Neural correlates of emotion word processing:

the interaction between emotional valence and arousal

By

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Declaration

I hereby declare that this thesis, whether in the same or different form, has not been previously submitted to this or any other University for a degree.

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Preface

This thesis was written in the European format, which consists of a collection of studies written in form of papers for publication. The studies are preceded by an overview chapter, which consists in a general introduction, an outline of the studies conducted, a brief summary of the results and a discussion. The discussion aims to connect and integrate the findings from each single study and relate them to the issues addressed by the thesis.

After the overview chapter, I reported a publication plan with a reference for each empirical study included in the thesis, which has already been submitted or is ready to be submitted to a scientific journal.

Summary

Emotion is characterised by two-dimensions: emotional valence describes the extent to which an emotion is positive or negative, and arousal represents its intensity. Emotional content of verbal material affects cognitive processing, although research on word recognition has only recently taken emotion into account, primarily focusing on valence, while neglecting arousal.

The present work aimed to disentangle the effects of valence and arousal during a lexical decision task, using reaction times (RTs), event-related potentials (ERPs) and BOLD responses in an event-related fMRI design. These methods were chosen to determine when affective features have an effect, and which neural systems are involved.

The material for three experiments was based on a word corpus created by collecting ratings for emotional and lexico-semantic features. A first and novel finding was that arousal interacted with valence. Specifically, lexical decision times were slower for high-arousal positive stimuli (PH) and low-arousal negative ones (NL) compared to low-arousal positive (PL) and high arousal negative (NH) stimuli.

ERPs also showed an interaction between 200-300 ms on the early posterior negativity (EPN), a component which is sensitive to emotional stimuli. At this processing stage people access their mental lexicon. Its amplitude was greater for PH and NL words, suggesting a higher processing load for conflicting stimuli. Positive valence and low arousal elicit an approach schema, whereas negative valence and high arousal elicit an avoidance schema (Robinson, Storbeck, Meier & Kirkeby, 2004).

BOLD responses showed a similar interaction in the insula bilaterally, with increased activation for PH and NL words. This region is associated with integration of information on visceral states with higher-order cognitive and emotional processing, suggesting higher difficulty in integrating conflicting stimuli.

Taken together, these studies indicate that emotion affects word processing during lexical access, and models of word recognition need to take into account both valence and arousal.

I. Emotion word processing: An overview

1. Theoretical and empirical research on emotion

Theoretical models of emotion suggest a two-dimensional structure of affect, consisting of emotional valence, which describes the extent to which an emotion is positive or negative, and arousal, which refers to its intensity, how exciting/agitating or calming an emotion is (Feldman Barrett & Russell, 1999; Russell, 1980). For example, *furious* is a negative emotion and is very intense (arousing), whereas *sad* is negative but low in arousal, additionally *excited* and *serene* are both positive emotions but differ in arousal. A third dimension has also been suggested, called potency (Osgood, Suci, & Tannenbaum, 1957) or dominance (e.g. Bradley & Lang, 1994), which provided an additional but constrained contribution to understanding of human emotion and will therefore not be considered further here.

Not only emotions, but also objects or concepts eliciting an emotional reaction can be positioned along the two-dimensional structure; for example, the pictorial representation or abstract concept of *war* is negative and very intense (arousing), whereas a *flower* represents a positive low-arousal stimulus or concept. Neutral stimuli or concepts such as *chair* or *indifferent* are neither positive nor negative in valence and very low in arousal.

Emotional valence and arousal seem to represent distinct dimensions (Feldman Barrett & Russell, 1999; Reisenzein, 1994), although they are associated to some extent; in fact, highly valenced stimuli (very positive or very negative) tend to be highly arousing as well. Nevertheless, differences in this respect have been observed: negative stimuli tend to be higher in arousal compared to positive stimuli (Lang, Bradley & Cuthbert, 1999), suggesting a different relationship with arousal for different levels of valence and an independence of positive and negative valence (Feldman Barrett & Russell, 1998).

Emotional content of pictorial as well as verbal material has been shown to affect cognitive processing, as reflected by behavioural performance (Algom, Chajut, & Lev, 2004; Estes & Verges, 2008; Kuchinke, Võ, Hofmann, & Jacobs, 2007), intracranial recording (Naccache et al., 2005) and brain activity (Kissler, Herbert, Peyk, & Junghofer, 2007; Lewis, Critchley, Rotshtein, & Dolan, 2007; Nakic, Smith, Busis, Vythilingam, & Blair, 2006; Olofsson, Nordin, Sequeira, & Polich, 2008; Scott, O'Donnell, Leuthold, & Sereno, 2009).

Empirical research on emotion has been guided by different theoretical frameworks formulating predictions about behavioural, physiological and/or neural responses to emotional stimuli. A first approach, focused on the valence dimension, is based on the automatic vigilance hypothesis (Pratto & John, 1991) and the mobilisation-minimisation hypothesis (Taylor, 1991), which both state that negative stimuli capture and withhold attention, due to their potentially threatening nature, therefore reducing the amount of resources available for the task at hand. Hence, performance is predicted to be worse for negative compared to positive or neutral stimuli. This prediction was supported by studies manipulating word stimuli in different tasks, such as the Stroop paradigm, lexical decision, and naming (e.g. Algom et al., 2004; Estes & Adelman, 2008; Nasrallah, Carmel, & Lavie, 2009). For details about the tasks see Sections 2 and 3.1.

From a more physiological perspective, Lang, Bradley and Cuthbert (1990) proposed that appetitive and aversive (defensive) responses are enhanced or inhibited depending on whether an emotion-eliciting stimulus matches or mismatches the response. The startle reflex is an aversive response of mind and body to a sudden unexpected stimulus (e.g. a loud noise or a flash of light) including movement away from it, the contraction of leg and arm muscles, or blinking. The authors showed that this reflex is enhanced during a fear emotional state and diminished during a positive emotional state. In line with this view, Estes and Verges (2008) found that cognitive performance in word processing is influenced differently by positive and negative valence depending on the task at hand, and not by valence per se. Empirical studies supporting this second approach considered arousal as a possible confounding variable which needs to be experimentally controlled, but did not explicitly manipulate it in addition to valence.

A third approach to emotion research proposed a model which suggests an early integration of valence and arousal dimensions during processing of emotional stimuli (Robinson, 1998; Robinson, Storbeck, Meier, & Kirkeby, 2004). Negative or highly arousing stimuli are proposed to elicit a withdrawal reaction or mental set, whereas positive or low-arousal stimuli elicit approach. Integration of these dimensions for emotional evaluation and subsequent action initiation will be easy for stimuli which elicit congruent mental sets (i.e. negative high-arousal and positive low-arousal stimuli), but difficult for stimuli eliciting conflicting approach-withdrawal orientations (i.e. negative low-arousal and positive high-arousal stimuli). The authors provided empirical evidence in support of this model, showing slower reaction times to pictorial or verbal stimuli eliciting conflicting reactions during visual discrimination as well as motor tasks.

Research on emotion word processing has led to advances within each theoretical framework presented and will be reviewed in Section 4.

The aim of the present dissertation was to investigate the effect of emotion on single word recognition in healthy populations by manipulating both emotional valence and arousal dimensions and by employing different methodological approaches (i.e. behavioural, electrophysiological and neuroimaging) which provide diverse, sometimes complementary contributions.

The present overview first reviews two of the most influential models of word recognition and describes several lexico-semantic properties known to affect lexical access. Second, it provides a description of different tasks and methodologies used to study emotion word processing. Third, it reviews the main findings in the emotion word processing literature, followed by an outline of the studies conducted and their main results. Finally, a general discussion aims to integrate the results from the different studies and to highlight their contributions to research on emotion.

2. Single word recognition and lexical access

Lexical access is the process of matching a visual or auditory word stimulus with its mental representation, which leads to word recognition. The most consistently used tasks to investigate lexical access are lexical decision and naming: the former consists of judging whether a letter string is a real word or not, during presentation of intermixed word and non-word stimuli; the latter consists of reading a word aloud. Accuracy and latency measures are collected and allow inferences to be made about the ease or difficulty of recognition. Two models, which most successfully describe the process of lexical access are briefly presented here below, followed by a review of the main lexical and semantic word properties which have been shown to influence word recognition.

The Dual Route Cascaded model (DRC, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) proposes two different mechanisms of visual word recognition. An assembled route uses a system of grapheme-phoneme correspondence rules in order to pronounce a given word aloud; this route is time consuming because it requires single letter identification in a serial manner and it leads to successful reading only when words follow the spelling-to-sound rules of the language (i.e. regular words). A lexical or direct route, instead, postulates the existence of orthographic and phonological word representations (lexicon): when a written word is presented, this will be mapped onto an lexical representation, which will either directly access the articulatory programmes necessary for pronunciation, or pass through a semantic representation. This route is much faster than the assembled route because it does not require a letter-by-letter analysis, but capitalises on the existence of learned lexical and semantic representations and from forward and backward interactions between the orthographic and phonological lexicons, as well as the semantic system; it allows reading of irregular words and it is mostly used for highly frequent words. Infrequent or unknown words are preferentially read through the assembled route; similarly, non-words can only be read through spelling-to-sound translation.

An alternative connectionist model of word recognition is the Parallel Distributed Processing model (PDP, Plaut, McClelland, Seidenberg, & Patterson, 1996), which creates word representations through learning from exposure to word spellings and pronunciations. This model postulates the existence of a set of input units that code the orthography of the stimulus, and another set of input units that code the phonology, implying pronunciation. All input units are connected to a set of hidden units which have no direct contact with external systems and are connected to a set of output units. The weights of all connections have no organised mapping prior to training; during training the model is presented with orthographic strings and produces some phonological output, whereby weights are adjusted to reduce the discrepancy between its output and the correct pronunciation. The model is able to learn phonology of regular words, highly frequent irregular words and some non-words. The lexical representations created through training are distributed, i.e. there is no single unit representation for a word (e.g. *cat*), but a pattern of activations among several different units, which are partly shared by other words.

Both models account for lexical tasks such as word naming and lexical decision and capture effects of word frequency and regularity on performance, i.e. frequently used words and words which obey spelling-to-sound rules of a language are recognised faster. Nevertheless, the DRC model is better at accounting for non-word reading and can account for acquired surface dyslexia, which implies a poor orthographic lexicon and therefore the preferential use of the assembled route: surface dyslexics are typically good at reading regular words and non-words, but not irregular words. The PDP model, instead, can account for spelling-to-sound consistency effects of a word's orthographic neighbourhood. A word's (e.g. *fame*) orthographic neighbours are words which differ from the former for one letter (e.g. *fate, lame)*, whereas consistency refers to the degree to which similarly spelled words are pronounced similarly (e.g. *gave, have*). Naming performance is improved for words with consistent neighbours, beyond the effect of word regularity.

Important contributions to understanding single word recognition were provided by the models described above, as well as by an extensive literature investigating the effects of word properties on lexical access, which is reviewed here below. Lexical properties refer to variables which are quantified at the whole word level, as opposed to variables reflecting sub-parts of a word (e.g. onset syllable, rhyme); semantic properties still have to do with the whole word, but refer to representations of its meaning.

Word length is a lexical property and consists of the number of letters, phonemes or syllables forming a word; it generally affects word recognition by eliciting longer reaction times to longer words. This property typically interacts with word frequency, i.e. length effects are more pronounced during recognition of low frequency words; this is due to the fact that length mostly affects the spelling-to-sound correspondence route (Balota, Yap, & Cortese, 2006). Spoken and written word frequency is a lexical variable which refers to how often a word occurs in a large sample of words and can be determined by using databases such as CELEX (Max Planck Institute for Psycholinguistics, 2001) or BNC (Leech, Rayson, & Wilson, 2001). Its effect on word recognition has been shown in many different task: frequent words show faster lexical decision and naming latencies, better perceptual identification, and shorter fixation duration (Balota et al., 2006). Furthermore, frequency effects can be accounted for by both models of reading: frequent words are recognised through the lexical route and activate more units and connections in the PDP system.

Familiarity is another lexical property which refers to the subjective frequency of exposure to a word and is determined by collecting subjective ratings on a Likert scale (e.g. from not familiar to very familiar). This property has been shown to be a more accurate measure of frequency, in fact frequency corpora are based on a selected, even though very large, word sample, which might not be updated (e.g. the MRC database, Coltheart, 1981). An issue with familiarity ratings is that it is not clear what people are evaluating when thinking of a word's familiarity; in fact more meaningful stimuli (words with many different meanings) might be rated as more familiar. Balota, Pilotti and Cortese (2001) asked participants to rate how often they encounter a word on a scale from "never" to "several times a day" and found that this variable was not much influenced by meaningfulness and predicted additional variance in lexical decision and naming latencies, beyond objective frequency, length and other variables.

Another variable influencing word recognition is age of acquisition (AoA), i.e. the age at which a word was acquired, which is accurately reflected by adult ratings (Morrison, Chappell, & Ellis, 1997). Early acquired words are usually recognised faster than later acquired ones, although it is difficult to determine the extent of AoA's unique effect because this variable is correlated with word frequency, length and imageability (Bird, Franklin, & Howard, 2001). There is evidence for a frequency-related effect of AoA on lexical decision and word naming, which suggests it to be a lexical word property, but also a frequency-independent effect on picture naming, possibly due to competition for the selection of a unique concept selection; this evidence suggests a semantic component of AoA (Juhasz, 2005). AoA effects might also be due to cumulative frequency (the total frequency of exposure to a word throughout life), which is higher for earlier acquired words if objective frequency is controlled; AoA effects might also be due to frequency trajectory: some early acquired words are frequent during childhood only (e.g. *tummy*), some late acquired words become very frequent in adulthood (e.g. *fax*); a unique effect of cumulative frequency was found in naming, but little evidence for frequency trajectory was shown (Zevin & Seidenberg, 2004).

Purely semantic variables include concreteness and imageability; Concreteness refers to whether a word represents an object which can be experienced in a sensory modality (e.g. *chair, apple)*, whereas imageability represents the ease with which a word evokes a sensory mental image and it better reflects picturing activity, in particular with respect to highly imageable abstract words such as emotions (Altarriba & Bauer, 2004). These variables are correlated (Paivio, Yuille, & Madigan, 1968) and affect word recognition: concrete or highly imageable words elicit faster lexical decision latencies and this effect is larger for low-frequency words, which are more weakly represented in the lexicon and therefore benefit from semantic representations (Balota et al., 2006). Furthermore, concreteness shows a bimodal distribution (Kousta, Vigliocco, Vinson, Andrews, & Del Campo, in press), which neglects to represent words with intermediate values.

A recent growing body of literature has begun to investigate the effects of emotional variables on word recognition. Nevertheless, it is not clear yet how affective variables relate to other lexico-semantic variables. A review of the state of the art of research on emotion word recognition is given in Section 4, after a presentation of the tasks and methods used to study emotion word processing in Section 3 here below.

3. Methods to study emotion word processing

3.1. Types of task

A cognitive task typically requires participants to process one or more characteristics of a perceptual stimulus either by physically responding to it (e.g. through button press), or by directing attention toward its target characteristic(s) through eye movements, retrieval of mental images related to it, or an attempt to memorise it. If the target characteristic of a stimulus corresponds to one of the experimentally manipulated variables, this variable is said to be “explicitly” processed: the participant pays selective attention to the variable of interest for the experimenter. Participants’ attention can also be drawn to a target characteristic which does not correspond to the experimentally manipulated variable, for example participants are asked to respond to the colour (blue or yellow) of different geometric shapes (circles, squares), where shape is the experimental variable. In this way participants will explicitly process and respond to colour; if a difference in performance is found between circles and squares, this means that shape was “implicitly” processed along with colour.

3.1.1. Implicit and explicit emotion processing. Tasks which require explicit processing of the emotional content of verbal stimuli consist of valence and/or arousal evaluation: participants are required to rate emotional dimensions for each word on Likert scales; alternatively, valence or emotionality judgements require participants to classify words in two categories: positive versus negative, or emotional versus neutral, respectively. The advantage of these tasks is that they ensure emotional processing of the stimuli; the disadvantage is that selective attention toward the specific emotional category or rating is measured, given that different responses to the different stimulus categories are required. Hence, a reaction time difference between valenced and neutral words, for example, would be driven by both the word affective property and the selective attention allocated to each affective connotation.

Tasks which require implicit emotion processing usually overcome this problem. For example, a lexical decision task (LDT), in which participants are asked to judge whether a letter string represents a real word or not, requires selective attention to the lexicality of the stimulus; hence, all words are explicitly processed in the same way (responding “yes”), and differences in performance between words differing in valence or arousal will be attributable to their emotional content per se, without additional influence from top-down, task-dependent processes.

Another task which has been widely used to study implicit emotion word processing in healthy as well as clinical populations is the emotional Stroop task, which is an adaptation of the classical Stroop task. In the Stroop task, colour-denoting words printed in congruent or incongruent font colours are presented to participants, who are required to name the font colour. Naming latencies are typically longer and accuracy lower for incongruent stimuli, because there is interference between the orthographic input, which very quickly activates the phonological representation of the written word, and the process of retrieval of a lexical representation of the font colour (Stroop, 1935) . In the emotional Stroop task, valenced and neutral words are employed, rather than colour-denoting words, so no congruency between word meaning and colour is manipulated. The task draws attention to the font colour and differences in performance in response to differently valenced words could again be attributed to implicit emotion processing (Pratto & John, 1991). Clinical populations typically show longer colour-naming latencies in response to disorder-related words compared to other words, because they attract attention and subtract cognitive resources needed for the task at hand (Williams, Mathews, & MacLeod, 1996).

The advantage of these tasks is that emotion processing is implicit and task-independent, but they do not necessarily ensure that participants process the emotional content of the stimuli. This issue will be addressed more in detail below, when comparing different degrees of processing depth.

Other tasks requiring implicit emotion processing have been shown to cause some biases. A self-referential task, for example, which requires participants to judge whether (or not) and to what extent a word describes themselves, showed a bias toward positive words: people judged or rated positive words as more self-describing than negative or neutral words (Lewis et al., 2007). A similar example refers to familiarity ratings. Familiarity refers to the subjective frequency with which a person encounters a specific word. Again, participants rated positive words as more familiar (Citron, Weekes, & Ferstl, 2009).

3.1.2. Depth of processing. In order to ensure affective processing of words, it is necessary to employ a task which allows access to their emotional content. Intuitively, one would think that people need to access a word's meaning in order to retrieve its emotional connotation; empirically, though, some studies employing event-related potentials (ERPs; see Section 3.2.2) have shown very early, pre-lexical emotion processing (e.g. Hofmann, Kuchinke, Tamm, Võ, & Jacobs, 2009; Scott et al., 2009), also with subliminal presentation (Bernat, Bunce, & Shevrin, 2001; Naccache et al., 2005).

Hence, a classical LDT allows the detection of processing differences between words with differing degrees of emotionality as well as a semantic task does, i.e. judging the congruency of the target word with a preceding word (Schacht & Sommer, 2009b); this was revealed by both reaction time (RT) and ERP measures. Even a more superficial, structural task, consisting of judging whether a word's letters are all written in the same font, elicited differential RT and early ERP responses depending on the word's emotionality; nevertheless, later ERP effects, associated with deeper, task-dependent processing, were absent (Schacht & Sommer, 2009b).

Furthermore, in a variant of the LDT, consisting of the identification of meaningful words among pseudo words, or among non-recognisable stimuli, differential emotional ERP responses were found only in the former condition (Hinojosa, Méndez-Bértolo, & Pozo, 2010), suggesting that a minimum degree of linguistic processing is needed to direct attention to the affective content of words.

Finally, silent reading of single words has proven useful in detecting differential ERP and neuroimaging emotional responses (Herbert et al., 2009; Kissler et al., 2007). Nevertheless, the use of this task might provide experimenters with noisy data: in fact, without collection of behavioural measures (RTs, accuracy), it is difficult to check whether participants are actually engaged in the task, and outlier correction is also less straightforward.

3.2. Methodologies

The present section aims to introduce and discuss all methodological aspects which are relevant for the present dissertation. For more detailed information on behavioural tasks please refer to a handbook of Cognitive Psychology; for the ERP and fMRI techniques refer to Zani and Proverbio (2002) and Huettel (2009), respectively. For the eye-tracking technique refer to Richardson and Spivey (2004).

3.2.1. Behavioural measures. To gain insight into emotion word processing, behavioural measures such as norms (i.e. ratings), reaction times (RTs) and accuracy rates can be collected. Norms are usually collected off-line, i.e. participants are not given any time limit for the responses, and provide information about the expicit evaluation of stimulus properties. Norms are used to classify and select stimuli with certain properties (e.g. emotionality) and employ them as material for experiments manipulating or controlling those properties. These measures are usually reliable, but they might be subject to response biases or reflect socially-desirable responses. RT and accuracy measures, instead, are usually collected online, i.e. time or accuracy constraints are given, and provide information about the output of cognitive processes; for example, a stimulus which causes processing difficulty will require more cognitive resources and more time, leading to longer RTs and lower accuracy compared to a simpler stimulus. From behavioural measures we can only infer what happened prior to response, while the stimulus was processed, but we have no direct, concomitant measure of the ongoing process. Hence, early processing differences between stimuli belonging to different conditions might not necessarily become apparent at the time of response; furthermore, no information can be obtained regarding when processing differences arise (and/or disappear) and which cognitive resources are involved.

Research on emotion word processing has benefited from studies reporting RT results, which have often constituted the basis for confirming or adapting theoretical models of emotion, as well as for designing online experiments. Accuracy rates are usually reported together with RTs to give an idea of the overall performance and of possible differences between experimental conditions. This measure might be more or less informative depending on the task employed. In most tasks reported so far, accuracy tends to be very high, with ceiling rates and very low variability; in this case, differences between experimental conditions are very likely to be detected, although their interpretation might be difficult. Tasks which lead to a high percentage of mistakes, such as the false memory paradigm (Roediger & McDermott, 1995; Ruci, Tomes, & Zelenzki, 2008) or tasks involving masked stimuli (e.g. Nasrallah et al., 2009) mostly benefit from accuracy (or error) rate measures.

3.2.2. Event-related potentials (ERPs). An online methodology, extensively used to study emotion word processing, consists of the event-related potentials (ERPs). This technique is based on the recording of electro-encephalographic (EEG) activity from the scalp by means of electrodes, while participants perform a cognitive task. The signal recorded comes from populations of cortical neurons firing at the same time, which are positioned in radial (i.e. perpendicular) orientation with respect to the scalp. A cap or net with a variable number of electrodes (usually from 64 to 128) is worn by the participant in order to record electrical activity from different loci, covering the whole scalp. The electric signal is very weak and needs to be amplified prior to analogical-to-digital transformation, which allows recording of EEG in a computer.

For each experimental condition, many stimuli are presented, in randomised order across conditions. At the onset of each stimulus presentation, a trigger marks the EEG, labelling which condition the stimulus belongs to. After data acquisition, the EEG is segmented into epochs, time-locked to the onset of each stimulus, and lasting one-to-two seconds post-stimulus; Then, segments belonging to the same condition are averaged together to obtain the ERP, in the same way in which RTs to single trials belonging to the same condition are averaged together for each participant prior to within-participant statistical analyses. This averaging procedure allows optimisation of signal-to-noise ratio in order to obtain a pattern of ERP components elicited by the cognitive processing of stimuli belonging to the same condition.

ERP components consist of positive and negative (polarity) electrical deflections which vary in amplitude (measured in μV), latency (ms) and scalp distribution (different locations of single electrodes). Electrophysiological research has identified specific components with typical polarity, latency and distribution, reflecting specific cognitive processes. The components elicited by emotion word processing will be presented in Section 4.

After single-participant averaging, grand-average ERPs across participants for different conditions are finally obtained and superimposed for visual inspection, in order to identify which components show a difference in amplitude or latency across conditions. ERP inspection is usually guided by a priori hypotheses on which components will be affected by the experimental manipulation and which scalp distribution they will show. Once the components of interest are identified, mean amplitudes and/or latencies for each condition and each participant are calculated and extracted for statistical analyses.

This technique is characterised by a high temporal resolution (in order of ms), which allows researchers to draw a time-line of a specific cognitive process, from the onset of stimulus presentation until the response. Nevertheless, its spatial resolution is poor, in fact it is constrained by the number of electrodes used; In addition, electrodes can detect the signal coming from the cerebral cortex, but not from deeper brain structures. Finally, the scalp location where an ERP effect is observed is not necessarily close to its neural generator. Source localisation techniques based on algorithms are used to make up for this limitation, but the results obtained consist in approximate estimates.

3.2.3. Functional magnetic resonance imaging (fMRI). The following description is based on Brown and Semelka (2001) and Paulesu, Scifo and Fazio (1998). This technique allows the identification of brain regions activated in response to a specific cognitive process, by using an indirect measure of blood oxygenation. During brain activation, oxygen metabolism increases in smaller proportion compared to blood flow; during rest conditions instead, they both increase in the same proportion. Oxygen metabolism is reflected by the increase of deoxy-haemoglobin, which has different magnetic properties (paramagnetic) compared to oxy-haemoglobin (diamagnetic). Variations in the level of blood oxygenation can be detected by means of a static magnetic field, which aligns all magnetic dipoles of the hydrogen nuclei contained in the haemoglobin in the same direction, either parallel or anti-parallel to the magnetic field. This alignment causes the nuclei to precess around an axis along the direction of the field at a certain frequency, by creating a macroscopic longitudinal magnetisation. A radio-frequency pulse is then sent to create an oscillating magnetic field, orthogonal to the static one. The longitudinal magnetisation precesses along the new magnetic field by creating a transverse magnetisation. When the radio-frequency pulse is turned off, the transversal magnetisation disintegrates and the longitudinal magnetisation recovers; its time of recovery is called T1 relaxation and varies between different substances (e.g. cerebro-spinal fluid, gray matter). Similarly, there's a loss of phase coherence in the transverse plane, which is called T2 relaxation, and is always less than or equal to T1. The time constant for the observed decay is called T2* relaxation time and it is always shorter than T2. The time between two radio-frequency pulses is the repetition time (TR) and the delay from a pulse to the onset of data acquisition is the echo time (TE); both TR and TE are related to the relaxation parameters. The combination of TR and TE in a pulse sequence determines its sensitivity to different types of tissue. During brain activity and therefore oxygen metabolism, deoxy-haemoglobin creates local inhomogeneities in the magnetic field, which causes greater signal loss in T2* weighted images. Hence, the blood oxygenation level dependent (BOLD) signal is used to detect brain activity.

The BOLD response consists of an initial dip, when oxygen metabolism starts, a large increase above baseline, reflecting a substantial supply of oxygenated blood in the area, and the return to a state slightly below baseline, when the amount of oxygenated blood diminishes. This sequence takes several seconds.

Therefore, the advantage in spatial resolution (mm) obtained with this technique is accompanied by a disadvantage in temporal resolution (seconds). Also, what is measured is not the neural activity itself (as with EEG), but rather a consequence of it.

With the event-related design, fMRI images for each single trial are acquired, which can then be used for both factorial or parametric statistical analyses. The classical ERP analyses are factorial.

Furthermore, the patterns of fMRI activations observed never reflect absolute activations, but relative activations to a baseline, obtained by contrasting activations associated with the different experimental conditions with activations associated with a baseline (e.g. resting) condition. Instead, with the ERP technique, an ERP for each experimental condition is obtained, and the different conditions are directly compared.

3.2.4. Eye-tracking. This technique consists in the recording of eye movements during normal reading of texts, usually by means of an infra-red camera which detects the position of the pupil. Under the right conditions, eye-tracking allows experimenters to know what a participant is looking at; in reading, for example, how long they spend looking at certain words.

Eye-tracking produces a variety of measures, some of which are particularly useful for investigating early word processing. In particular, the first fixation duration on a single word of short or medium length is supposed to reflect the difficulty with which the word is recognised and mapped onto a lexical representation. To recognise longer words instead, a second fixation might be necessary, leading to an intra-word saccade. A classical example of resource allocation indexed by the first fixation duration is the word frequency effect: low-frequency words elicit longer fixation durations than high-frequency words (Sereno & Rayner, 2003; Sereno, Rayner, & Posner, 1998).

The eye-tracking technique has high ecological validity as it measures word processing during normal reading; whereas the presentation of single words in sequence, requiring a response to each trial, disrupts the natural reading process. Therefore, the experimental effects found with single word reading (e.g. LDT) cannot be easily generalised to natural reading (see Sereno & Rayner, 2003).

Eye-movement measures have been shown to be sensitive to lexical word properties such as frequency or regularity (Sereno et al., 1998) and this sensitivity shows up very quickly. In fact, the average word fixation duration lasts approximately 250 ms; after that, a subsequent word is fixated. Therefore, differences in affective word properties, along with lexical ones, might also be detected by this technique.

4 The impact of affective variables on single word recognition

In order to manipulate affective word properties, corpora containing ratings for emotional valence and arousal for many words can be used (e.g. Bradley & Lang, 1999; Võ et al., 2009). In addition, lexico-semantic features known to affect word recognition, such as word frequency, age of acquisition and imageability need to be controlled, to partial out their possible indirect effects. In fact, affective and lexico-semantic properties might be correlated to some extent.

Extant word corpora contain ratings either for affective or for lexico-semantic features (see Part II of this dissertation for more detailed information); therefore, little is known about whether and how they are related. Furthermore, it is not yet clear whether affective properties constitute a distinct cluster, or whether their variability can be explained by other lexico-semantic properties.

Behavioural studies investigating emotion word processing mostly focus on valence or emotionality distinctions, by comparing positive versus negative stimuli or emotionally valenced versus neutral stimuli, respectively (e.g. Algom et al., 2004). Traditionally literature on the emotional Stroop effect has reported longer colour-naming latencies and lower accuracy for negative words compared to positive (and neutral) words and has interpreted this effect according to the automatic vigilance hypothesis (Pratto & John, 1991). These results were questioned by Larsen, Mercer & Balota (2006), who found that the material was not controlled for important lexical features, such as word frequency and length, and showed no emotion effects after statistical control of the former variables.

More recent studies employing thoroughly controlled linguistic material and different types of task have repeatedly reported faster reaction times to emotionally valenced words compared to neutral words (Kousta, Vinson, & Vigliocco, 2009; Kuchinke et al., 2007; Scott et al., 2009), suggesting prioritisation of stimuli with emotional connotation. Results are mixed with regards to emotional valence, but no clear-cut differences between positive and negative words have been reported (e.g. Kousta et al., 2009). Estes and Verges (2008), for example, replicated the slowdown effect for negative words in a LDT, but the effect was reversed in a valence judgement task.

To our knowledge, only one behavioural study has manipulated both valence and arousal dimensions (Robinson et al., 2004), and also proposed an approach-withdrawal theoretical framework integrating the effects of these two variables. According to this model, positive, as well as low-arousal stimuli elicit an approach orientation, whereas negative or highly arousing stimuli elicit withdrawal. Reaction time results confirmed the prediction that stimuli eliciting conflicting orientations (i.e. positive high-arousal and negative low-arousal) will take longer to process due to integration difficulty, whereas stimuli eliciting congruent orientations will be easier to process and elicit faster responses.

Electrophysiological (ERP) research on emotion word processing is less theoretically-driven than behavioural research, but more thorough in the selection and manipulation of the materials. Its aim was to investigate when emotion affects word processing mainly focussed on the emotionality distinction by employing emotionally valenced (positive and negative) as well as neutral words (e.g. Kissler et al., 2007; Scott et al., 2009).

Two main ERP components sensitive to emotionality and valence, respectively, have been repeatedly reported (e.g. Herbert, Junghofer, & Kissler, 2008; Kanske & Kotz, 2007; Scott et al., 2009): an early posterior negativity (EPN) between 200-300 ms, showing greater amplitude for valenced words compared to neutral in temporo-occipital electrodes, which indexes implicit orientation of attention toward emotional material; a long-lasting late positive complex (LPC) between 500-800 ms, with centro-parietal distribution, showing different amplitudes not only for valenced words compared to neutral, but also between positive and negative words. This latter component indexes conscious processing of the stimuli prior to response and is influenced by the type of task.

Overall, these results suggest an early discrimination between emotional and non-emotional verbal material, namely at the stage of lexical access, when the linguistic stimulus is matched with a corresponding mental representation. At a later stage, when people are explicitly processing the word meaning for the response, a more subtle discrimination between different aspects of emotionality (positive versus negative valence) is achieved. ERP research contributed a great deal in drawing a time-line of the effects of emotion on word recognition. Nevertheless, valence and arousal dimensions were not independently manipulated but rather confounded; in fact the differences in amplitude for valenced compared to neutral stimuli were often labelled “arousal effects”, even though the two categories also differ along the valence (or emotionality) dimension.

Neuroimaging research on emotion has traditionally used an emotion-specific approach (Ekman, Levenson, & Friesen, 1983), investigating the neural correlates of single emotions (e.g. *fear, disgust*). More recently, research along dimensional models, based on dichotomies (positive vs. negative valence or approach vs. withdrawal) has been pursued (Cacioppo, Gardner, & Berntson, 1999; Davidson, 1992; Feldman Barrett & Russell, 1998), aiming to find patterns of activations shared by several emotions or emotional orientations toward a stimulus. Overall, brain regions responding to the emotional connotation of verbal stimuli were the prefrontal cortex (PFC), not responding to specific emotions but to differences along the valence dimension (Phan, Wager, Taylor, & Liberzon, 2002); the anterior cingulate cortex (ACC), associated with cognitive demand and episodic memory retrieval (Wager, Phan, Liberzon, & Taylor, 2003); the insula, mapping visceral states to emotional experience and giving rise to conscious feelings (Damasio et al., 2000), and the amygdala, preferentially responding to intense emotional stimuli, in absence of cognitively demanding tasks (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Wager et al., 2003). See Part V for a detailed review.

A few brain imaging studies manipulating both valence and arousal dimensions revealed dissociation in patterns of brain activation, with the orbitofrontal cortex (part of PFC) responding to valence and the amygdala responding to arousal (Lewis et al., 2007; Winston, Gottfried, Kilner, & Dolan, 2005). Overall, neuroimaging research has provided insight into which brain areas respond to emotion or to the integration of emotion and cognition, but only a few studies have investigated the independent effects of valence and arousal; furthermore, these studies did not take into account possible indirect effects of lexico-semantic word properties.

The general aim of the present dissertation was to advance research on emotion word processing by benefiting from the contributions provided by the different research strands presented, and by integrating psycholinguistic, electrophysiological and neuroimaging approaches in order to gain a broader and more complete view of the phenomenon. More specifically, the focus was on the manipulation of both emotional valence and arousal dimensions independently, and on the collection of behavioural, ERP and fMRI measures during a lexical decision task (LDT). Research hypotheses and outline of the studies conducted are presented in the next sub-section.

4.1. Outline of studies and hypotheses

4.1.1. Corpus study. In order to investigate the relationship between affective and lexico-semantic features, ratings of emotional valence, arousal, familiarity, AoA and imageability for 300 English words were collected and correlations between all word properties were calculated. The study was explorative with regards to whether affective variables are correlated with lexico-semantic ones, or whether they constitute a distinct cluster. This issue was also addressed in the behavioural study (see next sub-section). On the basis of the theoretical and empirical distinction between valence and arousal, differential patterns of correlations between lexico-semantic features and each of the affective variables was predicted.

4.1.2. Behavioural study. In order to investigate the effects of emotional valence and arousal on lexical processing, these variables were orthogonally manipulated by carefully controlling for a range of lexico-semantic features (see Part III for details). Furthermore, in order to determine whether emotion contributes to word recognition beyond other word properties and whether affective properties constitute a distinct cluster, affective and lexico-semantic variables were used as predictors of the lexical decision latencies.

This study is an advance of Robinson et al. (2004), who matched their stimuli for word frequency only and who used a design requiring explicit emotion processing. It also provides novel information regarding the contribution of affective dimensions during word recognition.

According to previous literature, faster reaction times for valenced words compared to neutral were predicted. According to the model by Robinson et al. (2004), an interaction between valence and arousal was predicted, with emotionally conflicting stimuli eliciting longer lexical decision latencies compared to congruent stimuli. Finally, it was predicted that affective features will show a unique contribution to predicting lexical decision latencies beyond other word properties.

4.1.3. ERP study. In order to determine which stages of word recognition are affected by valence and arousal, EEG was recorded during a LDT employing the same material used for the behavioural study. This study further aims to test the model by Robinson et al. (2004) by means of event-related potential measures, as an extension of their results based on behavioural measures.

An early interaction of valence and arousal was expected, with conflicting stimuli eliciting enhanced processing, which will be reflected in both lexical decision latencies and ERP amplitudes. The study was explorative with regards to which components will show an interactive effect; nevertheless, because Robinson et al. suggest that integration takes place at an early, pre-attentive stage, we expect to find an interaction in early ERP components.

Furthermore, an advantage of emotionally valenced words over neutral words was also predicted, reflected by faster lexical decision latencies and larger amplitude of the EPN component; more generally, a difference in amplitude between valenced and neutral words in the LPC was also expected.

4.1.4. fMRI study. In order to investigate the neural correlates of valence and arousal, these variables were orthogonally manipulated following a similar procedure as in the previous two studies, but increasing the number of stimuli per condition. Full-brain MR images were acquired during a LDT with an event-related design. This study is an advance on previous ones because a thorough control of lexico-semantic variables was applied and a non-biasing task requiring implicit emotion processing was chosen.

Based on the model by Robinson et al. (2004), it was predicted that higher integration difficulty will be observed for conflicting stimuli compared to congruent ones, as reflected by increased BOLD responses in brain regions shared by valence and arousal: namely insula and anterior cingulate cortex (ACC). Second, higher activation in the amygdala was predicted for high-arousal compared to low-arousal stimuli. This study also aimed to replicate previous findings reporting prefrontal activations for valenced compared to neutral words. Predictions regarding reaction time results replicated the ones formulated in the two previous studies.

5. Results

5.1. Corpus study

As expected, differential patterns of correlation between lexico-semantic word properties and each of the affective variables were observed: rated imageability correlated with arousal but not valence, and rated familiarity correlated with valence but not arousal, supporting theoretical and empirical distinction between the emotional dimensions. Also, valence and arousal were highly correlated with each other, whereas the only two correlations with lexico-semantic variables were weak, suggesting that affective features constitute a distinct cluster. The correlations found showed that highly arousing valenced words are also high in imageability and vice versa, but neutral words did not show this trend; in addition, positive words tend to be more familiar than negative words, which might be due to a rating bias. Finally, values for rated arousal were higher for negative than positive words.

The corpus generated can be used as a tool for designing psycholinguistic experiments investigating single word processing.

5.2. Behavioural study

Valenced words showed a processing advantage over neutral words, reflected by faster lexical decision latencies. Nevertheless, this difference was mainly due to faster RTs for positive words, which were found to be more familiar than negative and neutral words. After controlling for this variable, the emotionality effect was no longer significant.

In addition, emotional valence and arousal affected word processing in an interactive way, showing slower lexical decision latencies for emotionally conflicting stimuli (positive high-arousal and negative low-arousal words) compared to congruent stimuli (positive low-arousal and negative high-arousal words).

Finally, a unique contribution of emotion in predicting lexical decision latencies beyond lexical and semantic properties (including familiarity) was shown, as well as a clear distinction of affective variables from other lexico-semantic ones.

5.3. ERP study

A processing advantage for emotionally valenced words compared to neutral words was found, reflected by faster lexical decision latencies and larger amplitude of the EPN component between 250-310 ms. This effect was also significant in a subsequent negativity (370-430 ms). A difference in amplitude in the LPC component (430-650 ms) was also found, with larger amplitude for neutral words compared to valenced words.

A trend toward a significant interaction was found in lexical decision latencies, which were slower for conflicting stimuli compared to congruent stimuli; as well as in the EPN component and in a subsequent negativity, both showing larger amplitude for conflicting compared to congruent stimuli. This pattern suggests enhanced processing for conflicting stimuli and early integration of valence and arousal dimensions, during lexical access.

An unexpected result was the observation of an emotionality effect on a very early component: N1 (150-210 ms), showing larger amplitude for positive words compared to neutral. N1 indexes attention orientation toward a stimulus and was shown to respond to word frequency (Sereno et al., 1998) as well as an interaction between frequency and emotionality (Scott et al., 2009). A possible interpretation is that very salient stimuli (very highly arousing or very frequent) capture attention at an extremely early stage of word recognition.

5.4. fMRI study

Imaging results revealed an interaction between valence and arousal, with higher activation in the left posterior and right insula, as well as right cerebellum, for stimuli eliciting conflicting emotional orientations compared to congruent stimuli. The insula has been shown to map visceral bodily states into emotional representations to give rise to conscious feelings (e.g. Critchley, Wiens, Rotshtein, Ohman & Dolan, 2004), and in the present study it might well index integration of conflicting emotional orientations. This pattern was further confirmed by the contrast between high and low arousal positive words, which showed increased activation in the left posterior and right insula, as well as in the left parahippocampal gyrus.

No amygdala activation was found in response to different levels of emotional arousal, possibly due to the fact that the stimuli employed were not intense enough. Also, no difference between valenced and neutral words was observed, with the exception of activation within the inferior frontal gyrus for neutral compared to negative words; this could possibly reflect the requirement of more effortful conscious processing for the lexical decision, as neutral words are less salient than emotionally valenced words.

Finally, reaction time results showed an advantage of positive words over negative, but no difference between emotionally valenced and neutral words was found; no interaction between valence and arousal was found either.

6. Discussion

The present dissertation has contributed to advancing research on emotion word processing by integrating psycholinguistic and psycho-physiological approaches. The research suggests that the two dimensions of emotion (valence and arousal) affect word recognition in an interactive way at all processing stages, from the very early retrieval of word-form representations to lexical access.

Firstly, it was demonstrated that affective word properties are distinct from other lexico-semantic properties and have an impact on word recognition. Secondly, all studies provided empirical evidence of a two-dimensional structure of emotion, constituted by emotional valence and arousal: these dimensions are distinct and interact with each other during word processing. More specifically, emotional variables were shown to affect word recognition at very early stages, namely when word-forms are retrieved from the mental lexicon. Furthermore, emotion word processing activated brain areas associated with the mapping between visceral states and emotional experience, which gives rise to conscious feelings. Finally, the present research provided word norms for affective and lexico-semantic properties, which can be employed for designing psycholinguistic experiments.

Taken together, these results support the approach-withdrawal framework as proposed by Robinson et al. (2004). The results extend their empirical findings by showing enhanced processing or higher integration difficulty in response to stimuli eliciting contrasting approach-withdrawal reactions, compared to stimuli eliciting congruent approach or withdrawal reactions. This effect was observed in behavioural measures (lexical decision latencies), as well as psychophysiological measures, showing early sustained interactive effects of valence and arousal, implemented in brain regions associated with mapping of the emotional characteristics of the stimulus with its cognitive evaluation.

6.1. Single complementary contributions of the different studies

The various methodologies used provided insight into different aspects of emotion processing. The corpus study helped to obtain an idea of how emotional valence and arousal correlate with other lexico-semantic word properties, as well as with each other. This allowed thorough manipulation of the emotional variables and control of indirect effects of correlated variables during stimuli selection for the empirical studies and subsequent data analysis.

The behavioural study provided information on implicit processing of emotional content, which was not the target of the lexical decision task. Furthermore, the combined use of ratings and lexical decision latencies collected in these two studies was advantageous. It allowed for the determination of whether any residual variance not explained by lexico-semantic variables could be accounted for by affective variables; which was indeed the case. In addition, it enabled a better investigation of whether affective word properties are distinct from lexico-semantic properties, also supported by the results.

The electrophysiological approach provided information on the timing of emotion effects during word recognition, hence which processing stages are affected, and also on the scalp distribution of these effects. The neuroimaging approach could instead define the anatomical underpinnings of the emotion effects and allowed inferences on what brain functions subserve the cognitive process at play.

6.2. Inconsistent and reconcilable differences across studies

The results from all four studies were consistent overall, especially with respect to the valence by arousal interaction and its direction; nevertheless, some inconsistencies were also found. In particular, the prioritisation of emotionally valenced words compared to neutral words, reflected in RT as well as ERP measures, in both behavioural and ERP studies, was not confirmed by the RTs collected in the fMRI study, nor by the imaging results. However, these latter results might be somehow compatible with results from the previous two studies.

The higher activation observed for neutral words compared to negative in the inferior frontal gyrus suggests that neutral words require more effortful conscious processing for the lexical decision, as they are less salient than emotionally valenced words and cannot benefit from the recruitment of affective limbic regions. This is in line with the larger amplitude for neutral words found in the LPC, a component which reflects explicit processing of the stimulus prior to the response. Nevertheless, it is not clear why the same difference was not found between neutral and positive words.

The RT inconsistency is less of a concern because behavioural data collected in the fMRI scanner are usually less reliable than data collected in a classical behavioural experiment. In fact, participants are in a lying position, cannot move their body or their head, and need to pay attention to this and many other possibly confounding factors while performing the task. Their response times are typically longer than in a more comfortable experimental setting (as was also the case in this research) and more variability is introduced.

6.2.1 Positive words are special. In the fMRI study a clear advantage of positive words over neutral and negative ones was not only observed in the RTs, but also in the BOLD responses, showing a modulation of arousal within positive words but not negative ones. This advantage could be explained by the fact that positive words have a more interconnected lexical and semantic network compared to negative, but also neutral words; therefore, they are easier to process (see Ashby, Isen, & Turken, 1999). These findings are compatible with an interaction of emotionality and hemisphere found in the LPC time-window, showing smaller amplitude for positive compared to neutral words, but also for positive compared to negative words, in the right hemisphere only. Also, the emotionality effect found in the early N1 component, showing larger amplitude for positive compared to neutral and negative words, might be considered to point in the same direction as the LPC effect, if we interpret larger amplitude in the N1 as early enhanced orientation of attention toward positive words.

If we also consider the findings regarding the familiarity (and self-referentiality) bias reported in both corpus and behavioural studies, the consistent processing advantage shown by positive material has two possible interpretations. First, positive words are naturally more salient than negative and neutral words given that healthy people show an automatic preference toward positive information (Fredrickson & Branigan, 2005), which is also compatible with the idea of a more highly interconnected lexical and semantic network. Therefore, attention is automatically driven toward positive words even before matching of a lexical mental representation with the input stimulus, as reflected by the emotionality effect in the N1, but also by the activation of the insula, a region proposed as part of a “salience network” (Seeley et al., 2007). This salience effect might have been enhanced in the ERP study by the specific material used: in fact the positive words were matched in arousal with negative words, but were slightly higher in absolute valence, i.e. “extremely valenced”. This was not the case for the material used in the fMRI study though, where positive and negative words were also matched for absolute valence.

An alternative interpretation, partly compatible with the first one, but more difficult to reconcile with the results from all studies, proposes that people show a bias toward positive material when asked to evaluate its familiarity or its possible reference to themselves (Citron et al., 2009; Lewis et al., 2007). This might also be the case when they need to evaluate or judge verbal material with regards to different emotional or non-emotional properties (e.g. its lexicality). This interpretation would reconcile the familiarity bias observed in the rating study with the emotionality by hemisphere interaction observed in the LPC, a component associated with stimulus evaluation; this is also in line with the general processing advantage observed in the imaging study, which cannot clearly establish whether the advantage occurred at a perceptual, attentional or evaluative processing stage. This interpretation is not compatible with the effect found in the N1 though, a component which does not index stimulus evaluation.

6.2.2. Subtle emotion effects. Generally, the psychophysiological results show subtle interactive effects of the two emotion dimensions, possibly due to the fact that the stimuli used were not intense enough, but only showed discrete degrees of differentiation across conditions. This is partly due to the thorough manipulation and control of affective and lexico-semantic variables; for example, because negative words are usually more intense than positive stimuli (Citron et al., 2009; Lewis et al., 2007), matching them for arousal and for absolute valence led to the use of less intense negative words and less extremely valenced positive words (the latter one only in the fMRI study).

Subtle differences in the material led to subtle differences in brain activity, but the sensitivity of psychophysiological measures could have been improved by employing more trials in the ERP study, where only 25 stimuli per condition were employed in the valence by arousal design, as well as by the definition of regions of interest (ROIs) for the analysis of the fMRI data. In this study, the number of trials per condition was increased (N=35), but the analysis of the full brain might have very likely hidden subtle emotional effects. By having a priori hypotheses on the regions responding to the experimental manipulation, the analyses can be tailored on specific areas and the likelihood of finding significant effects increases.

6.2.3. Other technical comparisons. Scalp distribution of the ERP effects and areas of activation found in the fMRI study cannot be compared; in fact the electro-cortical activity recorded from the posterior electrodes might originate from different cortical and sub-cortical regions, its distribution is only the output of brain activity detected by the electrodes. In order to identify the neural generator of this cortical activity, a source localisation technique can be used, which uses an algorithm to determine the possible source of electrical activity. The neural generator could then be compared with the anatomical correlate found in the fMRI study.

6.3 What comes next? Suggestions for future research

Future research should consider individual differences in emotion word processing. In fact, mood states, as well as personality traits, have been shown to influence cognitive processing of verbal material, emotional or non emotional (Fredrickson & Branigan, 2005; Mathews & MacLeod, 1994; Storbeck & Clore, 2007). These variables could be controlled in order to reduce additional variability in the results, which is not directly due to the emotional properties of the material employed. Arousal in particular has been shown to affect off-line measures in a less stable manner compared to valence (Kousta et al., 2009).

Furthermore, it would be interesting to investigate how individual differences affect emotion processing in the healthy population (e.g. Taake, Jaspers-Fayer, & Liotti, 2009); This could inform extant research on clinical populations (Mathews & MacLeod, 1994), as well as research aimed to improve health and well-being.

Publication plan

1. Corpus study (Section II):

Citron, F.M.M., Weekes, B.S. & Ferstl, E.C. (under review). How are affective word ratings related to lexico-semantic properties? Evidence from the Sussex Affective Word List (SAWL). *Cognition & Emotion.*

Part of this study has already been published (not included in the present dissertation):

Citron, F., Weekes, B. & Ferstl, E. (2009). Evaluation of lexical and semantic features for English emotion words. In K. Alter, M. Horle, M. Lindgren, M. Roll & J. von Koss Torkildsen (Eds.), Brain talk: discourse with and in the brain (pp. 11-20). Lund: Media-Tryck. ISBN 978-91-633-5561-5

2. Behavioural study (Section III):

Citron, F.M.M., Weekes, B.S. & Ferstl, E.C. (in preparation). Emotional valence and arousal affect word recognition in an interactive way. *Psychonomic Bulletin & Review.*

3. ERP study (Section IV):

Citron, F.M.M., Weekes, B.S. & Ferstl, E.C. (in preparation). Time course of interactive effects of emotional valence and arousal during word processing: An ERP study. *Journal of Cognitive Neuroscience.*

4. fMRI study (Section V):

Citron, F.M.M., Gray, M.A., Critchley, H.D., Weekes, B.S. & Ferstl, E.C. (in preparation). Neural correlates of the interaction between emotional valence and arousal during lexical processing: Evidence for an integrated approach-withdrawal framework. *Neuroimage.*

II. How are affective word ratings related to lexico-semantic properties? Evidence from the Sussex Affective Word List (SAWL)

Abstract

Emotion has an effect on the speed of visual word recognition in various cognitive tasks that is independent of lexico-semantic variables. However, little is known about how the dimensions of emotional arousal and emotional valence interact with the lexico-semantic properties of words such as age of acquisition (AoA), concreteness and imageability that determine word recognition performance. The aim of this study was to examine these relationships using English ratings for affective and lexico-semantic features. Eighty-two native English speakers rated 300 words for emotional valence, emotional arousal, word familiarity, AoA, concreteness and imageability. Although both dimensions of emotion (valence and arousal) were correlated with lexico-semantic variables, a unique emotion cluster produced the strongest correlation. This finding suggests that emotion should be included in models of word recognition as it is likely to make an independent contribution.

Key words: Emotional valence, arousal, age of acquisition, imageability, familiarity, word processing

Introduction

Emotional valence and arousal are generally considered the two dimensions that define the structure of affect. Valence describes the extent to which an affect is pleasant or unpleasant (positive, negative), whereas arousal refers to its degree of activation, i.e. how exciting, agitating or otherwise calming an emotion is perceived (Feldman Barrett & Russell, 1999). Despite the utility of these dimensions in affect research (Russell, 2003), there are several unresolved issues. For example, it is not clear whether these dimensions are independent. Moreover, no consensus has been achieved on the relation between positive and negative affect. For example, it is not known whether these are distinct aspects or bipolar opposites (Feldman Barrett & Russell, 1999).

Emotional arousal has often been defined as the intensity of an affective response that can be positive, negative or neutral in valence. Emotionally valenced words are in fact typically more arousing than neutral words (Bradley & Lang, 1999). Although arousal is associated with valence (Kissler et al., 2007; Scott et al., 2009), several models of emotion assume that valence and arousal are distinct variables (Reisenzein, 1994; Russell, 2003). Support for this assumption comes from behavioural and neuroimaging research on emotion word processing (Lewis et al., 2007). For example, Lewis et al. (2007) reported a double dissociation in brain activation between emotional valence and arousal during word processing. The amygdala was sensitive to arousal, whereas activation in the orbitofrontal cortex was influenced by emotional valence. Furthermore, different sub-regions of the orbitofrontal cortex were modulated by increasing positive or negative valence, apparently supporting a characterization of valence in terms of independent axes (positive, negative), rather than a bipolar continuum.

Emotional variables have an effect on single word recognition during a variety of cognitive tasks including lexical decision, valence judgement, silent reading, emotional Stroop and self-referential judgement (Estes & Verges, 2008; Kanske & Kotz, 2007; Kissler et al., 2007; Larsen et al., 2006; Lewis et al., 2007; Scott et al., 2009; Võ, Jacobs, & Conrad, 2006). These studies generally report a different pattern of processing for emotionally valenced words compared to neutral words.

Emotion processing during text comprehension has also been investigated by means of short stories describing events and the subsequent emotional reaction of the protagonist. These texts typically consist of a context sentence (or paragraph) and a following target sentence containing an emotion word, which matches or mismatches with the context (consistency paradigm, Gernsbacher, Goldsmith, & Robertson, 1992). Texts containing emotional information are processed in a qualitatively different way to texts containing chronological or spatial information (Ferstl, Rinck, & von Cramon, 2005).

We know that word recognition is influenced by a myriad of lexico-semantic features including word length, frequency, familiarity, age of acquisition (AoA), imageability and concreteness, all of which predict word naming and lexical decision latencies (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). These variables need to be taken into account and controlled when manipulating affective variables, otherwise their effects on performance might be confounded with lexico-semantic effects, as was the case in many studies using the emotional Stroop task (see Larsen et al., 2006 for a review). The same is true for studies manipulating lexico-semantic features; for example, abstract words seem to have more affective associations compared to concrete words (Kousta et al., in press).

Norms for lexico-semantic variables are usually strongly correlated, making it difficult to attribute variability in word recognition to any one dimension alone (Cutler, 1981). Affective variables are also positively correlated with each other: the higher the valence, the higher the level of rated arousal, suggesting that emotion variables may be unitised into a single cluster. It is also possible, however, that each affective variable will be correlated with different lexico-semantic features. Knowing exactly which variables correlate with arousal and valence would therefore be informative to the question of whether emotion is a distinct cluster, whose effects on performance cannot be simply accounted for by the well-known lexico-semantic predictors.

This question has partly been investigated in previous studies. For example, in order to manipulate the affective and lexico-semantic features of single words, experimenters used large word corpora which include information on features such as length and frequency (CELEX, Max Planck Institute for Psycholinguistics, 2001), and subjective ratings of word properties from naïve participants on features such as word familiarity, AoA and imageability. Extant databases in English do not include ratings of emotion variables (Bird et al., 2001; MRC database, Coltheart, 1981; The Bristol Norms, Stadthagen-Gonzales & Davis, 2006) and corpora with affective ratings do not include ratings of lexico-semantic features (ANEW, Bradley & Lang, 1999). Therefore, little is known about the correlations between emotion ratings and lexico-semantic variables. One consequence of this gap is that experimenters must retrieve ratings for the same word from different corpora, which often do not overlap in terms of words sampled and scales used. For example, according to Kousta, Vinson and Vigliocco (2009), rated AoA and imageability for English words are available for only about a third of the words contained in the ANEW database.

The primary aim of the present study was, therefore, to generate a corpus of English words suitable for experiments investigating effects of affective as well as lexico-semantic features on single word recognition and on text comprehension. To ensure homogeneous evaluations across words and variables, 300 words were rated in a within-subjects design for emotional valence, arousal, familiarity, AoA and imageability. The reliability of the results was tested against extant ratings from other corpora. Imageability was chosen, rather than concreteness, as the former feature has repeatedly been shown to better reflect human picturing activity compared to the latter one, in particular with respect to highly imageable abstract words and emotion words (Altarriba & Bauer, 2004; Paivio et al., 1968).

The corpus includes approximately 100 neutral words to allow comparison between valenced and non-valenced items. A subset of words were adjectives denoting emotions (e.g. *happy, sad, indifferent*), which are useful for creating texts describing emotional reactions of the protagonists. Different possible pairs of antonyms were included for the emotion word subset as well as for other words (i.e. *delighted-disappointed*, *abandon-adopt*), in order to aid the construction of texts for consistency paradigms (Ferstl et al., 2005; Gernsbacher et al., 1992). See Appendix B for proposed pairs of antonyms.

The second aim of the study was to explore whether affective variables are correlated with lexico-semantic ones, or whether they constitute a distinct cluster. The latter case would confirm that emotion effects cannot be simply accounted for by other word features, but rather they contribute to explain additional variance in performance.

If emotional valence and arousal are independent dimensions of affect, we should expect to observe differential patterns of correlations between lexico-semantic features and each of the affective variables. An additional prediction was that positive and negative words would differ in rated levels of arousal. Correlations between word length, familiarity, AoA, frequency and imageability were also expected, in line with previous studies (Bird et al., 2001; Stadthagen-Gonzales & Davis, 2006).

Method

Participants

Eighty-two students from the University of Sussex (71 women, 11 men) took part in the experiment and received course credits or £7.50. They were all native speakers of English, aged between 18-42 years (M=20.5, SD=3.98).

Materials

Word selection. Some words were selected from pre-existing emotion word lists: the BAWL (Võ et al., 2006) and the Compass DeRose guide to emotion words (DeRose, 2005). These items were supplemented with additional words, including emotions expressed as adjectives, ranging from very positive (e.g. *delighted*) to very negative (e.g. *terrified*), through neutral (e.g. *apathetic*) as well as pairs of antonyms. To create possible pairs of antonyms, we picked words whose meanings can be considered opposite in different contexts, bearing in mind the most common use of the two words. A total of 525 words were initially categorised as positive, negative or neutral by two native English speakers. 300 words were subsequently selected with approximately one third in each category of positive, negative and neutral stimuli, by eliminating semantically ambiguous and very infrequent words.

The word corpus. The corpus used in the rating study comprised 300 words, approximately 1/3 positive, 1/3 negative and 1/3 neutral, with 90 adjectives, 118 nouns, 24 verbs, 55 words that can be either verbs or nouns in English, and an additional 13 words belonging to more than 2 categories. Sixty-one items were concrete, 153 were abstract and 86 were emotions or adjectives which can be used to express feelings (e.g. “I am happy”, “I feel brave”). Items were classified as concrete or abstract according to Paivio et al. (1968): “Concreteness was defined in terms of directness of reference to sense experience” (p. 1). Frequency of use per million (spoken and written combined) and length in letters, phonemes and syllables were taken from the web-based CELEX database (Max Planck Institute for Psycholinguistics, 2001).

The questionnaire. Online questionnaires were created using the software Macromedia Dreamweaver MX 2004. For each feature a definition for subjective rating was given, together with instructions including two examples of words at the extremes of a 7-point Likert scale. Definitions of familiarity, AoA and imageability were adapted from the Bristol Norms (Stadthagen-Gonzales & Davis, 2006). The extremes were labelled as follows: The scale for emotional valence ranged from -3 (very negative) to +3 (very positive); arousal, familiarity and imageability were scaled from 1 (not at all) to 7 (very high), and the AoA scale was labelled using the following age ranges: 0-2, 2-4, 4-6, 6-9, 9-12, 12-16, older than 16. At the right end of each scale the option “unknown word” was given.

Procedure

The participants were given a URL via email to access the questionnaire and enter their details. Then, they read general instructions first, followed by the specific instructions for the first feature to be rated. The words were then presented, each one at the centre of the page immediately followed by the 7-point scale. When all 300 words were rated for one feature, instructions for the next feature rating appeared. In this way, no influence among ratings for different features for the same word was ensured. The order of features and the order of words within each rating task were varied for each participant. Because of their similarity, familiarity and AoA were never adjacent, nor were emotional valence and arousal. The rating task was self-paced and could be completed in one or two sessions within a week. Completion took approximately 1 hour and 15 minutes.

Data Analysis

Overall, less than 0.19% of responses were rated “unknown”. Only four words in the corpus (1.3%) generated “unknown” responses: abundance, antagonist, apathetic, intonation. Means and standard deviations of ratings were calculated for each feature for each word. In addition, a categorical variable “valence category” was created based on the following criteria: words rated from +3 to +1 were categorised as positive, from +0.8 to -0.8 as neutral, and from -1 to -3 as negative. A gap between positive and neutral words, as well as between neutral and negative words was left to reduce ambiguity in categorisation. The absolute values of emotional valence were used to form an additional variable called “emotionality”. This variable gives a measure of valence that is independent of the direction of the rating (positive versus negative) and thus provides a measure of the emotionality.

Given the large number of abstract words compared to concrete ones and given the fact that all emotion words are abstract, it was decided to control for concreteness while computing the correlations between all other features. Partial correlations were calculated for the following features: emotional valence, emotionality, arousal, familiarity, age of acquisition, imageability, frequency of use, and word length. Given the high number of correlations among all features, a conservative significance level of .001 was applied throughout, in order to gain a more concise and meaningful picture of the results. Reliability analyses were carried out, correlating the ratings of appropriate subsets of words from the current corpus with ratings from other corpora.

Results

The full word list of items and their associated variables as well as means and standard deviations of all the ratings, are provided in Appendix A.

Descriptive statistics

The descriptive statistics for all features are shown in Table 1 for the three categories defined according to emotional valence.

Table 1. Descriptive statistics of rated and objective features broken down by valence category: positive (from 3 to 1), negative (from -3 to -1) and neutral (from 0.8 to -0.8) words. Words which fell in between positive and neutral categories (10 words) or negative and neutral categories (10 words) are not included.

	Positive (106 words)				**Neutral (80 words)**				**Negative (94 words)**			
	Mean	SD	Min	Max	**Mean**	SD	Min	Max	**Mean**	SD	Min	Max
Emotionality	**1,61**	.39	.99	2.52	**.39**	0,25	.00	.80	**1.66**	.41	1.00	2.66
Arousal	**3,55**	.73	2.08	5.35	**2.49**	0,56	1.50	4.15	**4.44**	.76	2.61	5.96
Familiarity	**5,11**	.80	3.06	6.62	**4.58**	1,04	2.29	6.52	**4.56**	.75	2.80	6.55
Age of Acquisition	**3,74**	1.02	1.62	5.63	**3.90**	1.00	1.73	6.18	**4.02**	.84	1.84	5.46
Imageability	**3,94**	1.40	1.93	6.71	**4.00**	1,51	1.87	6.67	**3.93**	1.06	1.96	6.51
Length in letters	**7 .00**	2 .00	3 .00	12 .00	**6 .00**	2 .00	3 .00	12 .00	**7 .00**	2 .00	3 .00	13 .00
Length in phonemes	**6 .00**	2 .00	2 .00	13 .00	**5 .00**	2 .00	2 .00	12 .00	**6 .00**	2 .00	2 .00	12 .00
Length in syllables	**2 .00**	1 .00	1 .00	5 .00	**2 .00**	1 .00	1 .00	4 .00	**2 .00**	1 .00	1 .00	4 .00
Log Frequency	**.61**	.58	0	2.97	**1.50**	.56	.30	2.48	**1.28**	.52	0	2.43

Reliability Analyses

The ANEW corpus (Bradley & Lang, 1999) contains valence and arousal ratings for 113 out of the 300 words used in the current study. Pearson correlations between the ANEW ratings and the present ratings were highly significant (Valence: r = .97, p < .0001; Arousal: r = .73, p < .0001). The MRC Psycholinguistic database (Coltheart, 1981) contains familiarity and imageability ratings for 181, and AoA ratings for 72 words out of the 300 items. Correlations with ratings from MRC database were highly significant (familiarity: r = .78, p < .0001; imageability: r = .92, p < .0001; AoA: r = .93, p < .0001). Finally, in the Bristol Norms (Stadthagen-Gonzales & Davis, 2006) familiarity, imageability and AoA ratings for 53 words were available. Despite the lower number of shared words, correlations were high (familiarity: r = .91, p < .0001; imageability: r = .96, p < .0001; AoA: r = .95, p < .0001).

Correlation analyses

The results (P < .001) are shown in Figure 1a. Less restrictive levels of significance did not show a very different pattern of results, but a more noisy pattern (see Table 2 for correlation matrix).

Correlations among lexico-semantic features. As expected, familiarity, AoA and frequency were all highly correlated (see Figure 1a). Imageability correlated highly with AoA as well as familiarity. Word length in letters was highly correlated with AoA, frequency of use, familiarity and imageability.

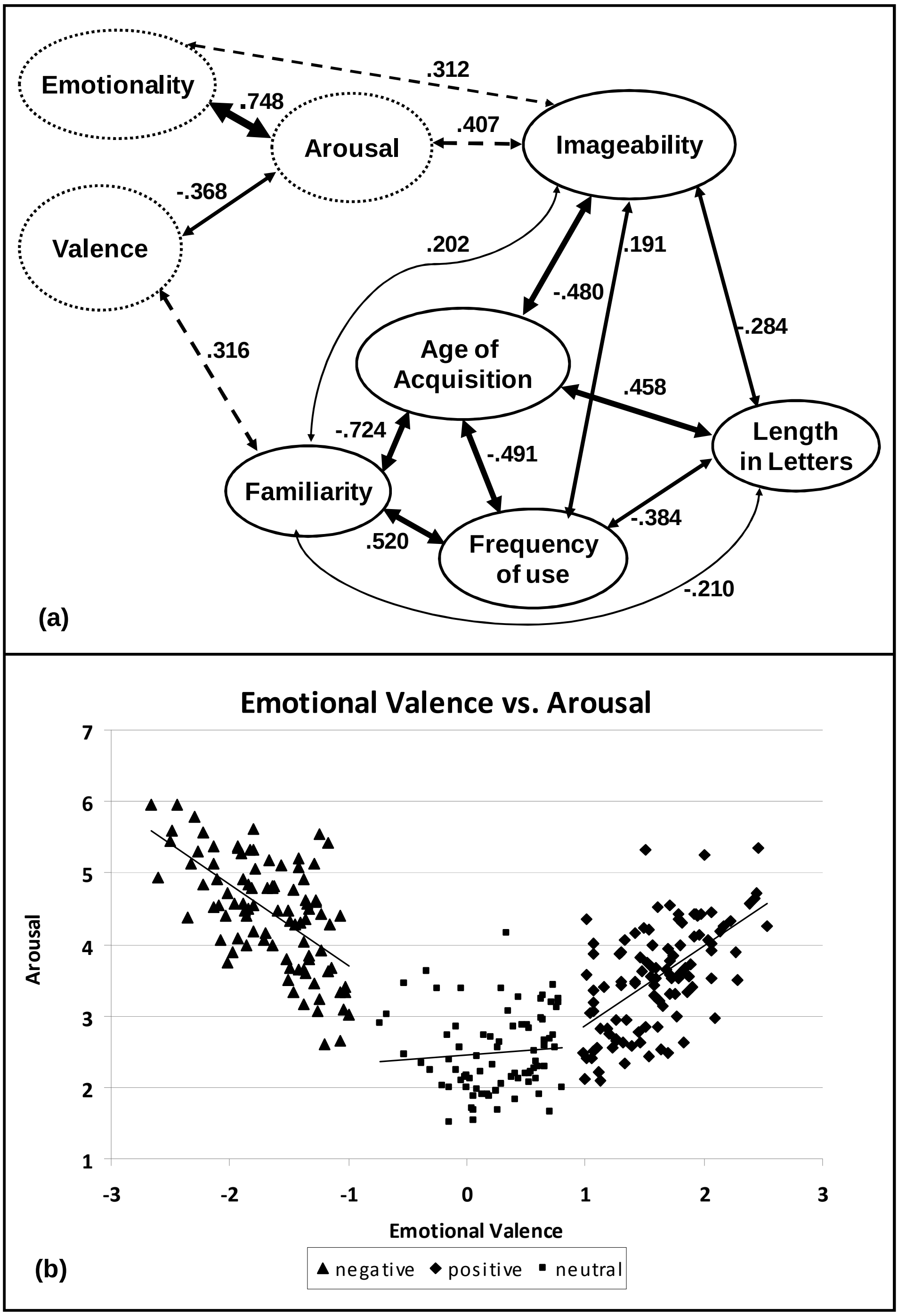

Figure 1 (a). Pearson correlations among affective, lexical and semantic features (p < .001) by controlling for concreteness. The arrow thickness refers to the strength of the correlations. Word length is reported as number of letters. AoA = Age of Acquisition; *(b).* Emotional valence ratings plotted with arousal ratings. Valence ratings are categorized as positive, neutral and negative.

Table 2. Matrix of Pearson correlations among affective, lexical and semantic features by controlling for concreteness.

	Em. Valence	Emotionality	Arousal	Familiarity	AoA	Imageability	Log Freq	Letters	Phonemes	Syllables
Em. Valence	1	-.04	-.37***	.32***	-.16**	-.04	.13*	.06	.04	.1
Emotionality	-.04	1	.75***	.16**	-.15**	.31***	-.06	-.03	-.01	-.01
Arousal	-.37***	.75***	1	.02	-.08	.41***	-.07	-.07	-.05	-.08
Familiarity	.32***	.16**	.02	1	-.72***	.20***	.52***	-.21***	-.19**	-.21***
AoA	-.16**	-.15**	-.08	-.72***	1	-.48***	-.49***	.46***	.46***	.44***
Imageability	-.04	.31***	.41***	.20***	-.48***	1	.19**	-.28***	-.32***	-.26***
Log Freq	.13*	-.06	-.07	.52***	-.49***	.19**	1	-.38***	-.37***	-.29***
Letters	.06	-.03	-.07	-.21***	.46***	-.28***	-.38***	1	.90***	.78***
Phonemes	.04	-.01	-.05	-.19**	.46***	-.32***	-.37***	.90***	1	.84***
Syllables	.1	-.01	-.08	-.21***	.44***	-.26***	-.29***	.78***	.84***	1

***significance level=.001, **=.01, *=.05

Correlations among affective features. In Figure 1b we can see a U-shaped function, in which both positively and negatively valenced words are higher in arousal compared to neutral words (Bradley & Lang, 1999). As expected, there is a positive correlation between emotionality and rated arousal, with valenced words (positive and negative) being highly arousing. Highly negative words were rated more arousing than highly positive words however (see Figure 1b). A t-test revealed that rated arousal was significantly higher for negative words than positive words ($t(198) = -8.46$, $p < .0001$), whereas they did not differ in emotionality ($t(198) = -.94$, *n.s.*).

Correlations between affective and lexico-semantic features. Rated imageability was positively correlated with both arousal and emotionality but not valence, with highly imageable words being more arousing. However, when these correlations were examined separately for each category of valence, there was a relationship between imageability and positive words ($r = .45$, $p < .0001$) and negative words ($r = .60$, $p < .0001$), but not neutral items ($r = -.07$, *n.s*). Familiarity was positively correlated with emotional valence, i.e. positive words were rated as more familiar. There was no correlation between rated familiarity and arousal or emotionality. It is notable that rating the imageability of a word draws on the sensory properties which can be imagined out of context, whereas rated familiarity of words draws on cognitive appraisal, similar to the meta-judgement that is required for assessing emotional valence.

Discussion

As expected, we observed differential patterns of correlation between the lexico-semantic features of single words and each of the affective variables. Rated imageability was correlated with arousal but not valence, and rated familiarity was correlated with valence but not arousal. In addition, values for rated arousal were higher for negative than positive words. Furthermore, a high but not perfect correlation between emotionality and arousal was found, suggesting that arousal is not reducible to the emotionality of a valenced stimulus, but it rather represents a different dimension. Our results suggest that, although emotional valence and arousal are correlated, they must be distinguished carefully in studies manipulating affect. For example, studies that manipulate valence must control for differences in arousal.

The corpus reported here can be used as a tool for designing psycholinguistic experiments investigating single word processing as well as text comprehension. Other similar corpora comprise only a subset of these features and usually do not contain both affective and lexico-semantic features rated by the same participants. Furthermore, the present corpus is particularly suitable for text comprehension experiments employing the consistency paradigm (Gernsbacher et al., 1992) because it contains emotion adjectives and possible pairs of antonyms. Approximately eighty-six words in the form of adjectives refer to emotions or feelings.

We have demonstrated high reliability of the SAWL with other corpora. Ratings for familiarity, AoA and imageability were highly correlated with the ratings from the MRC database and the Bristol Norms. There was little overlap between words in the SAWL and the Bristol Norms; in fact the latter corpus is not rich in emotionally valenced words. In addition, within the words referring to emotions or feelings in the SAWL, only 11 overlapped with the Bristol Norms, whereas 13 emotion adjectives were present in the form of verb or noun in the Bristol Norms. This shows that extant databases are limited in their utility for designing experiments using single words and the SAWL will therefore prove to be a useful resource in the future.

Nevertheless, the sample size of our norms is small (300 words) compared to other databases containing over a thousand words (e.g. the ANEW); this might limit its usability for designing experiments for which many trials are needed, e.g. ERP experiments usually require 40 trials per condition.

Our ratings for emotional valence and arousal were highly correlated with the ANEW norms, with arousal showing a slightly lower correlation. This might suggest that arousal is a less stable property, more influenced by environmental factors (e.g. mood changes). Many words referring to emotions or feelings were non-overlapping in the two corpora (approximately half of the emotion adjectives from the SAWL), with some emotions included in the form of nouns or verbs in the ANEW (i.e. *excitement* vs. *excited*; *annoy* vs. *annoyed*) and with some emotions lacking an antonym compared to the SAWL (i.e. *anxious* vs. *anxious-calm*; *lively* vs. *lively-apathetic*; *confident* vs. *confident-unsure*). The SAWL is an advance on the ANEW because a wider range of ratings for affective and lexico-semantic features were taken from the same participants.

A second aim of the study was to explore possible relationships between affective and lexico-semantic features by looking at their pattern of correlations. Affective variables were highly correlated with each other, but they only showed relatively weak correlations with other variables, suggesting that affective features are distinct from lexico-semantic ones and therefore they might contribute to explain additional variance in performance beyond other features. The specific correlations are discussed below.

The correlations found between familiarity, AoA and frequency are in line with previous findings (Bird et al., 2001; Stadthagen-Gonzales & Davis, 2006), suggesting that words that are familiar are also frequently used and are acquired early. Imageability correlated with AoA, confirming that highly imageable words are acquired earlier than less imageable words (Bird et al., 2001). Finally, word length correlated with all lexical and semantic features, suggesting that shorter words are more familiar, more imageable, more frequently used and earlier acquired than longer words (Bird et al., 2001; Stadthagen-Gonzales & Davis, 2006).

There are no prior reports of a relationship between arousal and imageability. The present results suggest that valenced words with higher levels of arousal more easily evoke a mental image. Arousing stimuli might represent a threat and require immediate action. These stimuli might be associated with intense experiences early in life, by forming a mental image of the event. In further support of this idea, we found a weak correlation between emotionality and AoA (r = -.15, $p <$ .01). Besides this result, the pattern of correlations remains the same when considering lower levels of significance.

The correlation between emotional valence and familiarity could be accounted for by a response bias instead, with participants being reluctant to admit that they are very familiar with negative words. In a self-referential task, Lewis et al. (2007) presented participants with affective words and asked them to indicate whether each word could be used to describe themselves (i.e. “yes/no”). A tendency to respond “yes” more often for positive words was found.

Positive and negative words with comparable levels of emotionality differed in levels of rated arousal, with negative words being more arousing than positive words. This might suggest that positive and negative valences do not represent increases in emotionality values, from neutral to extremely valenced, toward mirror directions (as a symmetrical picture), but rather, their trends differ with respect to their intensity (arousal), for example, showing different slopes or trends. We suggest that highly negative words are naturally more arousing than highly positive ones. Negative stimuli can be extremely threatening and need to be quickly avoided or tackled; therefore heightened physiological changes are tightly associated with them. Positive stimuli are associated with safety and wealth instead, so very positive stimuli are not necessarily high in arousal (e.g. *friend, paradise*); furthermore, extremely arousing positive stimuli are often associated with risk and might elicit negative feelings beyond a certain threshold (e.g. *rollercoaster, desire*). An interesting but slightly different idea was proposed by Robinson, Storbeck, Meier & Kirkeby (2004), who suggested that stimuli with positive valence or low arousal elicit approach, whereas stimuli with negative valence or high arousal elicit avoidance.

It is important to mention, though, that the different levels of arousal found for positive and negative words could be accounted for by the selection of particular words. For example, in a rating study with the aim of validating the Velten Mood Induction Statements, Jennings, McGinnis, Lovejoy and Stirling (2000) obtained an opposite pattern of results: higher arousal ratings for positive statements than negative ones. Although this study is not comparable with the current one because the stimuli rated are different, the contrasting results could be due to the selection of particular material.

In sum, the present study showed that affective features are distinct from lexico-semantic features of single words, suggesting that consideration of the latter ones only in order to account for cognitive performance might uncover the effects of the emotion factor. Hence, models of word recognition should be integrated with affective features.

Emotional valence and arousal were also shown to be at least in part distinct from each other. In addition, valence appears to be a multifaceted variable and not a continuum (Feldman Barrett & Russell, 1999), raising several questions about the role of affect in cognition. It is likely that this corpus will be suitable for studies investigating the effects of affective and lexico-semantic features on single word processing. It also allows a well-balanced selection of words employed for text processing research, so that the effect of text context can be separated from word level effects. The corpus finally has potential utility for application in research on affective disorders, neuropsychology and social cognitive neuroscience.

III. Emotional valence and arousal affect word recognition in an interactive way

Abstract

Emotion, constituted by the two dimensions of valence and arousal, affects cognition, as revealed by behavioural, physiological and neuroimaging data showing a prioritisation of emotional material over neutral in a variety of cognitive tasks. Previous research employing verbal stimuli has mainly focused on valence manipulations without considering arousal. Furthermore, possible confounding effects of lexico-semantic properties known to affect word recognition have often not been controlled.

The aim of the present study was to investigate the effects of valence and arousal on lexical decision by orthogonally manipulating these variables while carefully controlling other correlated variables (e.g. word length, frequency, imageability). A further aim was to explore whether emotion variables contribute to predicting lexical decision latencies, beyond other lexico-semantic word properties.

Results showed that valence and arousal affect word recognition in an interactive way, they represent a distinct cluster compared to sub-lexical, lexical and semantic variables, and they contribute to explaining additional variance in lexical decision latencies. Furthermore, our results support findings from previous studies employing controlled material: a general advantage of emotionally valenced stimuli over neutral and no difference between positive and negative stimuli.

Key words: word recognition, valence, arousal, emotion, lexical access

Introduction

Emotion is characterised by a two-dimensional structure, constituted by emotional valence, which describes the extent to which an emotion is positive or negative, and arousal, which refers to the intensity of an emotion: how exciting/agitating or calming/boring an emotion is (Feldman Barrett & Russell, 1999; Russell, 1980). Valenced stimuli (positive and negative) tend to be higher in arousal compared to neutral stimuli (Bradley & Lang, 1999; Citron et al., 2009).

Emotional content of pictorial as well as verbal material affects behavioural performance and brain activity in a variety of cognitive tasks: lexical decision, naming, silent reading, self-referential tasks, the emotional Stroop paradigm and valence judgement (Algom et al., 2004; Estes & Verges, 2008; Kissler et al., 2007; Lewis et al., 2007; Scott et al., 2009).

Three different predictions have been derived regarding the effects of emotion on cognitive performance and these have received support from empirical findings: the first two approaches mainly focus on the valence dimension, whereas the third model aims to integrate both valence and arousal. According to the automatic vigilance hypothesis (Pratto & John, 1991) and the mobilisation-minimisation hypothesis (Taylor, 1991), negative stimuli capture and withhold attention, due to their potentially threatening nature. Therefore, fewer resources are available for the cognitive task at hand and performance will be worse, compared to processing of positive or neutral stimuli. Support for this prediction comes mainly from studies employing the emotional Stroop paradigm, in which naming the colour of negative words takes longer than positive or neutral words. However, similar findings were obtained with lexical decision, naming and emotionality judgement tasks (e.g. Algom et al., 2004; Estes & Adelman, 2008; Nasrallah et al., 2009).

From a more physiological perspective, Lang, Bradley and Cuthbert (1990; see also Feldman Barrett & Russell, 1998), proposed that appetitive and aversive (defensive) responses are enhanced or inhibited depending on whether an emotion-eliciting stimulus matches or mismatches the response. For example, the startle reflex (an aversive response) is enhanced during a fear emotional state and diminished during a positive emotional state. In line with this view, Estes and Verges (2008) found that cognitive performance is influenced differently by positive and negative valence depending on the task at hand, and not by valence per se. Recent behavioural and electrophysiological studies show that valenced stimuli (positive, negative) are prioritised compared to neutral ones, showing faster reaction times and enhanced early event-related potential (ERP) responses, with no main effect of valence (Hofmann et al., 2009; Kanske & Kotz, 2007; Kissler et al., 2007; Kousta et al., 2009; Scott et al., 2009). A similar advantage for valenced words over neutral ones in lexical decision latencies was reported by Kuchinke et al. (2007) and Scott et al. (2009), but only for low-frequency words; high-frequency words, instead, showed an advantage for positive stimuli over negative and neutral ones.

Empirical research supporting this second approach suggests that the arousal dimension is a possible confounding variable and has usually controlled positive and negative material for arousal levels. Nevertheless, no explicit manipulation or predictions about its possible effects on cognitive processing have been reported.

A different theoretical framework claims that, in order to evaluate affective stimuli, emotional valence and arousal need to be first integrated (Robinson, 1998; Robinson et al., 2004). Stimuli with negative valence or with high arousal elicit a withdrawal mental set, whereas stimuli with positive valence or with low-arousal elicit approach. Integration of these dimensions will therefore be easy for negative highly arousing stimuli and positive mildly arousing ones; whereas difficulty of integration will arise for material eliciting conflicting mental sets, i.e. negative low-arousal and positive high-arousal stimuli. In a series of experiments employing pictorial as well as verbal material, the authors found an interaction of valence and arousal: affective evaluation latencies were faster for stimuli whose affective dimensions both elicited either withdrawal or approach, compared to stimuli whose affective dimensions elicited two contrasting mental sets. Of interest, the same results were obtained with different tasks (visual discrimination and motor tasks).

Only a handful of studies have manipulated both dimensions of emotion. Hofmann et al. (2009) found modulation of arousal within negative stimuli, reflected by enhanced early negative event-related potentials to highly arousing words; Lewis et al. (2007) found a dissociation in brain activations between valence and arousal, localised in the orbito-frontal cortex and amygdala, respectively. Posner et al. (2009) also found evidence for two neural networks subserving the valence and arousal dimensions.

Some other studies have confounded valence and arousal by attributing performance, ERP or BOLD-response differences between valenced and neutral words to arousal differences (e.g. Kissler et al., 2007; Kuchinke et al., 2005; Scott et al., 2009), although valenced and neutral stimuli do not only differ in arousal, but also in valence. Furthermore, empirical research employing verbal stimuli has often not controlled for lexico-semantic word properties known to affect cognitive performance, such as word length, frequency of use and imageability, to cite some (see Balota et al., 2004 for an overview). This oversight confounds the effects of emotion, which might have been driven by other word properties. A clear example was given by Larsen, Mercer & Balota (2006), who reanalysed data from many studies employing the emotional Stroop paradigm by controlling for lexico-semantic properties not matched in the original experiments. The authors found no emotion effect after partialling out the contribution of other variables such as word length, neighbourhoods and frequency of use; these results do not confirm the slowdown effect for negative words supporting the automatic vigilance and mobilisation-minimisation hypotheses, which can therefore be questioned.

The aim of the present study was to investigate the effects of emotional valence and arousal on lexical processing, by orthogonally manipulating both variables and by carefully controlling for correlated lexico-semantic variables (see below). Furthermore, we sought to determine whether emotion predicts lexical decision latencies beyond other word properties, and to what extent.

We selected 50 positive, 50 negative and 50 neutral words from our norms (Citron et al., 2009); valenced words were half low and half high in arousal and level of arousal was matched between positive and negative words. The different conditions were matched for word length, orthographic neighbourhood size (N-size), frequency of use, age of acquisition (AoA) and imageability. Words were intermixed with 150 non-words while participants performed a lexical decision task (LDT). Reaction times (RTs) and accuracy rates were analysed with a factorial design. Scores for affective and lexico-semantic word properties were then used as predictors of lexical decision latencies in a regression analysis.

According to Lang et al.'s (1990) hypothesis, faster reaction times for valenced words compared to neutral were predicted. However, according to Robinson et al.'s (2004) model, an interaction between valence and arousal was predicted. Furthermore, because emotion has been shown to affect cognitive performance, it was expected that affective features would contribute to predicting lexical decision latencies beyond other word properties. Finally, faster reaction times for words compared to non-words were also expected, in line with previous literature (e.g. C. Fiebach & Friederici, 2003; Ziegler, Besson, Jacobs, Nazir, & Carr, 1997).

Method

Participants

Forty-three native speakers of English from Sussex University (25 women, age range: 19-36 years, *M* = 23.63, *SD* = 4.89) performed a lexical decision task (LDT). Participants were all right-handed, with normal or corrected-to-normal vision, and none of them had had any learning disability. Their participation was voluntary and they were either given course credits or paid £5.

Materials

Word selection and manipulation. 150 words were selected from a corpus of emotionally valenced and neutral words (Citron et al., 2009) containing ratings for affective features (emotional valence, arousal) and lexico-semantic features (familiarity, age of acquisition, imageability), as well as measures of length in letters, phonemes, syllables and frequency of use (spoken and written) taken from the web-based CELEX (18.6 million word tokens, Max Planck Institute for Psycholinguistics, 2001). Ratings were collected by means of 7-point Likert scales: the scale for emotional valence ranged from -3 (very negative) to +3 (very positive); arousal, familiarity and imageability were scaled from 1 (not at all) to 7 (very high), and for AoA the scale was labelled with the following age ranges: 0-2, 2-4, 4-6, 6-9, 9-12, 12-16, older than 16, recoded in 1-to-7 points after collection. In addition, neighbourhood size (N-size) and frequency (N-frequency) values were taken from the ELP database (Balota et al., 2007).

Emotionality was manipulated by selecting 50 positive words (POS; M = 1.74, SD = 0.36), 50 negative words (NEG; M = -1.51, SD = 0.34) and 50 neutral words (NEU; M = 0.23, SD = 0.42). Words in these 3 conditions were matched for length in letters, phonemes, syllables, N-size, N-frequency, frequency of use (Log10), rated age of acquisition (AoA) and imageability, with all $Fs(2,147) < 1.66$ and spanned through all grammatical categories (nouns, adjectives, verbs and mixed categories). Furthermore, each condition contained both emotion-denoting words (e.g. happy, sad) as well as other emotionally valenced words (e.g. flower, rain), in relatively consistent proportions across conditions (see Table 1). Positive and negative words were matched for arousal ($t(98) = -.98$, $p = .33$), whereas neutral words were lower in arousal compared to the valenced words.

Ratings of imageability were chosen, rather than ratings of word concreteness. This was because rated imageability better reflects imagery, particularly with respect to highly imageable abstract and emotion words (Altarriba & Bauer, 2004; Paivio et al., 1968). Rated familiarity was not included as a variable because the ratings were shown to be biased towards positive words in Citron et al. (2009).

Rated arousal was also manipulated within valenced words (positive, negative), with half of the positive and negative words being high, and half low in rated arousal, resulting in four experimental conditions. The average values of the lexical properties of stimuli in the four conditions could be matched for all of the lexical features discussed above, $Fs(3,96) < 1.57$, with the exception of rated imageability, $F(3,96) = 18.39$, $p < .001$: high-arousal words were higher in rated imageability than low-arousal words. This difference was expected because rated arousal and rated imageability are highly correlated (see Citron et al., 2009). To explore the indirect effect of imageability further, additional regression analyses were also conducted (see data analysis subsection). Descriptive statistics for the stimuli in each condition are shown in Table 2.

Table 1. Proportions of emotion-denoting and other emotionally valenced words for each condition.

Conditions	Emotion-denoting words	Other emotionally valenced words	Total
Positive high arousal	15	10	25
Positive low arousal	17	8	25
Negative high arousal	18	7	25
Negative low arousal	17	8	25
Neutral	46	4	50

Non-word selection. 150 non-words were selected from the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002). Stimuli length ranged between 4-10 letters and 3-8 phonemes. The majority of items were word-like, according to the criterion that they follow the orthographic and phonological rules of English. Non-words were matched with the words for number of letters $t(289.22) = 1.51$, *ns* and phonemes $t(298) = 0.55$, *ns*.

Table 2. Descriptive statistics for affective, lexical and semantic features of the stimuli. Mean, minimum and maximum scores for each condition are reported. Emotionality refers to the absolute valence ratings. N-size and N-frequency refer to neighbourhood size and frequency respectively.

	Neutral (50 words)			**Positive high arousal (25 words)**			**Positive low arousal (25 words)**			**Negative high arousal (25 words)**			**Negative low arousal (25 words)**		
	Mean	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max
Emotionality	**.38**	.00	.96	**1.92**	1.01	2.52	**1.58**	1.06	2.13	**1.63**	1.16	2.33	**1.38**	.99	2.07
Emotional Valence	**.24**	-.73	.96	**1.92**	1.01	2.52	**1.58**	1.06	2.13	**-1.63**	-1.16	-2.33	**-1.38**	-.99	-2.07
Arousal	**2.47**	1.50	4.15	**4.46**	4.04	5.35	**3.63**	2.84	4.18	**4.58**	4.02	5.21	**3.55**	2.61	4.06
Imageability	**4.02**	2.05	6.57	**4.65**	2.56	6.38	**3.35**	2.07	6.33	**4.61**	3.02	6.18	**3.05**	1.96	4.61
Age of Acquisition	**4.05**	1.73	5.23	**3.52**	1.99	5.63	**4.11**	1.88	5.54	**4.01**	2.39	4.90	**4.12**	2.30	5.21
Log Frequency	**1.34**	.48	2.44	**1.32**	.00	2.24	**1.24**	.30	2.44	**1.39**	.60	1.98	**1.26**	.30	2.43
Letters	**6**	4	10	**7**	4	9	**7**	4	10	**6**	4	10	**6**	4	10
Phonemes	**5**	3	10	**5**	3	8	**6**	3	9	**5**	3	8	**5**	3	9
Syllables	**2**	1	4	**2**	1	3	**2**	1	4	**2**	1	3	**2**	1	4
N-Size	**3**	0	22	**3**	0	12	**2**	0	8	**3**	0	17	**4**	0	20
N-Frequency	**4**	0	9	**4**	0	9	**3**	0	8	**4**	0	9	**4**	0	8

Apparatus

The experiment was programmed with E-Prime software. Participants were seated in front of a computer monitor (CRT screen) at a distance of approximately 70 cm. The word stimuli were presented at the centre of the screen in non-capitalized white letters on a black background (24-point Courier font); 2 letters subtended 1° of visual angle. A button box for the responses was provided.

Procedure

Participants were presented with instructions requiring them to read letter strings and decide whether they were English words or not, as accurately and as quickly as possible. A response box with two buttons corresponding to “yes/no” answers was provided and the button configuration was counterbalanced across participants. Then, a fixation cross appeared in the centre for 800 ms, followed by a letter string, which remained on the screen until participants made the lexical decision by pressing the YES or NO button. No time limit for the response was given. The screen was then blank for 1000 ms and then a new trial would start.

A practice block of 10 trials was presented first, followed by 6 experimental blocks divided in 2 sessions, with a short break in between (after 3 blocks). 150 words and non-words were mixed together and divided between the six blocks. Each block contained 25 words and 25 non-words, and an almost equal amount of positive, negative and neutral words. Block order and word order within blocks were randomised across participants. Reaction times (RTs) and accuracy to each item were recorded. The experiment lasted approximately half an hour.

Data analysis

For each participant, outlying RTs exceeding +/-3 SDs were excluded from the analysis. Only the correct trials were used for RT analysis. Mean RTs, mean accuracy rates and SDs for each participant and each condition, as well as for each stimulus, were calculated. Analyses by participant and by item were conducted: a T-test comparing words versus non-words (Lexicality), with further ANOVAs on the 150 words with factor Emotionality (neutral, positive, negative), and on the 100 valenced words with 2 factors: Valence (positive, negative) x Arousal (high, low). In the Valence by Arousal design, imageability was controlled by regressing its ratings on both raw RTs and accuracy measures, and their standardised residuals were used as the dependent variables in the subsequent ANOVAs by participant; in the ANOVAs by item, imageability was used as a covariate. A stepwise multiple regression analysis was also carried out to investigate whether affective features contribute to predicting the mean lexical decision latency for each word, beyond lexico-semantic features.

Subsequently, a principal component analysis (PCA) was performed on all words from the corpus and 50 additional items[1], in

[1] Ratings for 50 more items were collected after having created the corpus; these items were included in the PCA, because increasing the number of items is beneficial for this analysis.

order to extract the latent factors from all lexico-semantic and affective variables to see how single variables cluster together, and to determine whether affective variables are distinct from the others. The factors extracted were also entered in a multiple regression to predict lexical decision latencies.

Results

Mean accuracy overall was 0.98 (SD = 0.02).

Lexicality

Words were responded to significantly faster $t_1(42) = 3.47$, $p = .001$; $t_2(257.97)$[2] $= 12.64$, $p < .001$ and more accurately $t_1(42) = 2.54$, $p = .015$; $t_2(223.67) = 4.13$, $p < .001$ than non-words. See Table 3 for descriptive statistics.

Emotionality

RT results showed a main effect of emotionality only in the participant analysis $F_1(2,84) = 5.92$, $p = .004$; $F_2(2,147) = 2.09$, *ns*. Planned pair-wise comparisons revealed faster RTs for valenced words compared to neutral in both participant and item analyses $F_1(1,42) = 9.21$, $p = .004$; $t_2(147) = 1.98$, $p = .049$, with no difference between positive and negative words, $F_1(1,42) = 1.46$, *ns*; $t_2(147) = 0.50$, *ns*.

Accuracy results also showed a main effect of emotionality, $F_1(2,84) = 9.27$, $p < .0001$; $F_2(2,147) = 4.36$, $p = .014$, with higher accuracy for positive words compared to negative and neutral $F_1(1,42) =$

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[2] T-values and degrees of freedom for non-homogeneous variance were reported in the analysis by item.

20.34, p < .0001; t_2(147) = 2.94, p = .004. However, there was no difference between negative and neutral words F_1(1,42) = 0.05, *ns*; t_2(147) = 0.24, *ns*. See Table 3 for descriptive statistics.

Table 3. Descriptive statistics of RTs and accuracy rates for Lexicality, Emotionality and Valence by arousal designs (analysis by item). PH = positive high-arousal, PL = positive low-arousal, NH = negative high-arousal, NL = negative low-arousal.

Design	**Condition**	**mean RT (SE)**	**mean acc. % (SE)**
Lexicality	Words	**585.09** (3.24)	**98** (.2)
	Non-words	**659.46** (4.91)	**96** (.5)
Emotionality	Positive	**578.60** (5.64)	**99** (.4)
	Negative	**582.55** (5.19)	**97** (.4)
	Neutral	**594.11** (5.86)	**97** (.4)
Valence by arousal	PH	**572.07** (7.39)	**99** (.6)
	PL	**585.13** (7.39)	**98** (.6)
	NH	**567.77** (7.39)	**98** (.6)
	NL	**597.33** (7.39)	**97** (.6)

Emotional valence and arousal

In the imageability-corrected, standardised residuals of RTs, as well as in the RTs in the item analysis, no main effect of valence or arousal was found. In the participant analysis only, a significant interaction showed larger absolute mean residual values in response to PH and NL words compared to PL and NH words, indicative of slower RTs for the former conditions F_1(1,42) = 6.05, p = .018; F_2(1,95) = 0.89, *ns*. Further planned pair-wise comparisons revealed significant differences between PH and PL, and between PH and NH only.

Accuracy results showed a main effect of arousal in the participant analysis only $F_1(1,42) = 13.18$, $p = .001$; $F_2(1,95) = 0.40$, *ns*, with a larger absolute mean residual value for high-arousal words, indicating higher accuracy. A main effect of valence was found in the item analysis only $F_1(1,42) = 1.22$, *ns*; $F_2(1,95) = 5.68$, $p = .019$, with higher accuracy for positive words. See Table 3 for descriptive statistics.

Indirect effects of familiarity and self-referentiality

As positive, negative and neutral stimuli were not controlled for rated familiarity, this variable might partly account for the effect of emotionality. In particular, positive words were significantly more familiar than negative and neutral words $t(147) = 4.33$, $p < .0001$. This difference might be due either to the stimuli selection, or to a bias towards positive words while rating them (Citron et al., 2009); a similar bias was found by Lewis et al. (2007) in a self-referential task. Therefore, we decided to control familiarity and self-referentiality in the analyses, after having collected ratings for the latter word feature[3]. Self-referentiality ratings were highly correlated with familiarity ratings ($r = 0.62$, $p < .0001$) and positive words were significantly higher in self-referentiality compared to negative and neutral words $t(147) = 10.81$, $p < .0001$ (see Table 4).

[3] 69 participants (64 women), aged 18-34 years ($M = 19.64$; $SD = 2.19$) were instructed to rate “how much does each of the following words describe yourself” on a likert scale from 1 (not at all) to 7 (very much). All 150 words and some additional fillers were rated.

Table 4. Descriptive statistics of familiarity and self-referentiality ratings broken down by emotionality.

	Familiarity			Self-referentiality		
Condition	**Mean**	Min	Max	**Mean**	Min	Max
Positive	**5.07**	3.34	6.62	**4.12**	2.46	5.84
Negative	**4.52**	3.43	6.55	**2.51**	1.49	4.32
Neutral	**4.35**	2.29	6.51	**2.93**	1.69	5.88

In the corrected, standardised residuals of the RTs, as well as in the RTs in the item analysis, no main effect of emotionality was found $F_1(2,84) = 0.57$, *ns;* $F_2(2,145) = 0.82$, *ns*, nor it was in the accuracy data $F_1(2,84) = 0.74$, *ns;* $F_2(2,145) = 1.49$, *ns*.

In the Valence by Arousal design, corrected residuals of the RTs, as well as RTs, showed no main effect of valence $F_1(1,42) = 0.41$, *ns;* $F_2(1,93) = .05$, *ns* or arousal $F_1(1,42) = 0.34$, *ns;* $F_2(1,93) = 0.18$, *ns*. A significant interaction between these variables was found in both participant and item analyses $F_1(1,42) = 9.04$, $p = .004$; $F_2(1,93) = 4.36$, $p = .040$, with larger absolute mean residual values (and slower RTs) in response to PH and NL words compared to PL and NH words. Subsequent pair-wise comparisons were all significant in the participant analysis only. See Figure 1 for descriptive statistics.

Corrected residuals of the accuracy data only showed a main effect of arousal, not confirmed in the item analysis $F_1(1,42) = 8.73$, $p = .005$; $F_2(1,93) = 0.35$, *ns*, with a larger absolute mean residual value for high-arousal words, indicating higher accuracy (high arousal: $M = 0.034$, $SE = 0.014$; low arousal: $M = -0.037$, $SE = 0.015$).

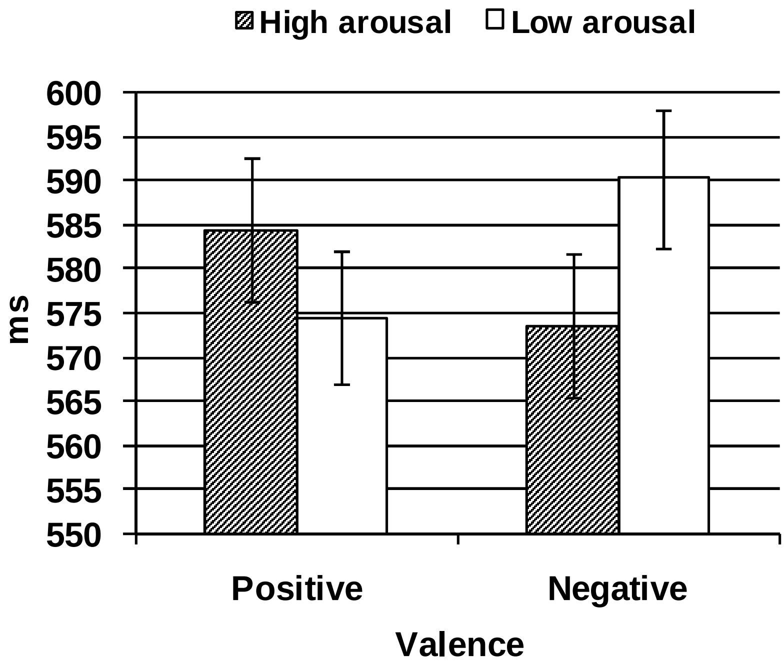


Figure 1. Valence by Arousal design. Estimated marginal means and SEs of the RTs, corrected for familiarity, self-referentiality and imageability (analysis by item).

Multiple regression analysis

Mean lexical decision latencies for each word constituted the criterion variable. Measures of length were highly correlated with each other, as well as emotionality and arousal (r > 0.75). To minimise potential effects of collinearity, only one length variable was entered into the regression. An interaction term for emotionality by arousal was also calculated and entered into the regression. A total of nine predictors were entered in the analysis: length in letters, N-size, N-frequency, word log-frequency, familiarity, self-referentiality, AoA and imageability in a first step, and the emotional interaction term in a second step. Predictors included in the model were in order: length in letters (35% of variance explained), familiarity (13.8%), Log-frequency (2%), emotionality by arousal interaction (2.7%) for a total of 53.5% of variance explained (see Table 5). This demonstrates that emotion provides a unique contribution in predicting lexical decision latencies beyond other word properties, including familiarity.

Table 5. Regression of affective and lexico-semantic variables on the mean lexical decision latency for each word.

	b	**SE b**	**β**	**% Variance**
(Constant)	594.87	16.42		
Length in letters	11.05	1.37	.49***	35.0***
Familiarity	-11.29	2.97	-.25***	13.8***
Log-frequency	-14.71	5.14	-.19**	2.0*
Emotionality*arousal	-2.11	.73	-.17**	2.7**

*****p<.001, **p<.01, *p<.05**

Principal component analysis

Correlations between all variables are reported in Table 6. A total of eleven variables were entered in the analysis: rated emotionality, arousal, familiarity, AoA, imageability, log-frequency, word length in letters, phonemes and syllables, N-size, N-frequency. Four factors with eigenvalues greater than 0.9 emerged. All length and neighbourhood measures loaded on the first factor, which accounted for 42.1% of the variance. Frequency, familiarity and AoA loaded on the second factor, which accounted for 16.4% of the variance. The two emotion measures

Table 6. Correlations between lexico-semantic and affective features from Citron, Weekes & Ferstl (2009) corpus, integrated with 50 additional words.

	Emotionality	Arousal	Familiarity	Log Freq	AoA	Imageability	Letters	Phonemes	Syllables	N-size	N-freq
Emotionality	1	.76***	.14***	-.09	.04	-.05	.12*	.12*	.11*	-.14*	-.12*
Arousal	.76***	1	.03	-.09	.08	.01	.06	.07	.06	-.13*	-.07
Familiarity	.14***	.03	1	.51***	-.62***	.11*	-.21***	-.17***	-.21***	.23***	.13*
Log Freq	-.09	-.09	.51***	1	-.51***	.21***	-.41***	-.38***	-.32***	.25***	.09
AoA	.04	.08	-.62***	-.51***	1	-.60***	.55***	.54***	.52***	-.42***	-.34***
Imageability	-.05	.01	.11*	.21***	-.60***	1	-.43***	-.44***	-.38***	.27***	.21***
Letters	.12*	.06	-.21***	-.41***	.55***	-.43***	1	.91***	.81***	-.63***	-.51***
Phonemes	.12*	.07	-.17***	-.38***	.54***	-.44***	.91***	1	.86***	-.55***	-.49***
Syllables	.11*	.06	-.21***	-.32***	.52***	-.38***	.81***	.86***	1	-.52***	-.50***
N-size	-.14*	-.13*	.23***	.25***	-.42***	.27***	-.63***	-.55***	-.52***	1	.58***
N-frequency	-.12*	-.07	.13*	.09	-.34***	.21***	-.51***	-.49***	-.50***	.58***	1

***significance level=.001, **=.01, *=.05

loaded on the third factor, which accounted for 12.8% of the variance. Finally, imageability loaded heavily on the fourth factor, together with AoA and length in phonemes, accounting for 8.3% of the variance. Factor loadings are displayed in Table 7a and the rotated component matrix is shown in Table 7b.

These results show that affective variables cluster together and are distinct from lexico-semantic variables, which each respectively cluster together. The fact that AoA loads on both lexical and semantic factors with approximately equal weight is not surprising, given that this word property is considered partly lexical and partly semantic (see Juhasz, 2005 for a review).

Beyond the high correlations among length measures and between affective dimensions, other variables showed correlations ranging between r = 0.5-0.6 (i.e. familiarity and frequency; AoA and imageability). Because of this, some variables were excluded as predictors in the previous regression analysis because of shared variance with other variables. Their relative contribution was underestimated and the importance of other variables was overestimated. Therefore, using the extracted factors as predictors could show a clearer picture.

Lexico-semantic factors were entered in a first step, followed by the emotion factor. All of them were significant predictors. As shown in Table 8, the final model accounted for 53.4% of the variance overall, with the first lexical factor accounting for 24.2%, the second lexical factor for 24%, the semantic one for 2.5% and the emotion factor for an additional 2.6%.

Table 7. (a) Factor score coefficients; (b) Rotated component matrix.

(a)	Components			
Variables	**1**	**2**	**3**	**4**
Letters	**.22**	.05	-.02	.10
Phonemes	**.21**	.09	-.02	.16
Syllables	**.22**	.08	-.03	.10
N-Size	**-.33**	.03	-.01	**.28**
N-Frequency	**-.38**	-.07	.03	**.32**
Familiarity	.05	**.57**	.06	**.25**
Log Freq	.08	**.43**	-.07	.02
AoA	-.08	**-.28**	.01	**.26**
Emotionality	-.03	.04	**.53**	.04
Arousal	-.04	-.06	**.53**	-.04
Imageability	**.19**	-.11	.00	**-.76**

(b)	Components			
Variables	**1**	**2**	**3**	**4**
Letters	.81			
Phonemes	.79			.44
Syllables	.78			
N-Size	-.79			
N-Frequency	-.81			
Familiarity		.91		
Log Freq		.77		
AoA		-.66		.51
Emotionality			.93	
Arousal			.93	
Imageability				-.89

Table 8. Regression of factor scores for the 150 words employed (in the experiment) on the mean lexical decision latency for each word.

	b	**SE b**	**β**	**% Variance**
(Constant)	583.77	2.32		
Factor 1: LEXICAL (length, neighbourhood)	25.40	2.81	.51***	24.2***
Factor 2: LEXICAL (frequency measures)	-20.59	2.50	-.49***	24.1***
Factor 3: SEMANTIC	-6.76	2.39	-.16**	2.5**
Factor 4: EMOTIONAL	-6.50	2.27	-.17**	2.6**

*****p < .001, **p < .01, *p < .05**

Discussion

Our experiment showed that valenced words have a processing advantage over neutral words, reflected by lexical decision latencies. These results are in line with the idea that emotional material is prioritised, independently of the direction of valence (Feldman Barrett &

Russell, 1998; Peter J. Lang et al., 1990). Models that predict a processing disadvantage for negative stimuli only (Pratto & John, 1991; Taylor, 1991) are not supported by our study. One reason for the difference with the results from previous studies (e.g. Nasrallah et al., 2009), is that positive, negative and neutral stimuli were not controlled for lexico-semantic word properties in those studies. The present results are most compatible with other studies where these stimuli were controlled (e.g. Kousta et al., 2009; Larsen et al., 2006).

The emotionality effect found is in line with findings from Kuchinke et al. (2007) and Scott et al. (2009) employing low-frequency words (approximately 4 and 8 occurrences per million, respectively). High-frequency stimuli (62 and 59 occurrences per million), instead, showed a prioritization of positive words only over neutral and negative ones. Our stimuli's mean frequency per million was 38.6, which is much higher than the low-frequency stimuli used in the studies above, but also lower than the high-frequency stimuli. This might suggest that a positive bias or preference arises only over a certain threshold of "high frequency".

The present results also suggest that valence and arousal have an impact on lexical processing in an interactive way, thus supporting the model of Robinson et al. (2004), and replicating their empirical findings with controlled verbal material and a task which required no explicit emotional evaluation. Our study is a progression on previous experiments because the two emotional dimensions were manipulated orthogonally and different arousal levels were compared within valenced words, as opposed to studies confounding arousal and valence effects (Kissler et al., 2007; Kuchinke et al., 2005; Scott et al., 2009), or manipulating arousal only within negative stimuli (Hofmann et al., 2009).

Accuracy was very high overall (98% correct responses), but showed a different direction compared to reaction times (RTs) in both emotionality and valence by arousal designs: positive words were responded to more accurately than negative and neutral words. This could be accounted for by a natural attentional bias toward positive words; in fact, according to mood manipulation studies, healthy participants are naturally in a positive mood and prefer positive information over negative information (Fredrickson & Branigan, 2005). This bias was only reflected in accuracy measures, probably because reaction times to negative stimuli need to be equally fast, due to their threatening nature. Similar biases towards positive words were observed by Lewis et al. (2007) in a self-referential task, in which people more often judged positive words as referring to themselves compared to negative words, and also in our corpus study (Citron et al., 2009), in which positive words were rated as more familiar. Even though this study did not require participants to judge self-referentiality or familiarity, they might still have perceived positive words as more self-referential compared to negative and neutral words.

Familiarity was not included in the analyses because of the bias observed in the ratings. By reanalysing the material, we found that positive words in this study were significantly more familiar than negative and neutral words. Furthermore, after having collected post-hoc ratings for self-referentiality, we found the same difference and a high correlation between the two variables.

By statistically controlling these variables, our emotionality effects disappeared in both RT and accuracy measures. This was probably due to the fact that both main effects were mostly driven by positive words. The valence by arousal RT interaction was confirmed instead, and further supported by both participant and item analyses. These results suggest that manipulation of both emotional dimensions provides a more precise and robust picture of what's happening during cognitive processing, whereas consideration of only one dimension, namely valence (here called emotionality), might hide some effects and reduce statistical power. It is also worth mentioning that our stimuli were not very extreme in arousal: we avoided very highly arousing negative words (e.g. *war, rape)* and taboo words because they would be impossible to match for arousal with positive words; in fact negative words tend to be higher in arousal (Citron et al., 2009; Lewis et al., 2007). Therefore, the effects found might not be strong enough, even though the interaction held even after additional control.

Finally, our study showed a unique contribution of the emotion factor in predicting lexical decision latencies beyond lexico-semantic properties (including familiarity), as well as a clear distinction of affective variables from other lexico-semantic ones. These results suggest that affective variables should be integrated in models of single word reading and lexical access.

A limitation of our study consists in the selection of non-words from the ARC Nonword Database (Rastle et al., 2002), which has a limited number of word-like (legal) non-words. As it was not possible to match all our words for length with an equal amount of legal non-words, we had to include illegal non-words. The latter ones are very easy to reject in an LDT, which becomes less demanding; Word recognition will be based on faster and more shallow processes, which don't allow full access to lexical representations of words and can therefore make the emotion effects become more subtle or even disappear. For future studies it would be helpful to obtain a higher number of legal non-words from other researchers.

Future research could investigate at what stage of single word processing emotion effects take place, by means of ERP measures. Several ERP studies have already investigated emotion word processing, but failed to manipulate valence and arousal independently.

IV. Time course of interactive effects of emotional valence and arousal during word processing: An ERP study

Abstract

Theoretical models of emotion suggest a two-dimensional structure of affect, composed of emotional valence (positive, negative) and arousal (i.e. intensity). This distinction has been supported by neuroimaging studies showing dissociations between brain regions responding to valence and to arousal during single word processing (e.g. Lewis et al., 2007). Nevertheless, these dimensions are often confounded in electrophysiological research, whereby greater amplitude in early ERP components for valenced, arousing words (positive, negative) compared to neutral, not arousing words has been interpreted as an “arousal effect” (e.g. Kissler et al., 2007).

The aim of the present study is to orthogonally manipulate valence and arousal dimensions during a lexical decision task, to identify whether ERP components are modulated by these variables and whether these variables have independent or interactive effects on brain activity.

Results showed an early sustained interactive effect of these two dimensions in an early posterior negativity (EPN; 250-310 ms) and in a second, short-lasting negative component (370-430 ms). These effects were verified in reaction times (RTs). In addition, an advantage for valenced words compared to neutral words was observed in the EPN, LPC (late positive complex) and in the RTs, in line with previous findings.

The results support two-dimensional models of emotion (e.g. Feldman Barrett & Russell, 1999) and show an early interactive effect, at the stage of word-form retrieval. An interpretation of this interaction according to the approach-withdrawal model proposed by Robinson et al. (2004) is presented.

Key words: emotion, word recognition, lexical decision, ERP, EPN, LPC, N1.

Introduction

A general consensus has been achieved in emotion research on the two-dimensional structure of affect: valence describes the extent to which an affect is pleasant or unpleasant (positive or negative), whereas arousal refers to its intensity, i.e. how exciting/agitating, or calming/boring an emotion is (Feldman Barrett & Russell, 1999; Russell, 1980). Theories of emotional processing also assume a distinction between valence and arousal (Feldman Barrett & Russell, 1999; Reisenzein, 1994), although empirical research has often considered these dimensions as intrinsically associated (e.g. Kissler, Herbert, Winkler, & Junghofer, 2009; Kuchinke et al., 2005; Scott et al., 2009; Viinikainen et al., 2010). Despite this association, there is support for a distinction between valence and arousal from neuroimaging literature, which shows dissociations in patterns of brain activations (Lewis et al., 2007; Winston et al., 2005).

Emotional content of verbal as well as pictorial material affects cognitive processing in many different tasks, as revealed by behavioural, ERP and fMRI measures (Algom et al., 2004; Kensinger & Schacter, 2006; Kissler, Assadollahi, & Herbert, 2006; Olofsson et al., 2008; Robinson et al., 2004) .

Behavioural and electrophysiological studies have shown a processing advantage for emotionally valenced stimuli compared to neutral stimuli, reflected by faster reaction times, higher accuracy and enhanced ERP components associated with emotion processing (e.g. Kanske & Kotz, 2007; Kissler et al., 2007; Kousta et al., 2009; Larsen et al., 2006; Schupp, Junghöfer, Weike, & Hamm, 2004; Scott et al., 2009).

These findings are particularly interesting with respect to word processing. Intuitively, access to a word's meaning is necessary in order to process its emotional content; Nevertheless, very early, pre-lexical emotion effects have been found in ERPs after presentation of written words (e.g. Scott et al., 2009), which are described in detail below. The ERP technique is particularly suitable for examining the time-line of visual word recognition because of its high temporal resolution, which allows the observation of which stages of processing are modulated (influenced) by emotion variables.

Two ERP components have been repeatedly associated with emotion processing of both verbal and pictorial stimuli. The first component is an early posterior negativity (EPN), with occipito-temporal scalp distribution, peaking between 200-300 ms, which typically shows larger amplitude for emotionally valenced stimuli (positive and negative) compared to neutral stimuli in a variety of different tasks (e.g. Kissler et al., 2007). This component has been associated with effortless initial stages of attention orientation and evaluative processes during access to emotional information (Schupp et al., 2004). The EPN is task-independent, as its effect is not modulated by depth of processing or by the emotional nature of the task (Kissler et al., 2006; Schacht & Sommer, 2009b), although a minimal post-perceptual elaboration is needed for the emotion effect to appear (Hinojosa et al., 2010).

This early stage of processing (200-300 ms) is generally associated with early stimulus discrimination and response selection (see Olofsson et al., 2008). Furthermore, using rapid serial visual presentation (RSVP) designs, a similar occipito-temporal negativity has been observed, called recognition potential (RP), which is sensitive to meaningfulness and task-relevance of visually presented words. The RP has mostly been studied with verbal material, but it also appears in response to picture and face stimuli (see Martin-Loeches, 2007 for a review). It appears to originate in the fusiform gyrus, or visual word-form area (Hinojosa, Martin-Loeches, & Rubia, 2001). This suggests that a word's emotional connotation can be accessed in parallel with the retrieval of its visual form (Kissler et al., 2006), which would correspond to the stage of structural analysis of pictorial or face stimuli (Martin-Loeches, 2007).

The second component is a late positive complex (LPC), peaking between 500-800 ms, with a centro-parietal distribution. This component has been shown to respond to the emotional content of verbal and pictorial stimuli and, more specifically, to the valence dimension. Its amplitude is usually larger for emotionally valenced compared to neutral stimuli (Kanske & Kotz, 2007; Schacht & Sommer, 2009b; Schupp et al., 2004), but amplitude differences between positive and negative stimuli (Kissler et al., 2009), or a general advantage of positive words over neutral and negative words (Herbert et al., 2008; Kissler et al., 2009) have also been found. Furthermore, larger amplitude of this component for neutral words compared to valenced words was also reported in a word identification task, possibly indexing higher processing demand for less salient neutral stimuli (Hinojosa, Carretié, Valcarcel, Méndez-Bértolo, & Pozo, 2009). These contrasting results might be due to differences in materials and tasks, but the important point here is that this component seems to more subtly discriminate the emotional content of visually presented material compared to the EPN. The LPC is modulated by the type of task: in particular, Fischler and Bradley (2006) reviewed studies in which emotion effects were found only when the emotional content of the stimuli was task-relevant or when semantic processing was required, but not with lexical decision or orthographic judgement. An other study found emotion effects on the LPC with lexical and semantic tasks, but not with more shallow structural tasks (Schacht & Sommer, 2009b).

Although the LPC is more generally associated with conscious evaluation of the stimulus in order to respond according to the task requirements, it also indexes recollection of a mental representation or memory, and amplitude or latency differences of this component are correlated with behavioural performance (Polich, 2007).

It is important to note that emotion effects are also found in the very early P1 and N1 components (Hofmann et al., 2009; Scott et al., 2009), as well as in the P2 and N400 components (Herbert et al., 2008; Kanske & Kotz, 2007). These findings were not highly consistent across studies and therefore not specifically reviewed here. In addition, very early effects in P1 and N1 could be due to biases in the materials, e.g. positive, negative and neutral conditions might differ slightly in length, frequency (Scott et al., 2009) or in other sub-lexical properties which influence visual perception.

In most ERP studies manipulating emotion variables during single word processing, effects of emotional valence and arousal have been confounded. In particular, the EPN effect – larger amplitude for emotionally valenced compared to neutral stimuli – has been attributed to arousal (Herbert et al., 2008; Kanske & Kotz, 2007; Kissler et al., 2009; Olofsson et al., 2008; Schupp, Junghöfer, Weike, & Hamm, 2003; Scott et al., 2009). However, emotionally valenced stimuli (positive and negative) differ from neutral stimuli not only along the arousal dimension, but also in absolute valence (a continuum of increasing valence from neutral to extremely valenced, irrespective of its positive or negative connotation). We propose that this effect only reflects a discrimination between emotional and non-emotional stimuli and takes place at early stages of processing, when attention is automatically directed toward more salient, emotional stimuli. A later, conscious and task-driven evaluation of the stimuli still shows a differentiation between emotional and neutral stimuli (as reflected by the LPC), but also more subtle discrimination between positive and negative valence.

The aim of the present study was to more specifically determine when, during word recognition, emotional valence and arousal effects appear. According to neuroimaging findings, arousal and valence effects are anatomically dissociated: the orbitofrontal cortex responds to valence, independently of arousal, whereas the amygdala responds to arousal, independently of valence (Lewis et al., 2007; Winston et al., 2005). Also, arousal has usually been associated with autonomic physiological responses, whereas valence has more to do with cognitive processing of emotional content (Schachter & Singer, 1962). Nevertheless, these dimensions have also shown regions of shared activation, in the insula and subgenual cingulate cortex (Lewis et al., 2007).

Robinson (1998; Robinson et al., 2004) proposed that these dimensions interact at an early, implicit processing stage. In particular, stimuli with positive valence or with low arousal level both elicit an approach orientation or mental set, whereas stimuli with negative valence or high arousal elicit withdrawal. According to Robinson, these two orientations are initiated independently at a pre-attentive level and must be subsequently integrated in order to consciously evaluate the stimulus.

Hence, processing of congruent stimuli (positive low-arousal or negative high-arousal) is relatively straightforward, whereas conflicting stimuli (positive high-arousal or negative low-arousal) require more resources. Robinson et al. (2004) provide empirical evidence supporting their model in a series of behavioural tasks employing emotional pictures as well as words: They consistently found slower reaction times to conflicting stimuli compared to congruent ones, indexing higher integration difficulty.

To our knowledge, only one ERP study has manipulated both dimensions independently. Hofmann et al. (2009) presented participants with negative words high or low in arousal, as well as positive and neutral words both low in arousal, all intermixed with non-words, in a lexical decision task. They found emotion effects on an occipito-temporal negative ERP component peaking between 80 and 120 ms: negative high-arousal words and positive words elicited larger amplitudes compared with negative-low arousal and neutral words respectively. The same advantage was found in the reaction times. The authors claimed that arousal has a differential effect at early processing stages for positive and negative words. Through source localization, they found that this effect (for negative high-arousal words only) originated in the middle-temporal and fusiform gyri, regions known to mediate between visual word form and higher order stimulus processing.

In the present study, emotional valence and arousal were orthogonally manipulated. 50 positive and 50 negative words, half high and half low in arousal, together with 50 neural words, very low in arousal, were selected. All conditions were carefully matched for other lexico-semantic word properties. EEG was recorded while participants performed a lexical decision task (LDT), discriminating between 150 words and 150 non-words, randomly intermixed. Behavioural performance and ERP responses were compared in two different designs. In the Emotionality design, positive, negative and neutral words matched for differences in lexical, sublexical and semantic features were compared, in order to test previous findings. In the Valence by Arousal design, different levels of valence and arousal were compared within valenced words only (excluding neutral words), in order to extend previous research, which showed inconclusive results with respect to the independent manipulation of these variables.

Based on previous literature, our first hypothesis predicted an advantage of emotionally valenced words over neutral words, reflected by faster lexical decision latencies and larger amplitude of the EPN and LPC components.

Based on empirical evidence supporting the model by Robinson et al. (2004) and on previous ERP findings, our second hypothesis predicted an early interaction of the valence and arousal dimensions, with conflicting stimuli eliciting enhanced processing, which would be reflected in both lexical decision latencies and ERP amplitudes. This study is exploratory with respect to which ERP components will be affected by the emotional dimensions. If Robinson's model is thoroughly taken into account, an early interaction on the EPN time window is expected. However, given the fact that interactive effects were found in the reaction times, an interaction at a later, more explicit processing stage (i.e. LPC) could also be expected.

Method

Participants

Thirty-one native speakers of English from Sussex University (16 women, age range: 19-36 years, M=24, SD=5.1) performed a lexical decision task (LDT). Participants were all right-handed except one, who showed a similar ERP pattern to the others, they had normal or corrected-to-normal vision, and none of them had had any learning disability. They either received course credits or were paid £5 for their participation. 3 additional participants were excluded from the analysis because of noisy EEG (see Data analysis subsection).

Materials

Word selection and manipulation. 150 words were selected from a corpus of English emotion words (Citron et al., 2009), in which the rating scale for emotional valence ranged from from -3 (very negative) to +3 (very positive) and for arousal from 1 (not at all) to 7 (very high). Emotionality was manipulated by selecting 50 positive words (POS; M = 1.74, SD = 0.36), 50 negative (NEG; M = -1.51, SD = 0.34) and 50 neutral words (NEU; M = 0.23, SD = 0.42). Items in these three conditions were matched for length in letters, phonemes, syllables, N-size, N-frequency, frequency of use (Log10), age of acquisition (AoA) and imageability, with all $Fs(2,147) < 1.66$. The items were sampled from all grammatical categories (nouns, adjectives, verbs and mixed categories). Furthermore, each condition contained both emotion-denoting words (e.g. happy, sad) and other emotionally valenced words (e.g. flower, rain), in relatively consistent proportions across conditions (see Table 1). Positive and negative words were matched for arousal ($t(98) = -.98$, $p = .33$), whereas neutral words were lower in arousal compared to the valenced items.

Table 1. Proportions of emotion-denoting and other emotionally valenced words for each condition.

Conditions	**Emotion-denoting words**	**Other emotionally valenced words**	**Total**
Positive high arousal	15	10	25
Positive low arousal	17	8	25
Negative high arousal	18	7	25
Negative low arousal	17	8	25
Neutral	46	4	50

Arousal was also manipulated within positive and negative word sets, with half of the items high and half low in arousal. Words in the 4 sub-conditions obtained were matched for the features presented above, ($Fs(3,96) < 1.57$) except imageability ($F(3,96) = 18.39$, $p < .001$), which

Table 2. Descriptive statistics for affective, lexical and semantic features of the stimuli. Mean, minimum and maximum scores for each condition are reported. Emotionality refers to the absolute valence ratings. N-size and N-frequency refer to neighbourhood size and frequency respectively.

	Neutral (50 words)			**Positive high arousal (25 words)**			**Positive low arousal (25 words)**			**Negative high arousal (25 words)**			**Negative low arousal (25 words)**		
	Mean	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max
Emotionality	**.38**	.00	.96	**1.92**	1.01	2.52	**1.58**	1.06	2.13	**1.63**	1.16	2.33	**1.38**	.99	2.07
Emotional Valence	**.24**	-.73	.96	**1.92**	1.01	2.52	**1.58**	1.06	2.13	**-1.63**	-1.16	-2.33	**-1.38**	-.99	-2.07
Arousal	**2.47**	1.50	4.15	**4.46**	4.04	5.35	**3.63**	2.84	4.18	**4.58**	4.02	5.21	**3.55**	2.61	4.06
Imageability	**4.02**	2.05	6.57	**4.65**	2.56	6.38	**3.35**	2.07	6.33	**4.61**	3.02	6.18	**3.05**	1.96	4.61
Age of Acquisition	**4.05**	1.73	5.23	**3.52**	1.99	5.63	**4.11**	1.88	5.54	**4.01**	2.39	4.90	**4.12**	2.30	5.21
Log Frequency	**1.34**	.48	2.44	**1.32**	.00	2.24	**1.24**	.30	2.44	**1.39**	.60	1.98	**1.26**	.30	2.43
Letters	**6**	4	10	**7**	4	9	**7**	4	10	**6**	4	10	**6**	4	10
Phonemes	**5**	3	10	**5**	3	8	**6**	3	9	**5**	3	8	**5**	3	9
Syllables	**2**	1	4	**2**	1	3	**2**	1	4	**2**	1	3	**2**	1	4
N-Size	**3**	0	22	**3**	0	12	**2**	0	8	**3**	0	17	**4**	0	20
N-Frequency	**4**	0	9	**4**	0	9	**3**	0	8	**4**	0	9	**4**	0	8

was higher in high-arousal words. Therefore, the effect of imageability was controlled in the analyses. Descriptive statistics is presented in Table 2.

Non-word selection. 150 non-words were selected from the ARC Nonword Database (Rastle et al., 2002). They were matched with the words for number of letters ($t(289.22) = 1.51$, *ns*) and phonemes ($t(298) = 0.55$, *ns*).

Apparatus

The experiment was conducted at the Human Psychophysiology Laboratory (HPL) at the University of Sussex. E-Prime software was used to program the experiment. Participants were seated in a Faraday cage in front of a computer monitor (CRT screen) at a distance of approximately 70 cm. The word stimuli were presented at the centre of the screen in non-capitalized white letters on a black background (24-point Courier font); 2 letters subtended 1° of visual angle. A button box for the responses was provided. The EEG was recorded during the task using a Geodesic Sensor Net with 128 electrodes (Electric Geodesic Inc., Eugene, Oregon) and Netstation software was used for data acquisition.

Procedure

Participants were asked to wash and brush their hair before the application of a Geodesic Sensor Net to their head. Participants were instructed not to move during the recording, to avoid horizontal eye-movements and to try to blink only after each trial, when an eye-blink prompt was presented on the screen. They were required to read letter strings and decide whether they were English words or not, as accurately and as quickly as possible. A response box with two buttons corresponding to “yes/no” answers was provided and the button configuration was counterbalanced across participants.

The instructions above were presented on the screen before the experiment started. Then, a fixation cross appeared in the centre for 800 ms. After that, a letter string appeared and remained on the screen until participants made the lexical decision by pressing the YES or NO button. No time limit for the response was given. The screen was then blank for 1000 ms and a picture of two closed eyes was subsequently presented for 700 ms, during which time participants were allowed to blink.

A practice block of 10 trials was presented first, followed by 6 experimental blocks divided in 2 sessions, with a short break in between (after 3 blocks). 150 words and non-words were mixed together and divided between the six blocks. Each block contained 25 words and 25 non-words, and an almost equal amount of positive, negative and neutral words. Block order and word order within blocks were randomised across participants. Accuracy and reaction times (RTs) to each item were recorded, as well as EEG responses. Preparation and experiment lasted 1 hour overall, with the task lasting about 27 minutes.

EEG Recording

EEG was continuously recorded during the 2 sessions. Eye movement and blink artefacts were monitored by using two bipolar ocular electrodes. Impedance was kept below 50 kOhm and monitored during the break in between the two sessions. Sampling rate was 250 Hz. EEG was referenced online to the vertex electrode and band-passed filtered between 0.01 and 100 Hz.

Data analysis

For each participant, outlier correction on reaction times (RTs) +/- 3 SDs was applied. Only the correctly responded trials were used for the analyses. EEG was band-pass filtered between 0.3 and 40 Hz (offline) and segmented from 100 ms before to 1300 ms after stimulus onset. Segments were baseline corrected and re-referenced to the linked mastoids. Segments with artefacts exceeding +/- 75 micro Volts were automatically rejected. Manual artefact rejection was also used and only participants with at least 15 trials per condition were included in the analyses. On average, 18 trials per condition (out of 25) remained.

By inspection of ERPs and in line with previous literature, effects were observed on the posterior regions and time windows for statistical analyses of the mean amplitude were chosen as follows: EPN from 250 to 310 ms, LPC from 430 to 650 ms. Effects on other two components were also observed, and additional time windows were defined: N1 from 150 to 210 ms, N3 from 370 to 430 ms. Based on previous literature, two ROIs for the statistical analyses of all components were chosen:

posterior left (electrodes 60, 67, 59, 66, 72, 65, 71) and posterior right (78, 86, 77, 85, 92, 84, 91). In addition, a posterior midline ROI (electrodes 62, 68, 73, 76) was chosen for a separate analysis of the LPC only. See Figure 1 for a topographic map of the electrodes.

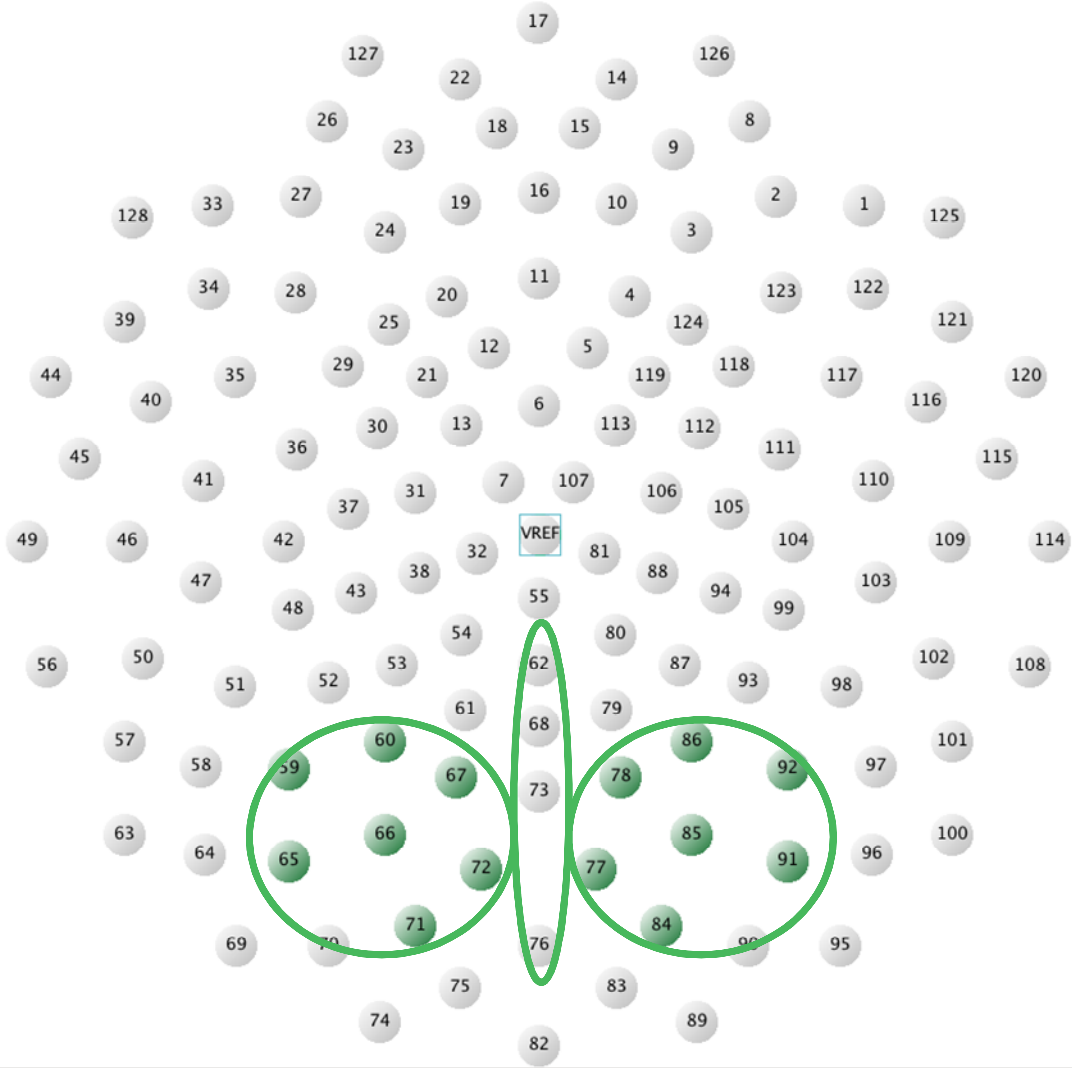


Figure 1. Topographic map of the 128 electrodes. The electrodes in which the effects were reported are highlighted and the regions of interest (ROIs) defined for the statistical analyses are circled.

For the valence design, repeated-measure ANOVAs were carried out with factors: VALENCE (3) x HEMISPHERE (2); for the valence by arousal design, factors were: VALENCE (2) x AROUSAL (2) x HEMISPHERE (2). A baseline analysis was also carried out to ensure that the effects observed are not due to noise in the data. For the midline analysis, the factor hemisphere was absent.

Results

Behavioural results

Emotionality. RT results showed a significant main effect of emotionality ($F(2,60) = 5.83$, $p = .005$). Planned contrasts revealed faster RTs for valenced words (positive, negative) compared to neutral ($F(1,30) = 9.79$, $p = .004$), with no difference between positive and negative words ($F(1,30) = 0.22$, *ns*).

Accuracy results also showed a main effect of emotionality ($F(2,60) = 5.82$, $p = .005$), with higher accuracy for positive words compared to negative and neutral ($F(1,30) = 13.08$, $p < .001$), but no difference between negative and neutral words ($F(1,30) = 0.08$, *ns*). See Table 3 for descriptive statistics.

Valence by arousal. In the imageability-corrected, standardised residuals of the RTs, only a marginally significant interaction of valence by arousal was found ($F(1,30) = 2.97$, $p = .095$), with larger absolute mean residual values for positive high-arousal (PH) and negative low-arousal (NL) conditions compared to positive low-arousal (PL) and negative high-arousal (NH) conditions, indexing slower lexical decision latencies. See Figure 2 for descriptive statistics.

Table 3. Descriptive statistics of RTs and accuracy rates for Emotionality and Valence by arousal designs.

Design	Condition	mean RT (SE)	mean accuracy % (SE)
Emotionality	Positive	**585.43** (19.51)	**99** (0.3)
	Negative	**587.80** (19.87)	**97** (0.5)
	Neutral	**602.98** (23.15)	**98** (0.5)
Valence by Arousal	PH	**577.13** (18.96)	**99** (0.3)
	PL	**594.21** (20.43)	**98** (0.5)
	NH	**572.87** (19.41)	**97** (0.7)
	NL	**602.53** (20.62)	**97** (0.7)

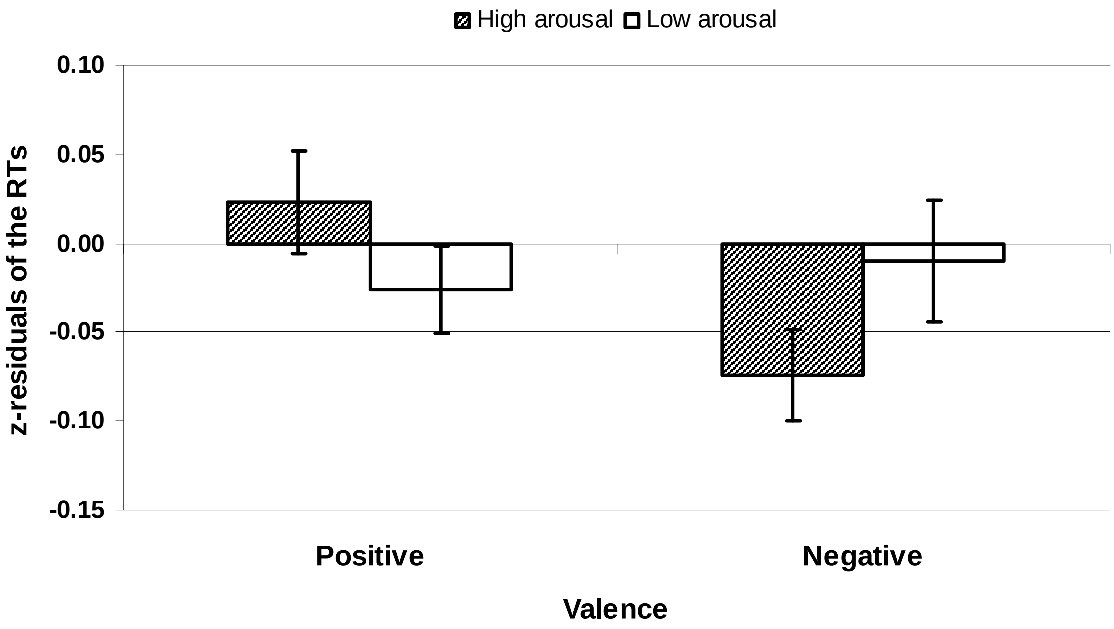


Figure 2. Valence by Arousal design. Mean residuals of the imageability-corrected reaction times. Error bars represent standard errors of the means.

Accuracy residuals showed a main effect of arousal ($F(1,30) = 7.47$, $p = .010$), with a larger absolute mean residual value for high-arousal words, indicating higher accuracy (high arousal: M = 0.05, SE = 0.02; low arousal: M = -0.03, SE = 0.02).

ERP Results

Analysis of the baseline time window revealed no significant differences among conditions for either emotionality or valence by arousal designs (all $Fs < 1$). Figure 3 shows the ERPs for emotionality and Figure 4 shows the mean amplitudes of the ERP components for valence by arousal.

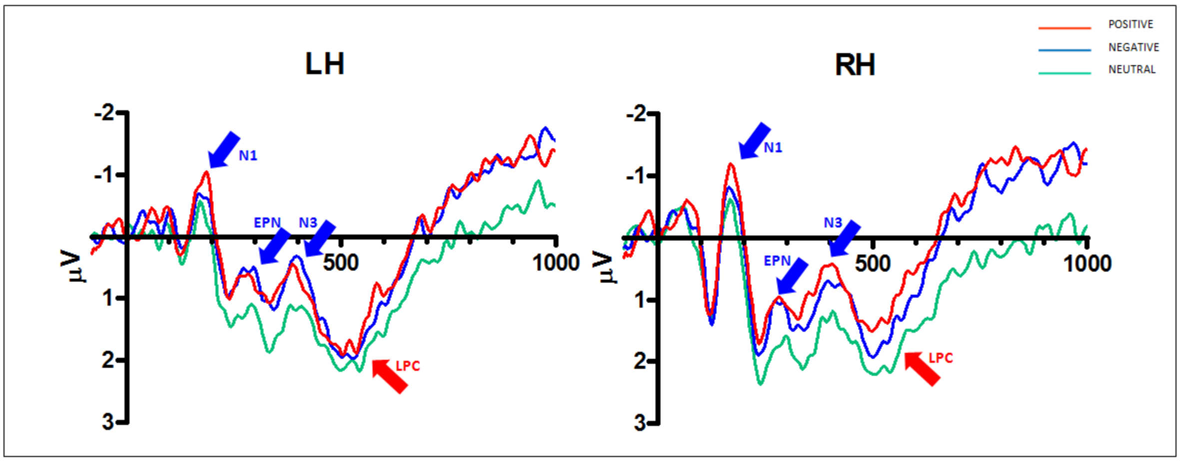


Figure 3. Grand-average ERPs, merged across electrodes in the two ROIs. Mean amplitudes were used for statistical analyses.

N1. A main effect of emotionality was found ($F(2,60) = 3.92$, p = .025); planned contrasts revealed a significant difference between valenced and neutral words ($F(1,30) = 5.36$, p = .028), with greater amplitude for valenced words, and no difference between positive and negative words ($F(1,30) < 1$). Furthermore, positive words showed a significantly greater amplitude compared to neutral words

(F(1,30)=5.51, p=.026). No significant effects were found in the valence by arousal design.

EPN. A main effect of emotionality was found (F(2,60) = 3.70, p = .031): planned contrasts showed a significantly greater amplitude for valenced words compared to neutral ones (F(1,30) = 5.40, p = .027) and no difference between positive and negative words (F(1,30) < 1). In the valence by arousal design a marginally significant interaction between valence and arousal was found (F(1,30) = 2.93, p = .097), with greater amplitude for PH and NL conditions compared to PL and NH.

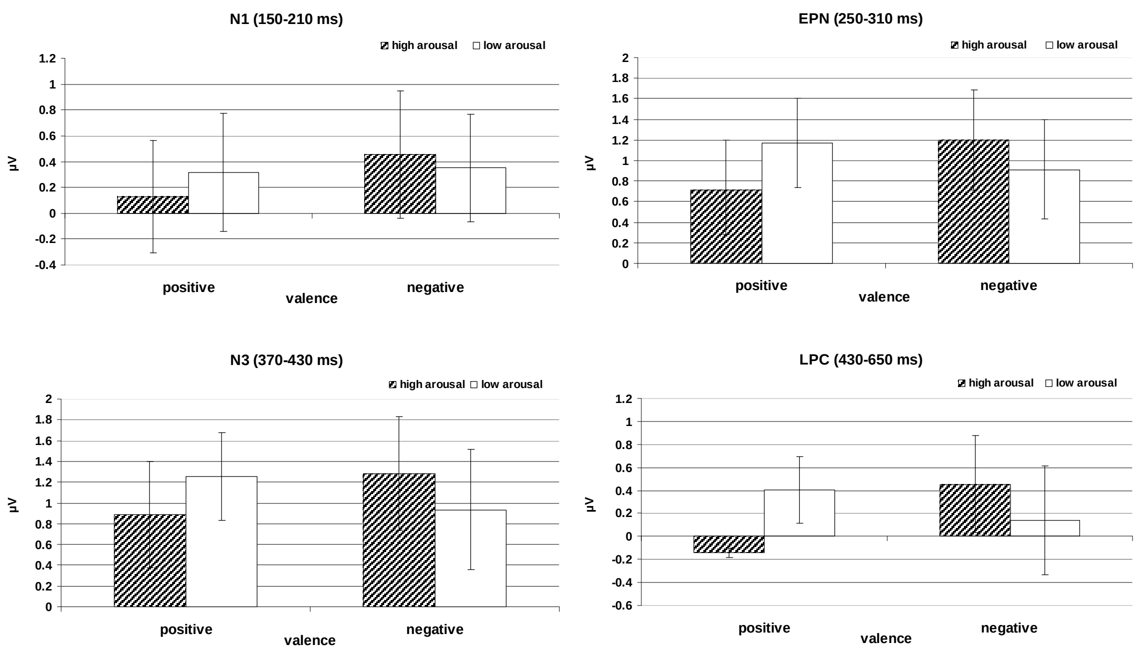


Figure 4. Valence by arousal design: Mean amplitudes and standard errors of the ERP components of interest. Smaller bars represent larger mean amplitudes for the three negative components (N1, EPN, N3). EPN and N3 amplitudes showed a trend toward a significant interaction between valence and arousal, whereas N1 and LPC amplitudes showed no significant results.

N3. A main effect of emotionality was found ($F(2,60) = 3.28$, $p = .044$), with larger amplitude for valenced words compared to neutral ($F(1,30) = 4.71$, $p = .038$), accompanied by a marginally significant interaction between emotionality and hemisphere ($F(2,60) = 2.77$, $p = .071$), showing greater amplitude for negative words compared to positive in the LH and for positive words compared to negative in the RH.

In the valence by arousal design, a significant interaction between valence and hemisphere was found ($F(1,30) = 5.10$, $p = .031$), confirming the trend observed in the emotionality design. Furthermore, a marginally significant interaction between valence and arousal was found ($F(1,30) = 2.91$, $p = .099$), with the same trend observed in the EPN time window.

LPC. A main effect of emotionality was found ($F(2,60) = 5.45$, $p = .007$), with greater amplitude for neutral compared to emotionally valenced words ($F(1,30) = 7.64$, $p = .010$). These effects were confirmed by the midline analysis ((2,60) = 4.51, p = ,015; $F(1,30) = 7.39$, $p = .011$). A significant interaction between emotionality and hemisphere was also found ($F(2,60) = 3.60$, $p = .033$), showing a more pronounced difference in amplitude between neutral and valenced words in the RH ($F(1,30) = 5.52$, $p = .026$) and significantly smaller amplitude for positive words compared to neutral words ($F(1,30) = 7.08$, $p = .012$). The latter difference was confirmed in the midline analysis ($F(1,30) = 7.04$, $p = .013$). In the valence by arousal design, a marginally significant interaction was found between arousal and hemisphere

($F(1,30) = 3.62$, $p = .067$), with greater amplitude for low-arousal words in the RH only and no difference between low and high arousal in the LH. The midline analysis showed no main effects.

Discussion

As expected, a processing advantage for emotionally valenced words compared to neutral words was found: faster lexical decision latencies index faster and more efficient processing; larger amplitude of the EPN component between 250-310 ms indexes early enhanced processing of valenced words (prioritization), which was also observed in a subsequent negative component (370-430 ms). A difference in amplitude in the LPC component (430-650 ms) was also found, with larger amplitude for neutral words, suggesting a later processing enhancement for these less-salient stimuli. Furthermore, this component showed discrimination of the valence dimension in the right hemisphere only, as revealed by a significantly smaller amplitude for positive compared to neutral words. A difference between positive and negative words was also visible but did not reach significance. This differentiation was significant in the preceding negative component.

These results suggest a general processing advantage or prioritization of emotional stimuli over neutral, and more specifically an early, pre-lexical differentiation, namely at the stage of visual word-form retrieval. Enhanced processing of emotional stimuli was sustained and also detected in a subsequent, short-lasting negative component.

The effect observed in the LPC time-window can be easily reconciled with the preceding effects by observing the ERPs and is logically grounded if we consider the literature reviewed in the introduction. The LPC component reflects conscious processing or evaluation of the stimulus in order to make the lexical decision (or the cognitive task at hand) and its sensitivity to emotional content is modulated by specific task requirements. The early advantage observed for emotional stimuli might have led to facilitated and faster processing, whereas neutral stimuli required more resources in order to be recognized. A similar effect on the LPC component was found by Hinojosa et al. (2009) in a word identification task (a variation of the lexical decision task or LTD) and interpreted as increased difficulty in discriminating neutral words from background stimuli. Furthermore, at this stage of processing we observed a more fine-grained discrimination between positive and negative valence in the right electrodes, probably starting in the immediately preceding time-window. This suggests that pure valence discrimination, independent of arousal level, is achieved at a later, explicit processing stage.

The more specific orthogonal manipulation of valence and arousal dimensions led to interesting results, supporting our hypothesis. Given the clear and consistent trend observed, and taking into account the fact that the number of stimuli per condition is low for an ERP experiment (N = 25), we still propose an interpretation of the results.

Lexical decision latencies were slower for stimuli eliciting conflicting approach-withdrawal orientations (positive high-arousal and negative low-arousal) compared to stimuli eliciting congruent approach or withdrawal orientations (positive low-arousal and negative high-arousal, respectively), suggesting a higher integration difficulty for the former conditions and in line with previous findings (Robinson et al., 2004). This interaction was also visible in the EPN component and in a subsequent negativity, both showing larger amplitude for conflicting compared to congruent stimuli. This pattern suggests enhanced processing for conflicting stimuli and an early integration of valence and arousal, at an implicit processing level. This is in line with the model proposed by Robinson et al. (2004), which suggests an automatic and implicit integration of these dimensions. Their empirical evidence could not determine when this integration takes place, as only behavioural, explicit measures were collected. The present study extended and supported their findings by employing more suitable measures.

Not even a marginally significant interaction was found in the LPC component, which might be surprising, given the fact that changes in the amplitude of this component usually correlate with behavioural performance. However, if we consider the results obtained in the emotionality design, the picture becomes clearer. The prioritization of emotionally valenced stimuli led to facilitated and faster processing, as reflected in early ERP effects (EPN and N3), and to a higher processing load for neutral stimuli later, in the LPC. Conflicting valenced stimuli led to enhanced processing in the early components, but not later, when processing resources were mostly allocated to neutral material. The enhanced activation for conflicting stimuli was no longer visible in the

LPC, or partly masked by the high “neutrality” effect (as opposed to emotionality), but its consequences were still apparent in the behavioural performance.

An unexpected result was an emotionality effect on a very early component: N1 (150-210 ms), showing larger amplitude for positive words compared to neutral, as well as for emotionally valenced words overall. This component has been shown to respond to word frequency (Sereno & Rayner, 2003), therefore suggesting a very early stage of lexical access. An interaction of emotion by frequency was also found on this component (Scott et al., 2009), showing larger amplitude for highly frequent negative words compared to highly frequent positive and neutral ones, as well as a main effect of emotion (Hofmann et al., 2009), with larger amplitude for highly arousing negative words compared to low-arousal ones and for low-arousal positive compared to neutral. Taken together, these results suggest that very salient stimuli (negative highly arousing, or highly frequent) capture attention at an extremely early stage of word recognition. In the present study, positive stimuli might well represent the most salient ones because they are highest in absolute valence. Negative words were higher in arousal compared to positive words in the specific sample of words used (Citron et al., 2009; Lewis et al., 2007); In order to match them for level of arousal we obtained positive words that were more highly valenced than negative ones. What we are suggesting here is that the N1 component maximally responded to “extremely valenced” words regardless of the direction of valence (i.e. positive versus negative).

An alternative, but still compatible, interpretation calls into question a natural bias towards positive stimuli. Research on mood induction has demonstrated that people typically show a preference for mood-congruent stimuli and it has also suggested that healthy participants are generally in a good mood; in fact, in various cognitive tasks they perform no differently to people who are induced into a positive mood experimentally (Fredrickson & Branigan, 2005). Our participants' attention could have been automatically directed toward positive stimuli. In line with this idea, people seem to show a bias towards positive concepts when rating words for familiarity (how often they come across a specific word in a defined amount of time): they rate positive words as more familiar than negative ones (Citron et al., 2009). Also, a self-referential bias has been shown: when people were asked to judge whether a word describes them, they responded "yes" more often to positive words (Lewis et al., 2007).

The negative component (N3) following EPN could possibly reflect sustained enhanced processing of emotionally valenced stimuli and valence discrimination (positive vs. negative valence). This finding is difficult to reconcile with the existing literature. Two previous ERP studies (Herbert et al., 2008; Kanske & Kotz, 2007) reported emotion effects on the N400 component, which typically indexes difficulty of semantic integration of a word with its preceding sentence context (Federmeier & Kutas, 1999). The same authors found decreased amplitude for emotionally valenced words compared to neutral and for positive words compared to negative, suggesting facilitated processing of emotional or positive stimuli. Our negativity showed an opposite effect and cannot be labeled "N400" because it is short-lasting (370-430 ms) and it shows a posterior (occipital) distribution, whereas the N400 component typically lasts about 200 ms, with a minimum of 100 ms (e.g. Herbert et al., 2008) and has a central scalp distribution.

The fact that imageability was not matched between valenced words with different arousal levels could be corrected in the analyses of behavioural data, but this was not feasible in the ERP analyses. Nevertheless, this didn't seem to affect the results. In fact, imageability is known to affect late and long-lasting negative components, such as N400 and N700 (West & Holcomb, 2000; Zhang, Guo, Ding, & Wang, 2006), but not earlier components, where the interaction between valence and arousal was observed (EPN, but also N3). Furthermore, if imageability had affected our ERP components, either early or late ones, a main effect of arousal among emotionally valenced word should have been found. Our results don't seem to confirm this interpretation and therefore we can reject that possibility.

The present study could be improved by employing more stimuli in each condition in the valence by arousal design.

More generally, future research on emotion should consider both dimensions of affect, not only because they are clearly distinct, but also because they appear to influence cognitive processing in a complex interactive way. The present results are also relevant for models of single word recognition (Coltheart et al., 2001; Jacobs & Grainger, 1994

; Perry, Ziegler, & Zorzi, 2007), which do not consider emotional aspects of words.

V. Neural correlates of the interaction between emotional valence and arousal during lexical processing: Evidence for an integrated approach-withdrawal framework

Abstract

Theoretical models of emotion suggest a two-dimensional structure constituted by emotional valence and arousal (intensity). Only a few neuroimaging studies on emotion have manipulated both dimensions independently so far, in contrast with previous emotion-specific or valence-driven neuroimaging studies.

The present study aimed to further neuroimaging research by employing controlled verbal material, in order to partial out the indirect effect of other known lexico-semantic word properties. Emotional valence and arousal were orthogonally manipulated to investigate interactive effects at the neural level, in line with an integrative framework of approach-withdrawal orientation proposed by Robinson (1998).

Behaviourally, a general advantage of positive words over negative and neutral was found, in line with the idea that positive words are better interconnected in the mental lexicon and therefore easier to process. Increased activation for words eliciting conflicting orientations (positive highly arousing and negative low in arousal) were found in the left posterior and right insula. These results more generally support the idea that valence and arousal dimensions interact during word

recognition and favour a two-dimensional approach to the study of emotion.

Key words: valence, arousal, approach, withdrawal, emotion, fMRI, lexicality, word processing

Introduction

Theoretical models of emotion suggest a dimensional structure along two or three measures that include emotional valence and emotional arousal (Feldman Barrett & Russell, 1999; Russell, 1980). In such models the appetitive or aversive aspects (positive or negative valence) are viewed as orthogonal or dissociable from the intensity (arousal) associated with an emotion (Feldman Barrett & Russell, 1999; Reisenzein, 1994). Nevertheless, empirical research has often considered these dimensions as intrinsically associated (e.g. Estes & Verges, 2008; Scott et al., 2009). A third dimension, potency (Osgood et al., 1957) or dominance (e.g. M. M. Bradley & Lang, 1994) has had arguably a limited contribution to theory-driven understanding of human emotion and it will not be considered further here.

Functional neuroimaging research on emotion has tended to adopt a different theoretical stance to that of specific emotions (Ekman et al., 1983), which is based on the notion that different emotions serve independent evolutionary imperatives. Similarly, evidence for discrete brain substrates for fear and disgust (Morris et al., 1996; Phillips et al., 1997) has been taken to endorse this view, yet attempts to extend this to other emotional states have been less successful. Neuroimaging research has also been pursued along dimensional models, typically focusing on dichotomies, e.g. positive and negative valence (Cacioppo et al., 1999; Feldman Barrett & Russell, 1998) or approach and withdrawal (Davidson, 1992). Whereas the valence distinction emphasizes emotional experience and its evaluation, the approach-withdrawal dichotomy emphasizes behavioural reactions. The two dimensions overlap substantially.

Together, this neuroimaging work has provided the following insight into the neural systems engaged during processing of affective stimuli or during the experience of different emotional states.

The medial prefrontal cortex (MPFC) is generally activated in response to emotional stimuli and is not specific to single emotions, induction methods or tasks (Phan et al., 2002). Nevertheless, differences according to the approach/withdrawal framework were found, with association of this region with approach overall, and with left-lateralised activations for the withdrawal dimension (Wager et al., 2003). In addition, the ventral portion of the MPFC responds more strongly to negative valence and the dorsal portion to positive valence (Viinikainen et al., 2010).

The anterior cingulate cortex (ACC) is mostly activated for cognitive demanding tasks (e.g. emotional recall), compared to passive viewing or listening tasks and perceptual tasks (Phan et al., 2002); this region interacts with the MPFC through numerous connections to regulate the emotional and cognitive aspects of the task (Phan et al., 2002). ACC activation has also repeatedly been found in response to tasks involving semantic processing and episodic memory (Cabeza & Nyberg, 2000). ACC, together with insula and amygdala, is further proposed as part of a “salience network”, which integrates sensory information with visceral, autonomic and hedonic responses (Seeley et al., 2007). Salient affective stimuli robustly engage components of this system in a manner distinguishable from executive processes, and activation of this network is closely coupled to bodily states of arousal (e.g. Critchley, 2009).

The insula cortex, similarly to ACC, is also more activated for emotional recall or cognitively demanding tasks compared to passive tasks (Phan et al., 2002). This region showed activation for both positive and negative pictures and facial expressions, compared to neutral ones (Jabbi, Swart, & Keysers, 2007; Viinikainen et al., 2010); it also responds to negative and withdrawal dimensions (Posner et al., 2009; Wager et al., 2003). This region has been associated with evaluative, experiential or expressive aspects of internally generated emotions (Phan et al., 2002). The role of insula cortex is strongly linked to viscero-sensory representation of motivational state and its elaboration as affective feelings (Brooks, Zambreanu, Godinez, Craig, & Tracey, 2005; Craig, 1998; Critchley et al., 2004; Damasio et al., 2000); it has been associated with empathy, but also with behavioural and physiological responses to risk prediction, suggesting the insula cortex plays a role not only in learning about feeling states, but also about risk associated with current decisions (Singer, Critchley, & Preuschoff, 2009).

The perceived role of human amygdala in affective processing is strongly influenced by animal studies of fear conditioning and it has taken longer to establish its role in processing both (arousing) positive and negative affective information (Garavan et al., 2001; Winston, O'Doherty, & Dolan, 2003). However, negative threat stimuli tend to be naturally more arousing than appetitive or affiliative stimuli, biasing amygdala engagement toward fear processing and withdrawal dimension (Maddock, Garrett, & Buonocore, 2003; Phan et al., 2002; Viinikainen et al., 2010; Wager et al., 2003). The amygdala also responds to more perceptual aspects of the stimulus, such as its salience (Wager et al., 2003) and its relevance to the current mood (e.g. Herbert et al., 2009).

In the chemosensory domain manipulations of valence and arousal indicate dissociation, with the orbitofrontal cortex responding more to valence and the amygdala responding to arousal, independently of valence (Small et al., 2003; Winston et al., 2005). A similar pattern of dissociation is observed with word stimuli (Lewis et al., 2007; Posner et al., 2009): Orbitofrontal and subgenual cingulate cortices respond to valence, whereas amygdala, anterior insula and pallidum to arousal. Moreover, increasing arousal for positive words enhances activity within the ventral striatum and subgenual cingulate cortex, while increasing ‘negative arousal’ engages brainstem amygdala and insula regions (Lewis et al., 2007). Typically however, studies of emotional word processing confound arousal with valence, instead, by comparing responses to arousing valenced words with low-arousal neutral words (Maddock et al., 2003; Viinikainen et al., 2010).

Posner et al. (2009) attempted to integrate emotion-specific and emotional-dimension approaches by asking participants to evaluate the valence and arousal dimensions of words denoting specific emotions; they also encouraged participants to think of situations or memories associated with each emotion prior to evaluation. The authors observed sensitivity of dorsal anterior and posterior CC and dorsolateral and medial prefrontal cortices to valence, as well as medial temporal lobe and dorsal ACC to arousal (Posner et al., 2009).

While the study of Lewis et al. (2007) directly mapped two emotional dimensions of word stimuli onto patterns of brain activation, there remain some unanswered issues. First of all, the study did not address lexical and semantic properties that affect word processing and recognition (for reviews see Balota et al., 2004; Larsen et al., 2006). Second, a self-referential task was used, which has limitations, notably through biasing responses: participants more often judged positive words as referring to themselves. These aspects were considered by Kuchinke et al. (2005), who reported faster lexical decision latencies and higher accuracy for positive words which, compared to neutral words, activated left orbitofrontal cortex and superior frontal gyrus, as well as bilateral middle temporal gyrus. Positive words also increased hippocampal and cingulate activity compared to negative words. Yet negative words only showed enhanced right inferior frontal activation compared to neutral words. These data support the notion that positive material shows a processing advantage because it is better elaborated and interconnected in the cognitive-emotional system than negative material (Ashby et al., 1999). A similar advantage was also observed in studies of memory retrieval and silent reading (e.g. Herbert et al., 2009), the latter showing enhanced engagement of amygdala and extrastriate cortex, consistent with a mood-congruent processing bias. Indeed healthy participants, not exposed to mood manipulation, are typically in a good mood and show a bias towards positive information (Fredrickson & Branigan, 2005).

The present study aimed to investigate further how valence and arousal interact during implicit word processing within the framework of a model which integrates both valence and arousal dimensions in the approach-withdrawal dichotomy of emotion (Robinson, 1998). Here it is proposed that both positive stimuli and low-arousal stimuli elicit an approach orientation, whilst highly arousing stimuli, which are sudden or very intense, evoke a withdrawal orientation, i.e. not just negative stimuli (Robinson et al., 2004). Approach and withdrawal orientations are initiated independently at a pre-attentive level and need to be subsequently integrated prior to the conscious evaluation of the stimulus. This theory generates the hypothesis that integration will be more difficult for stimuli eliciting conflicting orientations, i.e. positive high-arousal or negative low-arousal stimuli. We only have behavioural evidence (reaction times) supporting this model (Robinson et al., 2004), no neuroimaging studies have specifically tested it. Based on the findings by Lewis et al. (2007), we would expect conflicting stimuli to elicit greater activation in regions shared by valence and arousal dimensions, namely insula and ACC.

In the present study, the valence and arousal dimensions of words were orthogonally controlled, allowing comparison of different levels of arousal within the same valence, and the investigation of the neural correlates of their interaction in accordance with the above approach-withdrawal framework proposed by Robinson et al. (2004). A lexical decision task (LDT) was used to investigate implicit emotion processing. Furthermore, a rigorous control for lexical and semantic variables known to influence word recognition was applied.

The first and main hypothesis was that higher integration difficulty will be observed for conflicting stimuli (positive high-arousal and negative low-arousal words) compared to congruent ones (positive low-arousal and negative high-arousal words), as reflected by increased BOLD responses in brain regions shared by valence and arousal, namely insula and subgenual cingulate cortex. The second hypothesis predicted higher activation for high-arousal stimuli compared to low-arousal stimuli in the amygdala. Thirdly, possible differences between positive and negative valence may be found in the medial prefrontal cortex and in the insula. This study also anticipated to replicate previous findings reporting prefrontal activations for valenced compared to neutral words, as well as activation of left fronto-temporal and bilateral occipito-temporal areas associated with lexical and semantic processing in response to words compared to pseudo words. (C. J. Fiebach, Friederici, Mueller, & von Cramon, 2002; C. J. Fiebach, Ricker, Friederici, & Jacobs, 2007; Kuchinke et al., 2005).

Method

Participants

Nineteen native English-speakers from the University of Sussex (10 women), aged between 18 and 37 years (*M* = 23.7, *SD* = 5.6) took part in the experiment. They were all right-handed with normal or corrected-to-normal vision, had no learning disabilities and took no medication for mood disorders. They either received course credits or were paid £10 for their participation. Three participants were excluded from the fMRI analyses during image processing due to head movement artefacts exceeding 3 mm. Due to failure to record behavioural data from two other participants, only seventeen were included in the reaction time and accuracy analyses.

Materials

Word selection and manipulation. Two hundred and ten words were selected from a corpus of emotion words (Citron et al., 2009). Emotional valence and arousal were manipulated by selecting seventy positive, seventy negative and seventy neutral words. Half of the positive and negative words were high and half low in arousal, whereas the seventy neutral words were half low and half very low in arousal. Descriptive properties for the six conditions obtained are presented in Table 1. Words in all six conditions were matched for imageability, length in letters, phonemes and syllables, logarithm of frequency of use, neighbourhood size and also neighbourhood frequency (*Fs*(5,204) < 2.23, *ns*). Positive and negative high-arousal words were matched for emotionality (absolute valence ratings) and arousal, as well as positive and negative low-arousal words (*ts*(68) < 2.02, *ns*).

Pseudo word selection. Two hundred and ten pseudo words were selected from the ARC nonword database (Rastle et al., 2002). Pseudo words are non-existent words following the orthographic and phonological rules of English. Length ranged between 3-10 letters and 2-8 phonemes. Pseudo words were matched with the 210 words for length in letters (*t*(396.11) = 0.28, *ns*) and phonemes (*t*(372.21) = 1.32, *ns*).

Procedure

The experiment was conducted at the Clinical Imaging Sciences Centre (CISC) at the University of Sussex. The experiment was programmed in Matlab using the Cogent toolbox (Wellcome Laboratory of Neurobiology, http://www.vislab.ucl.ac.uk/cogent.php). Stimulus order and timings were optimized to maximise the statistical efficiency of the task design by means of the OPTSEQ2 software, which created a randomised sequence of experimental conditions and null events of varying durations (jitters). Using this sequence template, 4 different string (word or pseudo word) orders were implemented. The 420 experimental trials lasted 3300 to 5000 ms, and additional 166 null events lasted 3315 to 24061 ms.

Table 1. Descriptive statistics for the word selection and manipulation. Means, minimum and maximum scores for each condition are reported. Emotionality refers to the absolute valence ratings. Freq_log refers to the logarithm of frequency, N-size and N-frequency to neighbourhood size and frequency respectively.

	Positive, high arousal			Positive, low arousal			Negative, high arousal			Negative, low arousal			Neutral, low arousal			Neutral, very low arousal		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Emotionality	**1.92**	1.01	2.52	**1.46**	1.04	1.90	**1.77**	1.17	2.61	**1.33**	0.89	2.02	**0.57**	0.04	0.85	**0.29**	0.00	0.80
Em. Valence	**1.92**	1.01	2.52	**1.46**	1.04	1.90	**-1.77**	-2.61	-1.17	**-1.33**	-2.02	-0.89	**0.19**	-0.85	0.85	**0.20**	-0.62	0.80
Arousal	**4.45**	4.00	5.35	**3.41**	2.59	3.88	**4.60**	4.06	5.41	**3.52**	2.24	4.42	**3.32**	2.79	4.15	**2.06**	1.44	2.30
Imageability	**4.31**	2.51	6.37	**3.73**	2.07	6.71	**3.88**	2.20	6.51	**3.44**	1.96	6.48	**3.84**	2.05	6.44	**4.19**	2.05	6.56
Letters	**7**	4	12	**7**	3	11	**7**	3	11	**7**	3	13	**6**	3	12	**6**	3	11
Phonemes	**6**	3	13	**5**	2	10	**5**	2	10	**6**	3	12	**5**	2	12	**5**	3	9
Syllables	**2**	1	5	**2**	1	5	**2**	1	4	**2**	1	4	**2**	1	4	**2**	1	4
Frequency	**42**	0	172	**49**	1	272	**33**	2	148	**44**	1	267	**85**	1	996	**71**	2	762
Freq_log	**3.01**	0.00	5.15	**3.15**	0.00	5.61	**2.78**	0.69	5.00	**2.91**	0.00	5.59	**3.59**	0.00	6.90	**3.34**	0.69	6.64
N-size	**2**	0	12	**3**	0	21	**3**	0	18	**5**	0	23	**4**	0	34	**4**	0	15
N-freq	**6**	3	9	**6**	1	8	**6**	0	9	**6**	0	9	**6**	1	9	**6**	0	9

Participants gave informed consent for the fMRI procedure, following written and oral instructions on how to perform the task. A structural image scan lasting approximately five minutes was acquired before the main experiment. At the beginning of the experiment, three filler strings were presented, to briefly familiarise the participant with the trials: the very first trials might be accidentally unattended or responded to too late or too early. These strings were excluded from the analysis. The experiment was divided in three sessions containing 196, 196 and 197 events each (fillers, strings, null events). In between sessions, the volume acquisition was stopped and participants had a few minutes rest.

Each trial event began with a fixation cross presented in the middle of the screen, which remained for a variable (jittered) time between 1300 and 2299 ms. The duration of each trial without jitter is 2000 ms and the time of repetition (TR) of the scanner is 3300 ms; The jitter ranges above allowed us to have a minimum trial duration equal to the TR duration and a certain amount of variability across trials. Subsequently, a word appeared for 250 ms, followed by a 100-ms blank screen, then by a question mark, which prompted a response and remained present until a response was given. Participants were required to read the letter strings and decide whether the words were English or not, as accurately and as quickly as possible. A response pad with two buttons corresponding to “yes/no” answers was provided and the button configuration was counterbalanced across participants. A fixed time interval of 1650 ms between the onset of the question mark and presentation of the next trial was used to ensure that the minimum trial duration was always 3300 ms (corresponding to the TR). Overall the experiment lasted approximately 1 hour and 40 minutes, including preparation, structural scanning, 55 minutes functional scanning time and debriefing. Approximately 1000 functional volumes per participant were acquired.

MRI data acquisition and preprocessing

Hemodynamic responses were acquired by means of a 1.5 Tesla scanner (Siemens Avanto) with a standard head matrix coil. For each participant, full brain T1-weighted structural scans were acquired: 192 slices, 0.9 mm thick with a 15° flip angle, 0.9 mm isotropic voxels without gap, MPRAGE, TR 11.6 s, TE 4.4 s, 300 ms inversion time, 250×250 matrix per slice. For functional imaging 36 slices were acquired, 3 mm thick with 90° flip angle, 3x3x3.75 mm voxels with gap, TR 3300 ms, TE 50 ms, 64x64 mm matrix per slice.

Image processing and statistical analyses were performed using SPM5 (Wellcome Trust Centre, http://www.fil.ion.ucl.ac.uk/spm/), employing spatial realignment and sequential coregistration (6 parameter rigid body spatial transformation). Structural images were segmented into cerebrospinal fluid (CSF) and iteratively normalised to standard space (Montreal Neurologic Institute). Transformation parameters for structural images were then applied to functional images. Subsequently, functional volumes were spatially smoothed with an 8-mm Gaussian kernel to adjust for between-participants anatomical differences. The first 5 functional volumes were discarded to allow for equilibration of net magnetisation. The experiment (instruction on the screen, followed by filler strings and then actual trials) started after acquisition of the first 5 volumes. In order to detect further movement artefacts after realignment, the software ART was used (z threshold=11, movement threshold=3) to create additional movement regressors for outliers.

Statistical analysis

Behavioural data. Lexical decision latencies and accuracy were analysed by means of three different designs: Lexicality (words, pseudo words), Emotionality (positive, negative, neutral) and Valence (positive, negative) by Arousal (high, low). Both participant (1 subscripted) and item (2 subscripted) analyses were conducted using repeated-measures and independent-measures ANOVAs. Only correctly responded trials were included in the reaction time (RT) analyses and for each participant outlier correction on RTs +/-3 *SDs* was applied. Thresholds were considered significant when $P < 0.05$.

Neuroimaging data. A General Linear Model was used in an event-related design. Hemodynamic responses were time-locked to the stimulus onset and convolved with the canonical hemodynamic response function of SPM5. Seven separate regressors were used to model each condition (pseudo words, PH, PL, NH, NL, neutral low-arousal and neutral very low-arousal). In order to account for signal changes not related to the conditions of interest, six head movement regressors were added as covariates. For some participants extra artefact regressors, created with the ART toolbox, were added to the model.

Lexicality, Emotionality and Valence by Arousal factorial designs were used for the imaging data as well, by defining t-contrasts for each participant. For the Lexicality design words were contrasted with pseudo words. For the Emotionality design valenced words (positive and negative) were contrasted with neutral words and all pair-wise comparisons were performed.

For the Valence by Arousal design, main effects were tested by contrasting positive and negative words, as well as high and low arousal words. The interaction of these two factors was tested by contrasting positive high-arousal (PH) and negative low-arousal (NL) words with positive low-arousal (PL) and negative high-arousal (NH) ones. Further pair-wise comparisons were also performed.

At the second level (group) analysis, one-sample T-tests in both directions were performed by using the contrast images created at the single-participant level. For the significance levels, a cluster level threshold of $P < .01$ uncorrected was chosen at the voxel level.

Results

Behavioural results

Mean accuracy overall was 97%. Descriptive statistics are reported in Table 2 and Figure 1.

Lexicality. Real words were responded to significantly faster ($t_p(16) = 3.33$, $p = 0.004$; $t_i(405.37) = 15.36$, $p < .0001$) and more accurately ($t_p(16) = 3,58$, $p = 0.003$; $t_i(342.60) = 2.49$, $p = 0.013$) than pseudo words (see Table 2).

Emotionality. Reaction time (RT) results revealed a main effect of emotionality ($F_p(2,32) = 4.97$, $p = 0.013$), not confirmed by the item analysis ($F_i(2,207) = 2.24$, *ns*), with fastest RTs for positive words (POS) and slowest ones for negative words (NEG). No difference between emotionally valenced and neutral words (NEU) was found ($F_p(1,16) = 2.10$, *ns;* $t_i(207) = 0.23$, *ns*), but RTs for POS significantly differed from NEG ($F_p(1,16) = 8.18$, $p = 0.011$; $t_i(207) = 2.10$, $p = 0.037$) as well as NEG from NEU in the participant analysis only ($F_p(1,16) = 9$, $p = 0.008$; $t_i(207) = 1.25$, *ns*). See Table 2 for descriptive statistics.

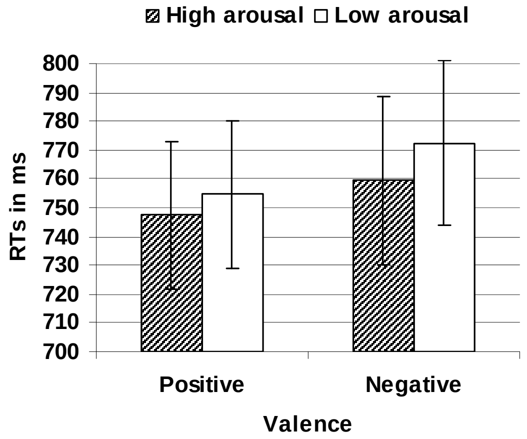
Accuracy results also revealed a main effect of emotionality ($Fp(2,32) = 6.31$, $p = 0.005$), only marginally significant in the item analysis ($Fi(2,207) = 2.94$, $p = 0.055$), with highest accuracy for POS, followed by NEG and then NEU. Planned contrasts revealed a significant difference between valenced words (POS+NEG) and neutral ones ($F(1,16) = 7.28$, $p = 0.016$), only marginal in the item analysis ($ti(207) = 1.82$, $p = 0.070$), as well as significant differences between POS and NEG, and POS and NEU ($F_p(1,16) = 5.34$, $p = 0.034$; $F_p(1,16) = 14$, $p = 0.002$), only partially confirmed in the item analysis ($t_i(207) = 1.60$, *ns*; $t_i(207) = 2.38$, $p = 0.018$).

Table 2. Descriptive statistics of behavioural results for Lexicality Emotionality and Valence by arousal designs. PH = positive high-arousal, PL = positive low-arousal, NH = negative high-arousal, NL = negative low-arousal.

Design	**Condition**	**mean RT (SE)**	**mean acc. % (SE)**
Lexicality	Words	**765.05 (**27.18)	**98** (0.5)
	Non-words	**831.83** (37.07)	**97** (0.7)
Emotionality	Positive	**751.00** (25.32)	**99** (0.5)
	Negative	**765.95** (28.60)	**98** (0.8)
	Neutral	**751.53** (27.90)	**97** (0.5)
Valence by arousal	PH	**747.33** (25.68)	**99** (0.6)
	PL	**754.67** (25,65)	**99** (0.4)
	NH	**759.40** (29.11)	**99** (0.7)
	NL	**772.50** (28.67)	**97** (1.1)

Valence by Arousal. RT results revealed a main effect of valence with faster RTs for POS than NEG ($F_p(1,16) = 8.18$, $p = 0.011$; $F_i(1,136) = 4.85$, $p = 0.029$). No main effect of arousal ($F_p(1,16) = 1.85$, *ns;* $F_i(1,136) = 0.55$, *ns)* and no interaction ($F_p(1,16) = 0.65$, *ns;* $F_i(1,136) = 0.02$, *ns*) were found (see Figure 1a).

Accuracy results revealed a main effect of valence with higher accuracy for POS compared to NEG ($F_p(1,16) = 5.34$, $p = 0.035$; $F_i(1,136) = 4.93$, $p = 0.028$), accompanied by a significant interaction ($F_p(1,16) = 8.13$, $p = 0.012$; $F_i(1,136) = 4.93$, $p = 0.028$), in which higher accuracy for high arousal compared to low arousal was observed only within negative words (see Figure 1b). Further pair-wise comparisons revealed no significant differences.



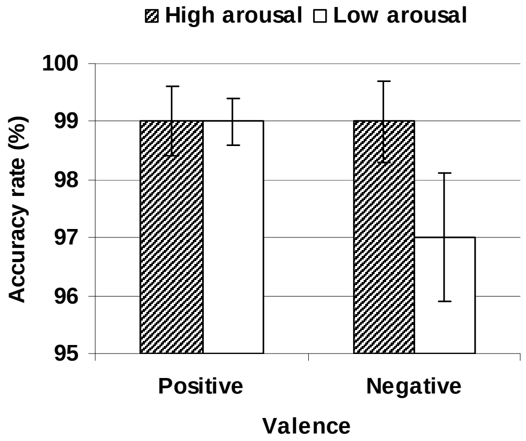


Figure 1. Descriptive statistics of reaction times (left histogram) and accuracy (right histogram) for the valence by arousal design. Error bars represent standard errors.

Functional imaging results

Lexicality. Several brain regions were significantly activated for the contrast: words > pseudo words (refer to Table 3 for a detailed list). Increased activations for words were found in the left inferior and middle frontal gyri (IFG, MFG) and bilaterally in the superior frontal gyrus (SFG). Clusters of activation were also found bilaterally in the middle temporal gyri (MTG), extending to the left inferior parietal lobule and to the right superior temporal gyrus. Increased activations for words were also found in the left cingulate and right posterior cingulate cortices. A decrese in activation was found in the left parieto-occipital sulcus and precuneus, greater for pseudo words. These areas are known to be part of a language network, activated in response to the retrieval of lexical and semantic word representations (Indefrey & Levelt, 2004; Price, Wise, & Frackowiak, 1996).

Table 3. Regions significantly activated in response to words. x, y, z= MNI coordinates, cluster size in voxels, T=peak T-value.

Words > Pseudo words									
Lobe	**Hemi.**	**Region**	**Cluster size**	**T**	**P uncorr**	**P corr**	**x**	**y**	**z**
Frontal	**L**	dorso-medial prefrontal cortex	113	5.35	**.000**	.012	**-50**	**24**	**12**
	L	dorso-medial prefrontal cortex	334	5.59	**.000**	.000	**-4**	**56**	**30**
	L	dorso-medial prefrontal cortex	56	4.75	**.007**	.202	**-6**	**40**	**50**
	R	superior frontal gyrus	72	5.23	**.003**	.087	**22**	**48**	**42**
Temporal	**L**	anterior middle temporal gyrus	217	5.68	**.000**	.000	**-54**	**-14**	**-16**
	R	anterior middle temporal gyrus	107	6.95	**.000**	.015	**52**	**-10**	**-10**
	L	posterior middle temporal gyrus	726	5.97	**.000**	.000	**-54**	**-50**	**8**
	R	posterior middle temporal gyrus	356	6.51	**.000**	.000	**52**	**-60**	**12**
Cingulate	**L**	anterior cingulate cortex	57	4.74	**.007**	.191	**-18**	**14**	**38**
	R	paracentral lobule/posterior CC	109	5.49	**.000**	.014	**8**	**-22**	**48**
Parietal	**L**	inferior parietal lobule	56	4.38	**.007**	.202	**-54**	**-40**	**30**
Occipital	**R**	inferior parietal lobule	58	5.09	**.006**	.181	**58**	**-36**	**26**
	L	parieto-occipital sulcus	58	4.81	**.006**	.181	**-10**	**-76**	**32**

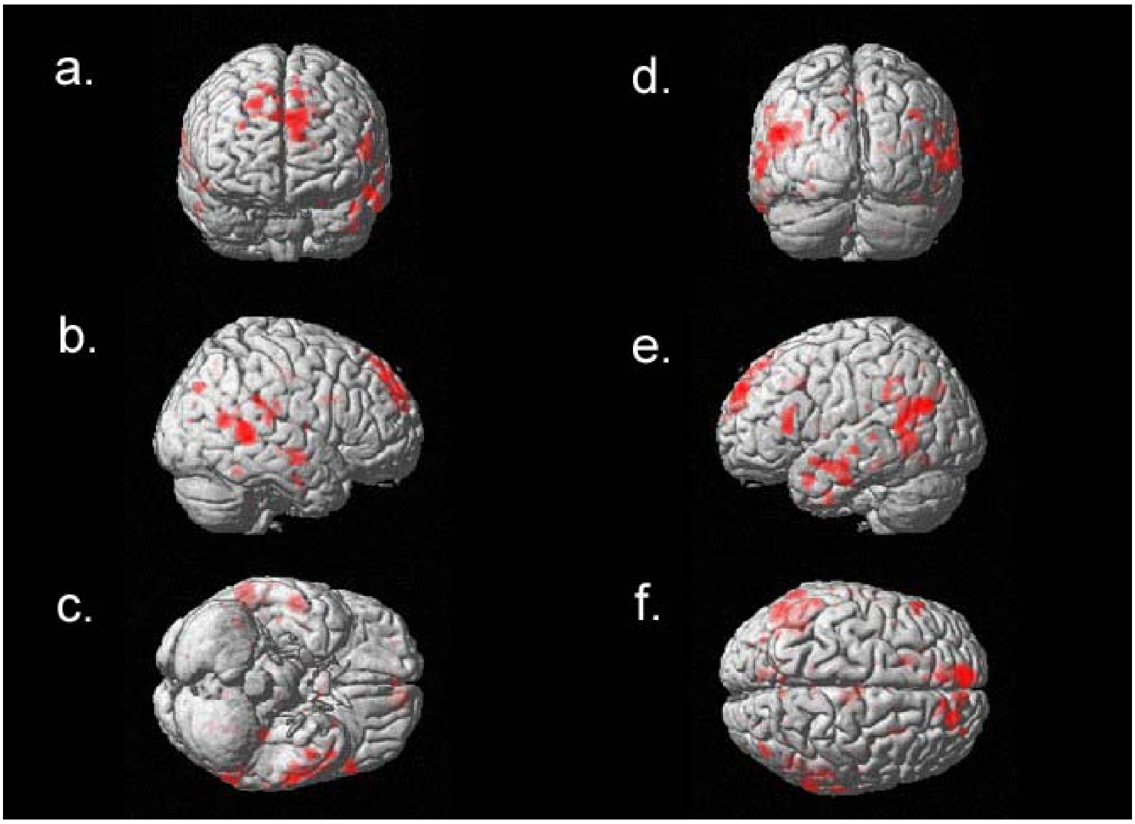


Figure 2. Lexicality. Activation of left dorsomedial prefrontal cortex (dmPFC) and left anterior and posterior MFG in e., left dmPFC and right SFG in a. and e. Right temporal activations in b.; inferior parietal lobule bilaterally, along with parieto-occipital sulcus in d. and f.

Emotionality. The contrast between emotionally valenced and neutral words (POS+NEG>NEU) revealed no significant activations in any directions, nor did pair-wise comparisons, except for the contrast NEU>NEG, which revealed increased activation in the right inferior frontal gyrus (see Table 4 and Figure 3).

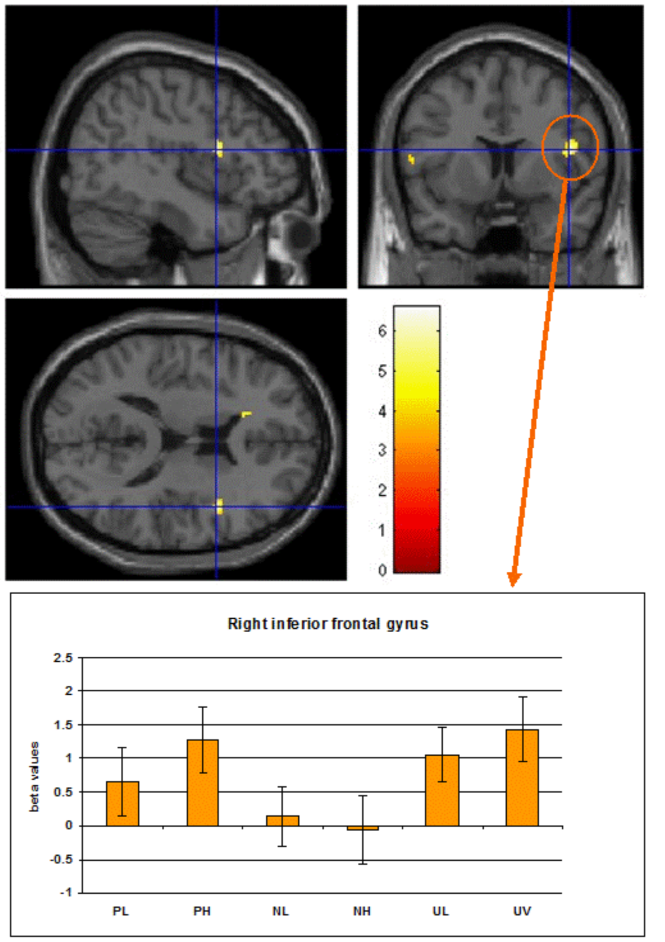


Figure 3. Regions showing significant BOLD signal changes to neutral compared to negative valence (NEU>NEG). A histogram of increased activations (beta values) is reported for the 6 emotional conditions. PL=positive low-arousal, PH=positive high-arousal, NL=negative low-arousal, NH=negative high-arousal, UL=neutral low-arousal, UV=neutral very low-arousal. Error bars represent standard errors.

Table 4. Regions showing significant BOLD signal changes in the Emotionality and Valence by arousal designs. x, y, z = MNI stereotactic space coordinates, L=left, R=right, cluster size is in voxels, T=peak T value. Significance levels threshold was P<.01 uncorrected.

Hemi.	Region	Cluster size	T	P uncorr	P corr	x	y	z
	Interaction valence by arousal: (PH+NL) > (PL+NH)							
R	**insula**	80	5.36	**.001**	.040	**42**	**-4**	**-2**
R	**cerebellum**	46	7.79	**.009**	.280	**32**	**-48**	**-32**
	PH > PL							
L	**posterior insula**	54	4.68	**.007**	.207	**-40**	**-24**	**8**
L	**parahippocampal gyrus**	88	8.31	**.001**	.034	**-20**	**-26**	**-18**
R	**insula**	79	5.62	**.002**	.054	**42**	**-4**	**-4**
	middle temporal gyrus					52	-10	-4
	insula					40	-4	-14
	NL > NH							
R	**pulvinar**	49	5.78	**.007**	.227	**16**	**-32**	**8**
	fornix					22	-32	2
	acqueduct/mesencephalon					0	-28	-10
	NEU > NEG							
R	**inferior frontal gyrus**	45	6.59	**.008**	.262	**44**	**8**	**16**

Valence by arousal. No main effects of valence and arousal were found. Their interaction (PH+NL>PL+NH) revealed significant activations within the left posterior insula, right insula and right cerebellum. Left posterior insula and right cerebellum responded with an increase in activation, higher for PH and NL compared to PL and NH. The right insula showed a similar trend, responding with increasing activation for PH and a slight activation for NL, whereas it showed a decrease in activation for both PL and NH (see Figure 4).

Further pair-wise comparisons showed a significant difference in activation between PH and PL, corroborating the interaction: the right insula and left posterior insula responded with increased activation for PH and decreased activation for PL. The left parahippocampal gyrus also showed increased activation for PH, but no response to PL (see Figure 5).

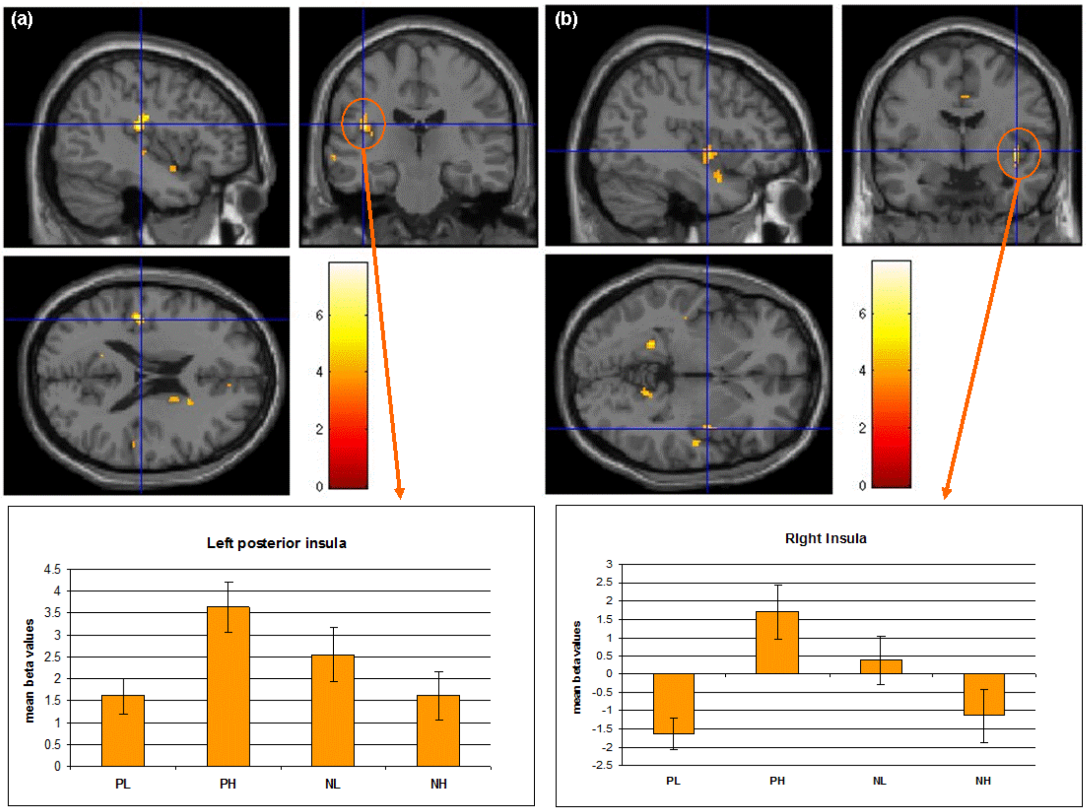


Figure 4. Regions showing significant BOLD signal changes to positive high-arousal (PH) and negative low-arousal (NL) words compared to positive low-arousal (PL) and negative high-arousal (NH) words (PH+NL>PL+NH). Refer to table 4 for exact MNI coordinates. Histograms of increase or decrease in activation (beta values) are reported for the 4 conditions. Error bars represent standard errors.

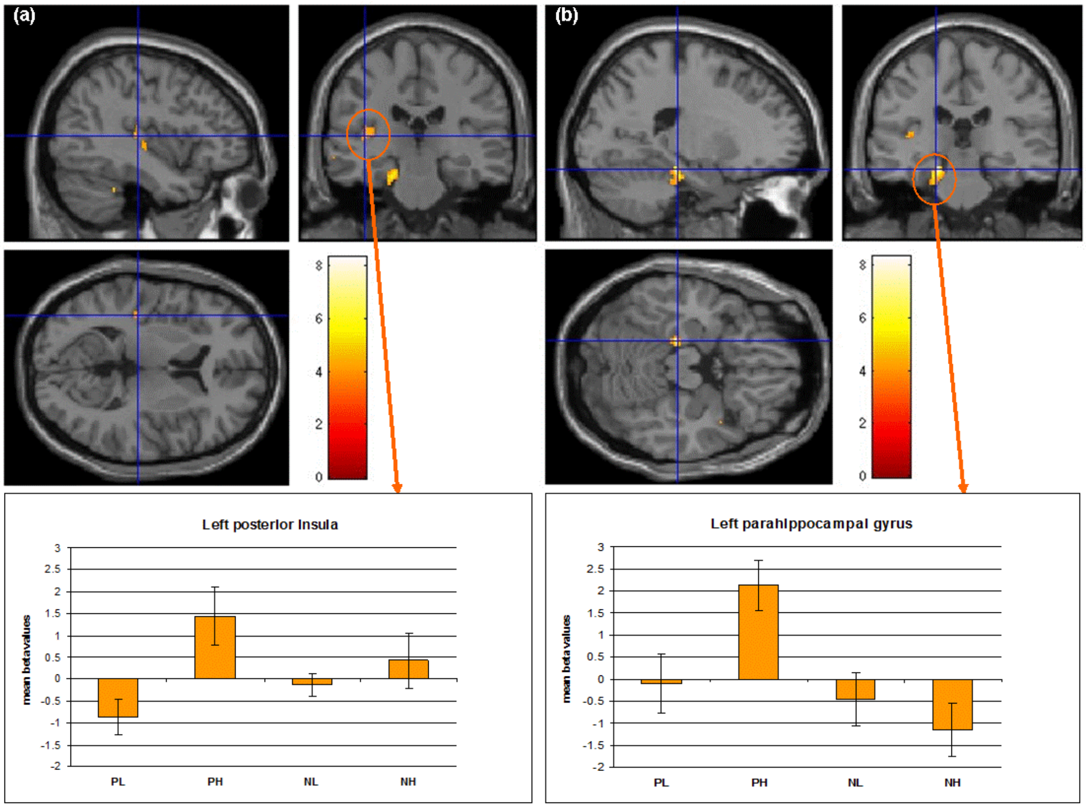


Figure 5. Regions showing significant BOLD signal changes to positive high-arousal compared to positive low-arousal words (PH>PL). Refer to table 4 for exact MNI coordinates. Histograms of increase or decrease in activation (beta values) are reported for the 2 conditions and for the respective negative ones (NL=negative low-arousal, NH=negative high-arousal). Error bars represent standard errors.

The contrast NL>NH showed activation in the right pulvinar, responding with high activation to NL and decrease in activation to NH (see Figure 6). No other pair-wise comparisons showed significant activations. This sub-region of the thalamus has widespread connections to visual, somatosensory, cingulated, posterior parietal and prefrontal cortex. Its damage leads to neglect syndrome and attentional deficits.

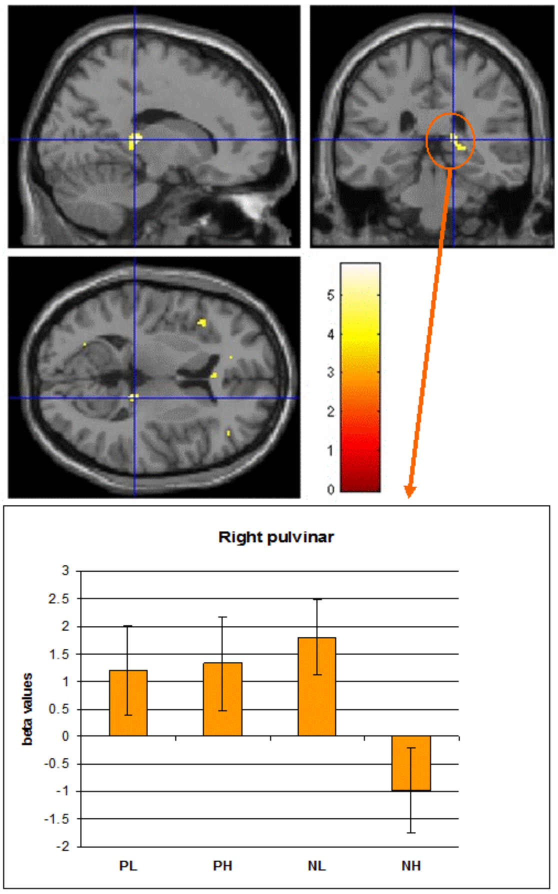


Figure 6. Regions showing significant BOLD signal changes to negative low-arousal words compared to negative high arousal ones (NL>NH). Refer to table 4 for exact MNI coordinates. Histograms of increase or decrease in activation (beta values) are reported for the 2 conditions and for the respective positive ones (PL=positive low-arousal, PH=positive high-arousal). Error bars represent standard errors.

Discussion

Our behavioural results showed a clear advantage for words over pseudo words, accompanied by increased neural activity within several areas associated with lexical processing, in line with previous literature (Binder et al., 2003; C. J. Fiebach et al., 2002; C. J. Fiebach et al., 2007; Kuchinke et al., 2005). Real words are represented in our mental lexicon and are therefore easier to recognise. Furthermore, word recognition extensively engages lexical and semantic networks in our brain, as supported by the pattern of activations found.

Reaction times for emotionally valenced words were no different to those for neutral words. The observed emotionality effect was driven by a difference between positive and negative words, discussed below. Accuracy results showed an advantage of valenced words compared to neutral, mostly due to positive words. Surprisingly, no difference between valenced and neutral words was observed in our imaging results, but there was a significant difference in the reversed contrast between neutral and negative words (NEU>NEG), showing increased activation in the inferior frontal gyrus, similarly to Kuchinke et al. (2005). This region is implicated in tasks which require inhibition of a prepotent response, such as go/no-go tasks (Aaron, Robbins, & Poldrack, 2004). Neutral words might plausibly recruit more effortful conscious processing for the lexical decision on account of being less salient than emotionally valenced words, hence do not benefit from the recruitment of affective limbic regions. Were that the case, we would expect to observe a similar difference between neutral and positive words; however there was no significant difference.

Behavioural results showed a clear advantage for positive words compared to negative. Positive words have a more interconnected lexical and semantic network compared to negative but also neutral words and are therefore easier to process (see for example Ashby et al., 1999). These results, together with the emotionality results, are consistent with and extend the observations of Kuchinke et al. (2005). However, an alternative interpretation is posed by the automatic vigilance hypothesis (e.g. Wentura, Rothermund, & Bak, 2000), which states that negative stimuli automatically attract attention because they might represent a threat; as a consequence, lexical decision latencies should be slower because less cognitive resources are available for the task at hand.

Our imaging results revealed an interaction between valence and arousal, with higher activation in the left posterior and right insula, as well as right cerebellum, for positive high-arousal (PH) and negative low-arousal (NL) words compared to PL and NH words. This pattern was further confirmed by the contrast PH>PL, which revealed increased activation in the left posterior and right insula, as well as in the left parahippocampal gyrus. Insula activation has been associated with the mapping of visceral states that are associated with emotional experience, giving rise to conscious feelings (Brooks et al., 2005; Craig, 1998; H.D. Critchley et al., 2004; Damasio et al., 2000; Singer et al., 2009). During fear conditioning, insula activation was modulated by perceptual awareness of the threatening stimulus (Hugo D. Critchley, Mathias, & Dolan, 2002). In the review by Phan et al. (2002), the insula, together with the ACC, showed activation for more cognitively demanding emotional tasks rather than passive tasks. Furthermore, the insula was one of the regions of shared activation between valence and arousal dimensions in the study by Lewis et al. (2007). Activation of the parahippocampal gyrus was not specifically predicted but is not surprising; in fact it is part of the Papez circuit, one of the major pathways of the limbic system, involved in the cortical control of emotion, as well as in memory storage (see Bear, Connors, & Paradiso, 2006).

According to the approach-withdrawal model by Robinson et al. (2004), PH and NL stimuli should lead to a processing conflict, as they elicit both approach and withdrawal reactions at the same time. Therefore, higher activation of the insula for these conditions might reflect integration of conflicting emotional responses prior to lexical decision, beyond the simple coding of emotional experience required for congruent PL and NH stimuli. In addition, this effect was more pronounced for PH than NL, possibly due to the general processing advantage for positive words compared to negative.

This difference cannot be attributed to an accidental higher level of arousal or emotionality (absolute valence) in positive words, because our positive and neutral stimuli were carefully matched for those features at both levels of arousal. Nevertheless, because negative stimuli tend to be naturally higher in arousal than positive stimuli (Citron et al., 2009; Lewis et al., 2007), matching them means that the most negative and highly arousing words used in our experiment might have been perceived as mild compared to aversive stimuli in everyday life, making our positive words appearing extremely valenced, arousing and salient.

The lack of an arousal effect expected in the amygdala might be due to an insufficient difference between high and low arousal levels. Other studies using a factorial design and reporting an arousal effect typically compared valenced words with neutral (Kensinger & Schacter, 2006; Maddock et al., 2003; Viinikainen et al., 2010), which are usually very low in arousal. The absence of supra-threshold amygdala activation is not a novel observation. The amygdala will respond to highly arousing or threatening stimuli (Maddock et al., 2003; Phan et al., 2002) and is engaged during non-demanding tasks such as silent reading (Herbert et al., 2009; Phan et al., 2002), which do not interfere with the implicit processing of emotion; whereas tasks requiring judgement of a specific stimulus property are cognitively more demanding and might inhibit amygdala activity (Costafreda, Brammer, David, & Fu, 2008). In the present study, our stimuli were not extreme in emotionality and arousal, especially the negative words; furthermore, the LDT is a cognitively demanding task. Kuchinke et al. (2005), who used a factorial design and a LDT, neither reported amygdala activation.

The apparent difference between the behavioural and brain imaging results might be accounted for by the fact that lexical decision latencies and accuracy reflect the final output of the cognitive evaluation, namely decision making, whereas brain activations reflect the processes involved during stimulus evaluation, from perception to response, and fMRI is much better at detecting subtle differences in emotional content. The subtle interaction between the two valence dimensions might therefore not be captured by reaction time measures. Furthermore, according to Robinson et al.'s model, integration of approach and withdrawal orientations takes place at an implicit processing level, prior to the conscious evaluation of the stimulus for the response.

Overall our results support the first hypothesis of an interaction of valence and arousal at the neural level, in line with Robinson et al.'s model, and extend their empirical evidence based on behavioural performance only. No amygdala activation in response to arousal independently of valence was found, thus not supporting our second hypothesis. No clear-cut differences in activations between positive and negative valence were found. This does not add clarity to the currently inconclusive results within the literature, but further supports the idea that emotion effects are more accurately detected when arousal is also taken into account. Only partial support for a neural differentiation between valenced and neutral words was shown. Finally, activations for real words compared with pseudo words confirm previous findings on the neural correlates of lexical access.

More generally, the observed processing advantage of emotionally valenced material upholds the idea that emotion affects cognition. The interaction found between valence and arousal points toward a two-dimensional approach for the study of emotion, as a more exhaustive and fine-grained model, superior to emotion-specific and one-dimensional, valence-driven approaches. The present study is inconclusive with regards to the general advantage found for positive words: It is not clear yet whether this advantage is driven by an natural bias toward positive material, or their more highly interconnected network of lexical and semantic representations. Future research could address these issues by including state (mood) and trait (personality) measures in the experimental design, to gain a more precise picture of emotion processing.

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References

Aaron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences, 8*, 170-177.

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. *Journal of Experimental Psychology, 133*, 323-338.

Altarriba, J., & Bauer, L. M. (2004). The distinctiveness of emotion concepts: A comparison between emotion, abstract and concrete words. *American Journal of Psychology, 117*, 389-410.

Ashby, F. G., Isen, A. M., & Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*(3), 529-550.

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133*, 283-316.

Balota, D. A., Pilotti, M., & Cortese, M. J. (2001). Subjective frequency estimates for 2,938 mono-syllabic words. *Memory & Cognition, 29*, 639-647.

Balota, D. A., Yap, M. J., & Cortese, M. J. (2006). Visual word recognition: The journey from features to meaning (a travel update). In M. Traxler & M. A. Gernsbacher (Eds.), *Handbook of Psycholinguistics* (2nd ed.). Amsterdam; Boston: Elsevier.

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchinson, K. A., Kessler, B., Loftis, B., et al. (2007). The English lexicon project. *Behavior Research Methods, 39*(3), 445-459.

Bear, M. F., Connors, B. W., & Paradiso, M. A. (2006). *Neuroscience: Exploring the brain* (3rd ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

Bernat, E., Bunce, S., & Shevrin, H. (2001). Event-related brain potentials differentiate positive and negative mood adjectives during both supraliminal and subliminal visual processing. *International Journal of Psychophysiology, 42*, 11-34.

Binder, J. R., McKiernan, K. A., Parsons, M. E., Westbury, C. F., Possing, E. T., Kaufman, J. N., et al. (2003). Neural correlates of lexical access during visual word recognition. *Journal of Cognitive Neuroscience, 15*(3), 372-393.

Bird, H., Franklin, S., & Howard, D. (2001). Age of acquisition and imageability ratings for a large set of words, including verbs and function words. *Behavior Research Methods, Instruments, & Computers, 33*(1), 73-79.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavioral Therapy and Experimental Psychiatry, 25*(1), 49-59.

Bradley, M. M., & Lang, P. J. (1999). *Affective norms for English words (ANEW): Simuli, instruction manual and affective ratings* (corpus, rating study No. C-1). Gainesville, FL: The Center for Research in Psychophysiology, University of Florida.

Brooks, J. C. W., Zambreanu, L., Godinez, A., Craig, A. D. B., & Tracey, I. (2005). Somatotopic organisation of the human insula to painful heat studied with high resolution functional imaging. *NeuroImage, 27*, 201-209.

Brown, T. A., & Semelka, R. C. (2001). *MRI basic principles and applications*. Hoboken, NJ: Wiley-Liss.

Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: an empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12*(1), 1-47.

Cacioppo, J. T., Gardner, W. L., & Berntson, G. G. (1999). The affect system has parallel and integrative processing components: form follows function. *Journal of Personality and Social Psychology, 76*(5), 839-855.

Citron, F. M. M., Weekes, B. S., & Ferstl, E. C. (2009). Evaluation of lexical and semantic features for English emotion words. In K. Alter, M. Horne, M. Lindgren, M. Roll & J. v. K. Torkildsen (Eds.), *Brain talk: discourse with and in the brain* (pp. 11-20). Lund, Sweden: Media-Tryck.

Coltheart, M. (1981). MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology, 33A*, 497-505.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. C. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256.

Costafreda, S. G., Brammer, M. J., David, A. S., & Fu, C. H. Y. (2008). Predictors of amygdala activation during the processing of emotional stimuli: A meta-analyis of 385 PET and fMRI studies. *Brain Research Reviews, 58*, 57-70.

Craig, A. D. B. (1998). A new version of the thalamic dishinibition hypothesis of central pain. *Pain forum, 7*(1), 1-14.

Critchley, H. D. (2009). Psychophysiology of neural, cognitive and affective integration: fMRI and autonomic indicants. *International Journal of Psychophysiology, 73*, 88-94.

Critchley, H. D., Mathias, C. J., & Dolan, R. J. (2002). Fear conditioning in humans: the influence of awareness and autonomic arousal on functional neuroanatomy. *Neuron, 33*, 653-663.

Critchley, H. D., Wiens, S., Rotshtein, P., Ohman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience, 7*(2), 189-195.

Cutler, A. (1981). Making up materials is a confounded nuisance, or: Will we be able to run any psycholinguistic experiments at all in 1990? *Cognition, 10*, 65-70.

Damasio, A. R., Grabowski, T. J., Bechara, A., Damasio, H., Ponto, L. L. B., Parvizi, J., et al. (2000). Subcortical and cortical brain activity during the feeling of self-generated emotions. *Nature Neuroscience, 3*, 1049-1056.

Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition, 20*, 125-151.

DeRose, S. J. (2005). The Compass DeRose Guide to Emotion Words. Retrieved November 2, 2007, from http://www.derose.net/steve/resources/emotion/index.html

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science, 221*, 1208-1210.

Estes, Z., & Adelman, J. S. (2008). Automatic vigilance for negative words in lexical decision and naming: Comment of Larsen, Mercer, and Balota (2006). *Emotion, 8*, 441-444.

Estes, Z., & Verges, M. (2008). Freeze or flee? Negative stimuli elicit selective responding. *Cognition, 108*, 557-565.

Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language, 41*, 469-495.

Feldman Barrett, L., & Russell, J. A. (1998). Independence and bipolarity in the structure of current affect. *Journal of Personality and Social Psychology, 74*(4), 967-984.

Feldman Barrett, L., & Russell, J. A. (1999). The structure of current affect: controversies and emerging consensus. *Current Directions in Psychological Science, 8*(1), 10-14.

Ferstl, E. C., Rinck, M., & von Cramon, D. Y. (2005). Emotional and temporal aspects of situation model processing during text comprehension: An event-related fMRI study. *Journal of Cognitive Neuroscience, 17*, 724-739.

Fiebach, C., & Friederici, A. D. (2003). Processing concrete words: fMRI evidence against a specific right-hemisphere involvement. *Neuropsychologia, 42*, 62-70.

Fiebach, C. J., Friederici, A. D., Mueller, K., & von Cramon, D. Y. (2002). fMRI evidence for dual routes to the mental lexicon in visual word recognition. *Journal of Cognitive Neuroscience, 14*(1), 11-23.

Fiebach, C. J., Ricker, B., Friederici, A. D., & Jacobs, A. M. (2007). Inhibition and facilitation in visual word recognition: prefrontal contribution to the orthographic neighborhood size effect. *NeuroImage, 36*, 901-911.

Fischler, I., & Bradley, M. M. (2006). Event-related potential studies of language and emotion: Words, phrases and task effects. *Progress in Brain Research, 156*, 185-203.

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition and Emotion, 19*(3), 313-332.

Garavan, H., Pendergrass, J. C., Ross, T. J., Stein, E. A., & Risinger, R. C. (2001). Amygdala response to both positively and negatively valenced stimuli. *NeuroReport, 12*(12), 2779-2783.

Gernsbacher, M. A., Goldsmith, H. H., & Robertson, R. R. W. (1992). Do readers mentally represent fictional characters' emotional states? *Cognition and Emotion, 6*, 89-111.

Herbert, C., Ethofer, T., Anders, S., Junghofer, M., Wildgruber, D., Grodd, W., et al. (2009). Amygdala activation during reading of emotional adjectives - an advantage for pleasant content. *Social Cognitive and Affective Neuroscience, 4*(1), 35-49.

Herbert, C., Junghofer, M., & Kissler, J. (2008). Event related potentials to emotional adjectives during reading. *Psychophysiology, 45*, 487-498.

Hinojosa, J. A., Carretié, L., Valcarcel, M. A., Méndez-Bértolo, C., & Pozo, M. A. (2009). Electrophysiological differences in the processing of affective information in words and pictures. *Cognitive, Affective & Behavioural Neuroscience, 9*(2), 173-189.

Hinojosa, J. A., Martin-Loeches, M., & Rubia, F. J. (2001). Event-related potentials and semantics: an overview and an integrative proposal. *Brain and Language, 78*, 128-139.

Hinojosa, J. A., Méndez-Bértolo, C., & Pozo, M. A. (2010). Looking at emotional words is not the same as reading emotional words: Behavioural and neural correlates. *Psychophysiology, 47*, 748-757.

Hofmann, M. J., Kuchinke, L., Tamm, S., Võ, M. L.-H., & Jacobs, A. M. (2009). Affective processing within 1/10th of a second: High arousal is necessary for early facilitative processing of negative but not positive words. *Cognitive, Affective & Behavioural Neuroscience, 9*(4), 389-397.

Huettel, S. A. (2009). *Functional magnetic resonance imaging* (2nd ed.): Sinauer Associates.

Indefrey, P., & Levelt, W. J. M. (2004). The spatial and temporal signatures of word production components. *Cognition, 92*, 101-144.

Jabbi, M., Swart, M., & Keysers, C. (2007). Empathy for positive and negative emotions in the gustatory cortex. *NeuroImage, 34*, 1744-1753.

Jacobs, A. M., & Grainger, J. (1994). Models of visual word recognition - Sampling the state of the art. *Journal of Experimental Psychology, 20*(6), 1311-1334.

Jennings, P. D., McGinnis, D., Lovejoy, S., & Stirling, J. (2000). Valence and arousal ratings for Velten Mood Induction Statements. *Motivation and Emotion, 24*, 285-297.

Juhasz, B. J. (2005). Age-of-acquisition effects in word and picture identification. *Psychological Bulletin, 131*, 684-712.

Kanske, P., & Kotz, S. A. (2007). Concreteness in emotional words: ERP evidence from a hemifield study. *Brain Research, 1148*, 138-148.

Kensinger, E. A., & Schacter, D. L. (2006). Processing emotional pictures and words: effects of valence and arousal. *Cognitive, Affective & Behavioural Neuroscience, 6*, 110-126.

Kissler, J., Assadollahi, R., & Herbert, C. (2006). Emotional and semantic networks in visual word processing: insights from ERP studies. *Progress in Brain Research, 156*, 147-183.

Kissler, J., Herbert, C., Peyk, P., & Junghofer, M. (2007). Buzzwords. Early cortical responses to emotional words during reading. *Psychological Science, 18*(6), 475-480.

Kissler, J., Herbert, C., Winkler, I., & Junghofer, M. (2009). Emotion and attention in visual word processing - An ERP study. *Biological Psychology, 80*, 75-83.

Kousta, S.-T., Vigliocco, G., Vinson, D. P., Andrews, M., & Del Campo, E. (in press). The representation of abstract words: Why emotion matters. *Journal of Experimental Psychology. General*.

Kousta, S.-T., Vinson, D. P., & Vigliocco, G. (2009). Emotion words, regardless of polarity, have a processing advantage over neutral words. *Cognition, 112*, 473-481.

Kuchinke, L., Jacobs, A. M., Gubrich, C., Võ, M. L.-H., Conrad, M., & Herrmann, M. (2005). Incidental effects of emotional valence in single word processing: An fMRI study. *NeuroImage, 28*, 1022-1032.

Kuchinke, L., Võ, M. L.-H., Hofmann, M., & Jacobs, A. M. (2007). Pupillary responses during lexical decisions vary with word frequency but not emotional valence. *International Journal of Psychophysiology, 65*, 132-140.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review, 97*(3), 377-395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1999). *International Affective Picture System (IAPS): instruction manual and affective ratings* (corpus No. A-4). Gainsville, FL: The Center for Research in Psychophysiology, University of Florida.

Larsen, R. J., Mercer, K. A., & Balota, D. A. (2006). Lexical characteristics of words used in emotional Stroop experiments. *Emotion, 6*, 62-72.

Leech, G. N., Rayson, P., & Wilson, A. (2001). *Word frequencies in written and spoken English*. Harlow: Longman.

Lewis, P. A., Critchley, H. D., Rotshtein, P., & Dolan, R. J. (2007). Neural correlates of processing valence and arousal in affective words. *Cerebral Cortex, 17*, 742-748.

Maddock, R. J., Garrett, A. S., & Buonocore, M. H. (2003). Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task. *Human Brain Mapping, 18*, 30-41.

Martin-Loeches, M. (2007). The gate for reading: Reflections on the recognition potential. *Brain Research Reviews, 53*, 89-97.

Mathews, A., & MacLeod, C. (1994). Cognitive approaches to emotion and emotional disorders. *Annual Review of Psychology, 45*, 25-50.

Max Planck Institute for Psycholinguistics. (2001). Web-based CELEX. Retrieved November 23, 2007, from http://celex.mpi.nl/

Morris, J. S., Frith, C. D., Perrett, D. I., Rowland, D., Young, A. W., Calder, A. J., et al. (1996). A differential neural response in the human amygdala to fearful and happy facial expressions. *Nature, 383*, 812-815.

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *The Quarterly Journal of Experimental Psychology, 50A*, 528-559.

Naccache, L., Gaillard, R., Adam, C., Hasboun, D., Clémenceau, S., Baulac, M., et al. (2005). A direct intracranial record of emotions evoked by subliminal words. *Proceedings of the National Academy of Sciences of the USA, 102*, 7713-7717.

Nakic, M., Smith, B. W., Busis, S., Vythilingam, M., & Blair, J. R. (2006). The impact of affect and frequency on lexical decision: The role of amygdala and inferior frontal cortex. *NeuroImage, 31*, 1752-1751.

Nasrallah, M., Carmel, D., & Lavie, N. (2009). Murder, she wrote: Enhanced sensitivity to negative word valence. *Emotion, 9*(5), 609-618.

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology, 77*, 247-265.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The measurement of meaning*. Urbana, Chicago, and London: University of Illinois Press.

Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery and meaningfulness values for 925 nouns. *Journal of Experimental Psychology Monograph Supplement, 76*, 1-25.

Paulesu, E., Scifo, F., & Fazio, F. (1998). Imaging funzionale. Attivazioni corticali. In A. D. M. e. al. (Ed.), *Trattato italiano di risonanza magnetica* (Vol. 1, pp. 121-133). Milano: Idelson-Gnocchi.

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*(2), 273-315.

Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *NeuroImage, 16*, 331-348.

Phillips, M. L., Young, A. W., Senior, C., Brammer, M., Andrew, C., Calder, A. J., et al. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature, 389*, 495-498.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*, 2128-2148.

Posner, J., Russell, J. A., Gerber, A., Gorman, D., Colibazzi, T., Yu, S., et al. (2009). The neurophysiological bases of emotion: an fMRI study of the affective circumplex using emotion-denoting words. *Human Brain Mapping, 30*, 883-895.

Pratto, F., & John, O. P. (1991). Automatic vigilance: the attention-grabbing power of negative social information. *Journal of Personality and Social Psychology, 61*(3), 380-391.

Price, C. J., Wise, R. J. S., & Frackowiak, R. S. J. (1996). Demonstrating the implicit processing of visually presented words and pseudowords. *Cerebral Cortex, 6*, 62-70.

Rastle, K., Harrington, J., & Coltheart, M. (2002). 358,534 nonwords: The ARC nonword database. *Quarterly Journal of Experimental Psychology, 55A*(4), 1339-1362.

Reisenzein, R. (1994). Pleasure-arousal theory and the intensity of emotions. *Journal of Personality and Social Psychology, 67*(3), 525-539.

Richardson, D. C., & Spivey, M. (2004). Eye tracking: Research areas and applications. In G. Wnek & G. Bowlin (Eds.), *Encyclopedia of Biomaterials and Biomedical Engineering* (pp. 573-582). New York: Marcel Dekker, Inc.

Robinson, M. D. (1998). Running from William James' bear: A review of preattentive mechanisms and their contributions to emotional experience. *Cognition and Emotion, 12*(5), 667-696.

Robinson, M. D., Storbeck, J., Meier, B. P., & Kirkeby, B. S. (2004). Watch out! That could be dangerous: Valence-arousal interactions in evaluative processing. *Personality and Social Psychology Bulletin, 30*, 1472-1484.

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 803-814.

Ruci, L., Tomes, J. L., & Zelenzki, J. M. (2008). Mood-congruent false memories in the DRM paradigm. *Cognition & Emotion, 23*(6), 1153-1165.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*, 1161-1178.

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110*(1), 145-172.

Schacht, A., & Sommer, W. (2009b). Time course and task dependence of emotion effects in word processing. *Cognitive, Affective & Behavioural Neuroscience, 9*(1), 28-43.

Schachter, S., & Singer, J. E. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review, 69*(5), 379-399.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2003). Emotional facilitation of sensory processing in the visual cortex. *Psychological Science, 14*, 7-13.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective propocessing of briefly presented affective pictures: An ERP analysis. *Psychophysiology, 41*, 441-449.

Scott, G. G., O'Donnell, P. J., Leuthold, H., & Sereno, S. C. (2009). Early emotion word processing: Evidence from event-related potentials. *Biological Psychology, 80*, 95-104.

Seeley, W. W., Menon, V., Schatzberg, A., F., Keller, J., Glover, G. H., Kenna, H., et al. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neuroscience, 27*(9), 2349-2356.

Sereno, S. C., & Rayner, K. (2003). Measuring word recognition in reading: eye movements and event-related potentials. *Trends in Cognitive Sciences, 7*(11), 489-493.

Sereno, S. C., Rayner, K., & Posner, M. I. (1998). Establishing a time-line of word recognition: evidence from eye movements and event-related potentials. *NeuroReport, 9*, 2195-2200.

Singer, T., Critchley, H. D., & Preuschoff, K. (2009). A common role of insula in feelings, empathy and uncertainty. *Trends in Cognitive Sciences, 13*(8), 334-340.

Small, D. M., Gregory, M. D., Mak, Y. E., Gitelman, D., Mesulam, M. M., & Parrish, T. (2003). Dissociation of neural representation of intensity and affective valuation in human gustation. *Neuron, 39*, 701-711.

Stadthagen-Gonzales, H., & Davis, C. (2006). The Bristol norms for age of acquisition, imageability and familiarity. *Behavior Research Methods, 38*, 598-605.

Storbeck, J., & Clore, G. L. (2007). On the interdependence of cognition and emotion. *Cognition and Emotion, 6*, 1212-1237.

Stroop, J. R. (1935). Studies of interference in serial-verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Taake, I., Jaspers-Fayer, F., & Liotti, M. (2009). Early frontal responses elicited by physical threat words in an emotional Stroop task: Modulation by anxiety sensitivity. *Biological Psychology, 81*, 48-57.

Taylor, S. E. (1991). Asymmetrical effects of positive and negative events: The mobilization-minimization hypothesis. *Psychological Bulletin, 110*(1), 67-85.

Viinikainen, M., Jääskeläinen, I. P., Alexandrov, Y., Balk, M. H., Autti, T., & Sams, M. (2010). Nonlinear relationship between emotional valence and brain activity: evidence of separate negative and positive valence dimensions. *Human Brain Mapping, 31*, 1030-1040.

Võ, M. L.-H., Conrad, M., Kuchinke, L., Urton, K., Hofmann, M. J., & Jacobs, A. M. (2009). The Berlin Affective Word List Reloaded (BAWL-R). *Behavior Research Methods, 41*, 534-538.

Võ, M. L.-H., Jacobs, A. M., & Conrad, M. (2006). Cross-validating the Berlin affective word list. *Behavior Research Methods, 38*, 606-609.

Wager, T. D., Phan, K. L., Liberzon, I., & Taylor, S. F. (2003). Valence, gender, and lateralization of functional brain anatomy in emotion: a meta-analysis of findings from neuroimaging. *NeuroImage, 19*, 513-531.

Wentura, D., Rothermund, K., & Bak, P. (2000). Automatic vigilance: The attention-grabbing power of approach- and avoidance-related social information. *Journal of Personality and Social Psychology, 78*, 1024-1037.

West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic, and surface-level processing of concrete and abstract words: An electrophysiological investigation. *Journal of Cognitive Neuroscience, 12*, 1024-1037.

Williams, J. M. G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop Task and Psychopathology. *Psychological Bulletin, 120*(1), 3-24.

Winston, J. S., Gottfried, J. A., Kilner, J. M., & Dolan, R. J. (2005). Integrated neural representations of odor intensity and affective valence in human amygdala. *Journal of Neuroscience, 25*(39), 8903-8907.

Winston, J. S., O'Doherty, J., & Dolan, R. J. (2003). Common and distinct neural responses during direct and incidental processing of multiple facial emotions. *Neuroimage, 20*(1), 84-97.

Zani, A., & Proverbio, A. M. (2002). *The cognitive electrophysiology of mind and brain*. London: Academic Press.

Zevin, J. D., & Seidenberg, M. S. (2004). Age-of-acquisition effects in reading aloud: Tests of cumulative frequency and frequency trajectory. *Memory & Cognition, 32*(1), 31-38.

Zhang, Q., Guo, C., Ding, J., & Wang, Z. (2006). Concreteness effects in the processing of Chinese words. *Brain and Language, 96*, 59-68.

Ziegler, J. C., Besson, M., Jacobs, A. M., Nazir, T. A., & Carr, T. H. (1997). Word, pseudoword, and nonword processing: a multitask comparison using event-related brain potentials. *Journal of Cognitive Neuroscience, 9*(6), 758-775.

Appendix A. Sussex Affective Word List (SAWL).

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concrete-ness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/concrete	no	no	no	no per million
abandon	verb	-1.89	0.86	negative	4.57	1.71	3.72	1.54	4.61	0.87	2.84	1.27	abstract	7	7	3	6
abbey	noun	0.04	0.66	neutral	1.71	1.17	2.48	1.59	5.12	0.87	5.23	1.80	concrete	5	3	2	10
abundance	noun	0.64	1.15	neutral	2.96	1.64	3.10	1.54	5.72	0.70	3.03	1.57	abstract	9	8	3	7
accent	noun	0.22	0.61	neutral	2.30	1.56	4.88	1.53	4.46	0.72	2.67	1.83	abstract	6	6	2	26
acceptance	noun	1.50	0.91	positive	2.84	1.67	4.40	1.55	4.89	0.85	2.45	1.53	abstract	10	9	3	23
accomplish	verb	1.80	0.94	positive	4.00	1.75	4.33	1.48	5.10	0.81	2.51	1.37	abstract	10	8	3	1
accused	noun, adjective	-1.50	0.76	negative	4.33	1.60	4.15	1.48	4.87	0.75	2.85	1.49	abstract	7	6	2	11
achievement	noun	2.17	0.80	positive	4.26	1.75	5.15	1.33	4.34	0.82	3.46	1.61	abstract	11	8	3	29
activity	noun	0.76	0.87	neutral	3.11	1.51	5.07	1.47	3.60	0.84	3.88	1.69	abstract	8	8	4	75
admire	verb	1.60	0.80	positive	3.52	1.60	4.71	1.34	4.74	0.84	2.93	1.45	abstract	6	6	3	4
affection	noun	2.05	0.86	positive	4.04	1.80	4.84	1.49	4.68	0.87	3.94	1.70	abstract	9	6	3	24
afraid	adjective	-1.65	0.73	negative	4.79	1.48	4.72	1.42	3.04	0.82	3.89	1.67	abstract	6	5	2	112
agitated	adjective	-1.34	0.61	negative	4.57	1.68	4.11	1.40	5.27	0.79	3.28	1.60	abstract	8	8	4	6
agony	noun	-2.49	0.74	negative	5.60	1.56	3.89	1.66	4.79	0.68	4.30	1.65	abstract	5	5	3	13
agreement	noun	1.10	0.88	positive	2.56	1.37	5.10	1.40	4.40	0.84	2.68	1.34	abstract	9	8	3	58
angel	noun	1.59	0.97	positive	3.29	1.72	3.98	1.75	2.76	0.76	6.37	0.96	concrete	5	5	2	11
angry	adjective	-1.94	0.82	negative	5.37	1.19	6.00	0.94	2.71	0.81	4.50	1.67	abstract	5	5	2	65
annoyed	adjective	-1.33	0.80	negative	4.50	1.61	5.78	1.11	3.84	0.92	3.43	1.51	abstract	7	4	2	3
antagonist	noun	-0.84	0.82	interm. negative	3.54	1.84	2.73	1.74	6.30	0.71	2.46	1.47	abstract	10	10	4	1
anxious	adjective	-1.43	0.88	negative	5.07	1.55	4.93	1.45	4.89	0.72	3.12	1.56	abstract	7	6	2	41
apathetic	adjective	-0.53	1.18	neutral	2.47	1.44	3.23	1.74	6.18	0.69	2.08	1.35	abstract	9	9	4	2
appreciated	adjective	1.78	0.93	positive	3.54	1.58	5.09	1.20	4.76	0.75	2.39	1.10	abstract	11	10	5	2
argument	noun	-1.56	0.83	negative	5.10	1.41	5.40	1.11	3.72	0.85	4.07	1.60	abstract	8	8	3	88
army	noun	-0.85	1.01	interm. negative	3.93	1.62	4.02	1.62	3.67	0.75	6.05	1.27	abstract	4	3	2	108
arrest	verb, noun	-1.23	0.79	negative	4.41	1.47	4.34	1.61	4.17	0.70	4.96	1.57	abstract	6	5	2	14
ashamed	adjective	-1.70	0.81	negative	4.15	1.73	4.46	1.48	4.55	1.03	3.37	1.69	abstract	7	5	2	22
assured	adjective	1.26	0.87	positive	2.67	1.49	4.20	1.49	5.16	0.79	2.16	1.15	abstract	7	4	2	11
astonished	adjective	0.33	0.82	neutral	4.15	1.49	3.68	1.46	5.06	0.73	3.26	1.65	abstract	10	8	3	2
attack	verb, noun	-1.79	0.83	negative	5.61	1.43	4.48	1.53	3.79	0.84	4.99	1.29	abstract	6	4	2	92
attic	noun	0.09	0.74	neutral	1.96	1.36	3.21	1.76	3.59	0.83	6.00	1.28	concrete	5	4	2	7
attracted	adjective	1.93	0.84	positive	4.43	1.66	5.57	1.30	4.57	0.83	3.55	1.63	abstract	9	8	3	5
avoid	verb	-0.99	0.82	interm. negative	3.39	1.65	5.01	1.30	4.35	0.81	2.60	1.39	abstract	5	4	2	19
bad	adjective	-1.63	0.91	negative	4.00	1.58	5.96	1.14	1.84	0.68	3.20	1.74	abstract	3	3	1	209
ban	verb, noun	-0.89	0.79	interm. negative	3.37	1.68	4.38	1.61	4.39	0.94	2.35	1.25	abstract	3	3	1	11
banner	noun	0.13	0.66	neutral	1.90	1.28	3.40	1.55	4.26	0.77	5.32	1.65	concrete	6	5	2	7
battle	noun	-1.27	0.99	negative	4.62	1.57	3.87	1.65	3.85	0.89	5.68	1.37	abstract	6	4	2	70
beach	noun	1.89	1.01	positive	3.72	1.85	5.67	1.37	2.76	0.70	6.68	0.70	concrete	5	3	1	59
benefit	verb, noun	1.26	0.83	positive	2.95	1.44	4.66	1.40	4.71	0.73	2.40	1.34	abstract	7	7	3	73
betrayed	adjective	-2.27	0.79	negative	5.29	1.57	4.17	1.59	4.79	0.84	2.98	1.55	abstract	8	6	2	2
bill	verb, noun	-0.89	0.89	interm. negative	2.63	1.64	4.96	1.54	4.23	0.93	5.02	1.75	concrete	4	3	1	54
birthday	noun	1.98	1.04	positive	4.41	1.87	6.05	1.04	1.99	0.71	5.83	1.37	abstract	8	5	2	20
bold	adjective	0.65	0.88	neutral	3.29	1.61	4.06	1.67	4.23	0.82	3.18	1.72	abstract	4	4	1	11
bomb	verb, noun	-2.29	0.79	negative	5.78	1.24	4.05	1.69	3.93	0.78	6.21	1.04	concrete	4	3	1	29
book	verb, noun	0.80	1.06	neutral	1.99	1.31	6.52	0.74	2.01	0.69	6.56	1.02	concrete	4	3	1	270
bored	adjective	-1.21	0.73	negative	2.61	1.51	6.18	1.16	3.16	0.81	3.61	1.63	abstract	5	3	1	5
boy	noun	0.66	0.92	neutral	2.65	1.68	6.43	0.93	1.82	0.57	6.50	0.93	concrete	3	2	1	216
brag	verb	-1.24	0.78	negative	3.24	1.61	3.84	1.67	4.66	0.80	2.98	1.49	abstract	4	4	1	0
brave	adjective	1.78	0.77	positive	4.43	1.56	4.55	1.44	3.23	0.82	3.49	1.60	abstract	5	4	1	19
build	verb	0.54	0.82	neutral	2.22	1.25	4.54	1.36	2.82	0.79	4.61	1.52	abstract	5	4	1	21
burden	verb, noun	-1.38	0.76	negative	3.65	1.60	3.62	1.60	5.21	0.83	2.94	1.52	abstract	6	4	2	27
burn	verb, noun	-1.35	0.87	negative	4.61	1.51	4.54	1.55	3.21	0.97	5.52	1.28	abstract	4	3	1	12

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concrete-ness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/ negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/ concrete	no	no	no	no per million
calm	verb, noun, adjective	1.54	0.86	positive	2.43	1.65	5.27	1.32	3.55	1.04	3.50	1.54	abstract	4	3	1	34
capable	adjective	1.32	0.89	positive	2.62	1.35	4.65	1.56	4.70	0.75	2.10	1.06	abstract	7	6	3	54
caring	verb, adjective	2.06	0.84	positive	3.54	1.58	5.61	1.15	3.61	0.89	3.51	1.64	abstract	6	5	2	14
carnival	noun	1.43	1.01	positive	4.16	1.88	3.34	1.63	4.13	0.86	5.85	1.41	abstract	8	6	3	3
ceiling	noun	0.06	0.33	neutral	1.54	1.02	4.49	1.67	3.20	0.79	6.20	1.23	concrete	7	5	2	26
celebrate	verb	2.06	0.79	positive	4.45	1.67	5.23	1.35	3.83	0.80	4.68	1.46	abstract	9	8	3	3
cellar	noun	-0.21	0.72	neutral	2.01	1.21	3.12	1.68	4.17	0.98	6.13	1.17	concrete	6	5	2	10
chance	noun	0.78	0.97	neutral	3.18	1.72	5.38	1.26	3.96	0.79	2.11	1.11	abstract	6	4	1	146
change	verb, noun	0.29	0.88	neutral	3.39	1.72	5.65	1.17	3.20	0.84	2.77	1.57	abstract	5	4	1	155
chaos	noun	-1.43	1.04	negative	5.21	1.42	3.99	1.75	4.90	0.78	4.71	1.61	abstract	5	4	2	15
cheerful	adjective	1.84	0.78	positive	3.67	1.69	5.13	1.42	3.65	0.79	4.00	1.66	abstract	8	5	2	18
chocolate	noun	1.60	1.03	positive	3.67	1.89	6.33	0.83	2.38	0.70	6.60	0.90	concrete	9	7	3	13
choose	verb	0.28	1.01	neutral	2.63	1.43	5.85	1.23	3.11	0.94	2.31	1.25	abstract	6	3	1	16
church	noun	-0.06	1.26	neutral	2.55	1.61	4.24	1.79	2.87	0.83	6.43	1.10	concrete	6	3	1	159
clearheaded	adjective	1.12	0.82	positive	2.09	1.24	3.63	1.70	5.17	0.77	2.35	1.47	abstract	11	9	3	0
collapse	verb, noun	-1.38	0.81	negative	4.02	1.65	3.83	1.57	4.45	0.77	4.41	1.43	abstract	8	6	2	17
collective	noun, adjective	0.52	0.74	neutral	2.07	1.23	3.83	1.52	4.99	0.87	2.73	1.55	abstract	10	8	3	29
comfortable	adjective	1.65	0.81	positive	2.54	1.44	5.73	1.13	3.78	0.94	3.48	1.62	abstract	11	9	4	44
command	verb, noun	-0.33	0.77	neutral	3.63	1.75	3.38	1.56	4.61	0.90	2.91	1.46	abstract	7	6	2	46
compel	verb	0.35	0.80	neutral	3.06	1.60	3.41	1.55	5.66	0.73	3.10	10.85	abstract	6	6	2	1
complaint	noun	-1.02	0.63	negative	3.41	1.46	4.94	1.45	4.56	0.77	2.62	1.43	abstract	9	8	2	13
concentrated	adjective	0.40	0.70	neutral	2.85	1.51	5.24	1.30	4.45	0.83	2.96	1.64	abstract	12	12	4	17
confident	adjective	1.57	0.70	positive	3.43	1.66	5.50	1.20	4.49	0.74	3.22	1.53	abstract	9	9	3	28
conflict	noun	-1.62	0.84	negative	4.80	1.44	4.46	1.63	4.83	0.77	4.18	1.44	abstract	8	8	2	47
confused	adjective	-0.98	0.68	interm. negative	3.40	1.55	5.79	1.07	3.95	0.90	3.17	1.65	abstract	8	8	2	19
corpse	noun	-2.61	0.58	negative	4.93	1.82	2.80	1.72	5.02	0.70	5.87	1.19	concrete	6	4	1	10
cowardly	adjective	-1.52	0.96	negative	3.79	1.65	3.57	1.46	4.60	1.04	2.99	1.37	abstract	8	6	3	3
crime	noun	-1.60	0.84	negative	4.46	1.45	4.91	1.64	4.00	0.77	4.84	1.59	abstract	5	4	1	49
crisis	noun	-1.83	0.77	negative	5.32	1.51	4.11	1.66	4.80	0.67	3.46	1.64	abstract	6	6	2	59
cry	verb, noun	-1.38	0.96	negative	4.90	1.53	5.94	1.00	1.99	0.68	5.91	1.17	abstract	3	3	1	27
culture	noun	0.88	1.01	interm. positive	2.95	1.55	4.74	1.55	5.02	0.82	3.48	1.71	abstract	7	6	2	68
curious	adjective	0.73	0.89	neutral	3.43	1.63	4.56	1.40	4.24	0.78	2.84	1.46	abstract	7	6	2	51
damage	verb, noun	-1.35	0.65	negative	4.34	1.48	4.74	1.46	3.65	0.76	4.29	1.65	abstract	6	5	2	46
dance	verb, noun	1.95	0.97	positive	4.40	1.80	6.00	1.04	2.46	0.76	6.07	1.18	abstract	5	4	1	34
dangerous	adjective	-1.79	0.87	negative	5.33	1.38	5.07	1.44	2.99	0.88	4.24	1.53	abstract	9	8	3	82
defeated	adjective	-1.79	0.78	negative	4.17	1.62	3.74	1.60	4.62	0.80	3.17	1.67	abstract	8	7	2	3
defence	noun	-0.04	0.91	neutral	3.38	1.45	4.16	1.52	4.61	0.80	3.17	1.41	abstract	7	6	2	103
delighted	adjective	2.22	0.82	positive	4.32	1.72	4.70	1.43	4.34	0.88	4.04	1.77	abstract	9	7	3	6
depressed	adjective	-2.10	0.81	negative	4.54	1.72	5.35	1.40	5.17	0.73	3.72	1.77	abstract	9	7	2	17
desert	verb, noun	0.21	0.99	neutral	2.71	1.67	3.89	1.66	3.67	0.83	6.20	1.20	concrete	6	5	2	37
despair	verb, noun	-2.11	0.89	negative	4.91	1.60	3.67	1.71	4.99	0.75	3.29	1.54	abstract	7	6	2	27
destroy	verb	-1.94	0.78	negative	5.35	1.58	4.27	1.62	4.02	0.80	4.72	1.50	abstract	7	6	2	11
devil	noun	-1.85	1.09	negative	4.39	1.86	3.43	1.80	3.63	0.90	6.02	1.29	concrete	5	4	2	26
disappointed	adjective	-1.51	0.69	negative	3.50	1.57	5.29	1.31	4.06	0.81	2.94	1.29	abstract	12	11	4	21
discouraged	adjective	-1.26	0.66	negative	3.07	1.32	3.80	1.63	5.07	0.72	2.01	1.06	abstract	11	9	3	2
discover	verb	1.07	0.94	positive	3.88	1.67	4.54	1.54	3.95	0.77	3.17	1.49	abstract	8	8	3	11
discussion	noun	0.52	0.91	neutral	2.82	1.63	5.54	1.21	4.51	0.81	3.24	1.65	abstract	10	7	3	61
disregarded	adjective	-1.38	0.88	negative	3.17	1.75	3.59	1.67	5.46	0.74	2.30	1.51	abstract	11	11	4	1
distracted	adjective	-0.73	0.69	neutral	2.90	1.44	5.41	1.38	4.48	0.86	2.61	1.35	abstract	10	10	3	4
distressed	adjective	-1.63	0.84	negative	4.80	1.49	4.48	1.46	4.82	0.92	3.72	1.62	abstract	10	8	2	2

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concreteness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/ negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/ concrete	no	no	no	no per million
divorce	verb, noun	-1.88	1.00	negative	4.46	1.83	4.49	1.69	4.33	0.83	3.38	1.79	abstract	7	5	2	21
doubt	verb, noun	-1.02	0.68	negative	3.33	1.47	5.04	1.39	4.40	0.77	2.04	1.12	abstract	5	3	1	138
dream	verb, noun	1.54	0.93	positive	4.21	1.74	6.07	0.93	2.88	0.76	4.83	1.76	abstract	5	4	1	50
drop	verb, noun	-0.38	0.60	neutral	2.33	1.33	5.32	1.44	2.67	0.83	4.18	1.72	concrete	4	4	1	34
easy	adjective	1.11	0.70	positive	2.21	1.23	6.10	1.01	2.67	0.67	2.23	1.23	abstract	4	3	2	150
embarrassed	adjective	-1.27	0.89	negative	4.59	1.49	5.67	1.20	3.94	0.92	4.16	1.62	abstract	11	8	3	4
encouraged	adjective	1.73	0.90	positive	3.52	1.74	5.32	1.30	4.51	0.74	3.00	1.49	abstract	10	8	3	8
enemy	noun	-1.89	0.79	negative	4.91	1.42	4.28	1.69	3.73	0.75	4.16	1.77	abstract	5	5	3	50
energised	adjective	1.61	0.83	positive	4.52	1.48	4.07	1.53	4.98	0.75	3.55	1.59	abstract	9	7	3	0
enjoy	verb	2.06	0.82	positive	3.91	1.58	6.11	1.01	3.11	0.79	3.50	1.53	abstract	5	4	2	17
enthusiastic	adjective	1.91	0.76	positive	4.41	1.81	5.28	1.27	4.87	0.72	3.48	1.53	abstract	12	13	5	15
evening	noun	0.94	0.99	interm. positive	2.41	1.48	6.33	1.01	3.06	0.76	5.22	1.65	abstract	7	5	3	183
evil	adjective	-2.33	0.85	negative	5.12	1.63	4.32	1.74	3.49	0.85	4.35	1.84	abstract	4	3	2	52
excited	adjective	2.00	0.79	positive	5.24	1.55	6.16	1.04	3.02	0.83	4.09	1.62	abstract	7	7	3	24
excluded	adjective	-1.85	0.88	negative	3.99	1.73	3.84	1.58	4.82	0.72	3.16	1.56	abstract	8	9	3	3
exhausted	adjective	-1.33	0.94	negative	3.85	1.66	5.44	1.32	4.56	0.74	3.73	1.59	abstract	9	8	3	5
failure	noun	-2.04	0.73	negative	4.39	1.59	4.79	1.61	4.35	0.88	2.85	1.54	abstract	7	6	2	67
faith	noun	0.77	1.26	neutral	3.24	1.67	4.34	1.69	4.56	0.92	2.91	1.71	abstract	5	3	1	51
familiar	adjective	1.01	0.82	positive	2.41	1.34	5.06	1.50	4.26	0.90	2.23	1.19	abstract	8	8	3	65
family	noun	2.27	1.02	positive	3.89	1.82	6.32	0.95	2.32	0.74	6.05	1.39	abstract	6	6	3	328
farewell	noun	-1.07	0.95	negative	3.33	1.51	3.56	1.87	4.30	0.90	3.68	1.72	abstract	8	6	2	8
father	verb, noun	1.85	1.22	positive	3.33	1.90	5.98	1.26	1.91	0.77	6.39	1.11	concrete	6	5	2	272
fault	noun	-1.17	0.66	negative	3.62	1.58	4.96	1.38	3.55	1.04	2.56	1.46	abstract	5	4	1	38
feel	verb	0.82	0.93	interm. positive	3.65	1.57	6.06	1.05	2.96	0.79	2.33	1.34	abstract	4	3	1	109
film	verb, noun	0.96	0.99	interm. positive	2.98	1.60	6.34	0.83	3.05	0.77	5.84	1.42	concrete	4	4	1	87
fire	verb, noun	-1.17	1.27	negative	5.41	1.37	4.79	1.55	2.41	0.75	6.51	0.96	concrete	4	4	2	148
follower	noun	-0.09	0.80	neutral	2.23	1.16	3.73	1.56	4.18	0.82	3.26	1.59	abstract	8	6	3	2
forest	noun	0.66	0.92	neutral	2.28	1.42	4.11	1.66	3.28	0.74	6.48	1.08	concrete	6	6	2	68
forget	verb	-0.90	0.70	interm. negative	2.99	1.45	5.90	1.19	3.40	0.80	2.32	1.12	abstract	6	5	2	19
fortune	noun	1.46	0.88	positive	3.82	1.69	4.22	1.55	4.56	0.83	4.05	1.85	abstract	7	5	2	29
fragrant	adjective	0.99	0.76	positive	2.48	1.58	3.06	1.69	5.24	0.71	2.91	1.66	abstract	8	8	2	3
friend	noun	2.52	0.67	positive	4.24	1.85	6.62	0.70	2.22	0.65	5.74	1.27	concrete	6	5	1	172
frightened	adjective	-1.78	0.70	negative	5.05	1.54	4.65	1.43	3.23	0.97	4.16	1.64	abstract	10	6	2	39
frustrated	adjective	-1.46	0.72	negative	4.76	1.51	5.18	1.40	4.46	0.88	3.26	1.51	abstract	10	10	3	3
fulfilled	adjective	1.76	0.99	positive	3.30	1.59	4.22	1.53	5.11	0.70	2.30	1.45	abstract	9	7	2	2
furious	adjective	-2.13	0.80	negative	5.37	1.63	4.48	1.64	4.22	0.89	4.22	1.60	abstract	7	6	2	15
garden	noun	1.00	1.02	positive	2.12	1.41	5.38	1.39	2.35	0.78	6.43	0.88	concrete	6	4	2	110
gift	noun	1.74	0.89	positive	3.84	1.81	4.87	1.46	3.30	0.87	5.93	1.12	concrete	4	4	1	31
giggle	verb, noun	2.13	0.86	positive	4.18	1.72	5.22	1.63	3.16	0.78	4.96	1.54	concrete	6	4	2	3
girl	noun	0.74	0.94	neutral	2.56	1.59	6.51	0.81	1.73	0.52	6.43	1.09	concrete	4	3	1	276
give	verb	1.20	0.85	positive	2.76	1.54	6.22	1.04	2.23	0.96	3.44	1.68	abstract	4	3	1	121
glass	noun	0.00	0.65	neutral	2.17	1.49	6.22	1.21	2.62	0.81	6.30	1.11	concrete	5	4	1	125
good	noun, adjective	1.77	0.84	positive	2.99	1.63	6.52	0.88	1.87	0.73	2.93	1.69	abstract	4	3	1	941
greeting	verb, noun	0.88	0.76	interm. positive	2.35	1.33	4.41	1.56	4.32	0.80	3.83	1.59	abstract	8	6	2	11
guest	noun	0.57	0.69	neutral	2.26	1.32	4.94	1.38	3.65	0.89	4.35	1.57	concrete	5	4	1	24
happy	adjective	2.45	0.67	positive	4.71	1.75	6.39	0.89	2.18	0.76	4.77	1.79	abstract	5	4	2	135
harm	verb, noun	-1.84	0.94	negative	4.83	1.58	4.38	1.62	3.71	0.90	3.45	1.56	abstract	4	3	1	31
hateful	adjective	-2.13	0.73	negative	5.12	1.48	3.95	1.71	4.29	0.94	3.12	1.55	abstract	7	6	2	4
healed	adjective	1.62	0.86	positive	3.21	1.47	4.21	1.67	4.09	0.95	3.44	1.47	abstract	6	4	1	1
health	noun	1.43	1.16	positive	3.48	1.74	5.67	1.22	3.79	0.75	3.18	1.63	abstract	6	4	1	132

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concrete-ness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/ negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/ concrete	no	no	no	no per million
heart	noun	1.49	1.05	positive	4.22	1.82	5.43	1.38	2.98	0.79	6.38	1.10	concrete	5	3	1	145
heaven	noun	1.56	1.08	positive	3.67	1.71	4.49	1.67	2.94	0.74	5.40	1.65	abstract	6	4	2	33
hell	noun	-2.22	0.90	negative	4.83	1.85	4.29	1.81	3.57	0.86	5.43	1.55	abstract	4	3	1	94
helpful	adjective	1.61	0.81	positive	2.84	1.46	5.50	1.23	3.13	0.73	3.30	1.71	abstract	7	7	2	26
hero	noun	1.82	0.96	positive	4.29	1.87	4.30	1.68	3.35	0.76	5.27	1.54	concrete	4	4	2	30
herring	noun	-0.15	0.76	neutral	1.50	1.07	2.29	1.62	5.20	0.83	5.42	1.73	concrete	7	5	2	3
holiday	noun	2.39	0.77	positive	4.57	1.91	5.90	1.18	2.80	0.66	5.96	1.22	abstract	7	6	3	58
housewife	noun	0.02	0.85	neutral	2.12	1.39	4.04	1.77	4.46	0.83	5.74	1.32	concrete	9	6	2	9
hurt	verb, noun, adjective	-1.68	0.91	negative	4.78	1.56	5.65	1.13	2.39	0.75	4.40	1.62	abstract	4	3	1	7
idea	noun	1.06	0.85	positive	3.06	1.64	5.85	1.02	3.43	0.69	3.11	1.65	abstract	4	3	2	272
illness	noun	-1.98	0.94	negative	3.89	1.71	5.00	1.51	3.28	0.91	4.61	1.58	abstract	7	5	2	34
imagine	verb	1.30	0.96	positive	3.44	1.59	5.46	1.15	3.73	0.86	2.68	1.55	abstract	7	6	3	21
incapable	adjective	-1.49	0.95	negative	3.68	1.62	3.93	1.53	5.13	0.70	2.11	1.10	abstract	9	8	4	14
indifferent	adjective	-0.30	0.70	neutral	2.23	1.27	3.77	1.80	5.44	0.79	2.05	1.21	abstract	11	9	3	13
individual	noun, adjective	0.93	0.93	interm. positive	2.90	1.51	5.27	1.32	4.63	0.85	3.68	1.79	abstract	10	10	4	146
initiative	noun	1.16	0.94	positive	3.40	1.62	4.17	1.58	5.54	0.69	2.07	1.20	abstract	10	8	4	18
innocent	noun, adjective	1.04	0.94	positive	3.04	1.60	4.68	1.46	4.40	0.86	3.09	1.74	abstract	8	6	3	39
inspired	adjective	1.78	0.74	positive	4.34	1.66	4.43	1.39	5.06	0.65	2.56	1.39	abstract	8	7	3	10
interested	adjective	1.43	0.79	positive	3.46	1.62	5.66	1.22	3.94	0.88	2.55	1.26	abstract	10	9	3	103
intonation	noun	0.05	0.52	neutral	1.88	1.05	2.68	1.51	6.16	0.81	1.87	1.21	abstract	10	9	4	4
invitation	noun	1.12	0.79	positive	2.82	1.48	4.78	1.53	3.63	0.81	4.78	1.72	abstract	10	9	4	20
job	noun	0.15	0.92	neutral	2.72	1.64	6.30	1.06	3.17	0.84	4.76	1.75	abstract	3	3	1	244
joining	verb	0.50	0.82	neutral	2.18	1.31	4.21	1.56	4.01	0.88	2.68	1.46	abstract	7	5	2	16
journey	verb, noun	1.07	0.97	positive	3.37	1.88	5.32	1.38	3.54	0.86	4.39	1.52	abstract	7	4	2	51
kiss	verb, noun	2.46	0.74	positive	5.35	1.63	6.34	0.80	2.34	0.82	6.37	1.01	concrete	4	3	1	17
lack	verb, noun	-1.06	0.62	negative	2.65	1.32	4.30	1.56	4.57	0.83	1.96	1.16	abstract	4	3	1	83
lake	noun	0.61	0.83	neutral	1.90	1.21	3.91	1.77	3.29	0.78	6.48	0.92	concrete	4	3	1	40
language	noun	0.44	0.86	neutral	2.11	1.20	5.11	1.73	3.82	0.79	2.33	1.45	abstract	8	7	2	131
laugh	verb, noun	2.43	0.77	positive	4.65	1.70	6.21	1.06	2.46	0.77	5.32	1.31	abstract	5	3	1	31
leader	noun	0.62	1.00	neutral	3.24	1.71	4.43	1.62	3.56	0.77	4.32	1.58	concrete	6	5	2	68
leave	verb, noun	-0.80	0.88	interm. negative	3.01	1.61	5.59	1.39	2.91	0.88	3.24	1.58	abstract	5	3	1	68
lie	verb, noun	-1.51	0.89	negative	4.48	1.63	5.63	1.14	2.73	0.79	2.83	1.62	abstract	3	2	1	28
lip	noun	0.57	0.83	neutral	2.51	1.60	5.16	1.49	2.50	0.79	6.45	0.90	concrete	3	3	1	17
lively	adjective	1.72	0.82	positive	4.55	1.77	5.29	1.19	4.13	0.78	4.05	1.57	abstract	6	5	2	14
lonely	adjective	-2.35	0.69	negative	4.38	1.82	5.10	1.54	3.85	0.86	3.63	1.64	abstract	6	5	2	28
loser	noun	-1.43	0.90	negative	3.65	1.48	5.24	1.61	3.71	0.92	3.47	1.61	concrete	5	5	2	3
loss	noun	-1.71	0.75	negative	4.06	1.78	4.55	1.66	3.89	0.96	2.74	1.49	abstract	4	3	1	78
lovable	adjective	1.96	0.82	positive	4.13	1.54	4.95	1.45	3.95	1.02	3.56	1.60	abstract	7	6	3	4
loyalty	noun	1.88	1.01	positive	3.56	1.66	4.55	1.45	4.80	0.81	2.54	1.36	abstract	7	6	3	18
lust	noun	1.51	0.96	positive	5.32	1.38	4.20	1.65	5.63	0.69	4.00	1.68	abstract	4	4	1	10
marriage	noun	1.30	1.39	positive	3.90	1.72	5.05	1.65	3.39	0.83	5.41	1.48	abstract	8	5	2	93
matching	verb, adjective	0.24	0.64	neutral	1.94	1.07	4.18	1.60	3.76	0.90	3.37	1.89	abstract	8	5	2	8
meeting	verb, noun	0.26	0.80	neutral	2.55	1.34	5.40	1.18	3.77	0.86	4.24	1.70	abstract	7	5	2	145
member	noun	0.52	0.71	neutral	2.18	1.30	4.56	1.53	4.00	0.72	3.06	1.53	concrete	6	6	2	97
memory	noun	0.73	0.94	neutral	2.73	1.58	5.60	1.32	3.91	0.82	2.59	1.59	abstract	6	6	3	64
merit	noun	1.05	0.90	positive	2.41	1.40	3.16	1.62	4.62	0.98	2.71	1.61	abstract	5	5	2	10
milk	verb, noun	0.26	0.84	neutral	1.67	1.09	6.10	1.34	1.82	0.83	6.38	1.23	concrete	4	4	1	101
million	noun	0.80	0.97	interm. positive	3.49	1.91	4.93	1.47	3.83	0.90	4.27	1.92	abstract	7	6	2	196
misfortune	noun	-1.37	0.75	negative	3.60	1.55	3.80	1.52	5.09	0.79	2.41	1.22	abstract	10	8	3	7
mistake	verb, noun	-1.33	0.79	negative	3.79	1.66	5.41	1.32	3.35	0.99	2.61	1.47	abstract	7	6	2	47
misunderstood	adjective	-1.04	0.67	negative	3.10	1.45	4.30	1.52	4.67	0.77	2.27	1.27	abstract	13	12	4	1

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concrete-ness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/ negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/ concrete	no	no	no	no per million
monster	noun	-1.07	1.10	negative	4.39	1.69	3.56	1.69	2.46	0.76	6.06	1.15	concrete	7	7	2	15
moon	verb, noun	0.85	0.94	interm. positive	2.45	1.46	5.12	1.47	2.45	0.76	6.56	0.89	concrete	4	3	1	53
morning	noun	0.66	1.06	neutral	2.66	1.51	6.44	1.04	2.46	0.79	5.57	1.48	abstract	7	5	2	301
mother	verb, noun	2.28	1.00	positive	3.51	1.87	6.33	0.98	1.79	0.75	6.40	1.12	concrete	6	5	2	410
motivated	adjective	1.56	0.82	positive	3.99	1.55	5.39	1.33	4.98	0.81	2.65	1.25	abstract	9	9	4	2
murder	verb, noun	-2.66	0.63	negative	5.95	1.29	4.35	1.63	4.13	0.80	5.45	1.42	abstract	6	5	2	46
Nazi	noun	-2.50	0.72	negative	5.44	1.56	3.78	1.90	5.13	0.73	6.04	1.26	abstract	4	5	2	13
nightmare	noun	-2.23	0.81	negative	5.56	1.33	5.24	1.32	2.90	0.81	5.04	1.71	abstract	9	6	2	13
opinion	noun	0.51	0.74	neutral	2.88	1.60	5.59	1.10	4.45	0.74	2.05	1.34	abstract	7	7	3	76
opposite	adjective	-0.01	0.56	neutral	2.13	1.24	5.27	1.30	3.73	0.93	3.00	1.73	abstract	8	6	3	73
ordinary	adjective	-0.15	0.79	neutral	1.99	1.28	4.76	1.44	4.24	0.79	2.34	1.34	abstract	8	5	3	96
organ	noun	0.12	0.67	neutral	2.22	1.30	3.79	1.66	4.57	0.79	5.53	1.34	concrete	5	4	2	13
original	noun, adjective	0.98	0.89	interm. positive	2.39	1.46	5.20	1.29	4.60	0.86	2.20	1.58	abstract	8	7	4	89
parting	verb, noun	-0.67	0.85	neutral	3.01	1.75	3.60	1.60	4.41	0.90	3.20	1.60	abstract	7	5	2	8
peace	noun	2.09	0.89	positive	2.98	1.68	4.74	1.61	3.87	0.84	3.74	1.75	abstract	5	3	1	89
play	verb, noun	1.55	0.98	positive	3.55	1.57	5.74	1.33	1.88	0.66	4.94	1.67	abstract	4	3	1	151
poet	noun	0.59	0.87	neutral	2.11	1.36	3.78	1.85	4.13	0.73	4.34	1.70	concrete	4	4	2	17
poverty	noun	-2.13	0.78	negative	4.52	1.73	4.32	1.65	4.79	0.90	5.04	1.45	abstract	7	6	3	57
praise	verb, noun	1.72	0.82	positive	3.57	1.56	4.29	1.61	4.02	0.93	2.91	1.50	abstract	6	4	1	15
prepared	adjective	1.06	0.85	positive	2.51	1.25	5.01	1.37	4.40	0.83	2.41	1.31	abstract	8	6	2	87
prison	noun	-1.96	0.82	negative	4.57	1.55	4.16	1.65	3.77	0.81	6.18	0.88	concrete	6	5	2	69
problem	noun	-1.15	0.67	negative	3.68	1.56	6.00	0.96	3.41	0.80	2.54	1.29	abstract	7	7	2	267
profit	verb, noun	1.06	1.06	positive	3.20	1.67	4.41	1.61	5.00	0.80	3.28	1.67	abstract	6	6	2	34
promotion	noun	1.48	0.83	positive	3.63	1.67	4.34	1.69	5.17	0.77	3.07	1.52	abstract	9	7	3	15
protected	adjective	1.66	0.86	positive	3.15	1.60	4.63	1.46	4.13	0.84	3.53	1.48	abstract	9	9	3	5
proud	adjective	1.71	0.91	positive	3.77	1.58	5.07	1.24	4.13	1.03	3.21	1.64	abstract	5	4	1	39
punch	verb, noun	-1.29	0.94	negative	5.13	1.57	4.26	1.59	3.12	0.91	5.80	1.44	concrete	5	4	1	6
punished	adjective	-1.80	0.89	negative	4.55	1.56	4.34	1.65	3.43	0.86	3.91	1.60	abstract	8	6	2	2
pupil	noun	0.17	0.70	neutral	1.89	1.10	4.82	1.72	3.74	0.87	5.76	1.24	concrete	5	5	2	14
reach	verb, noun	0.29	0.62	neutral	2.04	1.19	4.95	1.29	3.10	0.84	3.71	1.64	abstract	5	3	1	36
receiver	noun	0.38	0.70	neutral	2.13	1.13	3.46	1.49	4.84	0.81	2.89	1.59	concrete	8	7	3	14
recovery	noun	1.34	0.88	positive	2.95	1.29	4.17	1.57	4.52	0.80	3.02	1.49	abstract	8	8	4	17
rejection	noun	-2.01	0.79	negative	4.72	1.67	4.22	1.60	4.78	0.80	3.12	1.72	abstract	9	7	3	15
relaxed	adjective	1.70	0.76	positive	2.49	1.51	5.78	1.10	4.16	0.79	3.96	1.81	abstract	7	7	2	6
release	verb	0.72	0.77	neutral	3.18	1.52	4.46	1.42	4.51	0.81	2.99	1.57	abstract	7	5	2	27
remember	verb	0.71	0.76	neutral	2.67	1.41	5.94	1.07	3.22	0.82	2.24	1.30	abstract	8	8	3	64
repair	verb	0.60	0.80	neutral	2.28	1.31	4.50	1.63	4.10	0.83	3.66	1.64	abstract	6	5	2	9
return	verb, noun	0.41	0.70	neutral	2.18	1.33	5.28	1.35	3.56	0.85	2.98	1.59	abstract	6	5	2	100
rewarded	adjective	1.68	0.78	positive	3.65	1.78	4.54	1.48	4.00	0.77	3.29	1.52	abstract	8	7	3	2
rise	verb, noun	0.59	0.82	neutral	2.37	1.30	4.28	1.60	3.88	0.93	3.50	1.71	abstract	4	3	1	54
sad	adjective	-1.93	0.73	negative	4.09	1.57	5.83	1.17	2.01	0.73	4.44	1.89	abstract	3	3	1	46
safe	adjective	1.83	0.86	positive	2.62	1.53	5.56	1.21	3.11	0.79	3.50	1.69	abstract	4	3	1	79
salary	noun	0.65	0.92	neutral	2.95	1.72	4.13	1.69	5.23	0.84	3.35	1.64	abstract	6	6	3	20
scissors	noun	-0.16	0.58	neutral	2.72	1.63	4.82	1.45	2.73	0.70	6.57	0.98	concrete	8	5	2	4
scream	verb, noun	-1.24	0.88	negative	5.54	1.22	4.77	1.48	2.79	0.84	5.48	1.58	abstract	6	5	1	7
sea	noun	1.30	1.15	positive	3.49	1.85	5.87	1.40	2.39	0.75	6.71	0.78	concrete	3	2	1	160
sensation	noun	1.06	0.89	positive	4.01	1.89	4.17	1.62	4.96	0.79	2.76	1.48	abstract	9	7	3	15
sing	verb	1.52	0.93	positive	3.74	1.73	5.74	1.26	2.40	0.78	5.46	1.34	abstract	4	3	1	6
situation	noun	0.00	0.27	neutral	1.99	1.21	5.43	1.40	4.38	0.76	2.28	1.38	abstract	9	9	4	171

Word	Lexical Class	Valence			Arousal		Familiarity		Age of Acquisition		Imageability		Concrete-ness	Letters	Phonemes	Syllables	Frequency
	noun/verb/adjective	mean	sd	Category: neutral/positive/ negative	mean	sd	mean	sd	mean	sd	mean	sd	abstract/ concrete	no	no	no	no per million
solution	noun	1.18	0.97	positive	2.83	1.59	4.89	1.43	4.48	0.80	2.35	1.22	abstract	8	6	3	53
soul	noun	1.06	1.09	positive	3.35	1.79	4.18	1.77	4.45	0.86	2.85	1.80	abstract	4	3	1	41
source	verb, noun	0.20	0.46	neutral	1.87	1.11	3.95	1.65	4.87	0.80	2.38	1.47	abstract	6	3	1	77
stability	noun	1.33	0.92	positive	2.34	1.20	4.04	1.69	5.24	0.76	2.50	1.35	abstract	9	9	4	15
stinking	adjective	-1.46	0.85	negative	3.33	1.56	3.65	1.64	3.51	0.85	3.56	1.67	abstract	8	7	2	4
strange	adjective	-0.24	0.78	neutral	3.38	1.51	5.48	1.25	3.61	0.91	2.93	1.62	abstract	7	6	1	101
stressed	adjective	-1.82	0.76	negative	4.78	1.65	6.11	0.90	4.66	0.85	3.82	1.67	abstract	8	6	1	2
strong	adjective	1.33	0.85	positive	4.06	1.74	5.56	1.11	2.94	0.88	4.62	1.73	abstract	6	5	1	167
success	noun	2.04	0.78	positive	4.06	1.61	5.23	1.29	4.26	0.73	3.48	1.61	abstract	7	6	2	102
successful	adjective	2.06	0.82	positive	4.01	1.62	5.40	1.13	4.37	0.78	3.34	1.51	abstract	10	9	3	81
sun	noun	1.90	1.04	positive	3.40	1.88	6.21	0.93	2.09	0.69	6.70	0.93	concrete	3	3	1	150
surprised	adjective	1.01	0.85	positive	4.35	1.58	5.51	1.11	3.49	0.91	3.99	1.67	abstract	9	7	2	61
suspicious	adjective	-1.16	0.81	negative	4.28	1.53	4.70	1.36	4.85	0.72	3.02	1.57	abstract	10	8	3	19
sympathy	noun	0.44	1.19	neutral	3.27	1.47	4.93	1.36	4.65	0.82	2.89	1.41	abstract	8	7	3	32
take	verb, noun	-0.15	0.61	neutral	2.39	1.48	5.87	1.31	2.44	0.97	3.12	1.74	abstract	4	3	1	192
teacher	noun	0.66	0.96	neutral	2.59	1.38	5.87	1.43	2.61	0.56	5.83	1.30	concrete	7	5	2	79
tell	verb	-0.05	0.41	neutral	2.09	1.21	5.93	1.20	2.66	0.77	3.06	1.60	abstract	4	3	1	112
terrified	adjective	-2.45	0.72	negative	5.96	1.17	4.27	1.52	4.10	0.86	4.48	1.63	abstract	9	7	3	3
thank	verb	1.45	0.93	positive	2.77	1.53	6.33	1.02	2.32	0.81	3.38	1.76	abstract	5	4	1	25
threat	noun	-1.90	0.84	negative	5.28	1.42	4.40	1.54	4.37	0.76	3.68	1.72	abstract	6	4	1	61
tired	adjective	-1.00	0.65	negative	3.02	1.63	6.55	0.77	2.30	0.86	4.26	1.77	abstract	5	4	2	66
toy	noun	1.26	0.97	positive	2.66	1.49	4.96	1.64	1.62	0.62	6.23	0.96	concrete	3	2	1	15
trap	verb, noun	-1.23	0.81	negative	3.93	1.73	3.94	1.67	3.59	0.85	4.59	1.78	abstract	4	4	1	18
treasure	verb, noun	1.70	0.87	positive	3.95	1.81	3.35	1.72	3.09	0.72	6.33	0.90	concrete	8	6	2	9
tree	noun	0.71	0.90	neutral	1.65	1.19	5.46	1.56	1.96	0.74	6.67	0.85	concrete	4	3	1	72
tricky	adjective	-0.52	0.86	neutral	3.45	1.59	4.32	1.30	3.99	0.79	2.42	1.33	abstract	6	5	2	7
trusting	verb, adjective	1.71	0.85	positive	3.32	1.62	4.94	1.38	4.20	0.81	2.46	1.30	abstract	8	7	2	4
truth	noun	1.80	0.91	positive	3.60	1.62	5.62	1.23	2.96	0.95	2.21	1.25	abstract	5	4	1	127
understood	adjective	1.23	0.92	positive	2.55	1.35	5.68	1.08	3.79	0.87	2.27	1.29	abstract	10	9	3	14
uninterested	adjective	-0.99	0.66	interm. negative	2.24	1.24	4.21	1.52	4.66	0.89	2.21	1.30	abstract	12	12	4	2
unsure	adjective	-0.91	0.67	interm. negative	3.02	1.57	5.20	1.31	4.12	0.91	2.50	1.30	abstract	6	5	2	0
useless	adjective	-2.02	0.83	negative	3.74	1.83	4.82	1.45	4.11	0.72	2.50	1.29	abstract	7	6	2	21
valley	noun	0.41	0.82	neutral	1.82	1.27	3.28	1.72	4.44	0.93	5.75	1.45	concrete	6	4	2	49
victim	noun	-1.84	0.88	negative	4.49	1.52	4.15	1.62	4.61	0.68	4.16	1.52	abstract	6	6	2	28
vow	verb, noun	0.48	0.83	neutral	2.88	1.58	3.29	1.61	5.00	0.79	3.21	1.79	abstract	3	2	1	5
weak	adjective	-1.29	0.62	negative	3.45	1.55	4.95	1.43	3.85	0.83	3.73	1.72	abstract	4	3	1	47
wealth	noun	1.29	1.16	positive	3.88	1.70	4.57	1.53	4.57	0.74	4.56	1.60	abstract	6	4	1	58
weapon	noun	-1.67	0.83	negative	5.18	1.36	4.04	1.68	3.87	0.83	6.12	1.21	concrete	6	5	2	24
weave	verb	0.06	0.40	neutral	1.68	1.06	2.62	1.68	4.84	0.85	4.12	1.72	abstract	5	3	1	2
welcome	verb, adjective	1.39	0.86	positive	2.59	1.40	5.40	1.35	3.40	0.80	3.54	1.72	abstract	7	6	2	33
whisper	verb, noun	0.09	0.67	neutral	2.43	1.56	4.63	1.64	3.04	0.91	4.26	1.89	abstract	7	6	2	12
wine	noun	1.01	1.02	positive	3.59	1.71	6.20	1.01	4.17	0.86	6.55	0.93	concrete	4	3	1	73
winner	noun	1.91	0.82	positive	4.11	1.89	4.98	1.51	2.99	0.87	4.88	1.58	concrete	6	5	2	12
witness	verb, noun	-0.09	0.65	neutral	2.85	1.48	3.88	1.67	4.76	0.82	3.51	1.76	concrete	7	6	2	17
worried	adjective	-1.40	0.77	negative	4.29	1.58	5.62	1.10	3.70	0.90	3.24	1.41	abstract	7	5	2	47
worthless	adjective	-2.07	0.94	negative	4.06	1.69	3.73	1.48	4.90	0.83	2.20	1.08	abstract	9	6	2	5
worthwhile	adjective	1.46	0.85	positive	2.63	1.32	4.56	1.33	4.88	0.84	1.93	1.15	abstract	10	7	2	12
wound	noun, adjective	-1.45	0.82	negative	4.27	1.56	3.99	1.53	4.26	0.87	5.37	1.54	concrete	5	4	1	15
youth	noun	0.85	1.03	interm. positive	2.79	1.51	4.56	1.63	4.62	0.81	4.44	1.80	abstract	5	3	1	65

Appendix B. Pairs of antonyms from the SAWL.

SUGGESTIONS FOR ANTONYM PAIRS	
abundance, lack	exhausted, energised
acceptance, rejection	familiar, strange
accomplish, abandon	farewell, greeting
achievement, failure	father, mother
afraid, brave	fault, merit
agitated, relaxed	follower, leader
agreement, conflict	forget, remember
angel, devil	fortune, misfortune
angry, calm	fragrant, stinking
antagonist, hero	frustrated, fulfilled
appreciated, disregarded	give, take
arrest, release	happy, sad
ashamed, proud	hateful, lovable
astonished, prepared	healed, hurt
attack, defence	health, illness
attic, cellar	heaven, hell
bad, good	helpful, useless
benefit, harm	inspired, discouraged
betrayed, protected	interested, bored
boy, girl	invitation, rejection
build, destroy	lively, apathetic
capable, incapable	loser, winner
caring, indifferent	loss, profit
cheerful, depressed	matching, opposite
clearheaded, confused	misunderstood, understood
collective, individual	moon, sun
complaint, praise	motivated, uninterested
concentrated, distracted	ordinary, original
confident, unsure	parting, joining
cry, laugh	poverty, wealth
curious, uninterested	problem, solution
damage, repair	punished, rewarded
dangerous, safe	pupil, teacher
defeated, successful	return, leave
delighted, disappointed	scream, whisper
desert, forest	stressed, relaxed
distressed, calm	strong, weak
divorce, marriage	success, failure
dream, nightmare	suspicious, trusting
easy, tricky	terrified, bold
embarrassed, assured	tired, energised
encouraged, discouraged	toy, weapon
enemy, friend	trap, release
enthusiastic, apathetic	truth, lie
evening, morning	victim, witness
evil, good	worried, calm
excited, bored	worthless, worthwhile
excluded, welcome	

Appendix C. Stimuli for behavioural and ERP studies (Sections III, IV).

Serial number	Conditions		Words	Serial number	Conditions		Words	Serial number	Pseudo words	Serial number	Pseudo words
	Valence	Arousal			Valence	Arousal					
1	negative	high	annoyed	76	positive	low	accomplish	1	arshed	76	phlylfed
2	negative	high	arrest	77	positive	low	admire	2	bintse	77	phramped
3	negative	high	ashamed	78	positive	low	enjoy	3	blalvs	78	phrewf
4	negative	high	battle	79	positive	low	fortune	4	blimpsed	79	poonte
5	negative	high	burn	80	positive	low	fulfilled	5	blod	80	pranksed
6	negative	high	chaos	81	positive	low	giggle	6	blurgnth	81	pripe
7	negative	high	collapse	82	positive	low	healed	7	bouse	82	proapped
8	negative	high	conflict	83	positive	low	helpful	8	brampced	83	psargns
9	negative	high	crime	84	positive	low	idea	9	brife	84	psoarsh
10	negative	high	damage	85	positive	low	imagine	10	brunxed	85	psume
11	negative	high	defeated	86	positive	low	initiative	11	chonque	86	quipced
12	negative	high	devil	87	positive	low	loyalty	12	chuig	87	quynkced
13	negative	high	divorce	88	positive	low	motivated	13	clancsed	88	rauc
14	negative	high	enemy	89	positive	low	play	14	clompced	89	reedge
15	negative	high	evil	90	positive	low	praise	15	clourse	90	rerc
16	negative	high	hell	91	positive	low	profit	16	clusked	91	sckrighped
17	negative	high	hurt	92	positive	low	promotion	17	clyksts	92	sckrocsts
18	negative	high	poverty	93	positive	low	rewarded	18	craksts	93	sckruled
19	negative	high	prison	94	positive	low	sensation	19	cralphed	94	sckryncsed
20	negative	high	punch	95	positive	low	strong	20	creulds	95	sckwaxte
21	negative	high	suspicious	96	positive	low	successful	21	dobs	96	sckwirzed
22	negative	high	victim	97	positive	low	treasure	22	dreiced	97	sckwycsts
23	negative	high	weapon	98	positive	low	trusting	23	droarte	98	scrumpts
24	negative	high	worried	99	positive	low	truth	24	dryncsed	99	scruved
25	negative	high	wound	100	positive	low	wealth	25	dwaughged	100	scwoarce
26	negative	low	avoid	101	neutral	very low	abbey	26	dweite	101	scwoax
27	negative	low	bored	102	neutral	very low	accent	27	dwelcs	102	shawmn
28	negative	low	brag	103	neutral	very low	astonished	28	eente	103	shordes
29	negative	low	burden	104	neutral	very low	attic	29	falb	104	shrarnth
30	negative	low	complaint	105	neutral	very low	banner	30	filte	105	shrolth
31	negative	low	cowardly	106	neutral	very low	bold	31	finxed	106	skeanned
32	negative	low	doubt	107	neutral	very low	build	32	flawte	107	skruxts
33	negative	low	excluded	108	neutral	very low	cellar	33	flernths	108	skwaksts
34	negative	low	exhausted	109	neutral	very low	choose	34	flidd	109	skwenxed
35	negative	low	farewell	110	neutral	very low	collective	35	flished	110	skwompsed
36	negative	low	fault	111	neutral	very low	command	36	froones	111	skwowdged
37	negative	low	illness	112	neutral	very low	culture	37	frurf	112	skwurdged
38	negative	low	incapable	113	neutral	very low	curious	38	ghaumn	113	smimths
39	negative	low	lack	114	neutral	very low	defence	39	ghossed	114	smoldge
40	negative	low	loser	115	neutral	very low	desert	40	ghouze	115	snal
41	negative	low	loss	116	neutral	very low	distracted	41	ghreults	116	snoursed
42	negative	low	misfortune	117	neutral	very low	drop	42	ghrilks	117	speennth
43	negative	low	mistake	118	neutral	very low	film	43	ghwerm	118	splamph
44	negative	low	problem	119	neutral	very low	follower	44	ghwolged	119	splarps
45	negative	low	stinking	120	neutral	very low	forest	45	glaug	120	splencked
46	negative	low	tired	121	neutral	very low	girl	46	glorph	121	spluksts
47	negative	low	trap	122	neutral	very low	greeting	47	glurgnth	122	sponds
48	negative	low	useless	123	neutral	very low	guest	48	goante	123	spraksts
49	negative	low	weak	124	neutral	very low	herring	49	greivved	124	sprimpced
50	negative	low	worthless	125	neutral	very low	housewife	50	grimpte	125	sprompsed
51	positive	high	affection	126	neutral	very low	joining	51	groarst	126	spronkced
52	positive	high	attracted	127	neutral	very low	lake	52	gwaksts	127	sprunks
53	positive	high	birthday	128	neutral	very low	matching	53	gyldged	128	squaupped
54	positive	high	brave	129	neutral	very low	memory	54	hece	129	squoulde
55	positive	high	carnival	130	neutral	very low	opinion	55	hoxt	130	squyksts
56	positive	high	celebrate	131	neutral	very low	opposite	56	jaumbs	131	stisked
57	positive	high	dance	132	neutral	very low	ordinary	57	jeitts	132	strasp
58	positive	high	delighted	133	neutral	very low	organ	58	jexte	133	stricsts
59	positive	high	dream	134	neutral	very low	parting	59	joaphed	134	swourb
60	positive	high	energised	135	neutral	very low	poet	60	kife	135	thaughl
61	positive	high	excited	136	neutral	very low	pupil	61	klarmb	136	thrapsed
62	positive	high	friend	137	neutral	very low	reach	62	kleebbs	137	threin
63	positive	high	happy	138	neutral	very low	receiver	63	klilbed	138	tidd
64	positive	high	heart	139	neutral	very low	release	64	kloites	139	torsed
65	positive	high	hero	140	neutral	very low	repair	65	kneests	140	trynce
66	positive	high	holiday	141	neutral	very low	salary	66	knylge	141	twaughnths
67	positive	high	inspired	142	neutral	very low	scissors	67	kriefed	142	tweiffth
68	positive	high	kiss	143	neutral	very low	situation	68	krighnde	143	twoarp
69	positive	high	laugh	144	neutral	very low	sympathy	69	kroodds	144	twunksed
70	positive	high	lively	145	neutral	very low	tell	70	kwonksed	145	vomn
71	positive	high	lovable	146	neutral	very low	tricky	71	kwympced	146	weuth
72	positive	high	lust	147	neutral	very low	valley	72	misp	147	woole
73	positive	high	success	148	neutral	very low	weave	73	mowge	148	wroaf
74	positive	high	surprised	149	neutral	very low	whisper	74	oarmth	149	yeuk
75	positive	high	winner	150	neutral	very low	witness	75	phlowgns	150	zerts

Appendix D. Stimuli for the fMRI study (Section V).

Serial	Conditions		Words	Serial	Conditions		Words	Serial	Conditions		Words
number	Valence	Arousal		number	Valence	Arousal		number	Valence	Arousal	
1	negative	high	abandon	71	positive	high	accomplish	141	neutral	low	activity
2	negative	high	accused	72	positive	high	achievement	142	neutral	low	army
3	negative	high	afraid	73	positive	high	affection	143	neutral	low	astonished
4	negative	high	agitated	74	positive	high	attracted	144	neutral	low	bold
5	negative	high	annoyed	75	positive	high	beautiful	145	neutral	low	chance
6	negative	high	arrest	76	positive	high	birthday	146	neutral	low	change
7	negative	high	ashamed	77	positive	high	brave	147	neutral	low	city
8	negative	high	corpse	78	positive	high	carnival	148	neutral	low	command
9	negative	high	crime	79	positive	high	celebrate	149	neutral	low	compel
10	negative	high	damage	80	positive	high	dance	150	neutral	low	concentrated
11	negative	high	defeated	81	positive	high	delighted	151	neutral	low	curious
12	negative	high	depressed	82	positive	high	dream	152	neutral	low	defence
13	negative	high	despair	83	positive	high	energised	153	neutral	low	distracted
14	negative	high	distressed	84	positive	high	enthusiastic	154	neutral	low	doctor
15	negative	high	divorce	85	positive	high	excited	155	neutral	low	faith
16	negative	high	embarrassed	86	positive	high	friend	156	neutral	low	feel
17	negative	high	enemy	87	positive	high	giggle	157	neutral	low	king
18	negative	high	evil	88	positive	high	happy	158	neutral	low	leader
19	negative	high	failure	89	positive	high	hero	159	neutral	low	leave
20	negative	high	fire	90	positive	high	holiday	160	neutral	low	lion
21	negative	high	frustrated	91	positive	high	inspired	161	neutral	low	man
22	negative	high	harm	92	positive	high	justice	162	neutral	low	mountain
23	negative	high	hateful	93	positive	high	kiss	163	neutral	low	needle
24	negative	high	hell	94	positive	high	laugh	164	neutral	low	opinion
25	negative	high	hurt	95	positive	high	lively	165	neutral	low	parting
26	negative	high	lie	96	positive	high	lovable	166	neutral	low	release
27	negative	high	lonely	97	positive	high	lust	167	neutral	low	rough
28	negative	high	poverty	98	positive	high	music	168	neutral	low	salary
29	negative	high	punished	99	positive	high	sensation	169	neutral	low	smell
30	negative	high	stressed	100	positive	high	strong	170	neutral	low	smoke
31	negative	high	thief	101	positive	high	success	171	neutral	low	strange
32	negative	high	trouble	102	positive	high	successful	172	neutral	low	sympathy
33	negative	high	victim	103	positive	high	surprised	173	neutral	low	tricky
34	negative	high	worried	104	positive	high	winner	174	neutral	low	vow
35	negative	high	worthless	105	positive	high	wish	175	neutral	low	youth
36	negative	low	avoid	106	positive	low	admire	176	neutral	very low	abbey
37	negative	low	bad	107	positive	low	appreciated	177	neutral	very low	accent
38	negative	low	bill	108	positive	low	assured	178	neutral	very low	attic
39	negative	low	bitter	109	positive	low	benefit	179	neutral	very low	banner
40	negative	low	bored	110	positive	low	butterfly	180	neutral	very low	book
41	negative	low	burden	111	positive	low	cheerful	181	neutral	very low	bread
42	negative	low	cold	112	positive	low	confident	182	neutral	very low	build
43	negative	low	collapse	113	positive	low	discover	183	neutral	very low	cellar
44	negative	low	confused	114	positive	low	encouraged	184	neutral	very low	citizen
45	negative	low	cowardly	115	positive	low	fortune	185	neutral	very low	collective
46	negative	low	disappointed	116	positive	low	gift	186	neutral	very low	cup
47	negative	low	doubt	117	positive	low	healed	187	neutral	very low	flag
48	negative	low	excluded	118	positive	low	health	188	neutral	very low	follower
49	negative	low	exhausted	119	positive	low	heaven	189	neutral	very low	glass
50	negative	low	farewell	120	positive	low	idea	190	neutral	very low	indifferent
51	negative	low	fault	121	positive	low	imagine	191	neutral	very low	joining
52	negative	low	illness	122	positive	low	initiative	192	neutral	very low	language
53	negative	low	incapable	123	positive	low	innocent	193	neutral	very low	long
54	negative	low	lack	124	positive	low	invitation	194	neutral	very low	matching
55	negative	low	loser	125	positive	low	journey	195	neutral	very low	member
56	negative	low	loss	126	positive	low	play	196	neutral	very low	opposite
57	negative	low	misfortune	127	positive	low	praise	197	neutral	very low	ordinary
58	negative	low	mistake	128	positive	low	promotion	198	neutral	very low	organ
59	negative	low	misunderstood	129	positive	low	proud	199	neutral	very low	poet
60	negative	low	problem	130	positive	low	rewarded	200	neutral	very low	pupil
61	negative	low	sad	131	positive	low	sea	201	neutral	very low	reach
62	negative	low	spider	132	positive	low	sing	202	neutral	very low	receiver
63	negative	low	stinking	133	positive	low	solution	203	neutral	very low	repair
64	negative	low	tired	134	positive	low	soul	204	neutral	very low	return
65	negative	low	trap	135	positive	low	sun	205	neutral	very low	situation
66	negative	low	trash	136	positive	low	sweet	206	neutral	very low	slow
67	negative	low	uninterested	137	positive	low	trusting	207	neutral	very low	tell
68	negative	low	useless	138	positive	low	truth	208	neutral	very low	valley
69	negative	low	weak	139	positive	low	wealth	209	neutral	very low	weave
70	negative	low	wound	140	positive	low	welcome	210	neutral	very low	whistle