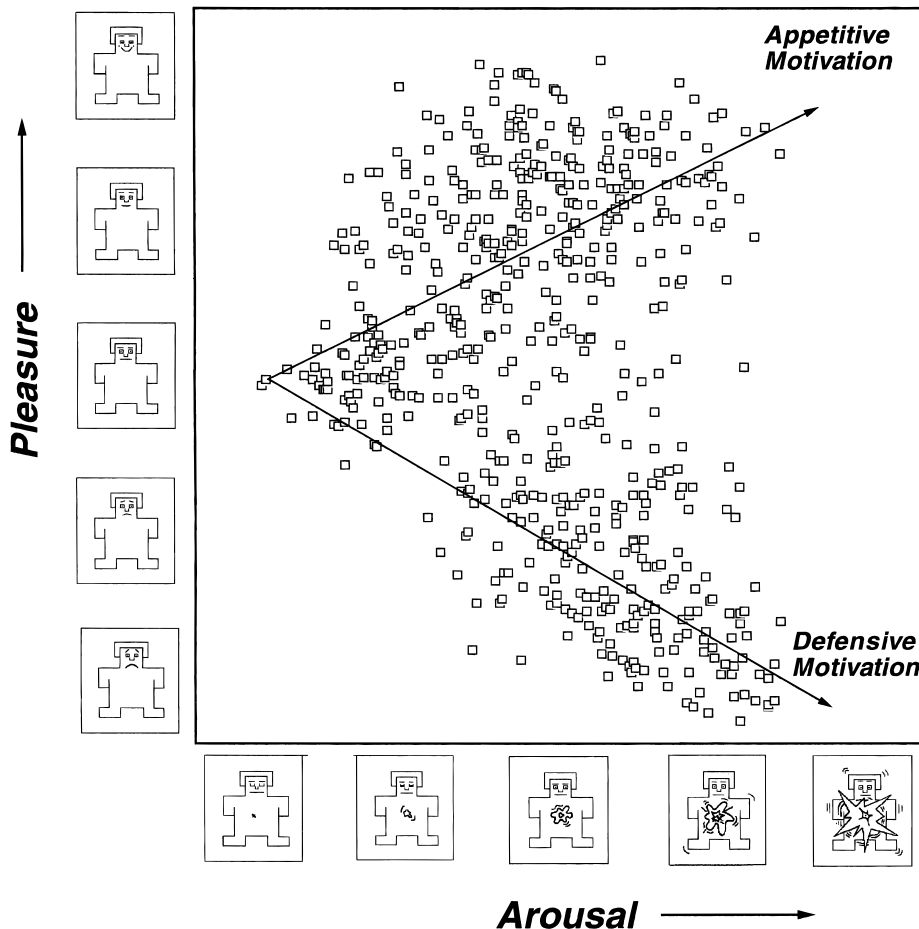


Figure 1. A plot of more than 700 pictures currently in the International Affective Picture System (CSEA, 1999) in a two-dimensional affective space defined by each picture's mean pleasure and arousal rating (Lang, Bradley, & Cuthbert, 1999). The arrows indicate the hypothetical appetitive (top half of plot) and defensive (bottom half of plot) motivational systems underlying affective judgments.

their necessarily chronological processing impact on physiological reactivity. That is, naturally occurring sounds differ primarily from nonmoving pictures in that they are dynamic and often require accrual of information over time in order to be interpreted. The information in a static picture, on the other hand, is presented all at once, and although scanning and focus may change over time, essentially remains the same during presentation. Because physiological systems such as heart rate and skin conductance activity may react reflexively, orienting to any change in the physical characteristics of stimulation, it is not clear that the affective import of auditory inputs will be as easily detectable. Thus, one question concerned whether physiological responses would continue to reflect emotional parameters of pleasure and arousal, when the perceptual array is (1) acoustic, rather than visual, and (2) contains dynamic, rather than static, information. Assuming that sound cues are effective in activating the same appetitive and defensive motivational systems that are activated by picture cues, similar effects of affective valence and arousal on physiological responding are expected. To the extent that sensory reflexes complicate autonomic reactions, effects may be weaker, different, or absent.

Affective modulation of the startle reflex during picture viewing is typically investigated in a cross-modal paradigm, in which an acoustic startle probe is presented during visual foreground processing. To keep the context of investigation comparable for pictures and sounds, we used a cross-modal startle probe in the current investigation: Startle reflexes were elicited using a visual stimulus (i.e., photographic flashgun) while the subject was listening to the sound. Like autonomic orienting responses, however, the startle reflex may also be affected by the dynamic nature of acoustic stimulation. Specifically, it is well known that the reflex blink is inhibited when it is preceded at a short latency by another stimulus (see Hackley & Boelhower, 1997, for a review), and these prepulse effects could interfere with affective modulation of startle when dynamically changing sounds, rather than static pictures, comprise the stimulus array. To minimize systematic effects of prepulse inhibition on startle reflex magnitude, the visual startle probe was presented at different (pseudorandomly determined) times during presentation both across sounds and subjects. In the absence of large inhibitory effects, we expected that the startle reflex would be modulated by affective valence of the sounds, as found with picture stimuli, because affective modulation of the startle reflex is thought to reflect engagement of defensive or appetitive motivational systems (Lang, Bradley, & Cuthbert, 1999).

EXPERIMENT 1

This experiment was designed to describe the distribution of a collection of meaningful sound stimuli in a two-dimensional space defined by pleasure and arousal ratings, and to determine the relationship between these affective dimensions and memory performance, measured in an incidental free recall task.

Method

Participants

The subjects were 116 (54 male) undergraduate college students from the University of Florida Introductory Psychology course who participated in partial fulfillment of course requirements. Data from three subjects were discarded before any analyses due to inattention during the sessions and failure to fill out the forms appropriately. Subjects were run in groups of 5–12.

Materials and Design

Sixty sounds¹ were obtained from a variety of formats (e.g., CD-ROM collections, audiotapes, recordings made in the laboratory using actors and actresses from the University of Florida's Theatre department), digitized using a Farallon MacRecorder and stored on a Macintosh computer. Each sound was subsequently edited digitally to a 6-s presentation. Peak sound intensity at presentation ranged from 64 to 81 dB (A) as measured using a Quest 1700 Precision Impulse Sound Level Meter, and generally varied according to respective natural volumes in the environment (i.e., screams or a jet taking off were generally louder than chirping birds or a whirring fan). Some studies have attempted to match sound stimuli more precisely for physical properties such as intensity and frequency (e.g., Benson et al., 1987). Beyond the above-mentioned range restriction, matching sound stimuli was not a practical option in the present research, as the primary goal was to use ecologically valid sounds that effectively communicate affect. Rise and fall times varied somewhat across stimuli as well, and were controlled to prevent eliciting startle responses (e.g., produced with instantaneous risetime) and so as not to give the stimulus a clipped sound at the end.

In the rating session, presentation of the sounds was controlled using a Macintosh computer; each sound was presented for 6 s over a pair of JBL 4311 Control Monitor speakers. Ratings were made using SAM (Lang, 1980), which involves a graphic figure depicting values along dimensions of pleasure, arousal, and dominance on a continuously varying scale. The axes in Figure 1 illustrate the SAM figures used in the paper-and-pencil version of SAM. SAM ranges from a smiling, happy figure to a frowning, unhappy figure when representing the pleasure dimension; on the other hand, SAM ranges from an excited, wide-eyed figure to a relaxed, sleepy figure for the arousal dimension. For the dominance dimension, SAM ranges from a large figure (in control) to a small figure (dominated). In the paper-and-pencil version of SAM, the subject can place an "X" over any of the five figures in each scale, or between any two figures, which results in a 9-point rating scale for each dimension. Previous studies (e.g., Bradley & Lang, 1994) have determined that ratings of the three major affective dimensions (e.g., pleasure, arousal, dominance) obtained using SAM are similar to those obtained using the verbal semantic differential scale devised by Mehrabian and Russell (1974).

Procedure

Subjects were seated in a carpeted classroom with good acoustic properties. After obtaining informed consent, subjects were instructed in the use of the paper and pencil version of SAM (see Figure 1). Each subject received a 60-page booklet, with one SAM rating page for each sound. Ratings were made on a scale from 1 to 9 for pleasure, arousal, and dominance. Subjects were instructed to rate how they felt while they were listening to each sound. Three practice sounds (babies crying, a bird twitter, and a woman sighing) were played during which subjects made practice SAM ratings. The sample sounds were chosen to illustrate the range of sounds in terms of pleasure, and to serve as anchors. The remain-

¹Stimulus materials and technical reports including ratings of pleasure, arousal, and dominance for sounds (currently 120 stimuli in the International Affective Digitized Sounds, Bradley & Lang, 1999), as well as pictures (currently more than 700 in the International Affective Picture System [Center for the Study of Emotion and Attention, 1999; Lang, Bradley, & Cuthbert, 1999]) are distributed on CD-ROM, and can be obtained on request from the authors.

ing 60 sounds were then presented in one of four different orders, which counterbalanced, across subjects, the position of a specific sound in each of the four 15-sound blocks of the study.

The specific procedure was as follows: Each trial began with a 5s preparation period beginning with the acoustically presented instruction: "Please rate the next sound on page ____." Immediately after this preparation period, a 6-s sound was presented. Immediately after the sound, a 15-s rating period began with the instruction: "Please make all three ratings now." This completed one 26-s trial. This procedure was repeated for 60 trials with pauses at trials 20 and 40 to check for correct page numbers. Following the last sound and collection of the ratings booklets, subjects completed a postexperimental questionnaire. Following the questionnaire, a 5-min incidental free recall test of the sounds was conducted, in which the subject was instructed to write down a word or brief phrase describing each of the sounds that could be remembered. After the recall period subjects were debriefed, given their credits, and thanked. Each session lasted approximately 1 hr and 10 min.

Results

Affective Ratings

Figure 2 (top) plots each of the 60 sounds rated in Experiment 1 in the two-dimensional space defined by the mean pleasure and arousal rating for each sound. Similar to affective pictures, acoustic stimuli vary dramatically in rated pleasure, ranging from a high of 7.8 (erotica) to a low of 1.48 (attack). This range compares favorably to that obtained for emotional pictures: pleasure ratings in the current International Affective Picture System (IAPS; Center for the Study of Emotion and Attention, 1999), which has many more stimuli, ranges from 8.34 (puppies) to 1.31 (burn victim). Sounds were also rated as varying widely in arousal, with a high of 8.07 (scream) and a low of 2.74 (bird). Again, this is similar to arousal ratings for IAPS pictures, which range from 7.35 (ski jump) to 1.72 (lamp).

The shape of affective space for sounds is similar to that obtained previously using picture stimuli: Sounds rated as either highly pleasant or highly unpleasant also tend to be rated high in arousal, as the significant quadratic relationship between ratings of valence and arousal indicate, $r = .74$. A significant quadratic relationship between pleasure and arousal has also been obtained when looking at pictures ($r = .43$ in Lang et al., 1993; $r = .55$ in the current IAPS [Lang et al., 1999] set).

A linear correlation of $r = -.48$ was also obtained between pleasure and arousal ratings across all stimuli, which is significantly larger than found previously for a small set of selected pictures ($r = -.05$, Lang et al., 1993) and opposite in direction to the correlation of these variables in the full IAPS (1999) set ($r = .26$). The size of the overall linear correlation will depend, to a large extent, on the number of highly arousing pleasant and unpleasant stimuli in the collection; the relatively large negative correlation between pleasure and arousal obtained for sounds suggests there were more unpleasant sounds rated as highly arousing in this initial set than pleasant sounds of similarly high arousal (see Figure 2, top panel). The linear relationship between pleasure and arousal ratings for unpleasant sounds alone (mean valence < 4.5) was significantly stronger ($r = -.88$) than for pleasant sounds ($r = .32$).

Physical Intensity

The linear correlation between ratings of pleasure and peak sound intensity across the 60 sounds was low and not significant ($r =$

Listening to sounds: Affective ratings

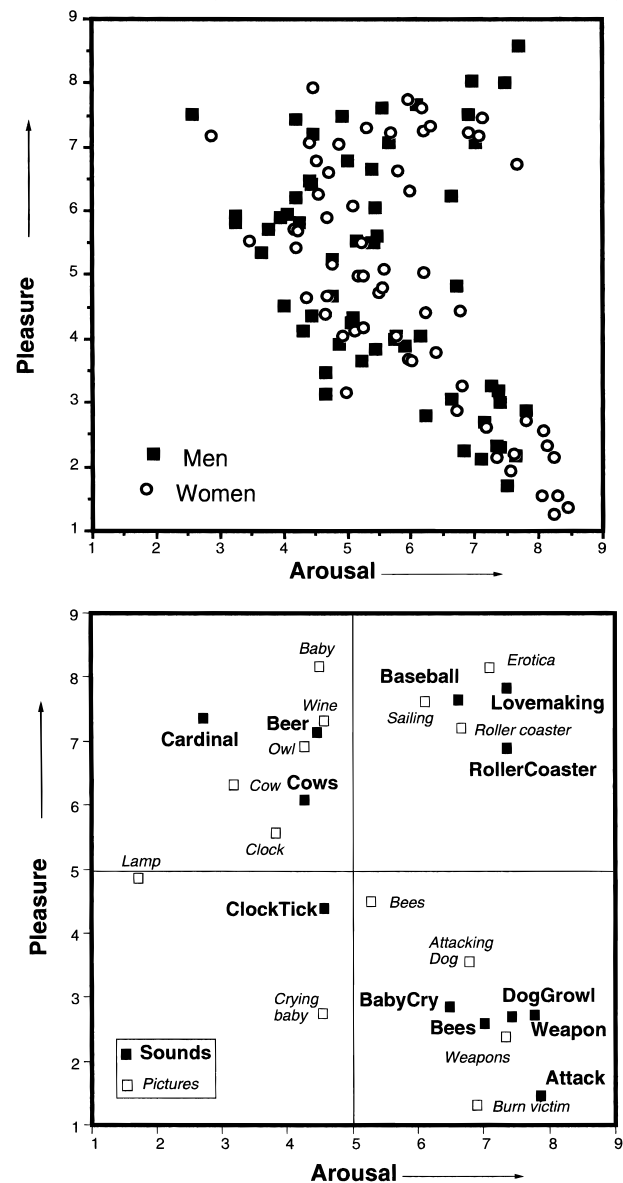


Figure 2. Top panel: A plot of the 60 sounds rated in Experiment 1 in the two-dimensional affective space defined by the mean pleasure and arousal rating of each sound, separately for men (filled squares) and women (open circles), results in a similar shape as depicted for pictures in Figure 1. Bottom panel: A plot of selected sounds from Experiment 1 (filled squares) and pictures from the International Affective Picture System (IAPS, 1999; open squares) demonstrates that, for many stimuli, items with similar semantic content (e.g., rollercoaster, cow, erotica, weapons) are located very close together in affective space. Changing an affective feature of the stimulus (e.g., picture of smiling baby and sound of crying baby), however, changes its location in affective space. In a few instances, items of similar content were rated differently, as when the sound of bees buzzing was rated more unpleasant and arousing than a picture of bees.

.07). The correlation between ratings of arousal and sound intensity ($r = .38$) reached significance, but only accounted for 14% of the arousal variance. To determine the extent to which this correlation occurs because physically intense sounds were more likely to be highly arousing (i.e., emotional), the 60 sounds were divided

into 20 pleasant, 20 neutral, and 20 unpleasant sounds, based on their mean valence ratings, and into 20 sounds of low intensity (peak intensity < 75 db), moderate intensity (peak intensity 75–78 db), and high intensity sounds (>78 db). As Table 1 indicates, the number of sounds at each level of physical intensity was comparable in each of the different valence categories, indicating that emotional (i.e., pleasant and unpleasant) sounds were not more likely to be physically intense. In addition, analysis of rated arousal for sounds high in physical intensity resulted in the expected valence effect, $F(2,224) = 279, p < .001$, with higher arousal ratings for unpleasant (mean = 7.5) and pleasant (mean = 6.5) sounds than for neutral, mean = 5.0; quadratic $F(1,112) = 563, p < .001$. Taken together, these data suggest that, whereas sound intensity contributes modestly to rated arousal, effects of emotion remain strong when sounds are matched for high intensity.

Memory Performance

The 9-point rating scale for each dimension was collapsed into a 5-point scale (following Bradley et al., 1992) to assess how recall varied as a function of variations in SAM ratings along dimensions of pleasure and arousal. Level of rated arousal had a clear effect on immediate recall performance, as Figure 3 (top left) illustrates, $F(4,352) = 6.14, p < .0001$. Both the linear and quadratic trends were significant, $F(1,88) = 11.87$ and $F(1,88) = 5.96$, respectively. Follow-up t tests indicated, as Figure 3 illustrates, that incidental free recall for sounds rated as highest in arousal was significantly better than recall of sounds rated at the other four levels of arousal.

Rated pleasantness of the sound also affected the pattern of recall performance (see Figure 3, top right), $F(4,436) = 20.01, p < .0001$. A quadratic trend indicated that memory for both highly pleasant and highly unpleasant sounds was greater than for sounds rated at intermediate positions on the valence scale, $F(1,109) = 58.62, p < .001$. A linear trend, $F(1,109) = 4.43, p = .04$, indicated that recall was slightly better for highly pleasant, compared with highly unpleasant, sounds. Because highly unpleasant and highly pleasant sounds are both rated as high in arousal (see Figure 2), these effects of rated pleasure on memory could be mediated solely by differences in arousal.

To determine whether there was any contribution of pleasantness to memory performance, when controlling for rated arousal, the following data set was constructed. First, the 60 sounds were rank ordered by valence ratings for each subject. The ranks for sounds given identical valence ratings were decided on the basis of the group valence means. The top 30 sounds for each subject were assigned to the pleasant category; the bottom 30 sounds were assigned to the unpleasant category. Within each valence category, sounds were then ranked by their arousal ratings. Ties in this

ranking were decided on the basis of the group arousal means. The top 15 sounds in each of the two valence categories were designated high arousal sounds; the bottom 15 were designated low arousal sounds. This procedure produced, for each subject, a mean recall score for four categories of sounds defined by the combination of valence (pleasant, unpleasant) and arousal (high, low), with 15 sounds in each category.

The mean proportion of sounds recalled as a function of these pleasure and arousal groupings is depicted in Figure 3 (bottom panel). The arousal level of the sound clearly affected recall, with memory for high arousal sounds better than memory for low arousal sounds, $F(1,111) = 49.94, p < .0001$. The lack of a main effect of picture pleasantness argues against a strong role of valence in memory performance, $F < 1$. A significant interaction between pleasure and arousal, $F(1,111) = 6.87, p < .01$, however, indicated that, whereas there was no effect of sound pleasantness when remembering highly arousing sounds, pleasant sounds of low arousal were remembered slightly better than unpleasant, low arousal sounds, $F(1,111) = 5.10, p = .03$ (see Figure 3, bottom).

EXPERIMENT 2

Experiment 1 indicates that sounds are distributed similarly to pictures in the two-dimensional affective space defined by pleasure

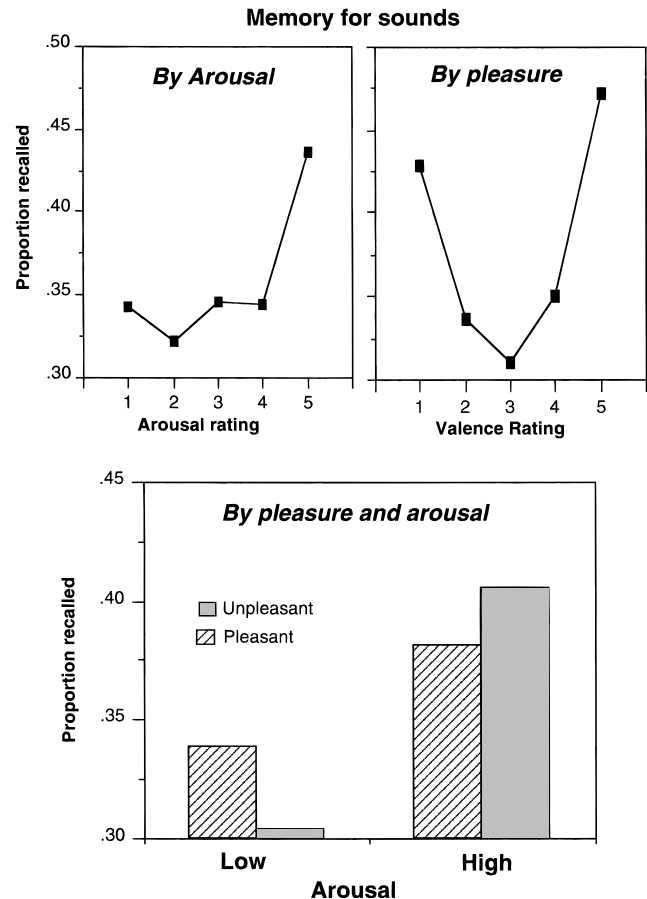


Figure 3. Top panel: Proportion of sounds recalled in an incidental free recall task as a function of the subject's arousal ratings (left panel) or pleasure ratings (right panel). Bottom panel: When pleasure and arousal of the sounds are covaried, free recall is highest for sounds rated as highly arousing, regardless of whether they are pleasant or unpleasant.

Table 1. Number of Affective Sounds in Each of Three Categories Defined by Loudness of Peak Sound Intensity

Valence category	Physical intensity		
	Low (≤75 dB)	Moderate (75–78 dB)	High (>78 dB)
Pleasant	7	5	8
Neutral	8	5	7
Unpleasant	6	5	9

and arousal ratings. In Experiment 2, the 60 sounds rated in Experiment 1 were divided into three categories of unpleasant ($n = 20$), neutral ($n = 20$), and pleasant ($n = 20$) sounds, based on the valence ratings obtained in Experiment 1. Autonomic (heart rate, skin conductance) and somatic (facial EMG) responses, as well as startle reflexes were measured while subjects listened to each sound, and then rated the sound using SAM. The goal was to assess (1) effects of a priori valence on physiological reactions to affective sounds, and (2) the covariation between individuals' affective reports of pleasure and arousal and their physiological response. For comparison purposes, the covariation relationships reported by Lang et al. (1993) when people look at pictures are provided.

Method

Participants

A new group of 67 (35 female) subjects from the University of Florida Introductory Psychology course participated in partial fulfillment of a course requirement. Equipment or recording errors led to missing data in one or more measures, resulting in: $n = 67$ for skin conductance, $n = 65$ for zygomatic EMG, orbicularis oculi EMG, and heart rate; $n = 64$ for corrugator EMG and SAM ratings, and $n = 61$ for startle blink (3 subjects omitted due to essentially no scorable startle responses; 3 due to equipment error).

Materials and Design

The 60 sounds were divided into three categories of pleasant ($n = 20$), neutral ($n = 20$), and unpleasant ($n = 20$) sounds, based on the valence ratings obtained in Experiment 1. Each 6-s sound was presented monophonically over Telephonics headphones, plugged into the RCA mini-plug of a Macintosh computer, and separated by an intertrial interval that varied between 10 and 18 s. The presentation and timing of the sound stimuli and the collection of physiological and self-report data were under the control of a Northgate 386SX-33 MHz (PC-compatible) computer, running VPM physiological data acquisition and experimental control software (Cook, 1994). Pleasure, arousal, and dominance ratings were obtained using the computerized version of the SAM (Lang, 1980), an animated interactive display, controlled by an IBM XT computer running VPM (Cook, Atkinson, & Lang, 1987).

Startle responses were elicited using a visual light flash that consisted of the simultaneous firing of three Rokunar Studio Pro 100 vertically aimed flash units. Units were placed on the floor approximately 30 cm apart, 2.1 m in front of the subject, and reflected off a white ceiling 2.3 m high. To prevent sound contamination from the firing of the flash, each unit was housed in a 7×7 -inch concrete block surround, covered by a $3\frac{1}{8}$ inch diffusing glass block.

Startle probes were presented on half of the 60 trials for each subject, balanced across sound valence (i.e., during 10 pleasant, 10 neutral, and 10 unpleasant). To accomplish this, the 60 sounds were divided into two sets of 30 sounds, and the specific set of 30 sounds probed with a startle stimulus was counterbalanced across subjects. The 60 sounds were presented in 10 blocks of 6 sounds, such that each block contained two unpleasant, two pleasant and two neutral sounds, with one sound of each valence probed with a visual startle stimulus and the other unprobed. Under these constraints, specific sounds were randomly assigned to each trial such that each subject listened to all 60 sounds in a different order. Startle probes were presented pseudorandomly between 3 and 5 s after sound onset.

Physiological Data Collection and Reduction

Physiological data were acquired for 11 s on each trial. Responses were measured for 3 s immediately preceding sound presentation, during the 6 s presentation of each sound, and for 2 s after sound offset.

The eyeblink component of the startle response was measured by recording EMG activity from the orbicularis oculi muscle beneath the left eye. The raw EMG signal was amplified, and frequencies below 90 Hz and above 250 Hz were filtered out, using a Coulbourn S75-01 bioamplifier. Amplification was set at 30,000. The raw signal was rectified and integrated using a Coulbourn S76-01 contour following integrator, with a calibrated time constant of 125 ms. Activity over the orbicularis oculi muscle was sampled at 20 Hz for most of the 11-s trial. Fifty milliseconds before the startle probe was delivered, however, the sampling rate was increased to 1000 Hz and continued at this rate for 250 ms following startle probe onset.

Other facial EMG activity was recorded over the left corrugator and zygomatic sites as recommended by Fridlund and Cacioppo (1986), using Sensormedics Ag-AgCl miniature electrodes and routed through Coulbourn S75 series bioamplifiers. Signals were bandpass filtered from 90 to 1000 Hz, rectified and then integrated using a time constant of 500 ms, and sampled at 20 Hz throughout the 11-s trial period.

Electrocardiograms (EKG) were recorded from the left forearm and the right forearm using Sensormedics Ag-AgCl electrodes filled with electrolyte. The signal was filtered using a Coulbourn S75-01 bioamplifier (with high and low cutoffs set at 40 and 8 Hz, respectively), and a Schmitt trigger interrupted the computer each time it detected a cardiac R-wave. Interbeat intervals were recorded to the nearest millisecond throughout the 11-s trial.

Skin conductance electrodes were placed adjacently on the hypothenar eminence of the left palmar surface, using Sensormedics Ag-AgCl standard electrodes (K-Y jelly; Grey & Smith, 1984; Lang et al., 1993), and sampled at 20 Hz for each 11-s trial. The signal was calibrated prior to each section to detect activity in the range from 0 to 40 microSiemens (μS).

Procedure

After filling out the informed consent, the physiological sensors were attached while the subject reclined in a comfortable chair. The subject was then instructed how to use the computerized SAM display to make ratings of pleasure, arousal, and dominance. Subjects were told to listen to a series of sounds would be presented over the headphones, and to use SAM to rate how they felt while listening to the sound. Subjects were also told to keep their eyes focused on a dot placed on a slide screen in front of them during the experiment, and to ignore any flashes of light that occurred. The room lights were dimmed, and the 60 sounds were presented and rated. After the experiment was completed, the subject was debriefed, given their credits, and thanked.

Data Reduction and Analysis

Startle blinks were scored from activity over the orbicularis oculi muscle using an interactive Macintosh program written by the first author that incorporates the peak scoring algorithm devised by Globisch, Hamm, Schneider, and Vaitl (1993) and outputs, for each scored blink response, an onset latency in milliseconds and peak magnitude in analog-to-digital units. Startle responses were scored as the peak response within a 20–250-ms window following startle probe onset. The raw blinks were standardized within subject to decrease variability due to differences in the absolute size of the

startle blink across subjects, and expressed as t scores (i.e., $(z * 10) + 50$), which produces a mean for each subject of 50 and a standard deviation of 10.

Orbicularis oculi, corrugator, and zygomatic EMG activity, as well as skin conductance and heart rate, were averaged offline into half-second bins in units of the measured system, and then deviated from a 1-s baseline immediately preceding sound onset. For analysis purposes, facial EMG and heart rate changes were averaged over the 6-s sound presentation interval. The maximum skin conductance response was scored as the largest half-second change score in the 1–4-s window following sound onset; a log transformation ($\text{Log}[\text{SCR}+1]$) was conducted to normalize these data (Venables & Christie, 1980).

Mixed model univariate analyses of variance (ANOVAs) were first conducted on each physiological measure averaged over the 20 pleasant, 20 neutral, and 20 unpleasant sounds, based on their a priori valence groupings. Gender (male, female) was a between-subject factor in these analyses and valence (pleasant, neutral, unpleasant) was a repeated measure. To assess whether level of arousal within each valence category affected the basic pattern of findings, a second set of analyses divided each valence category, post hoc, into two sets of sounds that were relatively higher and lower in arousal, based on the arousal ratings obtained in Experiment 1, and effects of arousal were examined. To determine whether presentation of a startle probe affects obtained patterns of physiological reactions (or self-report), a full set of analyses was conducted using only responses averaged across the 30 nonstartled trials (10 pleasant, 10 neutral, 10 unpleasant) for each subject.

To assess the relationship between individual's ratings of pleasure and arousal and their physiological responses, a covariation analysis was conducted, similar to that described in Lang et al. (1993). In this analysis, for each subject, pictures were ranked along each SAM dimension (valence, arousal) from high to low, based on each subject's ratings. If two or more pictures were rated identically on a dimension, group means were used to resolve the tie. This procedure yielded a set of 60 ranked ratings for each

subject on each dimension (or 30 rankings in analyses using non-startled trials only). The dimensional correlation was computed as the Pearson correlation between the mean rating at each rank for each dimension and the physiological response (averaged over subjects); the linear trend was tested in each case. Pearson correlations between affective ratings and physiological response were also computed for each subject, and these correlations were categorized as either exceeding significance ($|r| > .21$; $df = 58$, one-tailed $p < .05$) or not.

Results

Analysis of Reactions to A Priori Valence Categories

Table 2 presents the mean changes in skin conductance, corrugator EMG activity, zygomatic EMG activity, orbicularis oculi EMG activity, and heart rate, as well as ratings of pleasure, arousal, and dominance when listening to pleasant, neutral, and unpleasant sounds. The first three columns in Table 2 list the mean responses averaged over all 60 sounds for each subject; the second set of three columns list the mean responses on the 30 sounds that were not probed with a startle stimulus. There were no differences in results of separate analyses using the full (60 sound) set or partial (30 nonstartled trial) set, and therefore statistics using the full set are reported below. There were no effects involving gender in any of these analyses.

A second set of analyses was conducted to assess effects of physical intensity by crossing sound intensity (low [≤ 75 dB], moderate [$75-78$ dB], high [> 78 dB]) with valence category (pleasant, neutral, unpleasant) in a 3×3 repeated-measures design for each physiological measure. There were no significant effects involving sound intensity in any of these analyses, indicating that level of physical intensity did not affect the pattern of affective reactions reported below.

Startle blink reflex. Figure 4 (top panel) illustrates the pattern of blink modulation obtained when listening to affective sounds.

Table 2. Mean Responses for Physiological and Self-Report Measures of Emotion when Listening to Pleasant, Neutral, or Unpleasant Sounds. SEMs Are in Parentheses

Response System	All Trials ($n = 60$) Valence Category			Non-startled Trials ($n = 30$) Valence Category		
	Pleasant	Neutral	Unpleasant	Pleasant	Neutral	Unpleasant
Corrugator EMG, average change, μv	.04 (.06)	.29 (.08)	.47 (.10)	-.15 (.06)	.17 (.09)	.43 (.12)
Zygomatic EMG average change, μv	.06 (.06)	.00 (.06)	-.01 (.05)	.10 (.08)	.06 (.09)	.03 (.09)
Orbicularis oculi EMG average change, μv	.42 (.08)	.28 (.08)	.42 (.09)	.28 (.08)	.21 (.09)	.34 (.09)
Heart rate average change, (bpm)	-.99 (.21)	-.73 (.21)	-.85 (.22)	-.79 (.28)	-.65 (.25)	-.91 (.29)
Skin conductance log[max change + 1], μS	.03 (.007)	.025 (.005)	.033 (.007)	.032 (.008)	.025 (.006)	.036 (.007)
Pleasure rating 0–20 scale	13.1 (.28)	9.9 (.18)	5.6 (.29)	13.1 (.29)	10.0 (.20)	5.5 (.30)
Arousal rating 0–20 scale	10.3 (.35)	8.6 (.31)	12.3 (.38)	10.5 (.36)	8.5 (.34)	12.3 (.38)
Dominance rating 0–20 scale	11.4 (.39)	10.0 (.36)	5.6 (.41)	11.5 (.40)	10.3 (.38)	5.6 (.39)

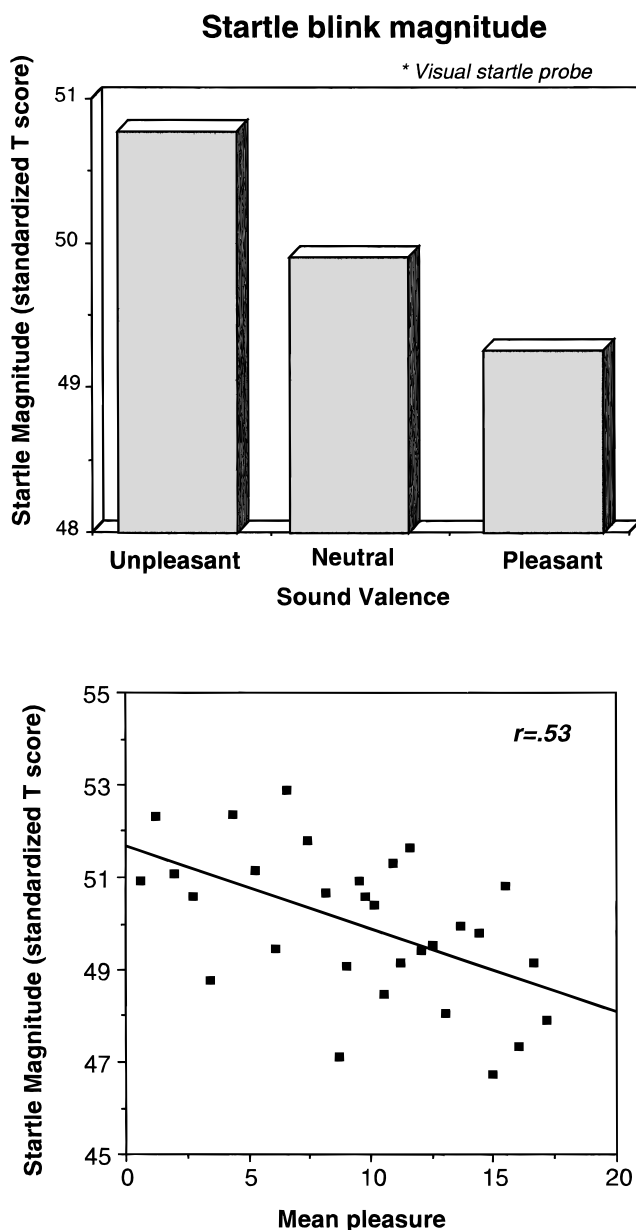


Figure 4. Top panel: Startle blink magnitude is greatest when listening to unpleasant sounds, and smallest when listening to pleasant sounds. Bottom panel: Startle blink magnitude covaries linearly with subjects' valence ratings of affective sounds.

The a priori valence of the sound affected the magnitude of the reflexive blink $F(2, 118) = 3.59$, $p < .03$, with larger blinks elicited to visual startle probes when listening to unpleasant, compared with pleasant, sounds, $F(1, 59) = 8.09$, $p < .01$. Compared with neutral sounds, reflexes elicited when listening to pleasant or unpleasant sounds did not significantly. When sounds were divided into high and low arousal within each valence category, there were no significant interactions involving arousal.

Startle onset latency was also affected by sound valence, $F(2, 118) = 6.18$, $p = .003$. The quadratic trend, $F(1, 59) = 16.38$, $p = .001$, indicates that blink reflexes were faster when listening to emotionally evocative sounds (pleasant [mean = 72 ms] or unpleasant [mean = 72 ms]), compared with when listening to neu-

tral sounds (mean = 76 ms). When sounds were divided into high and low arousal categories within each valence, arousal had no significant effects.

Facial EMG activity. A main effect of sound valence was obtained in analysis of corrugator EMG activity, $F(2, 124) = 11.27$, $p < .001$, with more corrugator activity occurring when listening to unpleasant, compared with pleasant, sounds, $F(1, 62) = 17.5$, $p < .001$. Compared with neutral sounds, corrugator activity was significantly lower when listening to pleasant sounds, $F(1, 62) = 11.36$, $p < .001$, and was marginally greater when listening to unpleasant sounds, $F(1, 62) = 3.62$, $p = .06$. The largest changes in corrugator EMG activity were obtained for sounds of attack (mean change = $1.35 \mu V$), screams (mean = $1.32 \mu V$), and heavy coughing (mean = $.70 \mu V$).

For zygomatic EMG activity, there were no significant differences as a function of sound valence, and, in general, when averaged over the 20 sounds in each valence category, changes in zygomatic activity, although in the predicted direction, were small (see Table 2). The largest changes in zygomatic EMG activity occurred for laughing (mean change = $.62 \mu V$), brushing teeth (mean = $.61 \mu V$), and snoring (mean = $.59 \mu V$).

Activity in the orbicularis oculi muscle (measured beneath the eye) was affected by the affective content of the sound, $F(2, 126) = 4.2$, $p = .02$, with more activity in this muscle when listening to pleasant or unpleasant, compared with neutral sounds, quadratic $F(1, 63) = 6.64$, $p = .01$. The same pattern of elevated activity in the orbicularis oculi muscle for arousing versus neutral stimuli, has also been obtained in picture perception (Bradley, Cuthbert, & Lang, 1991).

Analyses assessing level of arousal within each valence category produced no significant effects involving arousal for any of these facial activity measures.

Heart rate. There were no significant effects of a priori valence category in the analysis of average heart rate change, $F(2, 126) < 1$, (see Table 2 for mean changes). Figure 5 (top panel) illustrates the triphasic heart rate waveform that was obtained when averaging over all the sounds in each valence category, which indicates an initial deceleration, followed by acceleration, and then a secondary deceleration, and it is clear there are no differences as a function of sound pleasure. When sounds were divided into low and high arousal groups within each valence, however, a significant interaction was obtained between valence and arousal, $F(2, 126) = 2.99$, $p = .05$. Follow-up tests indicated that heart rate deceleration was significantly greater when listening to highly arousing unpleasant sounds (-1.36) than when listening to unpleasant sounds that were rated lower in arousal (mean change = $-.44$ bpm), $F(1, 63) = 5.5$, $p = .02$, and when compared with neutral sounds, $F(1, 63) = 4.09$, $p = .048$. Heart rate changes did not vary significantly for pleasant, compared with neutral, sounds.

Figure 5 (bottom) plots the heart rate waveform when listening to highly arousing pleasant and unpleasant sounds, and the inset in this panel illustrates the typical heart rate waveform obtained when people look at affective pictures. It is clear that the heart rate deceleration that occurs when viewing unpleasant pictures is also obtained when listening to unpleasant sounds, but only if these are highly arousing. For unpleasant arousing sounds, the largest heart rate decelerations were obtained for a male scream (-2.90 bpm), a female scream (-2.77 bpm), and sounds of attack (-2.17 bpm). For unpleasant sounds of lower arousal, the heart rate decelerations were smaller with the largest occurring when listening to the

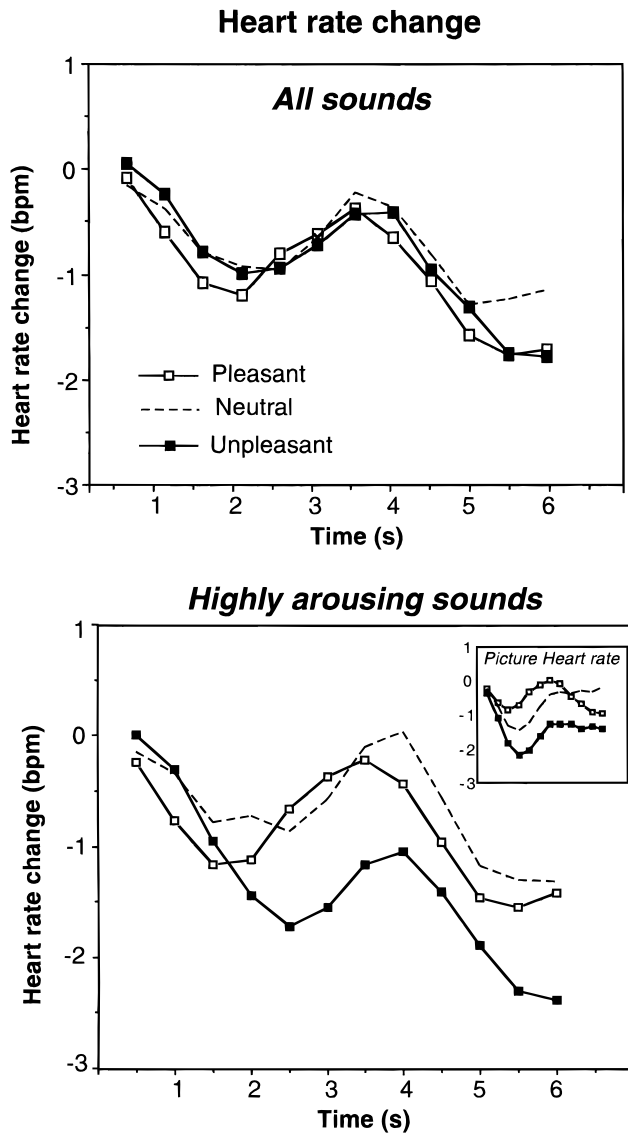


Figure 5. Top panel: Mean heart rate change when listening to pleasant, neutral, and unpleasant sounds across the 6-s presentation interval. Lower panel: When highly arousing sounds are assessed separately, heart rate deceleration is larger during unpleasant sounds, similar to effects of valence on heart rate response that are found when people look at pictures (inset).

sounds of a wild boar (-2.08 bpm), tuning of a radio (-1.85 bpm), and a heavy cough ($-.60$ bpm).

Skin conductance activity. Skin conductance activity was modulated by sound valence, $F(2,130) = 3.08$, $p < .05$, with larger responses elicited when listening to pleasant or unpleasant sounds, compared with neutral, quadratic $F(1,65) = 4.36$, $p = .04$. There was no difference in conductance responses when listening to pleasant or unpleasant sounds, $F(1,65) = 1.25$, $p = .27$. The largest skin conductance changes, however, were obtained for arousing pleasant sounds, including an erotic female (mean = $.06 \mu S$), erotic couple (mean = $.06 \mu S$), and a roller coaster ride (mean = $.05 \mu S$).

Ratings. As would be expected, the a priori valence of the sound stimulus affected both pleasure, $F(2,124) = 298.8$, $p < .001$, and arousal ratings, $F(2,124) = 94.8$, $p < .001$, with pleasure ratings varying linearly with the a priori pleasantness of the sound stimulus. Pleasant and unpleasant sounds were both rated as more arousing than neutral sounds, quadratic trend $F(1,62) = 166.9$, $p < .001$, and unpleasant sounds were rated as more arousing than pleasant sounds, linear trend $F(1,62) = 46.4$, $p < .001$. As Table 2 indicates, dominance ratings mirrored pleasure ratings, $F(1,62) = 203.25$ (as found with picture stimuli; Lang et al., 1993), suggesting that this third dimension, normally accounting for a much smaller portion of the variance in emotion judgments, does not add new information in the relatively passive perception context.

Covariation of Affective Ratings and Physiological Response

As noted above, a goal of this study was to assess the relationship between individual's ratings of pleasure and arousal and their physiological responses, as we have done previously with picture stimuli (e.g., Lang et al., 1993). In these analyses, the central question concerns whether physiological changes show systematic variation as ratings of pleasure or arousal increase (or decrease).

Facial EMG activity and rated pleasure. Figure 6 (top) illustrates changes in corrugator EMG activity when listening to sounds that were rank-ordered by each subject's pleasure ratings. Corrugator EMG activity was inversely related to judgments of pleasure, as the linear trend indicates, $F(1,58) = 78.3$, $p < .001$. The dimensional correlation between the mean rating at each rank and corrugator EMG activity was high ($-.76$, see Figure 6, inset) when all 60 trials were included in the analysis, and even higher when the analysis was restricted to the 30 trials in which no startle probe was presented ($r = -.85$). Figure 6 (bottom) illustrates the similar relationship previously found between judgments of pleasure and corrugator EMG activity when looking at pictures.

Eighty-three percent of the subjects show the expected negative correlation between valence ratings and corrugator EMG activity, which compares favorably to the 80% found when subjects look at pictures (Lang et al., 1993). Of those showing the expected relationship, 43% showed a significant correlation between judged pleasantness and corrugator EMG activity, which is slightly fewer than the 52% obtained when subjects look at pictures (Lang et al., 1993). When listening to sounds, 45% of the women and 45% of the men showed significant correlations between corrugator EMG activity and pleasure ratings. When looking at pictures, however, there was a larger proportion of women showing a significant correlation (.67), compared with men (.35).

Zygomatic EMG activity and ratings of pleasure showed a modest and significant linear dimensional correlation, $r = .35$, $F(1,58) = 7.98$, $p < .01$, with zygomatic EMG activity increasing as ratings of pleasantness increased. Consistent with this finding, Lang et al. (1993) also reported a significant linear correlation between zygomatic EMG and valence ratings, $r = .57$. Sixty-nine percent of the subjects listening to sounds showed a correlation in the expected direction, with a larger proportion of women (.25) showing a significant correlation than men (.10).

During picture viewing, Lang et al. (1993) found that the quadratic relationship between zygomatic EMG and pleasure ($r = .90$) was higher than the linear correlation ($r = .57$), indicating that zygomatic EMG was higher for both highly pleasant and highly unpleasant pictures, compared with neutral pictures. The quadratic correlation when listening to sounds was more modest ($r = .36$), but still significant.

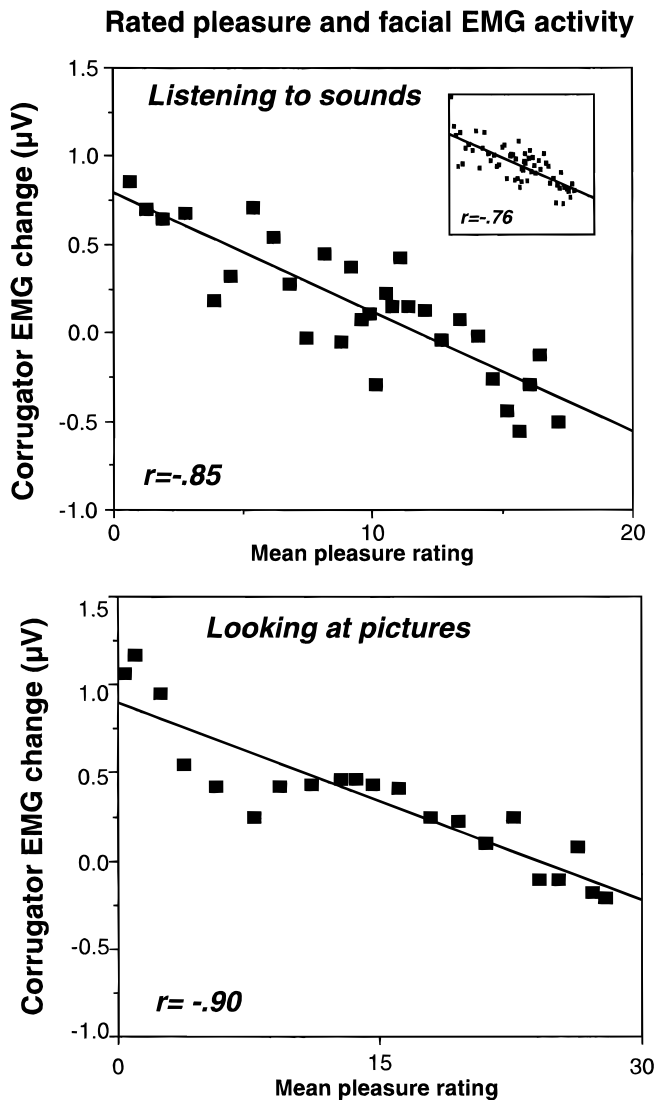


Figure 6. Top panel: Corrugator electromyographic (EMG) activity is linearly related to subjects' valence ratings across all 60 sound stimuli. As the sounds become increasingly unpleasant, corrugator EMG activity increases, similar to the function obtained between this facial EMG index and valence ratings when people look at pictures (bottom panel; from Lang et al., 1993). The inset in the top panel illustrates the relationship between corrugator EMG activity and rated pleasure for the 30 trials in which no startle probe was presented.

Startle blink and rated pleasure. Startle blink magnitude showed a relatively large dimensional correlation with ratings of pleasure, $r = -.53$, $F(1,28) = 9.87$, $p = .004$, with startle blinks increasing as ratings of pleasantness decreased (see bottom, Figure 4). About 55% of the subjects showed a correlation in this direction, with about 8% of this sample showing a correlation large enough to reach significance. Because startle magnitude changes with repeated reflex elicitation, correlations involving single trials may be dampened due to these effects. Although blink onset was found to be significantly faster for emotionally arousing sounds in the analysis of the a priori valence categories (see above), the relationship between blink onset and rated arousal was fairly weak and did not reach significance, $r = .20$.

Autonomic activity. Skin conductance responses increased with increases in rated arousal, resulting in a small, but significant dimensional correlation, $r = .26$, $F(1,58) = 4.11$, $p < .05$. Sixty-nine percent of the subjects showed a correlation in the expected direction. The correlation between skin conductance activity and arousal ratings was much stronger when viewing pictures ($r = .81$; Lang et al., 1993). In particular, when viewing pictures, 48% of the men showed significant correlations between conductance response and rated arousal, compared with only 19% of the men when listening to sounds. For women, the proportion showing significant correlations was comparable when listening to sounds (.18) or looking at pictures (.18).

Heart rate change did not consistently covary with either ratings of pleasure or arousal in this study. When indices of initial deceleration (i.e., maximum deceleration in the first 2 s) or peak acceleration (maximum acceleration in the 6-s interval) were assessed instead of average heart rate change across the whole 6-s interval, no significant dimensional correlations were obtained as a function of either pleasure or arousal ratings.

Affective ratings. The correlation between SAM ratings of pleasure in Experiment 2 (using a 20-point computerized SAM instrument) and in Experiment 1 (using a 9-point paper and pencil version of SAM) was .98; for arousal ratings, the correlation was .96. Not only do these data indicate that the two SAM instruments agree well (as found previously for pictures, Lang et al., 1993), but they also indicate that the affective ratings of these sound stimuli are stable across different subject samples.

DISCUSSION

The 60 sounds tested here varied widely in rated pleasure and arousal, and resulted in a two-dimensional affective space whose shape was similar to that obtained previously for pictures (Lang et al., 1993). The shape of this space is consistent with the notion that two motivational systems of appetitive and defensive motivation underlie affective judgments, as illustrated in Figure 1. Reports of valence primarily index which motivational system is active; reports of arousal index increased activation, intensity, or engagement within each system. As we have discussed more fully elsewhere (e.g., Lang, Bradley, & Cuthbert, 1997), pleasure and arousal can be considered to be motivational parameters, signaling which system is activated and to what degree.

In general, the pattern of physiological reactions elicited when listening to affective sounds was similar to those that occur when people look at affective pictures. In particular, corrugator EMG activity showed strong effects of a priori valence, with more activity in this muscle when listening to unpleasant sounds, and less activity when listening to pleasant sounds, compared with neutral sounds. Larger startle reflexes were elicited when listening to unpleasant, compared with pleasant, sounds. And, similar to picture viewing, skin conductance responses were significantly greater when listening to emotional, compared with neutral, sounds. The pattern of memory performance for affective sounds also mirrored that obtained previously for affective pictures (Bradley et al., 1992). Highly arousing sounds (either pleasant or unpleasant) were remembered better than sounds rated lower in arousal.

Taken together, these data indicate more similarities than differences in physiological, self-report, and behavioral (e.g., memory) measures when processing affective sounds and pictures. Rather than showing effects different from picture viewing, the patterns of modulation across all measures were either identical or similar, but

weaker, when listening to sounds. A number of factors could contribute to this difference, including (1) the specific exemplars and categories in the current stimulus set, (2) effects due to stimulus modality, and (3) the dynamic versus static nature of sounds and still pictures.

Compared with previous studies, the number of sounds tested in the current study is extensive, and we made an effort to sample widely across different types of environmentally relevant stimuli. Nonetheless, the number of different exemplars in specific semantic categories was small, with, for example, only two sounds related to erotica. Recent studies have indicated that, in picture viewing, highly arousing stimuli are more potent than others in modulating emotional response, with erotica, for instance, very effective in inhibiting the startle reflex (e.g., Bradley, Codispoti, Cuthbert, & Lang, 1998; Cuthbert, Bradley, & Lang, 1996). Inclusion of a larger number of stimuli from affectively potent categories could lead to stronger effects of emotion than obtained in this initial investigation.

A weaker pattern of affective modulation for sounds could also reflect real modality differences in processing visual and acoustic cues. For instance, acoustic stimuli could be characterized as more insistent, in terms of perceptual processing, than visual stimuli: One can close or avert one's eyes when looking at a picture, but there is no comparable way to "shut your ears." This hypothesis might predict that absolute changes in reactivity would be larger for sounds than pictures, however, and, based on our experience with the picture paradigm, the size of physiological changes when listening to sound stimuli did not seem unusually large. Second, it is possible that access to motivational systems is weaker or less probable for sound versus picture cues. This could occur if the neurocircuitry that routes visual or acoustic information to the subcortical circuits presumably mediating emotion differ in fundamental ways. Amaral, Price, Pitkanen, and Carmichael (1992) found that for nonhuman primates, who rely heavily on visual information, there are more extensive inputs from visual cortex to the amygdala, a subcortical structure heavily implicated in emotional responding, compared with other modalities. Conversely, for the rat, smell dominates the inputs to the amygdala. Whether sheer number of inputs is related to strength of activation remains to be tested, however.

A third factor of potential importance concerns the fact that sounds change dynamically across the presentation interval, whereas pictures do not. Because new sensory information is added serially during sound presentation, physiological systems that respond to simple changes in the physical stimulus may be continuously active, making affective signals difficult to detect. Information change over time can also obviously occur in visual affective processing, such as when films constitute the foreground stimulus. In a recent study investigating effects of visual motion (without a soundtrack) on affective response, Simons, Detenber, Roedema, and Reiss (1998) found sustained heart rate deceleration when subjects viewed moving, compared with still, pictures, suggesting a continued orienting over presentation time, greater for dynamically changing than for static, visual stimuli. Ratings of arousal were also higher for dynamic, compared with static, visual images. Because sound is inherently serial in nature, the study of dynamic versus static forms of stimulus presentation may be best to manipulate in the visual modality, as Simons et al. (1998) have done.

Over the past 10 years, we have learned much about affective picture processing. Physiological responses elicited by these visual stimuli appear to be organized fundamentally along dimensions of pleasure and arousal, implicating underlying motivational systems of appetite and defense. Broadening the investigation to include acoustic stimuli allows us to explore the reliability of these affective measures across sensory modality. Because similar patterns were obtained, the data provide support for the idea that a number of physiological systems are primarily sensitive to emotional activation, rather than to the specific mode of presentation, and suggest a methodology for sorting out the significant affect signal from physiological reactions mediated solely by the transient physical features of stimuli. This exercise is increasingly important as we begin to explore emotion circuits in the living brain, using methods such as positron emission tomography, functional magnetic resonance imaging, electroencephalography, or magnetoencephalography. Using stimuli in different modalities that are comparable in pleasure and arousal provides an essential methods check in neuroimaging, as well as in psychophysiological, paradigms, permitting a more precise determination of which neural and physiological events are related to emotion and which derive more generally from stimulus modality or medium.

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