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A DERIVED TRANSFER OF ELICITING EMOTIONAL FUNCTIONS USING DIFFERENCES AMONG ELECTROENCEPHALOGRAMS AS A DEPENDENT MEASURE

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Emotional responses have specific electroencephalographic (EEG) signatures that arise within a few hundred milliseconds post-stimulus onset. In this experiment, EEG measures were employed to assess for transfer of emotional functions across three 3-member equivalence classes in an extension of Dougher, Auguston, Markham, Greenway, & Wulfert's (1994) seminal work on the transfer of arousal functions. Specifically, 12 human participants were trained in the following match-to-sample performances A1 = B1, A2 = B2, A3 = B3 and B1 = C1, B2 = C2, B3 = C3. After successfully testing for the emergence of symmetry relations (B1 = A1, B2 = A2, B3 = A3 and C1 = B1, C2 = B2, C3 = B3), visual images depicting emotionally positive and emotionally negative content were presented with A1 and A3, respectively, using a mixed stimulus pairing–compounding procedure. A2 was paired with emotionally neutral images. Next, EEG data were recorded as participants were exposed to a forced-choice recognition task with stimuli A1, B1, C1, A2, B2, C2, A3, B3, C3 and three novel stimuli A4, B4 and C4. Results yielded differential EEG effects for stimuli paired directly with emotional versus neutral images. Critically, differential EEG effects were also recorded across the C stimuli that were equivalently related to the A stimulus set. The EEG data coincide with previous reports of emotion-specific EEG effects, indicating that the initial emotional impact of a stimulus may emerge based on direct stimulus pairing and derived stimulus relations.

Key words: equivalence classes, emotion, valence, affective neuroscience

Many of us are aware of how we seemingly develop and exhibit evaluative responses towards individuals and/or objects which we have never previously encountered, based solely upon their appearance (Kates, 1959). From a behavior-analytic perspective, Pavlovian conditioning and stimulus generalization processes have often been used to explain how initially neutral stimuli may come to acquire appetitive or aversive properties (Cartwright, 2000; Le Pelley et al., 2010; Watson & Raynor, 1920; Winberg, 2005). For example, if individual A behaves in a manner which is perceived to be aversive leading to the avoidant behavior of individual B, it is possible that another individual C, who looks a little like A, can acquire similar aversive properties when encountered initially by B. Functionally, the initial evaluation of any stimulus object, including other persons, involves the degree to which perceived likeability (valence) towards the target object changes due to well-established behavioral processes, such as classical conditioning and stimulus generalization (Domjan, 2005). Here, 'valence' simply refers to the *degree* to which a target stimulus is deemed appetitive (positively valenced) or aversive (negatively valenced) (Colombetti, 2005; Fazio, Eiser & Shook, 2004; Tolman, 1932).

Another behavioral process by which the valence of a stimulus may be established involves the derived transfer of stimulus functions through equivalence relations (Dougher, Augustson, Markham, Greenway, & Wulfert, 1994). This process is said to occur when a specific function established for one stimulus in an equivalence class transfers to other stimuli in the class. Imagine, for example, that a person is taught to match a novel stimulus A with another novel stimulus B and to match B with a third stimulus C and then demonstrates the formation of an equivalence relation (e.g., by matching C to A in the absence of differential reinforcement). If A is then used to predict the delivery of mild electric shock, and thus elicits evidence of fear, this fear function may also transfer to the B and C stimuli. Critically, the aversive properties observed for the B and C

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stimuli emerge due to their participation in a derived equivalence relation with A, rather than through a) direct pairings or association with the delivery of shock, or b) stimulus generalization. Almost 20 years ago, Dougher, Augustson et al. (1994) demonstrated this exact phenomenon in a seminal study; participants were trained to form two 4-member equivalence classes, A1–B1–C1–D1 and A2–B2–C2–D2, where a stimulus from the first equivalence class (B1) was repeatedly paired with electric shock until it came to elicit reactions indicative of physiological arousal (i.e., increased skin conductance). Subsequent measurements showed predicted variations in skin conductance levels in participants who were exposed to other members of the same stimulus class (i.e., A1 and C1) even though those stimuli had never been paired with shock. This basic effect has been replicated and extended to other arousal functions across a range of studies (e.g., Dymond & Rehfeldt, 2000; Perkins, Dougher & Greenway, 2007; Smyth, Barnes-Holmes & Forsyth, 2006).

Outside the stimulus-equivalence literature, studies utilizing temporally precise behavioral and neurological measures have demonstrated effects indicative of differential stimulus valence within 100–200 ms of being presented with a specific stimulus, not necessarily accompanied by any overt behavioral response (Luck, 1998; Wargo, 2006). Given the short time frame and low magnitude of the response, the current study used electroencephalographic (EEG) measures to assess the derived transformation of emotional functions. At the time of writing, no published study has attempted to use EEG measures to assess a derived transfer of emotional functions.

Although electrophysiological measures have been used to measure cortical activity in humans for almost a century (Berger, 1929), the use of such techniques in the measurement of emotional responding specifically is a somewhat more recent development (Davidson, 1998). Event-related potentials (ERPs) are EEG waveforms which illustrate the time signatures of electrical activity in the brain in relation to the onset of behavioral, cognitive, and emotional events, such as pressing a key, thinking about a word or viewing a visual image with emotional content (Hinojosa, Carretie, Valcarcel, Mendez-Bertolo & Pozo, 2009). Critically, certain ERP components deemed representative of emotional effects can be detected from 100 ms poststimulus onset (Smith, Dolan, & Rugg, 2004), rendering such effects more directly relevant in assessing the transfer of emotional functions across equivalence classes.

Two ERP components in particular have been identified in relation to emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Hinojosa, Bertolo & Pozo, 2010; Hinojosa et al., 2009; Jaeger, Johnson, Corona & Rugg, 2009; Maratos, Dolan, Morris, Henson, & Rugg, 2001; Smith et al., 2004). The first component is an early "negative-going" waveform that typically peaks 100–250 ms poststimulus onset over parietal-occipital and frontal-central sites (Junghöfer, Bradley, Elbert, & Lang, 2001; Makeig et al., 1999). This negative waveform is the amplitude difference seen between ERPs elicited by emotional and neutral stimuli (Smith et al., 2004). This difference is particularly prevalent when emotional stimuli are deemed "positive" or appetitive, such as pictures of babies and puppies (Bayer, Sommer & Schacht, 2010; Bradley, Hamby, Low & Lang, 2007; Schupp, Markus, Weike & Hamm, 2003). Given that this early negativity is typically recorded over posterior sites it is sometimes termed an 'early posterior negativity,' or EPN (Maratos et al., 2001) although the effect can be observed over anterior regions as well (Makeig et al., 1999).

A second component is the 'late positive potential', or LPP, a positive-going waveform that can be seen over frontal-parietal regions (Hinajosa et al., 2009; Smith et al., 2004). The LPP can be observed as an increasing discrepancy in the elicited P300 component that arises after the presentation of a visual image with emotional content, or a stimulus presented in an emotional context. The waveform can be observed usually 350–600 ms poststimulus onset and can last anywhere up to 1000 ms (Hinojosa et al., 2010; Jaeger et al., 2009; Smith et al., 2004; Schupp et al., 2004). Similar to the EPN, there are contradictory reports as to whether LPP amplitude is a function of emotional valence or arousal, although recent reports suggest it may be primarily indicative of valence (Bayer et al., 2010; Foti & Hajcak, 2008; Leite et al., 2012; Schupp, Markus, Weike & Hamm, 2003).

Researchers have confirmed that both ERP components occur in the presence of emotional pictures and words, though the effect is greater for emotional images (Hinojosa et al., 2010; Leite et al., 2012; Maratos et al., 2001; Smith

et al., 2004). These studies suggest that viewing emotional imagery is associated with higher levels of physiological arousal than emotional words, perhaps due to the greater evolutionary significance of visual imagery (Junghöfer et al., 2001). In any case, both components have been shown unequivocally to occur in response to emotion-eliciting images (Cuthbert et al., 2000; Delplanque, Silvert, Hot, Rigoulot, & Sequeira, 2006; Hajcak & Nieuwenhuis, 2006; Hinojosa et al., 2010; Maratos et al., 2001; Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp et al., 2003; Smith et al., 2004). Given the successful replication of these ERP components across numerous studies with large numbers of participants under controlled conditions, one may assume them to be reflective of emotional effects in human populations.

The primary purpose of the current study was to determine if the EPN and LPP waveforms were sensitive to the derived transfer of emotional functions across the members of equivalence classes. As such, the research constituted a partial replication of the seminal work reported by Dougher, Augustson et al. (1994), but using an electrophysiological measure of cortical activity rather than a measure of the sympathetic nervous system (i.e., skin conductance). The current study also differed from the research reported by Dougher, Augustson et al. by focusing on emotional *valence* as well as arousal. The eliciting functions of the stimuli we sought to transfer were produced using visual images with preestablished valence and arousal ratings rather than the delivery of electric shock.

The current experiment was conducted across three phases. First, participants were trained and tested for the formation of three 3-member equivalence classes (A1 = B1 = C1, A2 = B2 = C2 and A3 = B3 = C3) using a match-to-sample (MTS) conditional discrimination procedure (e.g., Barnes & Keenan, 1993; Dougher, 1998). In the second phase, the A stimuli were paired directly with images taken from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 1995) using a modified trace conditioning method (see Procedure). The pictorial stimuli consisted of images that had been deemed appetitive, aversive, and functionally neutral, with no differences in self-reported arousal ratings between image types, as noted by Ito, Cacioppo and Lang (1998). Critically, A1 was paired with appetitive images, A2 with neutral images and A3 with aversive images. In the final phase, participants were exposed to a forced-choice recognition task (Egan, 1958) during which they viewed the stimuli from the equivalence classes as well as novel stimuli, and indicated whether or not they had seen the item previously in the experiment. The main prediction was that differential EEG waveforms would be observed for the A1 and A3 stimuli that had been paired with emotional images, as well as their equivalent B and C class members (B1, B3, C1, C3), relative to the baseline waveforms observed for the A2 stimuli (and the equivalence class members B2 and C2) that had been paired with neutral images. EEG waveforms elicited by stimuli in the equivalence classes were also compared to those elicited by a second set of stimuli (A4, B4 and C4) that were not presented during the equivalence training and stimulus pairing procedures. As the A4–B4–C4 stimuli had not been paired with emotion-inducing stimuli, it is predicted that there will be no differences in ERPs elicited by A2–B2–C2 (paired with emotionally neutral imagery) and A4–B4–C4 stimuli during the prespecified EEG time windows.

Method

Participants

Twelve undergraduate psychology students from Saint Mary's University (Mode = 21 years of age) were recruited through online postings in exchange for course credit with approval from the Saint Mary's University Research Ethics Board. All participants were right-handed, native English speakers with normal or corrected-to-normal vision. The sole exclusionary criterion for participation was to have no prior knowledge of the Bengali language, from which characters were taken for the B stimulus set. Four participants wore corrective lenses, which they had to remove during the EEG recording phase of the experiment; nonetheless, they were able to discriminate accurately among the various characters in all phases of the experiment. The data from one of the participants had to be excluded from the final analysis due to excessive eye movement artefacts and electronic interference from popcorn being cooked in a microwave oven in the adjacent room, leading to a final sample of $n = 11$. Participants performed the experiment in a 430 cm x 350 cm x 305 cm whitewashed room within a

temperature range of 23 ± 1.5° Celsius. All participants were instructed to face a 42.7 cm Dell computer screen from a length of 69 ± 5 cm at a viewing angle of −29 ± 1°, in accordance with the optimal viewing distance and angles for preventing excessive visual convergence and potential electromagnetic interference (Jaschinski-Kruza, 1991; Von-Noorden, 1985, pp. 81–83). Two 40-watt, 122-cm General Electric fluorescent tubes illuminated the room with full luminosity for the first 80 min of the experiment prior to recording EEGs. During the EEG recording phase, both tubes were shut off to prevent excessive electromagnetic interference. The experiment took approximately 150 min to complete per participant.

Apparatus

The stimulus sets used for training and testing of equivalence relations consisted of Arabic numerals (stimulus Set A), characters from the Bengali language (stimulus Set B) and arrowheads (stimulus Set C), respectively. The stimuli Sets 'A' and 'C' were acquired from Microsoft Word 2007 and modified using Poster 8 image-editing software. The stimuli designated Set 'B' were created on Microsoft Paint. All stimuli were matched on the spatial dimensions of their outlying borders (2.3 cm x 2.5 cm) and contrast ratio (495:1 to 505:1 candela/m^2) to limit topography and luminosity incongruence during all phases of the experiment. There were three stimuli in each set (A1/A2/A3, B1/B2/B3, C1/C2/C3) with which participants were trained to form three 3-member equivalence classes. All stimuli were presented in black ink against a white background, the only exception being the IAPS images that were displayed in color on the 42.7-cm screen during the stimulus pairing phase.

Nine images from the IAPS (Lang et al., 1995) were selected based on their normative valence ratings and correspondingly identified as Positive, Negative, or Neutral (see Table 1). All images subtended maximum vertical and horizontal angles of 14.2° and 17.3°, respectively, at the 73.9-cm viewing distance. The images depicted a car crash, a kidnapping, a gun, an elderly man, a woman tourist, a lamp, piles of money, a ski resort, and a young bride. The IAPS identifications (Lang et al., 1995) for the images used are 9920, 6312, 6230, 2190, 2850, 7175, 8501, 8030 and 2209, respectively. Mean arousal ratings of Positive and Negative images had been matched so as to isolate any observable differences in the requisite ERPs as reflective of valence effects, as seen by Bayer et al. (2010). All experimental tasks were programmed using E-Prime 2.0 software on a dual-screen Dell 2.53 GHz Optiplex 755 computer running Microsoft Windows XP (v. 2002) based on paradigms typically used in derived relational responding and emotion research (Healy, Barnes-Holmes, & Smeets, 2000; Lang et al., 1995). Participants responded on all tasks by pressing keys on a response pad synchronized both to E-Prime and Net Station software, the latter installed on an Apple 2.66 GHz Quad-Core Intel Xeon running Mac OS 10.5.6.

The EEG data were collected using a 32-channel Geodesic HydroCel Sensor Array. The locations of the cap electrodes were based on the International 10–20 system and corresponded to midline sites from anterior to posterior electrode sites (Fz, Cz, Pz, Oz) as well as hemitropic (left/right) pairs of sites (Fp1/Fp2, F3/F4, C3/C4, T3/

Table 1

Normative Ratings of Images along Valence, Arousal and Dominance Dimensions

ID	Description	Mean Valence	Mean Arousal	Stimulus paired
2190	Old man (neutral)	4.83	2.41	A2
2850	Tourist (neutral)	5.22	3.00	A2
7175	Lamp (neutral)	4.87	1.72	A2
2209	Bride (positive)	7.64	5.59	A1
8030	Skier (positive)	7.33	7.35	A1
8501	Money (positive)	7.91	6.44	A1
6230	Aimed gun (negative)	2.37	7.35	A3
6312	Abduction (negative)	2.48	6.37	A3
9920	Auto accident (negative)	2.50	5.76	A3

Note. From "International affective picture system (IAPS): affective ratings of pictures and instruction manual" by Lang et al., 2008. University of Florida

T4, P3/P4, O1/O2). Data were acquired with EGI Net Amps 300 at a 275 Hz sampling rate and an amplifier bandwidth of 0.01–40 Hz. Electrode impedances were adjusted to below 50 Ω. Offline, EEG data were epoched to 1048 ms with a 100-ms prestimulus baseline. Observed time courses were to be segmented into three windows of 100–200, 300–450, and 600–1000 ms, which corresponds with the latency ranges of the target ERPs.

Procedure

Phase 1. In the first phase, two conditional discrimination (CD) procedures were used to train participants to form three 3-member equivalence classes (for a sample trial sequence, see Figure 1). A response keypad with four designated response keys, '1', '2', '3' and '4' (positioned from left to right) was placed 15.2 cm in front of the computer monitor at an angle of 23.2 degrees in respect to the screen center (key '4' was only used in the final phase of the procedure). Each CD procedure consisted of 10 training blocks with 18 trials in each block. The 18 trials were presented in a quasirandom order within each trial depicting one sample stimulus and three comparison stimuli, including one which was designated the correct (target) stimulus. The following instructions were presented:

> Welcome! You will see a number/character/arrow on top of the screen, and three symbols below it. Each number/character/arrow is to be matched with one of the three comparison stimuli below it. To match with the stimulus on the LEFT, press '1'. To match with the stimulus in the MIDDLE, press '2'. To match with the stimulus on the RIGHT, press '3'. You will receive feedback for correct/incorrect responses. Try to be as accurate as you can. Press any key to continue…"

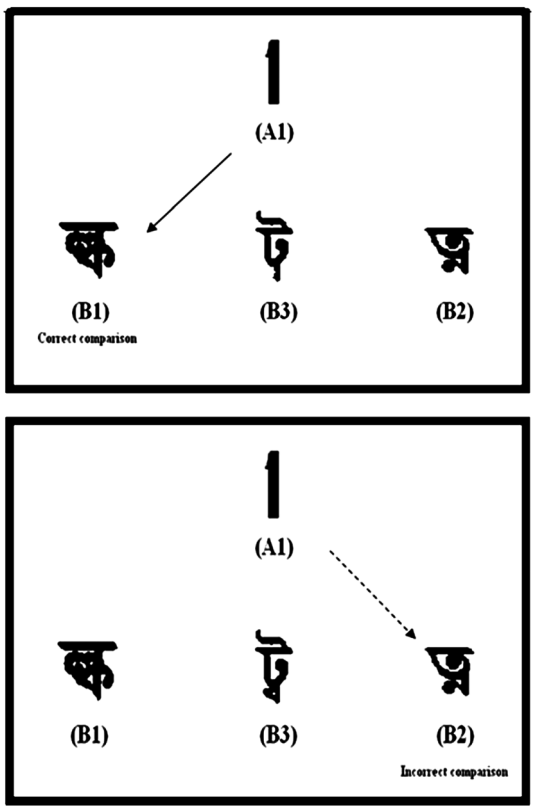

Fig. 1. Illustration of a sample trial-type from matching-to-sample training in Phase 1: A1 is the sample stimulus from stimulus set A (English numerals) and the B comparison stimuli, that is, B1, B2 or B3, are taken from stimulus set B (Bangla characters). In the illustrated example, selecting B1 would be followed by "Correct!" (upper panel) while selecting any of the incorrect comparisons would be followed by "Incorrect" (bottom panel).

After pressing a key on the response box, the trial initiated with the presentation of a sample stimulus from Set A (Arabic numerals) placed 5 cm above the center of the screen and three comparison stimuli from Set B (Bengali characters) located 5 cm below the center of the screen. All characters in the bottom sequence were spaced 7.1 cm apart. To choose a comparison, participants pressed the numeric key corresponding to the spatial location of the chosen comparison stimulus (i.e., choosing the left, middle, and right comparisons required pressing the '1', '2' or '3' keys, respectively; see Figure 1). If no response was detected before 5000 ms, a message stating "Too slow…" was presented on screen for 1000 ms after which the screen cleared and the next trial was presented. If a participant made a response within the 5000 ms window, either the word "Correct!" was presented in green if the response was deemed correct, or the word "Incorrect" was presented in red if the response was deemed incorrect.

Participants were first trained in the three A–B matching tasks. On each trial one of the A stimuli (A1, A2, or A3) was presented as a sample

stimulus along with the three B comparison stimuli (B1, B2, and B3). These three trial types were presented quasirandomly with each task being presented six times within each training block (18 training trials per block). Participants were required to emit a sequence of 20 consecutively correct responses to complete the A–B training. Subsequently, participants were tested for the emergence of B–A symmetry relations. Participants were required to produce 20 consecutively correct responses (matching B1 to A1, B2 to A2, and B3 to A3) in the absence of corrective feedback. If a participant failed to respond within 5000 ms on any trial, this was deemed an incorrect response, the screen cleared, and the next trial was presented immediately (the "Too Slow" message was not presented during testing). All participants successfully completed A–B training and demonstrated B–A symmetry.

A similar procedure was then used to train the three B–C relations and test for the C–B symmetry relations. Again, participants were required to emit 20 consecutively correct symmetry responses in the absence of corrective feedback to progress to Phase 2. Note that participants were not exposed to a test for combined symmetry and transitivity relations at this stage because doing so would involve presenting the A and C stimuli together on screen, and thus any evidence of subsequent transfer of emotional functions might be based to some extent on these direct A–C pairings (see Barnes & Keenan, 1993).

Phase 2. After completing Phase 1, participants underwent a stimulus pairing procedure in which stimuli from Set A were paired with images of neutral and emotional content (IAPS; Lang et al., 1995). All images were classified under one of three categories based on their normative valence and arousal ratings (from Ito et al., 1998). The three categories were designated Neutral, Positive and Negative (see Table 1 for IAPS image ratings). As shown in Figure 2, each

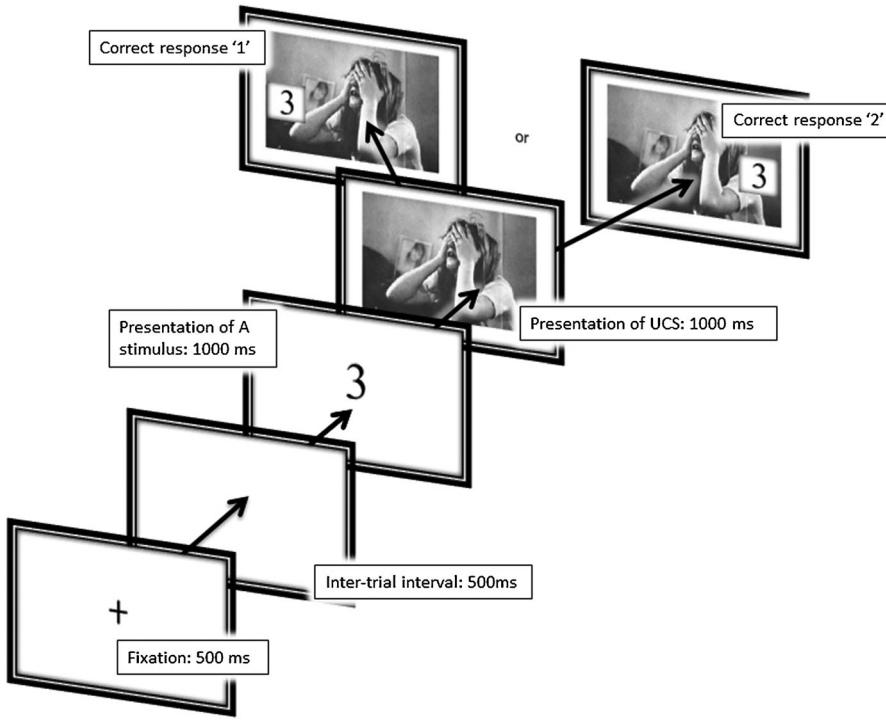

Fig. 2. Schematic illustration of the mixed stimulus pairing–compounding procedure. Trials would initiate with a fixation screen for 500 ms, followed by a sample stimulus from stimulus set A after an intertrial interval (blank white screen) of 500 ms. The A stimulus would remain on screen for 1000 ms, after which an image with either emotionally neutral or emotionally salient content would be presented for another 1000 ms. Finally, the sample stimulus initially presented ('3' in the above example) would reappear on either the left or right side of the display, requiring the participant to indicate which side the stimulus is displayed by pressing the corresponding key on the response pad.
Note: the image shown above is not from the IAPS.

trial displayed one stimulus from Set A and, subsequently, one IAPS image. There were nine trial types in total, each presented 10 times over the training block in a quasirandom sequence. Specifically, Stimulus A1 preceded the presentation of emotionally positive images of a bride, a skier, or piles of money. A3 was presented before the subsequent presentation of negative images of a gun aimed at the computer screen, a car crash, or a lady being abducted. A2 preceded the presentation of neutral images of an old man, a table lamp, or a middle-aged lady. At the beginning of phase 2, the following instructions were presented:

> "Welcome to Phase 2! You will see a blank screen with a cross, followed by a NUMBER presented at the center of the screen. Next, an IMAGE will appear in the foreground in front of the number. Please attend to the image closely. Finally, the NUMBER will reappear on either side of the IMAGE. If the NUMBER appears on the LEFT, press '1'. If the NUMBER appears on the RIGHT, press '3'. Remember to respond as soon as you see the number. Repeat for the duration of the phase.
>
> Press any key to continue…"

As shown in Figure 2, trials began with a black fixation cross (1.3 cm x 1.3 cm) against a white background for 500 ms. Depending on the trial type, stimulus A1/A2/A3 would then appear on screen for 1000 ms, followed by a blank screen for 500 ms. Next, a visual image depicting either emotionally positive, negative or neutral content would appear on the screen. After 1000 ms, the A stimulus that was presented at the initiation of the trial reappeared at either the left or right side of the screen, 14 cm from the screen center, superimposed over the IAPS image. Correct responses were as described in the instructions. Correct responses were followed by a blank, white screen for 1000 ms. Incorrect responses were followed by the on-screen message "Please try again" which was displayed for 1000 ms and followed by a repeat of the preceding trial. For each trial, participants had 5000 ms to press a button on the response pad after the A stimulus was displayed; if a participant did not respond in time, the "Too slow…" message was displayed for 1000 ms and the trial was repeated. The training criterion for Phase 2 entailed responding accurately for a minimum of 80 trials (out of the 90 trial block).

Phase 3. At the beginning of Phase 3, participants were fitted with the 32-channel electrode sensor array. Participants then began a forced-choice recognition task (Egan, 1958) during which the following 12 stimuli were presented randomly without replacement in each of 30 test blocks: A1, A2, A3, A4, B1, B2, B3, B4, C1, C2, C3, C4. Trials consisted of the presentation of the question "Do you remember seeing this?" at the top of the screen; a single A, B, or C stimulus in the middle of the screen; and prompts to press 1 to answer "yes" or 4 to answer "no". Upon initiation of Phase 3, the following instructions were presented:

> Welcome to the final phase. During this task, you will see sequences of numbers/characters/symbols, some of which are new and some of which you have previously encountered within the experiment. Please indicate whether you recall having seen the item in the experiment. Press '1' for YES (you remember seeing this item before). Press '4' for NO (you do not remember seeing this item). Please keep your eyes fixated on the CENTER of the screen at all times and please try to refrain from blinking during trial presentations.

Trials began with the presentation of a black fixation cross on a white background for 500 ms, after which the target stimulus was displayed with response prompts at the bottom of the screen (see Figure 3). The sizes of all target stimuli were increased to 11 cm x 10 cm to make them easier to discriminate. A 2000 ms limited hold was placed on pressing the "1" or "4" keys. The next trial began immediately after a response was made or 2000 ms had elapsed without a response.

Participants were next tested for the formation of A–C or C–A stimulus relations. For half of the participants the sample and comparison stimuli consisted of A1/A2/A3 and C1/C2/C3, respectively, which constituted a test for transitive relations. For the remaining participants, the C stimuli served as the samples with A stimuli as comparisons, which constituted a test for equivalence relations (i.e., combined symmetry

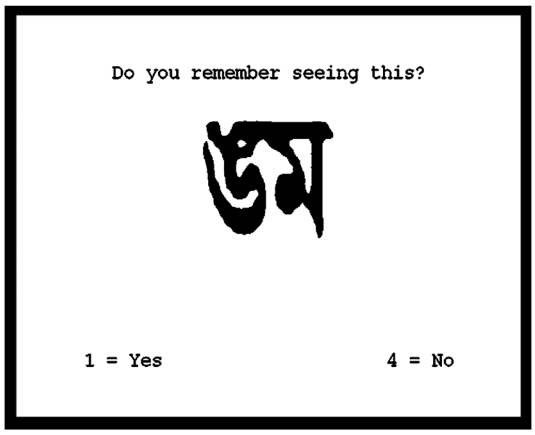

Fig. 3. In Phase 3, participants viewed stimuli from all classes (A, B and C) along with topographically matched novel stimuli (A4, B4, C4). Participants were required to identify stimuli they had encountered previously within the experiment in a forced-choice recognition paradigm (yes/no) while EEG data were collected. Following is an illustration of a trial type from the forced-choice recognition task. Note that the stimulus displayed in the sample trial above (B4), though novel, is nonetheless topographically coherent with other members of the B stimulus set. ERPs evoked by novel and neutral stimuli (A2, A4, B2, B4, C2, C4) compared with ERPs evoked by "emotional" stimuli (A1, A3, B1, B3, C1, C3).

and transitivity). Participants underwent 50 trials without receiving any corrective feedback, other than "Too slow…" if they did not respond within 5000 ms. In such cases, the trial was repeated.

EEG procedures. Continuous EEG data were recorded from the scalp over frontal (Fp1, Fp2, F3, F4, Fz), central (C3, C4), parietal (P3, P4, Pz), temporal (T3, T4) and occipital (O1, O2, Oz) electrode sites during the entire Phase 3 session. Participants were provided with 180- to 240-s intervals during which no EEG was recorded and participants could choose to rest. The rest intervals were presented approximately every 10 min. During these breaks impedance levels were checked and dry electrodes moistened. Scalp impedance for each sensor was kept below 50 Ω, which is appropriate for the type of amplifier used.

EEG was recorded at a sampling rate of 275 Hz with a low-pass filter set at 40 Hz using digital filtering. Stimuli synchronized epochs were extracted from 100 ms prestimulus onset to 1000 ms poststimulus onset, with the mastoid sensor serving as the reference electrode. To minimize artefacts, all segments with acquired signals from electrode channels exceeding 200 μV, alongside interference from eye movements and eye blinks exceeding 140 μV, were categorized as "bad" channels and removed from the final analysis. Trials containing a baseline drift of ± 40 μ*V*, excessive nonblink vertical/horizontal eye movements, as well as any EEG or EOG activity above ± 100 μV, were rejected from the final analysis (Schupp et al., 2003; Smith et al., 2004). All recordings were compiled on Net Station software. ERPs were averaged for all stimuli and scored as mean recorded activity in three temporal epochs of 100–200 ms, 300–450 ms and 600–1000 ms. Selection of these epochs was based on the time courses of emotion-related ERPs reported previously (Bayer et al., 2010; Hinojosa et al., 2009; Jaeger et al., 2009; Smith et al., 2004) as well as on visual inspection of the waveforms.

Results

Behavioral Data

Response latencies from Phase 1 are presented in Table 2. Averaged across participants, latencies were 2974 ms ($SD = 97$) and 3427 ms ($SD = 343$) for the A–B and B–C training procedures, respectively. Mean response latencies for B–A and C–B symmetry trials were 2851 ms ($SD = 105$) and 3549 ms ($SD = 225$), respectively. Mean response latencies for transitive and equivalent tests were 3791 ms ($SD = 208$) and 4110 ($SD = 9.4$), respectively.

All participants satisfied the training criterion (20 consecutively correct responses in less than 200 trials) within 10 training blocks. Similarly, all participants demonstrated symmetry by emitting 20 consecutively correct responses without corrective feedback in fewer than 50 trials. During the tests for transitivity and equivalence, all participants demonstrated response accuracies exceeding 80%; that is, participants responded correctly a minimum of 40 (out of 50) trials. Given the extensive history underlying the methodology for equivalence class formation, particularly for three-member equivalence classes (Sidman, 1994), further examination of individual participant data were deemed unnecessary. In Phase 2, all participants responded with 100% accuracy, with no response latencies exceeding 4000 ms.

In Phase 3, all participants correctly identified the location of the A stimulus on all trials with a

Table 2

The 18 trial types presented during equivalence formation in Phases 1 and 4.

Sm	Cr	Ir1	Ir2	Rl (in ms)
Directly Trained				
A1	B1	B2	B3	2850
A2	B2	B1	B3	2986
A3	B3	B1	B2	3087
B1	C1	C2	C3	3850
B2	C2	C1	C3	3011
B3	C3	C1	C2	3421
Symmetry				
B1	A1	A2	A3	2810
B2	A2	A1	A3	2995
B3	A3	A1	A2	2748
C1	B1	B2	B3	3840
C2	B2	B1	B3	3291
C3	B3	B1	B2	3516
Transitivity[a]				
A1	C1	C2	C3	3847
A2	C2	C1	C3	4012
A3	C3	C1	C2	3513
Equivalence[a]				
C1	A1	A2	A3	4106
C2	A2	A1	A3	4101
C3	A3	A1	A2	4123

Note. Mean response latencies for each trial type are presented. Sm = Sample stimulus, Cr = Correct comparison, Ir = Incorrect comparison, Rl = Response Latency

[a]Transitive and Equivalence relations were tested in Phase 4

mean response latency of 850 ms ($SD = 28$) and a response accuracy of >90%. During Phase 3, the mean latency for correctly identifying previously seen/unseen stimuli was 1036 ms ($SD = 54$). Latencies for erroneous responses (identifying a familiar stimulus as novel, or a novel stimulus as familiar) are not reported because, in general, there were so few such errors (see Table 3). Note, however, that higher error rates tended to occur for the four B stimuli, an issue to which we shall return in the Discussion. All participants showed 100% accuracy when asked to indicate if they had previously seen the A stimuli used within the experiment. In identifying the C stimuli, Participants 5 and 6 emitted two incorrect responses each, with the remaining participants showing 100% accuracy.

ERP Data

Analyzing the EEG data involved averaging mean waveform amplitudes elicited by the presentation of Positive (A1–B1–C1), Neutral (A2–B2–C2), Negative (A3–B3–C3) and Novel (A4–B4–C4) stimulus sets within each temporal epoch (i.e., 100–200, 300–450 and 600–1000 ms). Statistical analyses were conducted in three parts. First, mean ERP amplitudes elicited by stimuli A2, B2, and C2 were contrasted with those elicited by A4, B4, and C4, respectively. As noted previously, stimuli A4–B4–C4 were experimentally novel and were originally included to serve as a baseline comparison alongside A2–B2–C2. As predicted, these contrasts revealed no significant differences between the Neutral and Novel stimuli.

Table 3

Mean response accuracies in the forced-choice recognition task in Phase 4.

	"Do you remember seeing this item before?"										
Ts	Cr	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
A1[a]	Yes	30	30	30	30	30	30	30	30	30	30	30
A2[b]	Yes	30	30	30	30	30	30	30	30	30	30	30
A3[c]	Yes	30	30	30	30	30	30	30	30	30	30	30
A4[d]	No	30	30	30	30	30	30	30	30	30	30	30
B1	Yes	26	30	30	30	21	26	16	25	22	30	30
B2	Yes	30	23	30	25	15	23	12	29	19	30	30
B3	Yes	30	24	30	25	22	24	24	30	25	30	30
B4[d]	No	25	26	30	26	19	24	21	26	23	26	26
C1	Yes	30	30	30	30	30	30	30	30	30	30	30
C2	Yes	30	30	30	30	30	30	30	30	30	30	30
C3	Yes	30	30	30	30	26	30	30	26	30	30	30
C4[d]	No	30	30	30	30	30	30	30	30	30	30	30

Note. Ts = Target Stimulus, Cr = Correct Response, P(n) = Participant id and number of correct Responses (out of 30 presentations). Response accuracies <80% have been underlined.

[a]Paired with positive images

[b]Paired with neutral images

[c]Paired with negative images

[d]novel stimuli

Thus, ERPs from these six stimuli were collapsed to function as the baseline/neutral comparisons, hereafter referred to as A_N, B_N, and C_N.

In the second part of data analysis, ERPs elicited by Positive stimuli A1–B1–C1 and Negative stimuli A3–B3–C3 were contrasted with A_N–B_N–C_N at each temporal epoch using repeated-measures *t*-tests. Specifically, the contrasted ERPs were A1 versus A_N, A3 versus A_N, B1 versus B_N, B3 versus B_N, C1 versus C_N and C3 versus C_N. In the final part of data analysis, ERPs elicited by stimuli A1–B1–C1 were contrasted with ERPs elicited by stimuli A3–B3–C3 to examine differences between Positive and Negative conditions. The contrasted ERPs were A1 versus A3, B1 versus B3 and C1 versus C3. Because the comparisons were determined a priori and theoretically grounded, they are traditionally exempt from the effect of family-wise error rate (Howell, 2011). Nonetheless, because three sets of comparisons were conducted independently over each electrode site, a reasonable correction procedure is Tukey's q_{crit} statistic. For this data set, $q_{crit} = 3.877$ (df = 10) and *t* critical = 2.741 ($q/\sqrt{2}$). Post hoc comparisons notwithstanding, the *t* critical value would otherwise have been 2.228 (df = 10) to posit significant differences across the different comparisons. As the correction procedure employed is more conservative than is typical of theoretically sound a priori comparisons, the q_{crit} and its derived t_{crit} values have been presented for readers to use their own judgement in evaluating our findings. Values surpassing and approaching the adjusted t_{crit} value are reported in Table 4.

Grand averaged waveforms from the ERPs generated by the A and C stimuli from each of the three epochs are presented from electrodes from frontal, central, and parietal regions (identified below). Grand averaged waveforms are created by averaging together the averaged waveforms of individual participants (see Dietrich & Kanso, 2010 for a review of relevant ERP studies). Single-subject EEGs can be highly noisy, given multiple sources of variability not controlled for in this study; these include topographical complexity of the stimuli, hours of sleep the previous night, time since (as well as the content of) the last meal, and the idiosyncratic folding of sulci and gyri in individual brains (Luck, 2005). In the current study, ERP activity was noticeably different across participants, with some participants showing an early

Table 4

Mean amplitude differences observed in three temporal epochs over frontal (Fp1, Fp2, F3, F4, Fz), central (C3, C4) and parietal (P3, P4, Pz) electrode sites.

Epoch (ms)	Fp1	Fp2	F3	F4	Fz	C3	C4	P3	P4	Pz
A1 vs. A_N										
100–200			2.57			2.58				
300–450							2.92			
600–1000				2.78	4.32	3.69		4.22	3.14	
A1 vs. A3										
100–200		2.81*								
600–1000			2.23					2.86		
A3 vs. A_N										
300–450		2.86					2.76			
600–1000		4.22			4.14			2.98		
C1 vs. C_N										
100–200		2.65		2.57						
300–450	3.11			2.58	3.17		2.31			
600–1000	4.44		2.82	2.90	4.07		3.17	3.01	2.92	3.06
C1 vs. C3										
100–200		2.39*								
300–450	2.98				2.98					
600–1000	4.32		2.82	2.66						
C3 vs. C_N										
600–1000								2.88		

Note. Only statistically significant ($p < .05$) *t*-scores have been presented.

*Significant differences when the Positive stimuli (A1 and C1) were directly contrasted with Negative stimuli (A3 and C3) over right frontal electrode site (Fp2) in both conditions.

negative-going waveform earlier than 150 ms poststimulus onset, while for others a peak could be observed in windows exceeding 200 ms (not shown). This is quite typical of the variability seen using individual subjects in an EEG experiment (for example, see Potts, 2004), which is why as more trials are averaged together, the electrical noise as a consequence cancels out, whereas the ERP component becomes clearer *prima facie*. In summary, the pooled data, though it may not accurately reflect the pattern of individual results, nonetheless is a necessary evil to assess the consistencies in an otherwise highly variable measure.

The ERPs elicited by the presentation of the B stimuli were quite noisy and have consequently not been presented. Feature-sensitive ERP components reported elsewhere (Friedman, Cycowicz & Gaeta, 2001; Luck, 2005) may have mitigated ERP modulation and overshadowed emotion-related components of the topographically complex B stimulus set. In what follows, the ERP modulations were compared across frontal (Fp1, Fp2, F3, F4, Fz), central (C3, C4), and parietal (P3, P4, Pz) electrode sites. EEG signals from temporal and occipital channels were deemed too noisy even with stringent filtration procedures (Smith et al., 2004), warranting their exclusion from the subsequent presentations and analyses.

ERP activity within the 100–200 ms epoch. As shown in Figure 4, the A stimuli that previously preceded the delivery of emotion-eliciting stimuli produced an early pronounced negativity in ERPs in frontal electrode sites. Table 4 shows the obtained values of t from the repeated-measures tests. ERPs elicited by A1, which had been paired with "Positive" images, were significantly different from A_N over left frontal (F3) and central (C3) electrode sites. ERPs elicited by A3 were not significantly different from ERPs elicited by A_N. As shown in Figure 5, ERPs elicited by C1, a stimulus in the A1–B1–C1 equivalence class which had not been presented with the positive emotion-eliciting stimuli, showed significant differences from ERPs elicited by C_N over right frontal (Fp2, F4) electrode sites. No significant differences between the ERPs elicited by C3 and C_N were observed. Significant differences when the Positive stimuli (A1 and C1) were directly contrasted with Negative stimuli (A3 and C3), were observed over right frontal electrode site (Fp2) in both conditions. Interestingly, the polarities observed for the ERPs elicited by A1/A3 and C1/C3 differ in topography in comparison with ERPs recorded over other frontal electrode sites (see Figures 4 & 5).

The observed effects resemble EPN waveforms illustrated in previous studies (Hinojosa et al., 2010; Jaeger et al., 2009; Maratos et al., 2001), indicating a transfer of emotional properties across the A1–B1–C1 equivalence class. The findings favor the contention that an early "negativity" may thus be primarily indicative of emotional arousal more so than valence, given the differential, albeit nonsignificant, differences observed during earlier time windows between ERPs elicited by Neutral stimuli and the ERPs elicited by Positive/Negative stimuli. Given that the peak of this negative-going waveform is observed approximately 200 ms poststimulus onset, it can be typically referred to as a N200 component (Luck, 2005). The presence of the N200 elicited by A1–A3 and C1–C3 (in relation to A_N and C_N, respectively) indicates the derived transfer of arousal functions have taken place, replicating Dougher, Markham et al.'s (1994) findings at a neurophysiological level.

ERP activity within the 300–450 ms epoch. ERPs elicited by A1 and A_N stimuli were not significantly different in the second epoch of interest. Significant differences were observed between ERPs elicited by A3 and A_N over right frontal (Fp2) and central (C4) electrode sites. No significant differences were observed between A1 versus A3, though analysis of ERPs over frontal (Fz, F4) electrode sites yielded differences approaching significance ($p < .07$). Significant differences between C1 and C_N were observed over frontal (Fp1, F4, Fz) and right central (C4) electrode sites. No significant differences were found between ERPs elicited by C3 and C_N. Finally, significant differences between C1 versus C3 were observed across frontal (Fp1, Fz) electrode sites, suggesting differential electroencephalographic modulation for emotional valence effects, providing evidence that, as with arousal, emotional valence is a transformable stimulus function.

ERP activity within the 600–1000 ms epoch. Positive-going waveforms elicited by emotional stimuli became most visibly prominent in the third epoch (600–1000 ms) over frontal electrode sites. Closer inspection of the frontal and central electrode sites in the later epochs, as illustrated in Figures 4 and 5, reveal that ERPs

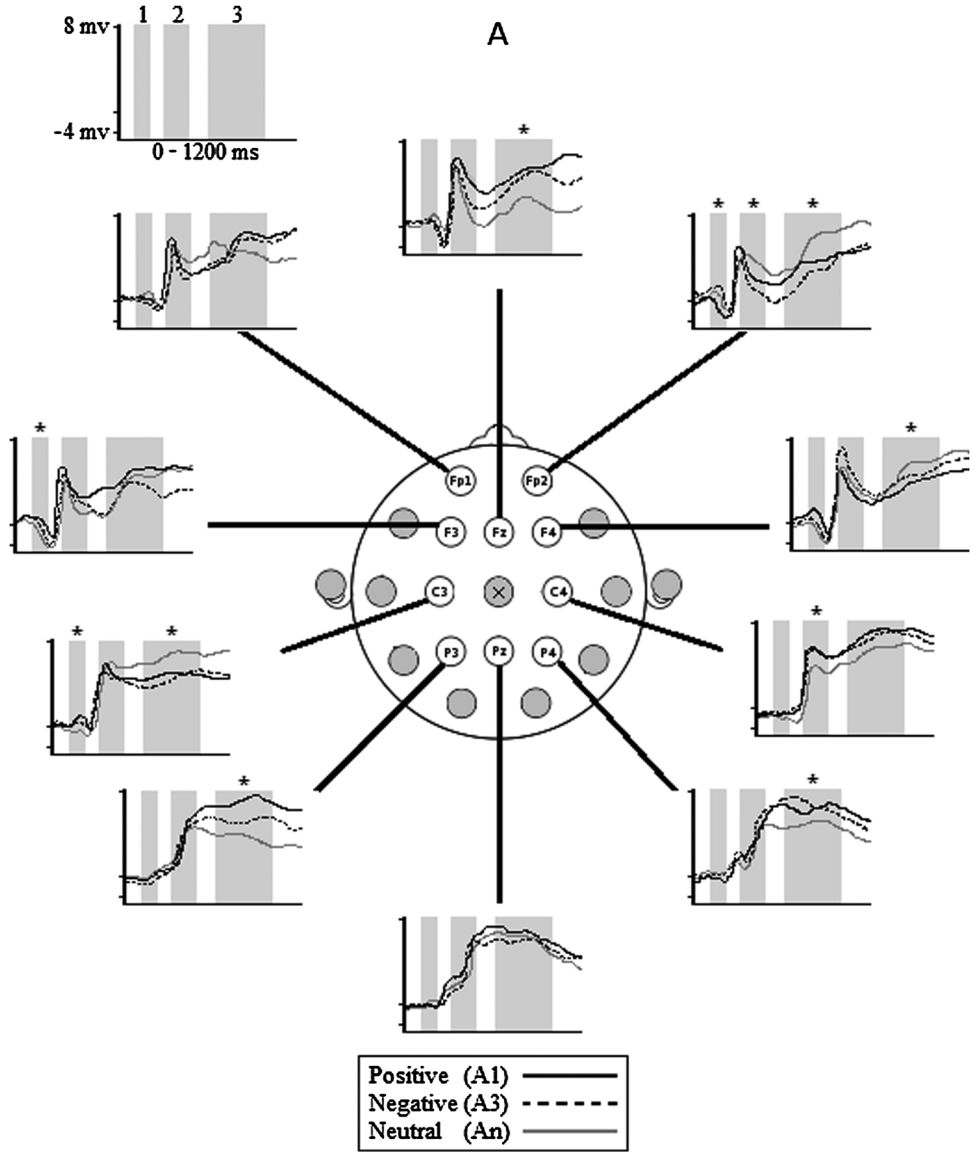

Fig. 4. Grand averaged electroencephalographic (GaEEG) activity across nine electrode channels as participants were presented with stimuli that had been directly paired with emotionally positive (A1), negative (A3) and emotionally neutral (A2) images, or were novel (A4). (An) represents GaEEGs recorded for the A2 and A4 stimuli. GaEEGs from frontal (Fp1, Fp2, F3, F4), central (C3, C4) and parietal (P3, P4, Pz) electrode sites are shown. Mean amplitude differences were compared within the 100–200 (**1**), 300–350 (**2**) and 600–1000 (**3**) ms time windows and have been parsed accordingly in shaded regions (top of image). Time windows over which significant differences were computed between at least two elicited event-related potentials (ERPs) have been marked with an asterisk (*).

elicited by Positive (A1) and Negative (A3) stimuli tend to differentiate from the ERPs elicited by neutral (A_N) stimuli in later epochs, albeit with contralateral differences in direction of individual polarities. For example, ERPs elicited by A1/A3 are more positive-going then ERPs elicited by A_N over left (Fp1) and central (Fz) electrode sites, whereas ERPs elicited by the same A1/A3 stimuli are more *negative*-going than ERPs elicited by A_N over right frontal (Fp2, F4) electrode sites. Similarly, ERPs elicited by the C_N stimuli are elevated

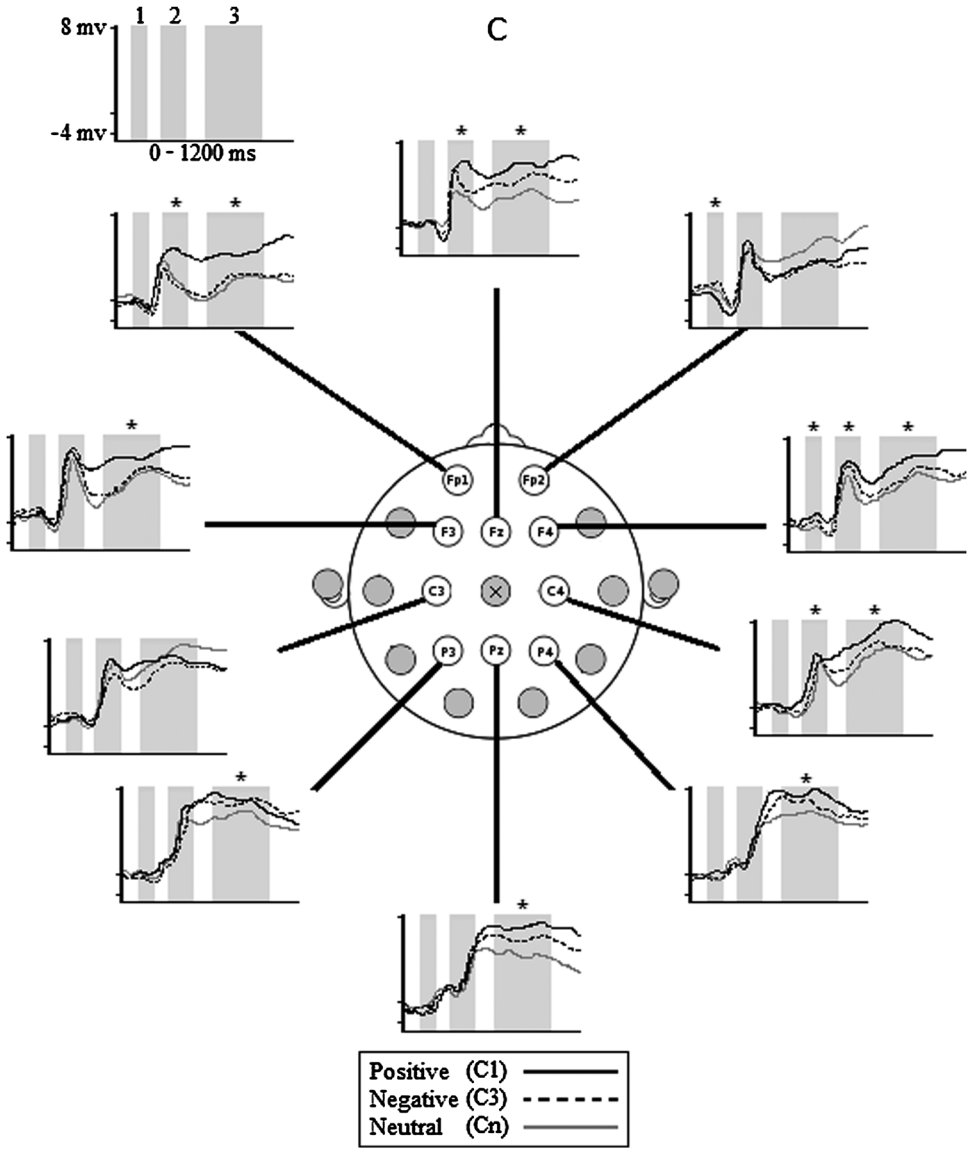

Fig. 5. GaEEG activity across nine electrode channels as participants were presented with the novel C4 stimulus, as well as the C1, C2 and C3 stimuli which were equivalently related to the A1, A2 and A3 stimuli. (Cn) represents GaEEGs recorded for the C2 and C4 stimuli. GaEEGs from frontal (Fp1, Fp2, F3, F4), central (C3, C4) and parietal (P3, P4, Pz) electrode sites are shown. Mean amplitude differences were compared within the 100–200 (**1**), 300–350 (**2**) and 600–1000 (**3**) ms time windows and have been parsed accordingly in shaded regions (top of image). Time windows over which significant differences were computed between at least two elicited event-related potentials (ERPs) have been marked with an asterisk (*).

above those elicited by the C1 and C3 stimuli over right frontal (Fp2) electrode sites only (see Figure 5). The observed reversal of voltage polarities resembles an emotion–ERP effect that can occur after an increase in training delay (Jaeger et al., 2009) as well as hemispheric differences (Luck, 2005), though critically, for our purposes, the effect can be considered representative of emotion effects. Significant differences were noted between ERPs elicited by A1 and A_N over frontal (Fz, F4), central (C3), and parietal (P3, P4) electrode sites. For ERPs elicited by A3 and A_N, differences were observed over right frontal (F4) and left parietal (P3)

electrode sites. Differences in ERPs elicited by C1 and C_N were observed over central (C4), parietal (P3, P4, Pz) and frontal (Fp1, F3, F4, Fz) electrode sites. Critically, significant differences were observed between ERPs elicited by A1 and A3 over left parietal (P3) and right frontal (F4) electrode sites, as well as between ERPs elicited by C1 and C3 over frontal (Fp1, F3, F4) electrode sites. The findings further support the notion of valence transfer across equivalence classes.

Discussion

Eleven adult participants completed MTS training and testing procedures in order to establish three 3-member equivalence classes (A1–B1–C1, A2–B2–C2, A3–B3–C3). A combination of both trace conditioning and stimulus pairing procedures were used to pair stimulus A1 with three positively valenced images, stimulus A2 with three emotionally neutral images and stimulus A3 with three negatively valenced images. Finally, stimuli from the three equivalence classes and three novel stimuli (A4, B4, and C4) were presented individually in a forced-choice recognition task while EEG data were recorded to check for stimulus-specific ERPs. The early N200 and late P300 components representative of emotional effects were observed when the A1, A3, C1 and C3 stimuli were presented, albeit with a greater frontal distribution than is typically reported (but see Wiens, Molapour, Overfeld & Sand, 2012).

The current design combines Dougher's (1998) extensive work on the transfer of functions across equivalence classes with Hinojosa et al.'s (2010) research underlying the neurophysiological correlates of emotional processes. At the very least, the findings demonstrate the potential utility of EEG for measuring responses associated with emotional reactions, and particularly those that occur within a few hundred milliseconds of the presentation of an emotionally relevant stimulus. Unlike Dougher, Augustson et al. (1994), the emotionally evocative stimuli employed in the current study were visual images rather than the delivery of electric shock, thus demonstrating the basic transfer effects beyond arousal to so-called valence. Specifically, elicited potentials for stimuli paired with emotional imagery (A1, A3) and those that were related through derived relations to the A stimuli (C1, C3) showed statistically significant differences in mean amplitudes when contrasted with elicited potentials from the baseline/neutral comparisons A_N and C_N in the early epoch of 100–200 ms over frontal (F3, Fp2) and central (C3) sites for comparisons across the A stimulus set, and over frontal (Fp2, F4) electrode sites only for comparisons across the C stimulus set. The only differences between positively valenced stimuli and negatively valenced stimuli in the early epoch for both sets of comparisons were seen over the right frontal electrode (Fp2) site for both conditions. The differential EEG effects resemble the EPN, albeit with a greater anterior distribution, and appear more indicative of emotional arousal (Smith et al., 2004).

In addition, sustained P300 components reflective of the 'late positive potential' (LPP) could be observed from the intermediate 300–450 ms epoch to the late 600–1000 ms epoch, where ERPs elicited by the valenced stimuli (A1, A3, C1, C3) were markedly different from ERPs elicited by the baseline/neutral comparisons (A_N, C_N) over multiple (Fp1, Fp2, F3, F4, C3, C4, P3, P4, Pz) electrode sites. The differential ERPs elicited by the valenced stimuli, in comparison to the baseline/neutral stimuli, are reflective of emotional effects reported previously (Hinajosa et al., 2010; Smith et al., 2004). Critically, differences between A1 versus A3 and C1 versus C3 observed across the later epochs of 300–450 ms and 600–1000 ms mostly over frontal electrode sites (Fp1, F3, F4, Fz) indicate differential modulation of the late P300 component as indicative of valence sensitivity (Hinojosa et al., 2010; Leite et al., 2012). When ERPs responsive to specific stimulus attributes emerge in formerly neutral stimuli along the appetitive–avoidant (valence) dimension, it can be considered as indirect evidence of structural changes in the brain. In terms of anatomy, it is notoriously difficult to spatially localize ERP generators, particularly given that a 32-channel electrode headset was used (Luck, 2005). This was the primary reason that specific electrode locations were not predicted beforehand, as the diffusion of potentials over the scalp surface, particularly if an ERP generator is located deep in the cortex, are not readily fixed. The primary advantage of ERPs lie in the temporal precision of observed responses to target and nontarget stimuli, more so than source localization, which, in order of relevance to the current study, allowed the prespecification of latency ranges

predicted to display ERP components related to the emotional functions manipulated.

One criticism of the current research might be that semantically familiar, topographically simple stimuli were employed (i.e., numbers for Stimulus Set A and Arrowheads for Stimulus Set C), rather than abstract shapes or nonsense syllables that are frequently employed in derived relations research. On balance, previous research has shown that the presentation of novel and/or topographically complex stimuli can induce neurological effects resembling appetitive or avoidance-related behaviors in and of themselves (Duckworth, Bargh, Garcia & Chaiken, 2002), potentially confounding the recording of EEG data. Indeed, it is worth noting that although the predicted difference effects emerged between classes for the familiar stimuli (i.e., mean amplitude differences between ERPs elicited by A1 vs. A3 resembled the waveform differences between ERPs elicited by C1 vs. C3), the effects generated by the B stimuli in the current study were deemed too "noisy" even with stringent filtration procedures (as employed by Smith et al., 2004). Evidence suggests that irregular ERPs can be elicited by topographically complex stimuli (Luck, 2005; Pazo-Alvarez, Cadaveira, & Amenedo, 2003), and indeed the reduced levels of response accuracy during the identification of the B stimuli in the forced-choice recognition task indicate differential stimulus control by complex stimulus topographies at a microbehavioral level (see McIlvane & Dube, 2003). Of course, it is possible to train and test for equivalence relations using topographically complex stimuli, as illustrated in Table 1, but researchers using sensitive EEG measures need to be more aware of elemental features (Czigler, Balázs & Winkler, 2002) that may serve to increase interference in this highly sensitive measure. In any case, subsequent research on the neurophysiological correlates underlying the transfer of stimulus functions should control for stimulus complexity by using topographically simple stimuli at all stages of derived relational training, in order to control for potential ERP irregularities.

Measures employing EEG signals have been used over the past two decades by researchers interested in human emotions (e.g., Davidson, 1998; Smith et al., 2004). The current study demonstrated elicited ERPs indicative of emotional properties for stimuli that had been directly paired with emotional imagery (A1 & A3), as has been previously reported (Hinojosa et al., 2010; Lang, Davis, & Öhman, 2000; Maratos et al., 2001; Smith et al., 2004). Critically, the current data also indicate that similar emotion-related ERPs were elicited by the C1 and C3 stimuli, which had been equivalently related to A1 and A3, but had never been presented together simultaneously. Given that the primary manipulated function was emotional *valence*, a difficult concept to operationalize within the social/behavioral sciences, the current study demonstrates how well-established behavioral principles examined with refined psychophysiological tools can be used to shed light on phenomena that have been typically regarded as too cognitive. Of course, a great deal more research is required in this area to explicate the behavioral processes involved in relatively rapid emotional reactions, but the current findings do indicate that using EEG may well be of value in pursuing this line of inquiry.

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