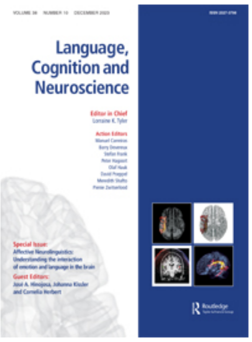

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Early, emotional and embodied? Processing of emotional words and body words in the native and a second language – evidence from early event-related brain potential modulation and rapid serial visual presentation

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ABSTRACT
Visual processing of emotional words modulates early event-related potentials (ERPs) such as the early posterior negativity (EPN). Questions remain as to whether this modulation reflects modality-specific processing, preferentially elicited by emotional words of the native language (L1). This study investigates the modulation of early ERPs during rapid serial visual presentation (RSVP) of adjectives or nouns referring to emotional feeling states, neutral traits, to an overweight or lean body or to concrete body parts or neutral objects, presented in the L1 and the second language (L2). Word ratings in the L2 were assessed in a pilot study. The N100 and the EPN were modulated by the emotional valence of the stimuli irrespective of the word class or the task (silent reading vs. word counting). The results suggest that early affective appraisal is obligatory, not restricted to privileged categories of linguistic information (emotions) or solely found for the embodied language (L1).

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Visual word processing; emotional words; body words; second language; appraisal

Introduction

There is theoretical consensus, that emotions are primarily physical reactions of the organism that reflect the basic need of every organism for physical protection and defense of survival, not only in the non-human species (e.g. Lang, 1994). Compared to emotions, human language has emerged only recently in the evolutionary history. Among the different language abilities, reading, i.e. making meaning from written symbols, is the most recent language ability developed in human history. Historically, the occurrence of reading in humans is too recent for the brain to have underwent genetic selection during evolution. Nevertheless, brain damage in the literate brain can cause pure or partial loss of letter- or word-recognition, phonological or semantic alexia or pure aphasia. Some language skills such as reading may reorganise brain functions in a way that specific neurons or neural networks become especially attuned to the processing of linguistic features and patterns (Rayner & Reichle, 2010). When exposed to words, the brains of adult literates do show changes in neural activity in a number of brain regions (e.g. Dehaene et al., 2010, 2015). Notably, the functional changes occurring with reading occur in visual brain regions belonging to the ventral occipito-temporal pathway for object recognition (Dehaene et al., 2015).

Therefore, it is legitimate to ask, how reading as well as the neural and mental processes corresponding to it, including word recognition and semantic processing, connect with the basic human brain functions of perceiving, acting, sensing, and feeling during reading. Systematic research into emotional word processing on the one hand, and on the other hand, shifts in theoretical thinking, the latter supported among others by embodiment theories (for an overview, e.g. Barsalou et al., 2008; Kiefer & Pulvermüller, 2012; Kousta et al., 2011) have paved the way for an in depth discussion of this question, for example by investigating when in the processing stream the emotional meaning of a word is appraised and at which sequential steps of word- and information processing, emotional processing might first occur (e.g. for reviews: Citron, 2012; Kissler et al., 2006; Scott et al., 2009).

Despite its automaticity in fluent readers, reading is complex. It involves several stages of processing, such as the perception, identification, and integration of orthographic, phonological, and semantic features (Massaro & Cohen, 1994). Consequently, serial word

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processing models assume a sequential and bottom-up driven processing cascade during which word processing progresses from perceptual to higher-order cognitive processes (for an overview Dien, 2009; Grainger & Holcomb, 2009). Converging with serial models of word processing are findings showing that orthographic processing occurs within the first 250 milliseconds (ms) after word presentation, lexical and semantic access occurs around 250 ms after word presentation, and subsequent processing of phonological features occurs around 250–350 ms (Taylor et al., 2013), and temporally before semantic integration that occurs at around 400 ms after word presentation in the way required by the context or the task at hand (for an overview Dien, 2009). In contrast to serial models, parallel word processing models propose that during reading some processes such as lexical and semantic processing might occur in parallel and that bottom-up and top-down processing can partially overlap, interact and feedback to earlier processing stages (for an overview, e.g. Pulvermüller et al., 2009). In this view, in certain instances, semantic processing could occur at the level of visual word recognition and, therefore, much earlier than assumed by conventional serial models of visual word processing (Yap & Seow, 2014).

The early posterior negativity (EPN) is a brain potential that was first identified by emotional picture processing studies when emotional and neutral scenes were presented in rapid visual streams of 3 Hz and faster (Junghofer et al., 2001). Consecutive research on the modulation of this brain potential by non-verbal stimuli suggests that the EPN can be considered a reliable electrophysiological marker and indicator of emotional arousal and valence processing (e.g. for an overview Schupp et al., 2006); the EPN amplitude modulation peaking for non-verbal stimuli around 180–280 ms at occipito-parietal electrodes. Research using nearly identical tasks and processing contexts of rapid serial visual presentation (RSVP at 3 Hz or 1 Hz, respectively), but emotional words instead of emotional scenes, showed that the EPN is elicited by words as well (e.g. Herbert et al., 2008; Kissler et al., 2007). For words like for picture stimuli, the EPN is modulated by the emotional content of the stimuli and sensitive to the two emotional dimensions of valence and arousal (for an overview, e.g. Scott et al., 2009). For words, the amplitude modulation of the EPN seems to occur across RSVP studies most robustly in the time window from 200 to 300 ms after word presentation (e.g. Herbert et al., 2008; Kissler et al., 2007).

Since its first discovery, the modulation of the EPN by emotional words has been investigated repeatedly in a number of studies systematically varying tasks affordances, word processing speed or the word category. Until now, the temporal processing of adjectives, nouns, verbs, or even of first versus third person referential emotional versus neutral pronoun-noun pairs has been investigated in several EEG-ERP studies during single stimulus processing tasks or within a phrase or sentence context (for an overview e.g. Herbert et al., 2018; Hinojosa et al., 2020). In addition, the modulation of the EPN by words was investigated in several studies using lexical decision tasks or passive viewing tasks such as silent reading, some of those studies additionally compared the processing of words versus pseudowords, or words versus pseudowords versus meaningless pseudowords derived from emotional versus neutral words (e.g. Hinojosa et al., 2010; Kissler & Herbert, 2013; Schacht & Sommer, 2009; Sulpizio et al., 2021). Besides some discrepancies in findings, the majority of the studies investigating the modulation of the EPN during silent reading or during tasks that allow lexico-semantic analysis support the interpretation that the EPN time window reflects facilitated lexico-semantic processing of emotional compared to neutral words in the ventral visual processing stream (for a discussion, e.g. Kissler et al., 2007). As far as the facilitated processing of emotional words versus neutral words as indicated by the EPN is concerned, it seems, that these processes are invariant to word repetitions across several runs of stimulus presentation (Herbert et al., 2008; Kissler et al., 2007) or to changes in bottom-up driven selective attention modulated by a secondary task such as counting or the attentional blink (Kissler et al., 2009; Singh & Sunny, 2020). However, EPN modulation by emotional words has for example not been found in tasks of merely shallow processing, in which words can be distinguished solely based on perceptual features (e.g. Hinojosa et al., 2010).

Early facilitated processing of emotional versus neutral words calls for answers to the question what makes emotional words special and superior to neutral words to benefit from early, possibly privileged lexico-semantic processing. Which linguistic dimensions and which stimulus features of a word including a word's reference to sensory or motor attributes, and which contextual, probably social and cultural factors, might play a role? And finally, which processing principles or theoretical framework can explain the effects?

As far as the impact of linguistic dimensions is concerned, the majority of the previous studies have matched emotional and neutral words for sublexical (e.g. bigram frequency, orthographic neighbourhood frequency) or for linguistic dimensions such as the word frequency or the concreteness/abstractness of the words. Some studies investigated interaction effects between the emotionality of a word and the word frequency or their concreteness/abstractness (e.g.

Méndez-Bértolo et al., 2011; Palazova et al., 2013; Sereno et al., 2020). Word frequency has been found to interact with the emotional valence or the emotional arousal of a word at various stages of word processing starting in the time window of the N100 potential, extending to the EPN and to later time windows of the P300 or LPP (late positive potential) (Méndez-Bértolo et al., 2011; Sereno et al., 2020). For a word's concreteness or abstractness, recent studies point to temporally rather late interaction effects between the emotional dimensions and the concreteness/abstractness dimension of a word in the time window of the late positive potential (LPP), the LPP sequentially following the EPN by emotion modulation (Palazova et al., 2013; Pauligk et al., 2019). Thus, it appears that although the linguistic dimensions are interacting, neither can linguistic dimensions such as the word frequency or the abstractness or concreteness dimensions of a word alone sufficiently explain why visual processing is boosted by emotional compared to neutral words in early time windows of word processing, especially in the time window of the EPN.

Theoretically, there exists no single embodiment theory. However, embodiment theories share a central premise in common, namely the grounding of higher-order cognitive processes and abstract concepts in bodily action and perception. From the view of embodied cognition, conceptual-semantic representations are distributed across brain networks that link linguistic concepts with the bodily states but also with the social, affective, internal states and experiences the concept refers to (Barsalou, 2010; Pezzulo et al., 2013). Prominent examples of embodiment theories that particularly influenced the language faculty are the "Perceptual Symbol" (PST) and the "Language and Situated Simulation" (LASS) theories, formulated by Barsalou and colleagues (2008). The theories assume that knowledge is built upon perceptual representations that are stored as "situated instances", i.e. patterns of brain activation distributed across the brain's sensory and motor system (Barsalou et al., 2008). During reading, these perceptual symbols become activated, and by their activation, the reader simulates the experiences he/she has made during the actual experience and interaction with the real object the word is referring to. Literally in the view of embodiment theories, reading a word or sentence means simulating past experience in terms of percepts and actions. In other words, any predication about the word's meaning during reading is possible only when the linguistic forms (e.g. orthographic word form) activate simulations.

Regarding the processing of emotional words, there is evidence that reading and lexical decisions of emotional words are associated with changes in emotional brain regions that do not form part of the brain's linguistic system, e.g. the amygdala (Herbert et al., 2009; Kuchinke et al., 2005). Moreover, there is evidence that reading and affective evaluations of emotional words are accompanied by peripheral-physiological bodily reactions such as changes in facial muscle activity, heart rate or skin conductance (e.g. Künecke et al., 2015; Weis & Herbert, 2017) with some of these changes (e.g. facial muscle activity) occurring already very quickly after word presentation (Halberstadt et al., 2009). Nevertheless, there is still little evidence and research demonstrating that fast and facilitated visual processing of emotional versus neutral words is associated with visual modality-preferential embodied processing. For example, in a recent study, reading of face-related words for whom a strong grounding in perception is expected because these words relate to concrete features and characteristics of emotionally salient body parts (e.g. mouth, face, or hand), modulation of the N170 component was found, a face specific early EEG-ERP marker preceding the EPN and preferentially triggered by face-related information. This suggests that visual modality-specific embodied processing of words occurs earlier than the EPN, but the findings are mixed (e.g. Frühholz et al., 2011). Similarly, findings of motor specific activation have been reported for emotional action words carrying action features of body parts with which the emotions can be expressed such as the face or upper extremities (e.g. Moseley et al., 2012). Again these effects have been found to occur earlier than in the time window of the EPN, and, as expected for modality specific effects, especially over central EEG sensors covering the motor cortex. Notably, for non-verbal emotional stimuli, sensitivity of the EPN to body parts has recently been discussed (Farkas et al., 2020).

Nevertheless, viewed from a temporal perspective of serial word processing, the question persists as to whether fast and facilitated visual processing of emotional words, most consistently found across studies as valence and arousal driven EPN modulation, is associated with modality-preferential embodied processing. One possibility of answering this question is to investigate how emotional and neutral words are processed in the native language (L1) versus a second language (L2), the latter (L2) being learned late in life and additionally not being the social language of the reader (i.e. the language used for daily communication). Theoretically, a later acquisition of a second language (e.g. at school), especially when L2 is not used for social interaction may lack the emotional learning context (for a discussion and overview see e.g. Kühne & Gianelli, 2019). Therefore, the words and concepts learned in L2 may miss the rich and situated emotional autobiographical experiences, that are usually associated with the native language (L1) and forming the embodied perceptual simulations and feeling states to be connected with the word (e.g. for an overview, e.g. Altarriba & Basnight-Brown, 2012; Caldwell-Harris, 2014; Kühne & Gianelli, 2019; Pulvermüller, 2018).

A number of previous studies have investigated language processing in fluent bilinguals, some studies investigated the processing of emotions in the native language and the second language. Some studies point to a processing disadvantage for the second language (e.g. Chen et al., 2015; Colbeck & Bowers, 2012) and this particularly when investigated in late learners who were not raised as bilinguals but who had acquired the L2 e.g. at school or later in life (for an overview e.g. Pavlenko, 2008, 2012). However, the suggestion of an emotional detachment hypothesis of the L2 as foreign or second language being less emotional than L1 (Altarriba, 2008; Dewaele & Pavlenko, 2002) seems not to be consistently supported by recent EEG-ERP studies. For example, in a study with German-Spanish bilinguals, all being late bilinguals, facilitated processing of emotional words as indicated by the EPN was observed in both languages during the lexical decision task (Conrad et al., 2011). The only difference that was found between the L1 and the L2 respectively was, that speakers of Spanish, who were currently living in the country of their L2, did not show preferential processing of negative words. The authors of the study (Conrad et al., 2011) suggest that their findings can show that the context in which the language (L2) is used can impact the processing of emotional concepts implicitly, which is lending indirect (though not directly tested) support for a situated embodied acquisition of emotion concepts in the L2. Akin to this evidence, a recent EEG-ERP study among late learners found EPN modulation for emotional compared to neutral words with no difference between L1 and L2 (Kissler & Bromberek-Dyzman, 2021). Yet another study found a positivity bias in the L1 in the time window of the EPN in late learners (Chen et al., 2015), whereas in another study, the processing of emotional words lead to larger EPN modulation in the L1 and the L2 in German-French and French-German late bilinguals, with the only difference between the L1 and the L2 in both groups being reflected by latency measures, i.e. later occurrence of the EPN effects in the L2 than in the L1 (Opitz & Degner, 2012).

Aim of the present study

The aim of the present EEG-ERP study is to further advance and elucidate the time course of emotional processing, and specifically, the role of the EPN in it. To this end, previous findings are extended from the processing of emotional and neutral words to emotional and neutral words being presented together with body-related and body-unrelated words in two different tasks (silent reading vs. shallow perceptual processing of word counting) and two languages; the native language (L1) being enriched with embodied experiences, and the second language (L2), learned at school, but varying in the frequency with which the L2 is used by the participants for daily social interaction. The emotional and neutral words in the L1 and the L2 comprise adjectives related to emotional or neutral feeling states and traits (sad, anxious, happy, civilian, etc.). The body-related words comprise body shape or body weight related adjectives as well as concrete words (nouns) related to upper or lower body parts (e.g. eyes, mouth, or arms, vs. legs, feet, or toes, etc.). The body adjectives describe body traits related either to a lean body (e.g. thin, athletic, or sporty) or an overweight body (e.g. corpulent, bulky, or plump). Although the adjectives related to a lean or overweight body are no carriers of emotions per se, such as, for example, emotional adjectives are that are conveying emotional feelings, the body adjectives chosen in the present study describe body traits that relate to culturally normed and internalised body image ideals, that are influenced by societal pressures and the social media. Traits related to a lean body portray the admirable ideal body image for women and men in Western societies (for an overview, e.g. Thompson & Stice, 2001). An overweight body is associated with a strong aversion of "being fat" and implicitly and automatically associated with negative beliefs about co-occurring traits (e.g. weak-willed, lazy, or sick). This aversion against "being fat" has been dubbed the anti-fat bias (Schupp & Renner, 2001). The anti-fat bias might manifest itself in a processing bias for negative body adjectives during word processing, even in the normal weight population not suffering from eating disorders. Likewise the longing for an ideal body image might be elicited specifically by body adjectives related to traits of a lean body shape and weight. Positive and negative attitudes towards particular body parts might also be triggered during reading of concrete body words (nouns) (face, eyes, mouth, arms, legs, lips, feet, or toes, etc.). Whether for body adjectives and body nouns this is like for emotional adjectives reflected by an early appraisal of the valence or the arousal intensity of a word in the EPN time window, or occurs at even earlier word processing stages (e.g. N100 time window), as could be theoretically assumed by embodiment theories, or is observed in the L1 during tasks such as reading or word counting that allow lexico-semantic access is investigated in the present study.

In summary, the following still open research questions that were outlined in detail in the Introduction of this manuscript are investigated:

(1) Is preferential processing of emotional words at early stages of word processing as for example indicated by the EPN specific to emotional words presented in the L1, or will EPN modulation also occur for abstract or concrete body shape/weight and body part related words? If so, do effects occur in the L1 or the L2 or in both languages?
(2) Will EPN modulation by the emotionality of a word be temporally the first indicator of facilitated visual processing of words belonging to different word categories (emotional, body-related, vs. neutral), or will there be temporally earlier ERP-effects indicative of modality preferential effects?
(3) Will emotion-driven facilitated processing of words also occur in the L2 and will it occur across tasks when the tasks are silent reading or word counting, the latter attracting attention only to the perceptual features of the words and not necessarily requiring semantic processing?
(4) Exploratory: Will the L1-L2 emotion effects be driven by the use of the second language as a warm and social language?

Materials and methods

Participants

Thirty-five ($N = 35$) women ($n = 20$) and men ($n = 15$), all healthy young adults with a mean age of 25.51 years, $SD = 4.14$, range: 20–35 years, participated in the study. Inclusion criteria for participation in the study were, an age of 18 years and older, German (L1) as native language and English (L2) as the second language (L2), no history of previous or current psychiatric, neurological, cardiovascular or other relevant (pre-) medical conditions, no medication intake or drug use affecting brain activity, corrected-to-normal vision and preferably right-handedness. Participants were recruited via flyers or email advertisements at the university. Upon arrival at the laboratory, the participants were debriefed about the purpose of the study, the inclusion and exclusion criteria were controlled and the participants gave oral and written informed consent for voluntary study participation[1].

Sociodemographics and self-reported language proficiency and questionnaires

After the debriefing and the informed consent, the participants filled in questions addressing their sociodemographic and language background and answered questions about their language proficiency, acquisition of the second language, and their use of the second language as a "social (warm) language". To this end, the participants were asked to fill in a digital version of the German Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007). Moreover, to more directly access the social warmness of the L2 use, i.e. the degree to which the participants were using L2 for their communication with partners, friends and family, the participants were asked to indicate on a six-point rating scale (1 = never, 2 = rarely, 3 = occasionally, 4 = sometimes, 5 = frequently, 6 = always) how often per day they communicate with their partner or family members or relatives or friends in English. Higher scores represent greater frequency. In addition, the participants filled in the Toronto Alexithymia Scale (Bagby et al., 1994; German version: Bach et al., 1996) and the subscales "body dissatisfaction" and "drive for thinness" of the Eating Disorder Inventory (EDI-2; German version: Thiel et al., 1997). Alexithymia is a personality trait characterised by difficulties in identifying and describing one's feelings, and is further characterised by a focus on externally oriented thinking versus insight into own feelings and appraisal of internal feelings (Taylor & Bagby, 2000). Accordingly, alexithymia was controlled in the present study because individuals scoring high on this personality trait might have difficulties in "embodying" the words they read. It is estimated that 10% of the general population are suffering from alexithymia with even higher prevalence in individuals at risk or suffering from mental health conditions (Ricciardi et al., 2015). Body dissatisfaction and drive for thinness are strong predictors of risk of eating disorders, specifically in women (Stice et al., 2011). Therefore, these two dimensions and scales of the EDI-2 questionnaire were included to control for individual differences in the extent to which body image ideals and social norms including anti-fat biases are internalised. The results of the sociodemographic data, language proficiency and language use are presented in the Results.

Procedure

Stimuli and experimental study design

The main experiment consisted of a rapid serial visual presentation (RSVP), in which the stimuli were presented without interstimulus intervals at a rate of 1 Hz. A rate of

Table 1. Word length, word frequency as well as arousal and valence ratings of the German (L1) emotional and neutral trait and state adjectives as per normative ratings (German, L1) obtained on the Self-Assessment Manikin (SAM, Bradley & Lang, 1994), and taken from previous studies, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pleasant/positive adjectives	German – L1	6.94[a]	1.39	5.15 [a]	1.04	8.40 [a]	2.35	12.50 [a]	2.74
Negative/unpleasant adjectives	German – L1	2.63 [b]	0.48	5.77 [a]	0.96	7.75 [a]	1.48	14.30 [a]	2.54
Neutral adjectives	German – L1	5.19 [c]	0.49	3.24 [b]	0.47	8.35 [a]	1.57	13.05 [a]	2.58

SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word length (number of letters), word frequency values were taken from the Leipzig Corpora Collection (Goldhahn et al., 2012). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations (SD).

1 Hz (1000 ms word duration) was chosen to avoid post perceptual inhibition or potential ERP component overlaps. In total, a set of 144 German (L1) words and 144 English (L2) words were presented (288 words in total). The German words consisted of 20 positive, 20 negative and 20 neutral adjectives, 30 body shape and weight related adjectives ($n = 15$ related to a lean shape, $n =$ 15 related to an overweight shape), and 36 body part related nouns (18 related to the upper body, 18 to the lower body) and 18 neutral nouns related to concrete objects (e.g. chair, fork, desk, etc.). The English L2 words were created from translations of the L1 German words and thus, the best semantic match of the German words. As illustrated in the Tables 1–6, word length and word frequency were controlled for all the words in both languages. Word frequency scores were taken from available normative databases including the Leipzig Corpora for German words (Biemann et al., 2007) and the Subtlex word data base for English words (Brysbaert et al., 2019). In addition, the German emotional and neutral adjectives were matched and controlled for emotional valence and arousal using the normative ratings available from previous studies (e.g. Herbert et al., 2008; Kissler et al., 2009) that included a list of about 500 German trait and state adjectives for which subjective ratings of valence and arousal were acquired from 45 female and male student subjects (mean age: 25.7 years) on the Self Assessment Manikin, SAM, 9-point scales (Bradley & Lang, 1994). In addition, valence and arousal ratings were available for the German neutral and body-related nouns from the ratings taken from previous studies (Herbert et al., 2013) including a list of 86 body nouns for which in previous studies (e.g. Herbert et al., 2013) subjective ratings of valence and arousal were acquired on the SAM on 9-point scales from a normative sample of 60 women (mean age: 23.5 years, $SD = 5.59$) and 37 men (mean age: 24.81 years, $SD = 6.26$). The body nouns were matched with neutral nouns that were taken from a list of 300 nouns for which normative subjective ratings of valence and arousal were acquired on the SAM on 9-point scales in previous studies from study samples ($N = 45$ student volunteers) with a social background and age comparable to the present study samples (e.g. Kissler et al., 2007). Because, no normative ratings are available for the German body adjectives and the L2 translations, a pilot study was conducted. In this pilot study, all the translated German L2 words as well as the German L1 body trait adjectives (for which no valence and arousal ratings were available from previous studies or databases) were rated in an online study by $N = 208$ healthy adults (women and men) for valence and arousal. Language proficiency of the L2 (English) and age of acquisition of the L2 (English) were controlled among the participants of the pilot study to achieve comparability with the participants taking part in the EEG study. The $N = 208$ participants ($n = 62$ men) of the online study were all native speakers of German with high language proficiency of the English language, $n = 14$ reporting fluency of a mother tongue, $n = 67$ reporting business

Table 2. Word length, word frequency as well as arousal and valence ratings of the German (L1) nouns related to upper body parts (first line), lower body parts (middle line) or neutral objects as per normative ratings (German, L1) obtained on the Self-Assessment Manikin (SAM, Bradley & Lang, 1994), and taken from previous studies, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nouns upper body parts	German – L1	5.67[a]	0.48	4.42 [a]	0.86	6.56 [a]	2.68	13.11 [a]	2.63
Nouns lower body parts	German – L1	4.23[b]	0.96	3.91 [a]	0.55	8.11 [a]	2.89	14.50 [a]	2.62
Nouns neutral objects	German – L1	5.00[b]	0.15	1.78 [b]	0.45	8.06 [a]	3.32	13.39 [a]	3.11

SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word length (number of letters), word frequency values were taken from the Leipzig Corpora Collection (Goldhahn et al., 2012). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations (SD).

Table 3. Word length, word frequency as well as arousal and valence ratings of the German (L1) body adjectives related to a lean or overweight body shape/weight as per normative ratings (German, L1), obtained from the pilot study reported in this manuscript, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lean body shape/weight adjectives	German – L1	5.80[a]	0.93	4.09 [a]	1.50	7.60 [a]	2.20	15.00 [a]	3.23
Overweight body shape/weight adjectives	German – L1	4.07 [b]	1.16	4.23 [a]	1.65	7.33 [a]	2.38	15.87 [a]	3.00

Ratings were assessed with the Self-Assessment Manikin (SAM, Bradley & Lang, 1994). The SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word length (number of letters), word frequency values were taken from the Leipzig Corpora Collection (Goldhahn et al., 2012). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations in brackets. Means and standard deviations (SD).

Table 4. Word length, word frequency as well as arousal and valence ratings of the English (L2) emotional and neutral adjectives, obtained from the pilot study reported in this manuscript, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pleasant/positive adjectives	English – L2	7.20[a]	1.00	5.54 [a]	1.74	7.40 [a]	2.58	2704.50 [a,b]	4530.73
Negative/unpleasant adjectives	English – L2	3.02 [b]	1.08	5.56 [a]	1.61	6.80 [a]	1.96	1543.70 [a,c]	1532.88
Neutral adjectives	English – L2	5.37 [c]	0.76	3.47 [b]	1.38	8.30 [a]	2.49	802.15 [a]	1252.52

Ratings were assessed with the Self-Assessment Manikin (SAM, Bradley & Lang, 1994). The SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word frequency values were taken from the SUBTLEX word frequency counts ($Freq_{count}$) (Brysbaert & New, 2009). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations in brackets. Means and standard deviations (SD).

status and $n = 86$ reporting fluent use, and $n = 41$ reporting good knowledge at a level learnt at school. They were asked to rate the L2 words and the L1 body shape/weight adjectives for emotional valence and arousal. In the online study, each word was presented on a separate frame to avoid carry over effects. The SAM, Self-Assessment Manikin (Bradley & Lang, 1994) was used for the ratings to assess affective judgments rather than judgments of semantic valence. The instructions of the ratings followed the rating instructions of Bradley and Lang (1994) to allow comparison of the ratings with the ratings reported for the German L1 words that were taken from databases used in previous studies (see above). The results of the pilot study are presented in the Results and summarised together with the descriptive data (ratings for the L1 words) in the Tables 1–6.

During the EEG study, the full set of words (German, L1 and English, L2) comprising the adjectives and the nouns was presented repeatedly in 12 random blocks, 6 blocks per language. Each block lasted about 2.5 min and contained the full list of words of one language. Within the blocks, word order was randomised. In addition, the order of the blocks (L1 vs. L2) was randomised across the participants. The first two blocks presented in each language were related to passive reading and were followed by two "active" blocks during which participants had to count the words written in red or green versus black colour (shallow word encoding task of word counting). The active blocks were then followed by a final passive reading block and a final word counting block. Figure 1 provides a graphical illustration of the experimental stimulus presentation design.

The stimuli were presented on a computer screen in a sound and light attenuated cabin using Presentation software (https://www.neurobs.com/). In the passive reading blocks the stimuli were presented in black letters on grey background (font: 90, Arial). In the active word counting blocks, half of the stimuli were

Table 5. Word length, word frequency as well as arousal and valence ratings of the English (L2) nouns related to upper body parts (first line), lower body parts (middle line) or neutral objects, obtained from the pilot study reported in this manuscript, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nouns upper body parts	English – L2	5.58[a]	0.77	3.38 [a]	1.43	6.44 [a]	3.33	1985.94 [a,c]	3634.01
Nouns lower body parts	English – L2	4.90 [b]	0.92	3.58 [b]	1.51	8.00 [a]	3.63	389.33 [a,b]	831.64
Nouns neutral objects	English – L2	5.30 [c]	0.78	2.89 [c]	1.48	7.11 [a]	3.18	881.22 [a]	1284.67

Ratings were assessed with the Self-Assessment Manikin (SAM, Bradley & Lang, 1994). The SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word frequency values were taken from the SUBTLEX word frequency counts ($Freq_{count}$) (Brysbaert & New, 2009). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations in brackets. Means and standard deviations in brackets.

Table 6. Word length, word frequency as well as arousal and valence ratings of the English (L2) body adjectives related to a lean or overweight body shape/weight, obtained from the pilot study reported in this manuscript, see for details the section on Stimuli and experimental study design.

		Valence		Arousal		Word length		Word frequency	
Word category	Language	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lean body shape/weight adjectives	English – L2	5.89[a]	0.85	4.06 [a]	1.50	5.93 [a]	1.53	251.73 [a]	353.54
Overweight body shape/weight adjectives	English – L2	4.23 [b]	0.99	4.12 [a]	1.53	6.93 [a]	3.81	438.73 [a]	1047.79

Ratings were assessed with the Self-Assessment Manikin (SAM, Bradley & Lang, 1994). The SAM scales ranged from 1 (very unpleasant, calm) to 9 (very pleasant, very arousing). Word frequency values were taken from the SUBTLEX word frequency counts ($Freq_{count}$) (Brysbaert & New, 2009). Same superscripts a,b, or c indicate no significant differences; different superscripts, a,b, or c indicate significant differences between the word categories. Means and standard deviations in brackets. Means and standard deviations (SD).

presented in red and green colour (the “to be counted” words) or black colour. The participants’ tasks were to read the words silently (silent reading task, 3 blocks per language) or to count the words written in red or green versus black colour (shallow word encoding task of word counting, 3 blocks per language). Between each of the passive and active stimulus presentation blocks, a break was included and a free recall memory test was performed in which the participants had to write down as many of the words they could remember in the serial order the words came to their mind.

The electroencephalogram (EEG) was continuously recorded from 64 electrodes across all RSVP blocks. The topography of the 64 EEG electrodes was in accord with the 10–20 system of electrode location and electrode placement. Active electrodes were used for EEG recordings to achieve high signal to noise quality (SNR). In addition, vertical and horizontal eye movements as well as blinks were recorded via the electrooculogram (EOG) from additional EEG electrodes attached to the left canthus and the right canthus and the left upper and lower eye regions.

The participants’ specific language competence of the words presented in L2 was assessed by means of a vocabulary test. The vocabulary test was carried out after the main EEG experiment and intended to test word proficiency, comprehension and familiarity with the English words used in the study. To this end, in the vocabulary test, the participants were asked to translate the English words into German. They received an excel sheet with all English words randomly presented in a row and had to type in the German translation of the word. Participants were asked to decide for the best matching translation and write down the best match. Synonyms and obvious typing errors were counted as correct. A maximum of 100% could be achieved in the vocabulary task corresponding to a correct translation of all the words.

Finally, a manipulation check was performed: the participants were asked to rate the word categories for self-reference, i.e. the degree to which they had related the words presented in the L1 or the L2 to themselves during the EEG study. Participants had to indicate their answer on 9-point Likert scales ranging from 1 = no

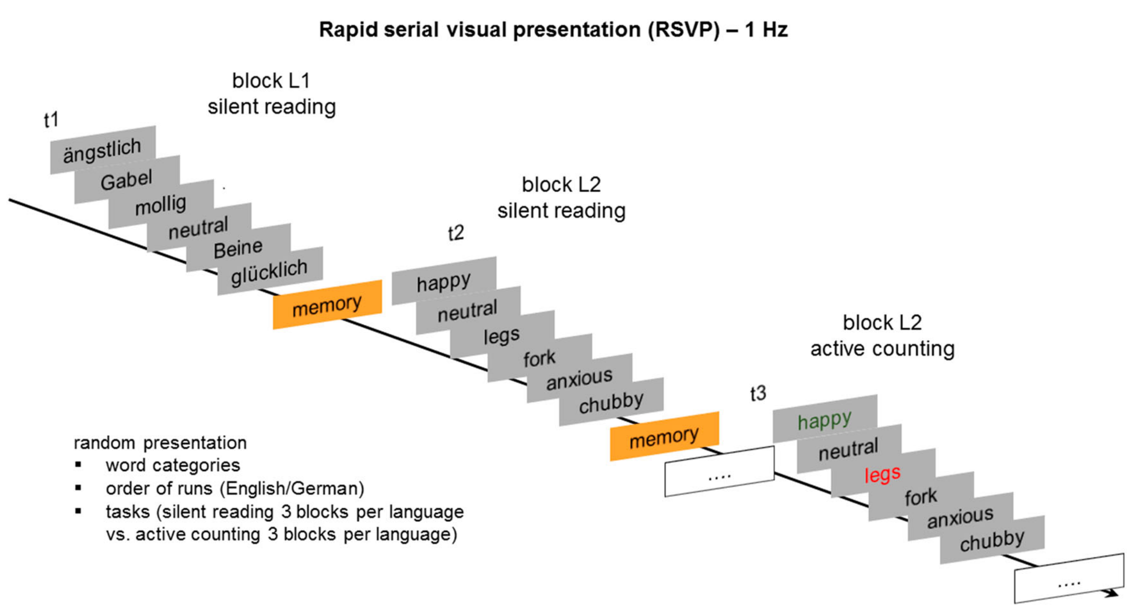


Figure 1. Illustration of the study paradigm consisting of the RSVP presentation of words at 1 Hz. For details, please see Materials and methods.

self-reference to 9, high self-reference. Finally, they were asked about "felt emotions" they might have experienced during word processing and to name the word categories that elicited emotional feelings or experiences. The results of the vocabulary test, the memory performance and the ratings of the manipulation check are presented in the Results.

Data analysis and statistics

The EEG and the EOG data were recorded with Brain Vision amplifiers (https://brainvision.com/) and Brain Vision recording software (https://brainvision.com/). The EEG and the EOG data were sampled at 1000 Hz. The preprocessing of the EEG and the EOG data followed offline and was performed with Brain Vision 2.1. Analyzer software (https://brainvision.com/). Offline, the data was filtered from 0.5 to 70 Hz, eye movements were corrected by the automated Gratton and Coles algorithm implemented in the Brain Vision 2.1. Analyzer software and the data were visually inspected for movement and other artifacts. The epoched data was re-referenced from an FCz reference (online) to an average reference offline, using all 64 EEG sensors without EOG electrodes for the average reference. The artifact-free EEG data were segmented into epochs starting from −1000 ms before until 1000 ms after word presentation and the −1000 ms to 0 ms epoch was used for baseline correction in line with previous EEG-RSVP studies (e.g. Herbert et al., 2008; Kissler et al., 2007). The baseline corrected EEG epochs were averaged separately for each word category, block and language (L1 vs. L2, respectively). Across the word categories, early event-related brain potentials (ERPs) were analysed in three different time intervals. The EEG-ERP time intervals corresponded to the P100 (80–120 ms), N100 (140–170), and the EPN (200–300 ms). The time intervals were selected in line with the literature including previous RSVP word processing studies (e.g. Herbert et al., 2008; Kissler et al., 2007) and by visual inspections of the ERP grand average waveforms. Moreover, and in line with these previous studies, the analysis of the amplitudes of the P100 (80–120 ms), the N100 (140–170 ms), and the EPN (200–300 ms) components was performed on a cluster-level including the occipito-parietal electrode cluster O1, PO7, PO3, and P7 as left hemisphere cluster and the occipito-parietal electrode cluster O2, PO8, PO4, and P8 as right hemisphere cluster. The averaged amplitudes of the electrodes of the left or the right hemisphere clusters in the respective time windows were included into the statistical analysis of the P100, the N100, and the EPN, respectively. The data of $N = 1$ participant had to be excluded from the analysis due to a missing last block in the EEG data, yielding finally a dataset of $N = 34$ participants for statistical analysis.

The modulation of the ERP amplitudes by the different word categories was statistically analysed separately for each of the ERP components (P1, N1, and EPN, respectively) within repeated measures of variance (ANOVAs). First, emotion effects were compared between the two languages (L1 vs. L2) and between the passive blocks of reading versus the active blocks of word counting, using emotional and neutral adjectives as word category only. The ANOVA designs of the P100, the N100 and the EPN included the following within-subject factors: the factor "emotion" (positive, negative, and neutral), "task" (passive vs. active) "language" (L1 vs. L2) and "hemisphere" (left, right). Second, the body-related adjectives and the body-related nouns were compared to the categories of neutral adjectives or neutral nouns. For the body-related adjectives, the ANOVA designs included the following factors: the factor "body shape/weight" (lean body shape, overweight body shape, neutral adjectives having no body reference), "task" (passive vs. active), "language" (L1 vs. L2) and "hemisphere" (left, right). For the body part nouns, the ANOVA designs included the following factors: the factor "body part" (upper body part, lower body part, and neutral nouns having no body reference), "task" (passive vs. active), "language" (L1 vs. L2) and "hemisphere" (left, right). If the sphericity assumption was violated in the ANOVA designs, the *p*-values were corrected according to the Huynh-Feldt procedure. Degrees of freedom are reported uncorrected. Partial eta2-squared is reported to describe effect sizes (Cohen, 1988). Significant main effects or interaction effects were explored by means of planned comparison tests comparing only those contrasts that were relevant for hypothesis testing, thereby avoiding unnecessary multiple testing. *P*-values are reported uncorrected (significance level: $p < .05$)

Sociodemographic data, manipulation check and memory performance

The sociodemographic variables and the answers to the questions asking for language proficiency, language use as well as the data of the participants' ratings of the emotionality and self-reference of the words (manipulation check) are reported descriptively. In addition, exploratory analysis were conducted to determine if the EEG-ERP modulation patterns varied as a function of the social language use of the second language (L2). To this end, ERP modulation was correlated with the scores obtained from the self-report scale "social language use" using Pearson correlation and two sided testing. Additionally, two groups of participants were selected based on high versus low scores on the scale asking for social language use. This grouping factor "social L2 use" was then used as between subject factor in the repeated measures ANOVA designs. The exploratory analysis was performed only if in the analysis described above, the factor "emotion", "body shape/weight" or "body part" showed a significant interaction with the factor language (L1 vs. L2). Then, it was explored whether the interaction was dependent on the participants' variation in the L2 language use as a "warm" or "distant" L2. The participants' memory data could be analysed only for the participants who provided free recall data across all blocks and in good type writing ($n = 11$). The correctly recalled words ("hits") were analysed and statistically compared between the L1 and the L2 and across word categories by means of non-parametric tests.

Pilot study: affective ratings of the words in L2 and ratings in L1

The affective ratings (mean scores) of valence and arousal in the L2 including the emotional and the neutral adjectives, the body shape/weight related adjectives, the nouns related to body parts or neutral objects as well as the body shape/weight related adjectives in the L1 that were rated from the $N = 208$ participants of the pilot study were statistically analysed within ANOVA designs using the factor "word category" as within-subject grouping factor; significant effects between the word categories were tested further by means of post-hoc tests using t-tests.

The affective ratings (mean scores) of valence and arousal of the German words (L1) (see Tables 1 and 2) that were taken from the available ratings of the word lists used in the previous studies (see for details the section *Stimuli and experimental study design*) as well as the scores for word frequency that were taken from standardised corpora (see for details the section *Stimuli and experimental study design*) and word length were tested for significant differences between the words of the different word categories by using non-parametric tests, where appropriate. *P*-values are reported uncorrected.

Results

EEG-ERP data

Emotion effects: processing of emotional versus neutral trait and state adjectives

P100. The amplitude modulation of the P100 showed the following significant main and interaction effects: the main factor "task" was significant, $F(1,33) = 26.47$, $p < .001$, $eta2 = .445$, $MQ = 51.31$. The P100 amplitudes were significantly more pronounced during the shallow encoding task of active counting in which words were presented in three different colours than during silent reading where all words were presented in black colour, $F(1,33) = 26.46$, $p = .00012$, $MQ = 51.31$. No other main factor was significant (all $p > .05$). The interaction effect of "task × language" was significant, $F(1,33) = 4.76$, $p < .036$, $eta2 = .126$, $MQ = 7.04$. The task effect, showing larger P100 amplitudes during active counting than during silent reading, was significantly more pronounced in the L1 than in the L2, $F(1,33) = 34.231$, $p = .0001$, $MQ = 48.19$. No other main effects or interaction effects reached significance (all $p > .05$).

N100. The N100 amplitudes were significantly modulated by the main factor "task", $F(1,33) = 10.59$, $p = .003$, $eta2 = .243$, $MQ = 41.79$. The amplitudes of the N100 were significantly larger during active counting than during silent reading, $F(1,33) = 10.584$, $p = .002$, $MQ = 41.79$. In addition, the N100 amplitudes were modulated by the main factor "emotion", $F(2,66) = 3.167$, $p = .053$, $eta2 = .088$, MQ = 5.50. The N100 amplitudes were significantly larger during the processing of positive adjectives than during the processing of neutral adjectives, $F(1,33) = 9.66$, $p = .003$, $MQ = 10.83$. The main effect of emotion was accompanied by a significant interaction effect of "emotion × language × hemisphere", $F(2,66) = 5.86$, $p = .008$, $eta2 = .151$, $MQ = 1.60$. The modulation of the amplitudes of the N100 by positive adjectives was found in the left and the right hemisphere in the L1 (left hemisphere: positive vs. neutral: $F(1,33) = 4.20$, $p = .048$, $MQ = 1.74$; positive vs. negative: $F(1,33) = 12.16$, $p = .001$, $MQ = 4.93$; right hemisphere: positive vs. neutral: $F(1,33) = 4.57$, $p = .040$, $MQ = 1.73$). In the L2, the N100 amplitudes were significantly more pronounced during the processing of negative and positive adjectives compared to neutral adjectives in the left hemisphere (left hemisphere: positive vs. neutral: $F(1,33) = 7.17$, $p = .011$, $MQ = 3.85$, negative vs. neutral: $F(1,33) = 5.86$, $p = .02$, $MQ = 12.64$) and during the processing of positive compared to neutral adjectives in the right hemisphere (right hemisphere: positive vs. neutral: $F(1,33) = 5.57$, $p = .024$, $MQ = 3.93$). No other main effects or interaction effects reached significance in the N100 time window (all $p > .05$).

EPN. The amplitudes of the EPN were significantly modulated by the main effects of "task", $F(1,33) = 6.46$, $p = .016$, $eta2 = .164$, $MQ = 28.68$, "emotion", $F(2,66) = 6.01$, $p = .015$, $eta2 = .154$, $MQ = 15.56$, and "hemisphere", $F(1,33) = 5.61$, $p = .024$, $eta2 = .148$, $MQ = 24.45$. In addition, the following interaction effects were significant: "language × hemisphere", $F(1,33) = 4.21$, $p = .048$, $MQ = 1.06$, $eta2 = .113$, and "emotion × language", $F(2,66) = 3.82$, $p = .054$, $eta2 = .104$, $MQ = 10.11$. No other main effects or interaction effects reached significance in the EPN time window (all $p > .05$). The amplitudes of the EPN were significantly more pronounced during active counting than during silent reading, $F(1,33) = 6.46$, $p = .0158$, $MQ = 28.67$, and more pronounced in the left hemisphere electrode cluster compared to the right hemisphere electrode cluster, $F(1,33) = 5.61$, $p = .023$, $MQ = 24.45$. This was further modulated by the language: for the L1, the EPN amplitudes were more pronounced in the left hemisphere cluster compared to the right hemisphere cluster, $F(1,33) = 7.10$, $p = .01$, $MQ = 17.86$, whereas in the L2, the size of the EPN amplitudes did not differ significantly between the left and right hemisphere. Moreover, the amplitudes of the EPN were significantly more pronounced during the processing of positive or negative adjectives than during the processing of neutral adjectives (positive vs. neutral: $F(1,33) = 11.08$, $p = .002$, $MQ = 4.90$; negative vs. neutral: $F(1,33) = 7.58$, $p = .01$, $MQ = 30.70$), irrespective of the task or the hemisphere and the emotion effect was modulated by the language. The processing of the positive adjectives as well as of the negative adjectives elicited significantly larger EPN amplitudes than neutral adjectives when words were presented in the L2 (positive vs. neutral: $F(1,33) = 14.63$, $p = .001$, MQ $= 5.45$; negative vs. neutral: $F(1,33) = 6.55$, $p = .01$, $MQ = 48.64$).

Processing of body-shape/weight related adjectives versus neutral adjectives and of body nouns versus neutral nouns

P100. Comparisons between the body shape/weight related adjectives and the neutral adjectives yielded a significant main effect the factor "task", $F(1,33) = 52.38$, $p = .000$, $eta2 = .618$, $MQ = 66.43$. In addition, the interaction between the factors "body shape/weight" × " hemisphere" × "task" was significant, $F(2,66) = 4.13$, $p = .02$, $eta2 = .278$, $MQ = 1.82$. The P100 amplitudes were more pronounced during active counting than during silent reading, $F(1,33) = 52.39$, $p = .001$. In addition, the processing of the body shape/weight adjectives related to a lean body elicited larger P100 amplitudes than the processing of neutral adjectives in the right hemisphere electrode cluster when the words had to be counted, $F(1,33) = 6.26$, $p = .017$, $MQ = 6.19$.

For the body nouns that were related to upper or lower body parts and the neutral nouns, the P100 modulation showed a main effect of "task", $F(1,33) = 63.43$, $p < .0001$, $eta2 = .658$, $MQ = 56.13$. No other effects were significant. The P100 amplitudes were more pronounced during active counting than during passive reading, $F(1,33) = 63.43$, $p < .0001$, $MQ = 56.13$.

N100. In the N100 time window, the main effect of "task", $F(1,33) = 6.74$, $p = .014$, $eta2 = .170$, $MQ = 14.41$, as well as the main effect of "language", $F(1,33) = 10.72$, $p = .002$, $eta2 = .245$, $MQ = 7.90$, were significant. The amplitude modulation of the N100 was significantly larger during active counting than during silent reading, $F(1,33) = 6.74$, $p = .001$, $MQ = 14.41$ as well as during the processing of the body adjectives and the neutral adjectives in the L1 compared to the L2, $F(1,33) = 10.72$, $p = .003$, $MQ = 7.90$. The latter effect (L1 vs. L2) was significantly more pronounced in the left than in the right hemisphere; this was indicated by the significant interaction between the factors "language" × "hemisphere", $F(1,33) = 9.71$, $p = .004$, $eta2 = .227$, $MQ = 2.07$. In addition, the interaction between the factors "body shape/weight" × "hemisphere", $F(1,33) = 8.58$, $p = .0000$, $eta2 = .206$, $MQ = 3.11$, was significant. The N100 amplitudes were more pronounced in the left hemisphere during the processing of body adjectives related to an overweight body shape/weight compared to the neutral adjectives, irrespective of the task or the language in which the words were presented, $F(1,33) = 5.51$, $p = .024$, $MQ = 9.95$.

The N100 modulation did not differ significantly between the body nouns and the neutral nouns. Only the factor "language", $F(1,33) = 10.29$, $p = .003$, $eta2 = .238$, $MQ = 10.52$, showed a significant impact on the modulation of the amplitudes of the N100 during the processing of nouns related to body parts versus neutral nouns. The amplitude modulation of the N100 was more pronounced during the processing of the body nouns and the neutral nouns presented in the L1 than in the L2, $F(1,33) = 10.28$, $p = .003$, $MQ = 10.28$.

EPN. In the EPN time window, the processing of the body-shape/weight related adjectives and the neutral adjectives showed the following main and interaction effects: there was a main effect of "language", $F(1,33) = 6.86$, $p = .013$, $eta2 = .172$, $MQ = 5.26$, and a main effect of "hemisphere", $F(1,33) = 4.05$, $p = .052$, $eta2 = .109$, $MQ = 33.10$, and a main effect of "body shape/weight", $F(1,33) = 10.35$, $p = .001$, $eta2 = .239$, $MQ = 6.65$, as well as a significant interaction effect of the factors "language" × "hemisphere", $F(2,66) = 13.50$, $p = .001$, $eta2 = .290$, $MQ = 2.30$. The EPN amplitudes were more pronounced during the processing of the body adjectives and the neutral adjectives when these were presented in the native language (L1) than in the L2, $F(1,33) = 6.86$, $p = .0132$, $MQ = 5.25$. Moreover, the amplitudes of the EPN were significantly more pronounced during the processing of the body shape/weight adjectives related to a lean or overweight body than during the processing of the neutral words that were having no reference to body weight/shape ((lean and overweight) versus neutral: $F(1,33) = 9.51$, $p = .004$, $MQ = 6.51$), and this effect occurred irrespective of the hemisphere (left vs. right) or the language (L1 or L2, respectively) in which the words had been presented or the task at hand, although irrespective of the word category, the EPN amplitudes were larger in the left than the right hemisphere in the L1 than in the L2, $F(1,33) = 8.58$, $p = .006$, $MQ = 3.40$.

During the processing of the body nouns and the neutral nouns, the amplitudes of the EPN were significantly modulated by the factor "language", $F(1,33) = 4.88$, $p = .034$, $eta2 = .129$, $MQ = 6.20$, and the factor "hemisphere", $F(1,33) = 7.52$, $p = .010$, $eta2 = .185$, $MQ = 33.57$. In addition, the effect of "language" showed an interaction with the factor "hemisphere", $F(1,33) = 12.04$, $p = .001$, $eta2 = .267$, $MQ = 12.04$. Moreover, the processing of the body nouns and of the neutral nouns differed significantly between the right and the left hemisphere; this was indicated by the interaction effect of the factors "body parts" × "hemisphere", $F(2,66) = 6.35$, $p = .003$, $eta2 = .101$, $MQ = 6.35$. This interaction effect was further modulated by the factor "language"; this was indicated by the significant interaction of the factors "body parts" × "hemisphere" × "language", $F(2,66) = 6.66$, $p = .002$, $eta2 = .168$, $MQ = 6.66$. Nouns in general elicited larger EPN amplitudes when presented in the L2 than when presented in the L1, $F(1,33) = 4.88$, $p = .034$, $MQ = 6.20$, particularly in the left compared the right posterior hemisphere, $F(1,33) = 4.31$, $p = .045$, $MQ = 10.02$. However, the processing of the body nouns, that is, the nouns that are related to upper or lower body parts, elicited significantly larger amplitude modulation of the EPN than the processing of the neutral nouns; and this was significant only in the electrode cluster of the left hemisphere and most pronounced for the nouns that were presented in the L1, $F(1,33) = 5.28$, $p = .028$, $MQ = .831$.

Exploratory analysis

EEG-ERP modulation by word categories as a function of social language use

Correlation analysis revealed significant interactions between the modulation of the ERPs and the extent to which the participants reported to use the L2 as a warm language for daily social interaction. Significant correlations ($p < .05$) were found in the EPN time window for the negative adjectives of the second language (L2). In addition, the modulation of the N100 by the emotional adjectives in the L1 and the L2 was varying with the between group factor "social L2 use"; and this was indicated by a significant interaction of the group factor with the factors "emotion" × "hemisphere", $F(64,2) = 3.188$, $p = .048$, $eta2 = .091$, $MQ = 1.11$: the modulation of the N100 amplitudes elicited by the positive adjectives compared to the neutral adjectives in the left as well as in the right hemisphere was specifically observed in the group of participants ($n = 20$) who used the L2 as a warm language (all $p < .058$). The ERP effects elicited during the processing of the different word categories are summarised in Figure 2.

Sociodemographics: language proficiency and language use

Vocabulary test

Overall, the performance in the vocabulary test was high. In total, on average 80% of the English words irrespective of the word category (emotional, neutral, body-related) or word class (nouns, adjectives) were correctly translated by the participants.

Language use (L2)

In line with the performance in the vocabulary test, 82.8% of the participants ($N = 29$) rated their language proficiency as very good (business fluent) or good (fluent). In terms of the frequency of language use, English was reported to be spoken predominantly abroad (holiday, vacation) and in a university context. 41.2% of the participants reported speaking English frequently in this context, 47.1% reported speaking it sometimes, and 11.4% of the participants reported speaking English barely at all. Regarding the use of English as a social language, 17.1% of the participants reported to use English frequently in everyday interaction (e.g. interacting with friends, family, school, work, study, social interaction, etc.), and 28.6% of the participants reported to use it frequently, whereas 45.7% ($N = 16$) and 5.7% ($N = 2$) reported to barely or not use English as L2 for social interaction at all.

Manipulation check

Emotionality and self-referentiality ratings (L1 and L2)

After the experiment, the participants were asked to report which of the word categories had elicited feelings of emotions during the EEG word processing experiment. Of all possible word categories, the emotional

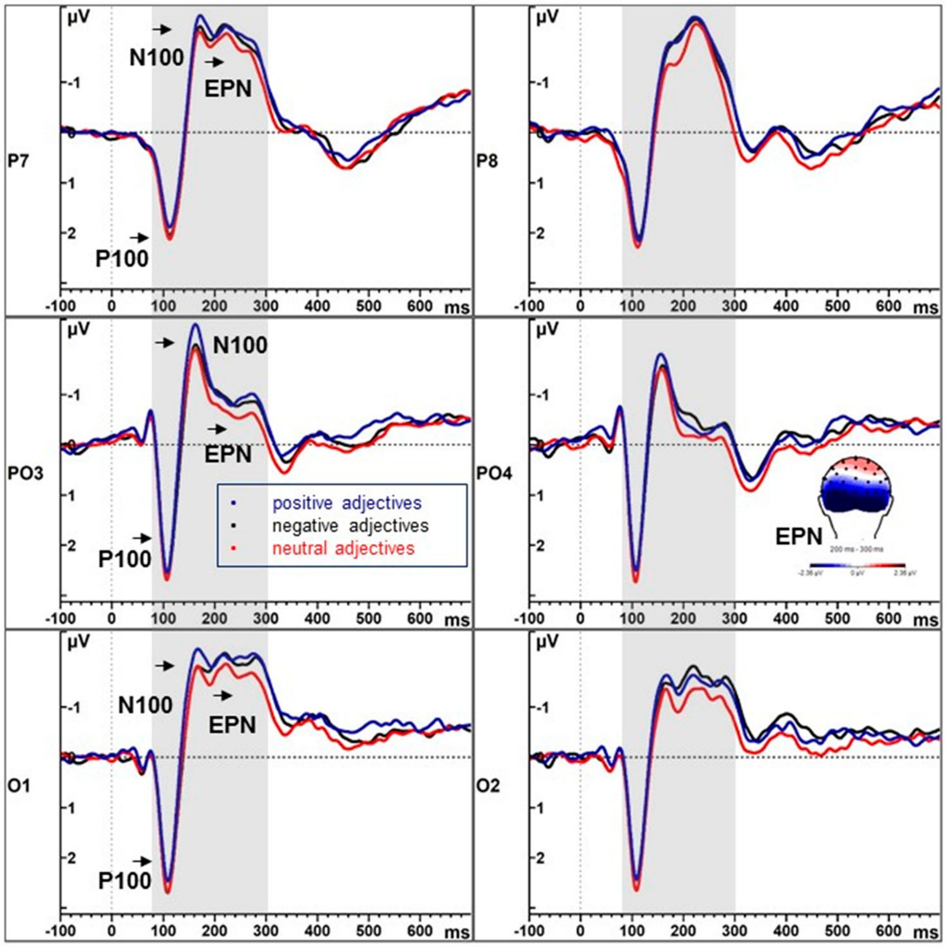


Figure 2. (a) Modulation of early event related brain potentials (P100, N100, and EPN, respectively) by emotional and neutral adjectives (grand averages across both languages, the L1 and the L2). Time windows are highlighted by boxes and arrows for the early ERPs (P100, N100 and EPN, respectively). For illustration, a high cut off of 30 Hz was applied and ERP curves are aligned to baseline, for details see *Material and Methods*. (b) Modulation of early event related brain potentials by emotional and neutral adjectives. Figure 2(b) shows the significant interaction effect with the factor "hemisphere" in the N100 time window and the EPN effects (bottom line) for the posterior electrode clusters. The plots in Figure 2(b) represent means and standard errors, for details, please see Results. (c) Modulation of early event related brain potentials (P100, N100, and EPN, respectively) by body shape/weight adjectives (grand averages across both languages, the L1 and the L2). Time windows are highlighted by boxes and arrows for the early ERPs (P100, N100 and EPN, respectively). For illustration, a high cut off of 30 Hz was applied and ERP curves are aligned to baseline, for details see *Material and Methods*. (d) Modulation of early event related brain potentials (P100, N100, and EPN) by body nouns (upper and lower body parts), (grand averages across both languages, the L1 and the L2). Time windows are highlighted by boxes and arrows for the early ERPs (P100, N100 and EPN, respectively). For illustration, a high cut off of 30 Hz was applied and ERP curves are aligned to baseline, for details see *Material and Methods*. (e) It shows the significant effects found during processing of body-related words (upper part: body-shape/weight adjectives; lower part: body nouns). The plots in Figure 2(e) represent means and standard errors, for details, please see Results.

adjectives and the adjectives related to body weight/shape were reported most consistently to have elicited emotional experiences followed by the nouns related to body parts, whereas neutral adjective or neutral nouns were never reported (0%) to having elicited feelings of emotion or emotional experiences, respectively during the experiment. When asked to indicate on a 9-point Likert scale whether the participants had related the words to themselves during processing, self-referential ratings showed the highest scores of self-reference for the positive trait and state adjectives presented in the L1 ($M = 6.13$, $SD = 1.73$), for the adjectives related to body weight/shape presented in L1 ($M = 5.88$, $SD = 2.55$), irrespective of a lean or overweight body shape, and for the positive adjectives presented in L2 ($M = 5.65$, $SD = 1.93$). All other word categories did not differ significantly from each other in self-reference ratings, achieving mean scores between 4 and 5 on the Likert scale (neither being rated high or low in self-reference), irrespective of the language (L1 or L2) in which they

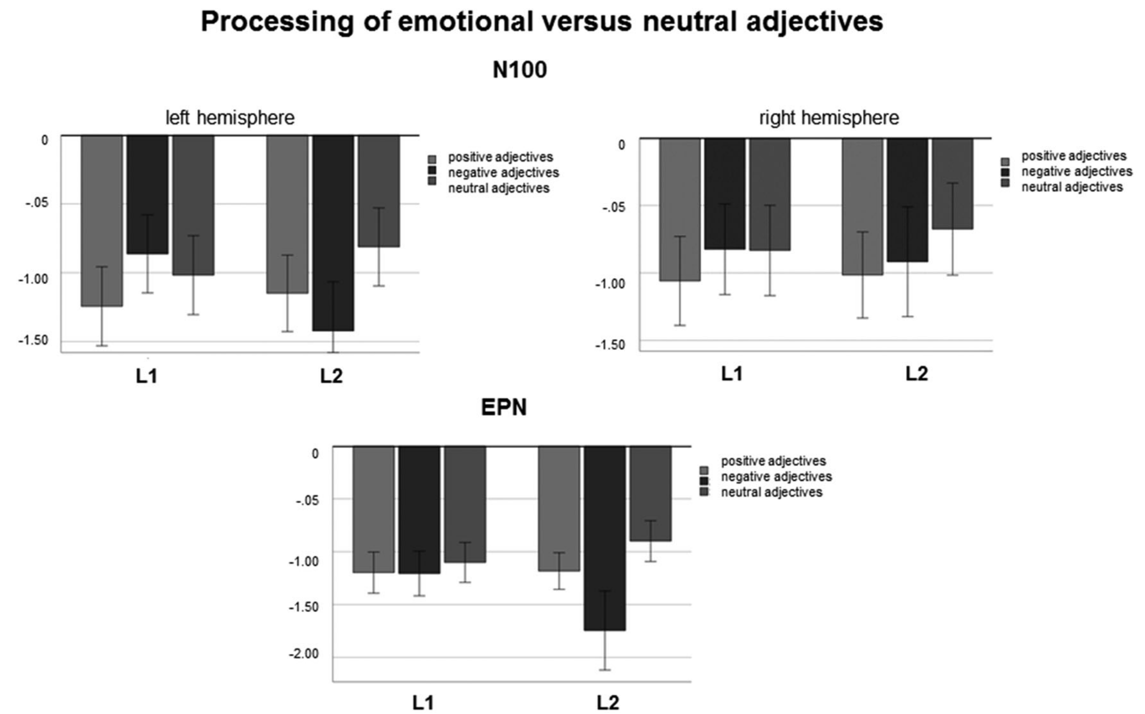


Figure 2 *Continued*

were presented. The neutral word categories (adjectives or nouns) were on average rated as not inducing self-referentiality (self-reference scores ranging below a score of 3) in both languages.

Memory

On average, only a few words were remembered (see Figure 3); and this is typical for free recall tasks (e.g. see Herbert et al., 2008; Kissler et al., 2007). Descriptively, different words were remembered in the L1 and the L2 across the blocks suggesting that participants had followed the instructions and only little carry over effects from one language to the other were elicited, possibly also due to the randomisation of the block order. Statistical analysis showed that overall, memory did not differ between the L1 and the L2, but that words from the different word categories were differently well remembered (Friedmans-ANOVA Chi^2 (15) = 32.26, $p = .006$). Post-hoc tests (Wilcoxon tests) showed that the positive emotional adjectives were remembered better than the neutral adjectives in the L1 ($Z = 2.091$, $p = .037$) and the L2 ($Z = 2.371$, $p = .018$). The body shape/weight adjectives related to an overweight body size/shape were remembered better than the neutral adjectives in the L1 ($Z = 2.312$, $p = .02$) and in the L2 ($Z = 1.937$, $p = .052$). Nouns referring to lower body parts were remembered better than the neutral nouns in the L1 ($Z = 2.001$, $p = .045$). For an overview, see Figure 3.

Self-report data (Questionnaires)

Difficulties in emotion processing (alexithymia)

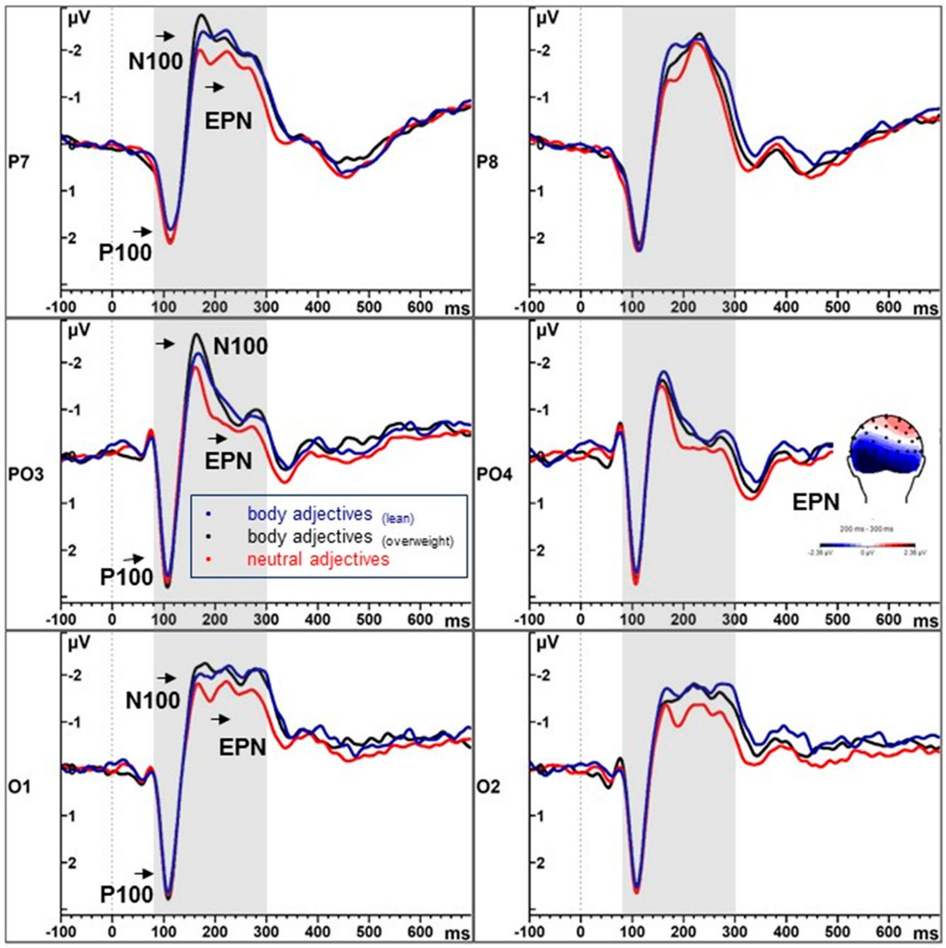
On average, the participants of the study sample scored below the critical cut off score of the Toronto Alexithymia Scale that differentiates between high (cut-off > 61), possible (cut-off between 52 and 56) and low alexithymia (cut-off equal or less than 52), $M = 39.57$, $SD = 8.45$. The range of the sum scores was between 22 and 56, and only $N = 3$ participants had a sum score indicating possible alexithymia (Ricciardi et al., 2015).

Body dissatisfaction and drive for thinness

On average, the mean sum scores of the EDI-2 body dissatisfaction scale ($M = 28.23$, $SD = 3.94$) and the drive for thinness scale ($M = 18.74$, $SD = 5.63$) of this mixed gender participant sample were below the mean sum scores of clinical samples reporting a risk or clinical diagnosis of an eating disorder such as anorexia nervosa or bulimia (e.g. Clausen et al., 2009).

Pilot study: affective ratings of the words in L2 and L1 ratings

Statistical analysis including all word categories of the pilot study including all words translated to English (L2) as well as the German (L1) body adjectives yielded significant main effects of the factors "valence", $F(1863,9) = 509.81$, $p = .001$, $eta2 = .771$, and "arousal", F



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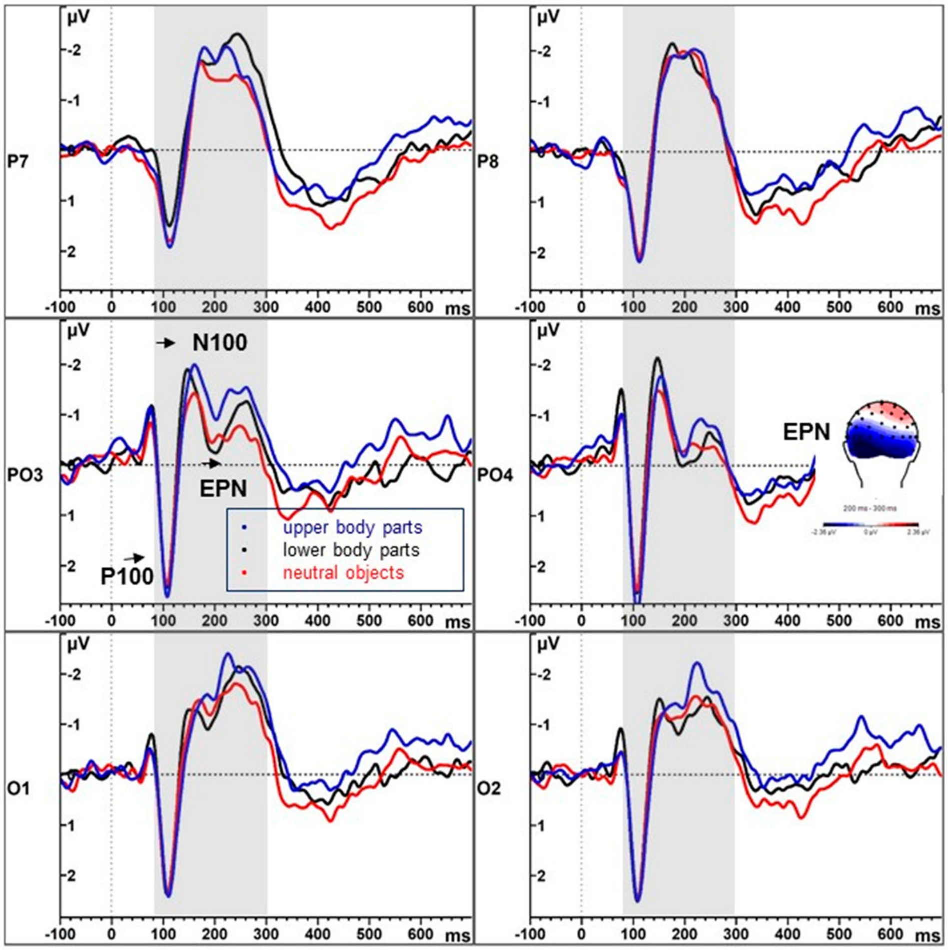
*(*1863,9) = 224.92, *p* = .001, *eta2* = .521. T-tests revealed significant differences (see Tables 4–6): the emotional (positive/negative) adjectives received the highest or the lowest valence scores, respectively (Table 4). The participants of the pilot study rated the positive emotional adjectives higher in valence than the neutral adjectives, $t(207) = 30.01$, $p < .001$, or the negative emotional adjectives, $t(207) = 35.39$, $p < .001$, and they rated the negative emotional adjectives lower in valence than the neutral adjectives, $t(207) = 30.01$, $p < .001$. The adjectives referring to a lean body shape (Table 6) received significantly higher valence scores than the neutral adjectives, $t(207) = 9.14$, $p < .001$. The nouns referring to upper body parts (Table 5) were rated significantly higher in valence than the neutral nouns, $t(207) = 7.51$, $p < .001$. The body adjectives referring to a lean body shape were rated significantly lower in valence than the positive emotional adjectives, but higher in valence than the negative emotional adjectives (both $p < .001$). Furthermore, the participants of the pilot study rated the adjectives referring to an overweight body shape (Table 6) as significantly lower in valence than the neutral adjectives, $t(207) = -77.18$, $p < .001$ (Table 4), and the nouns referring to lower body parts (Table 5) as significantly lower in valence than the neutral nouns, $t(207) = -7.75$, $p < .001$ (Table 5). However, body adjectives or body nouns were not rated as high in valence (pleasantness) or as low in valence (unpleasantness) as were the positive or the negative adjectives, see Tables 4–6 for an overview. As shown in Table 4, the positive and the negative adjectives received the highest arousal scores: the arousal ratings of the positive and the negative adjectives were both significantly higher compared to neutral adjectives, $t(207) = 9.15$, and $t(207) = 11.49$, both $p < .001$ (Table 4). Additionally, the adjectives referring to a lean or overweight body shape received significantly higher arousal scores than the neutral adjectives, both, $p < .001$, (Tables 4 and 6). The nouns referring to upper or lower body parts were rated higher in arousal than the neutral nouns, $t(207) = 21.28$ or $t(207) = 21.11$, both $p < .001$, (Table 6). The body adjectives referring to a lean or overweight body shape in the L2 were not rated differently in arousal within the language (L2)



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and were not rated differently in arousal or valence compared to the body adjectives presented in L1 (all $p > .06$), however, the body nouns or the body adjectives were rated lower in arousal compared to the emotional adjectives, and in both languages did not achieve the same high scores of unpleasantness/pleasantness (valence) as the emotional adjectives, see Tables 4–6 for the L2 words and Tables 1–3 for the L1 words. Moreover, as shown in Tables 1–6, the word categories did not differ significantly in word length in the German language (L1), (Kruskal–Wallis: $H(7) = 9.51$, $p = .22$), nor in the English language (L2), (Kruskal–Wallis: $H(7) = 11.71$, $p = .12$). Word frequency scores differed significantly across the word categories in L1 (Kruskal–Wallis: $H(7) = 16.65$, $p = .02$), however, as revealed by post-hoc multiple comparison tests, word frequency did not differ between the word categories of body nouns versus neutral nouns, or the emotional and neutral adjectives, or the body adjectives (lean vs. overweight body shape), all $p > .05$, because these word categories were matched in terms of word frequency. In the English language L2, the word frequency counts (SUBTLEX, Freqcount) differed across the word categories as well (Kruskal–Wallis: $H(7) = 14.06$, $p < .001$). Post-hoc multiple comparison tests showed no significant differences between the word categories of body nouns versus neutral nouns, or between the emotional adjectives, or between the body adjectives (lean vs. overweight body shape), all $p > .05$. However, the body nouns referring to upper body parts and lower body parts differed in word frequency ($T = -31.83$, $p = .022$). The German words (L1) differed significantly in terms of emotional valence, $H(5) = 81.71$, $p < .001$, and emotional arousal, $H(5) = 68.08$, $p < .001$: the positive adjectives, $Z = 5.26$, $p < .001$, and the negative adjectives, $Z = 4.80$, $p < .001$, scored significantly higher in emotional arousal than the neutral adjectives according to the rating data provided in previous emotional word processing studies in the German language. Furthermore, and in accord with previous studies, the positive adjectives had on average significantly higher emotional valence ratings than the negative adjectives, $Z = 4.86$, $p < .001$, or the neutral adjectives, $Z = 4.85$, $p < .001$, whereas the negative adjectives had on average

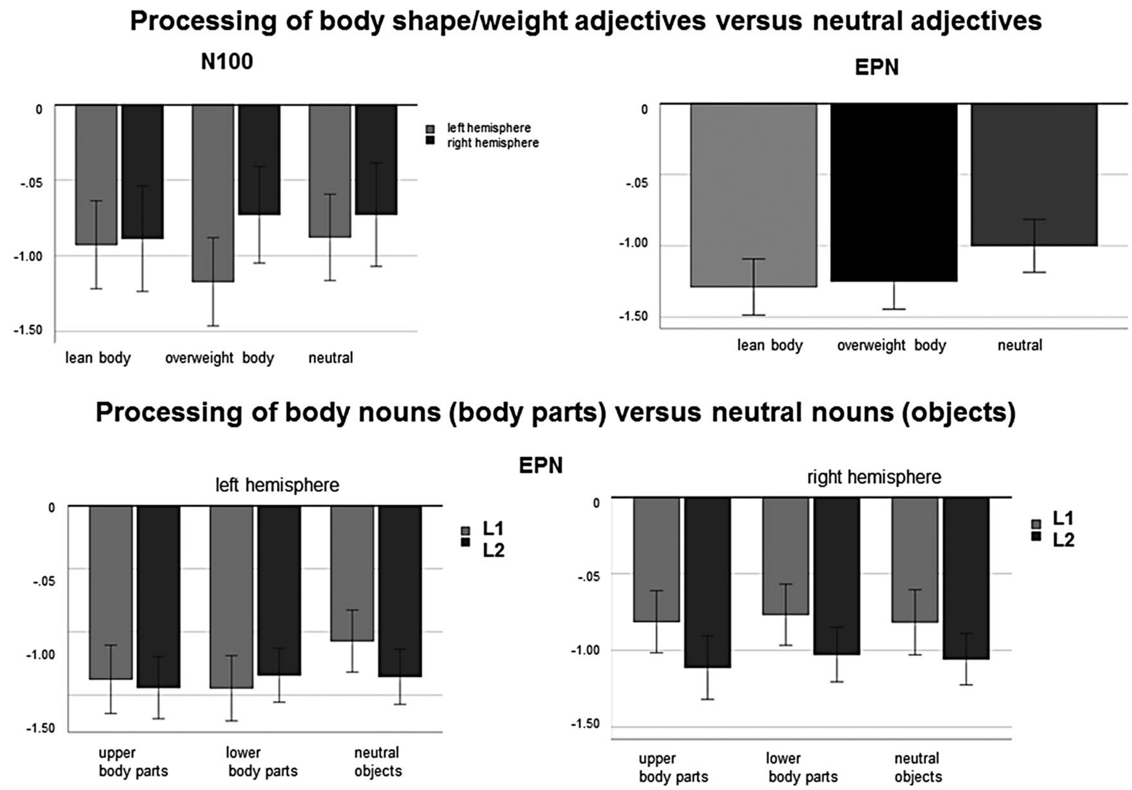

Figure 2 *Continued*

significantly lower emotional valence ratings than the positive or the neutral adjectives, $Z = -5.40$, $p < .001$, see Table 1. In addition, the German body nouns differed significantly in emotional valence (upper body, $Z = 3.48$, $p < .001$, lower body: $Z = -2.95$, $p < .003$) and arousal ratings (upper body, $Z = 5.11$, $p < .001$, lower body: $Z = 5.03$, $p < .001$) from the neutral nouns (for the results of the body adjectives, see the pilot study).

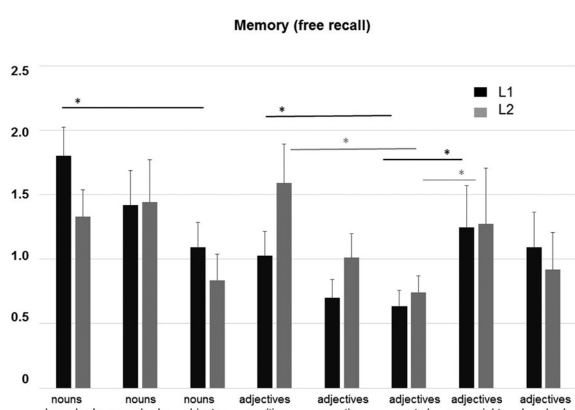

Figure 3. Memory performance (hits: correctly recalled words per language (L1 or L2) and word category, averaged across blocks) of the participants whose memory free recall could be analysed. The plots in Figure 3 represent means and standard errors, for details, please see *Material and methods and Results*.

The mean scores obtained from the pilot study for the L2 words as well as the mean scores of valence and arousal for the L1 words, and respective scores of word frequency and word length are presented in the Tables 3–6.

Discussion

This EEG-ERP study investigated the modulation of early ERP components elicited during processing of emotional and body-related and neutral words to examine whether modulation of the EPN is the ERP that is showing temporally earliest differential processing effects elicited by words belonging to different semantic word categories and word classes (adjectives vs. nouns) carrying explicit versus implicit emotional meaning. The study and its results add to the ongoing discussion of whether early emotion effects as observed in previous EEG-ERP studies, are, when conveyed by symbols such as words, electrophysiological emotion indicators. Embodiment theories have proposed a relationship between word processing, perceptual, motor and affective processing in the brain. More specifically, two different modes of processing linguistic information have been theoretically proposed. Linguistic processing based on modality independent processing and linguistic processing based on embodied and modality-dependent simulations (e.g. Barsalou et al., 2008). The current study and its result can contribute to this discussion about the function and driving factors of early ERP emotion effects in word processing by investigating whether modulation of early ERPs, specifically of the EPN, is specific to words of emotional content or observed for other word categories such as body-weight/shape and body-part related words as well and specially when presented in the native or the second language. Crucially, in contrast to emotional words, body-weight/shape or body part related words do not possess emotional content per se, nor do they explicitly refer to any emotional content or feelings as do emotional words. However, specifically, body-weight/shape related words might obtain emotionality from shared socio-cultural norms, selectively promoting a lean body image, and in conjunct with this, an aversion against overweight body shapes. If so, it was investigated if such emotionality effects will occur during the processing of body adjectives referring to a lean or overweight body shape or nouns referring to concrete body parts and if such effects will be observed in the second language too, across tasks comprising passive reading or shallow word encoding (word counting), respectively.

Time course of emotional versus neutral word processing in L1 and L2

Modulation of the EPN amplitudes averaged across left and right parieto-occipital electrode clusters showed a significant main effect of "emotion". Consistent with many findings reported in previous studies (e.g. Herbert et al., 2008; Kissler et al., 2009), the processing of emotional adjectives elicited significantly larger EPN amplitudes than the processing of neutral adjectives. Interestingly, this emotion effect occurred irrespective of task (silent reading or word counting), but not irrespective of the language in which the words were presented. The EPN amplitudes were more pronounced during active word counting than during silent reading supporting an influence of the factor "task" that was, however, independent from the EPN emotion effect. Moreover, the EPN modulation was more pronounced for the adjectives presented in the L1 compared to the L2 in the left hemisphere cluster. However, the EPN emotion effect (larger EPN amplitudes for emotional than neutral adjectives) was significantly modulated by the factor "language" irrespective of the task or the hemisphere and generally, significantly more pronounced in the L2 and for emotional adjectives compared to neutral adjectives.

The EPN effect observed in the present study cannot be explained by differences in emotional arousal or emotional valence between the words presented in the L1 or the L2. First, all L1 words including the adjectives presented in L1 were matched for emotional valence and arousal using previous word rating data (see section *Stimuli and experimental study design*). Second, as in many previous EEG-ERP studies, the emotional adjectives were significantly scoring higher in emotional arousal than neutral adjectives in both languages (L1 and L2); the negative adjectives were rated lower and the positive adjectives higher in emotional valence than the neutral adjective in the L1 and in the L2, the latter being shown in an online rating study in which women and men of comparable age and a L2 history comparable to the participants who took part in the EEG study were asked to rate the words presented in the EEG study using SAM ratings of valence and arousal (see Tables 1–6). The SAM scales provide a non-verbal judgment of valence and emotional arousal asking participants to appraise without cognitive reflection the degree of bodily physiological arousal elicited by a stimulus including a quick appraisal of the pleasantness and unpleasantness of the stimulus valence along a continuum of bodily pleasant/unpleasantness. Thus, at a subjective level, L2 adjectives referring to emotional feeling states and traits were judged to elicit similar bodily arousal states and experiences of pleasantness and unpleasantness as reported for the L1 adjectives of the previous word rating data and in both languages emotional adjectives received significantly higher arousal scores than neutral adjectives. Many previous studies found the EPN to be modulated by the emotional arousal dimension being larger for positive and negative words or pictures scoring higher in emotional arousal compared to the neutral words or pictures (e.g. Herbert et al., 2008; Kissler et al., 2007, 2009; Schacht & Sommer, 2009; for pictures e.g. Junghofer et al., 2001; Schupp et al., 2006). Some previous studies found the EPN to be modulated by the emotional valence dimension, for example EPN amplitudes being larger for positive words (matched in arousal with negative words) (Kissler et al., 2009), and this additionally when processed in a second language L2 (Conrad et al., 2011). Thus, in the brain, intuitive and by far and large non-semantic appraisals of the emotional valence and the emotional arousal intensity of a stimulus as assessed on a subjective level with the non-verbal Self-Assessment Manikin (SAM) scales (Bradley & Lang, 1994) might be reflected in the modulation of the EPN, even if the stimulus presented and to be appraised is a word. In line with this assumption, the present results suggest that during early stages of word processing, a word's emotional meaning is intuitively appraised in terms of valence and in terms of its bodily physiological arousal in the L1 as well as in the L2. This is at least in the EPN time window more pronounced in the L2, despite a general larger amplitude modulation of the EPN by the L1 irrespective of the word's content (emotional or neutral). Also, a recent study investigating affective judgments of e.g. emotional versus neutral adjectives did not find any significant processing differences between the L1 and the L2, neither in reaction times nor in the modulation of the EPN (Kissler & Bromberek-Dyzman, 2021).

In the present study, the EPN emotion effects were temporally not the earliest differentiation between emotional and neutral adjectives but preceded by an earlier emotion effect in the N100 time window. As found for the EPN modulation, the amplitudes of the N100 were modulated by the factor "emotion". However, in contrast to the EPN time window, in the N100 time window, positive adjectives describing positive feeling states and traits elicited larger N100 amplitude modulation than negative or neutral adjectives. This emotion advantage was not interacting with the factor "task", but interacting with the factors "language" and "hemisphere". In the L1 and the L2, the positive adjectives elicited significantly larger N100 modulation compared to the negative or the neutral adjectives suggesting a positivity bias. This positivity bias (positive > negative or neutral) was found in the L1 bilaterally, while in the L2 processing of negative and positive adjectives facilitated N100 amplitudes compared to neutral adjectives in the left posterior electrode cluster. A positivity bias in the N100 time window resembles the findings of a recent EEG-ERP affective judgment study using emotional and neutral adjectives presented in the L1 (German) and the L2 (English) under experimentally induced positive and negative mood induction (Kissler & Bromberek-Dyzman, 2021). Positive mood induction facilitated the processing of positive adjectives in the N100 time window. In the present study, mood was not induced experimentally. However, the participants' ratings obtained after the experiment showed that from all the word categories that were presented, positive adjectives induced self-referentiality, i.e. participants related the words to their own Self during processing. This self-referentiality effect is well known in the literature showing that participants tend to ascribe positive but not negative character and feeling states automatically to the Self (for an overview, Rogers et al., 1977). The present results are one of the few results suggesting that this self-positivity effect can operate very early in time during word processing (for later effects of positivity biases in ERP studies in a native language, see e.g. Fields & Kuperberg, 2016, 2016; Herbert et al., 2011; Watson et al., 2007). The present results furthermore imply that the N100 positivity bias can additionally occur in L2 (for positivity effects in L2 in the EPN time window see Conrad et al., 2011) and in the L2 is extended to the processing of negative words if the second language is used as a socially warm language for daily interaction.

Tentative evidence for this latter assumption comes from the exploratory analysis in which a comparison was made between the participants who reported to use English (L2) for their daily interaction or not. This showed that the positivity bias in the N100 time window selectively occurred in the group of participants who used English (L2) for daily social interaction. Thus, these early N100-related emotion effects for positive trait and state words can occur in both languages, the L1 and the L2 in time windows too early for semantic access. Critically, these effects may not be explained by word category differences in the lexical domains or by word category differences between negative and positive adjectives in emotional arousal. Word length or word frequency were controlled and did not differ between emotional and neutral words in the L1 nor in the L2, respectively. Alternatively, mood (Kissler & Bromberek-Dyzman, 2021) or, as suggested in the present study, self-referential stimulus appraisals and the use of the L2 as a warm social language for daily emotion exchange might be contextual or situational factors significantly determining which word categories are subject to early facilitated, probably pre-semantic processing. Theoretically, self-appraisals are considered internal contextual/situational factors that act on a pre-reflective experiental level as selective filters of attention or as amplifiers early during stimulus processing (Arnold, 1960; Scherer et al., 2001), with self-appraisal being independent from the stimulus modality or the stimulus' linguistic or non-linguistic nature. Interestingly, in contrast to positive adjectives, negative adjectives compared to neutral adjectives elicited larger N100 amplitudes in the L2 only and merely in the left hemisphere suggesting a negativity bias in the L2 in the language-dominant hemisphere. The stronger emotion effect for negative adjectives in the L2 continued in the L2 into the EPN time window and was positively correlated with the participants self-report of using the L2 as a social language. These L2 emotion advantages in the N100 and the EPN time windows run counter the emotional detachment hypothesis that suggests weaker or detached processing of emotions in the L2. Emotional detachment has been reported in many previous L1-L2 studies investigating primarily bodily responses to emotional L1 versus L2 words and especially using strongly unpleasant and arousing emotional words such as curse or taboo words (e.g.

Dewaele, 2004; Harris, 2004; for an overview Pavlenko, 2008, 2012). Similar to the present findings a number of recent studies using EEG or other methods do not support weaker emotion effects in the L2, and in line with the present findings suggest emotion effects in L2 as measured by eye tracking or early ERPs (Kissler & Bromberek-Dyzman, 2021; Ponari et al., 2015; Sheikh & Titone, 2016; for reaction time studies see e.g. Kühne & Gianelli, 2019 for a short review).

In sum, these findings support early, valence and arousal selective emotion effects in the L1 and the L2 in a time window of word processing of the N100 that is preceding lexico-semantic access and that is continuing into the EPN time window in which lexico-semantic access is according to previous research (e.g. Kissler et al., 2007) expected to be possibly occurring. In the present study, effects occurred bilaterally, for the left and the right posterior electrode clusters, or were more pronounced in the posterior electrode cluster of the left, language dominant hemisphere.

Research into the spatio-temporal processing of different object classes suggest that the visual object recognition system comprises subsystems of neural networks that are selectively responding to one type of visual input including words, or faces or objects (Rossion et al., 2003). According to these findings, the visual subsystems for words is more strongly lateralised to the left hemisphere compared the visual subsystems processing faces or objects, as is indicated by hemisphere specific modulation of N100-like ERP potentials to these classes of stimuli. One could, therefore, speculate that the N100 modulation found in the present study, comprising on the one hand, N100 modulation by negative adjectives in the second language (L2) in the language dominant, left hemisphere as well as on the other hand, the N100 modulation by positive adjectives in the L1 and the L2 in the left and right hemisphere, reflects two different modes of processing linguistic information: linguistic feature processing of negative, non-self-referential words in the left hemisphere and additionally non-linguistic processing of the sensory or functional (i.e. emotional) attributes of positive, self-referential words in the right, language-non dominant hemisphere. In line with this interpretation, a recent ERP-intracranial EEG study found right-hemisphere dominant N170 modulation and activity changes along the right-hemisphere dominant face processing network by words expressing facial emotions. In the present study, the processing of the emotional adjectives conveying positive feelings may similarly activate these sub-regions for non-linguistic conceptual processing (Proverbio et al., 2007). Why this is possible in the L1 or the L2 could be due to the social language use of the participants using the L2 as a warm language, albeit according to the assessment by questionnaire and a vocabulary test, all participants were similarly proficient and fluent in the L2. However, given that the present findings on social warmness of the L2 use are exploratory, the findings are speculative and preliminary and await future research and replication. According to the theoretical hypothesis of an embodied neural reuse (Pulvermüller, 2018), an intuitive understanding of the L2 emotional words in L2 users may develop in a valence-dependent manner as a cumulative experience between repeated use of the words, the emotions felt, and, as suggested and shown in previous studies by internal factors such as mood (Kissler & Bromberek-Dyzman, 2021) or by intuitive self-appraisals as suggested by the results of the present study.

Time course of body-related versus neutral word processing in the L1 and the L2

Self-reference appraisals and warm language use might not have been the only contextual factors that supported early facilitated and emotional processing of words in the L1 or the L2 in the present study. Adjectives referring to a lean or overweight body were like the emotional adjectives preferentially processed in the time window of the EPN, irrespective of the language (L1 or L2), the hemisphere or the task at hand. In addition, the processing of adjectives referring to an overweight body was associated with a more pronounced modulation of the N100 amplitudes compared to the processing of neutral adjectives, especially in the left posterior electrode cluster. Again, these effects cannot be explained by differences in lexical dimensions between the words because body adjectives and neutral adjectives did not significantly differ in word length or word frequency in the L1 or the L2. Moreover and apparently, emotional adjectives, neutral adjectives and body shape/weight related adjectives are similarly abstract and thus not more or less concrete than the other word category but certainly more abstract than the concrete body nouns.

The body shape/weight related adjectives referring to a lean or overweight body were rated as eliciting significantly higher feelings of unpleasantness/pleasantness and states of bodily arousal compared to the neutral adjectives. Valence and arousal ratings of body shape/weight related adjectives were significantly below the ratings of valence and arousal of emotional L1 or L2 adjectives but above those for the body nouns referring to upper or lower body parts. Particularly, in Western societies, women and men follow a drive for thinness, and a fear of getting fat (Levitt, 2003). Although the drive for thinness or fear of getting fat might be most pronounced in women and men with high body dissatisfaction, an anti-fat bias (intuitive aversion against overweight) and an ideal thin body image are the norm rather than the exception in the Western world, dictated by Western social norms of an ideal thin body image and body attitude stereotypes, learned early in life (Thompson & Stice, 2001). Critically, these emotionally and motivationally challenging social norms of a lean body image as well as the stigmatisation of an overweight physique are known to have a strong impact on body dissatisfaction (Hargreaves & Tiggemann, 2003) and on information processing, for example facilitating activation of approach and avoidance (e.g. Herbert et al., 2013) and attention (Markus et al., 1987). Correspondingly EEG studies found the anti-fat bias to drive selective attentive processing of pictures of obese body shapes in the time window of early affective evaluation indicated by EPN modulation (e.g. Schupp & Renner, 2001). Moreover, even earlier effects (N100, N170) have been reported for body-related adjectives and nouns referring to an overweight shape in selective samples of women scoring high on scales measuring the degree of thoughts, feelings, and behaviours related to fatness and overweight concerns (Gao et al., 2011). The present results corroborate that early facilitated processing of body-related stimuli with a socially and individually related positive or negative emotional connotation is not restricted to non-lexical stimuli or to women with a fear of fatness but that EPN modulation also occurs in a with respect to fear of fatness non-selective sample of women and men during the processing of body shape/weight related adjectives relative to neutral adjectives during both passive reading or shallow word encoding of word counting. This suggests that body traits connoting thinness or fatness undergo rapid appraisal of valence and arousal and this albeit not directly referring to a concrete feeling state such as emotional adjectives. Moreover for body-related words, such valence and arousal effects seem to occur rather spontaneously or implicitly, because the EPN effects were not interacting with the task at hand nor with the language (L1 or L2) in which the body-related adjectives were presented. For the body overweight adjectives, the EPN modulation was accompanied by N100 modulation in the language dominant left hemisphere. The modulation of the N100 and the EPN by body adjectives suggests that internal factors such as self-appraisal but also internalised social norms may promote fast linguistic feature processing (left-hemisphere dominant N100 modulation) and subsequent valence and arousal evaluation (EPN) of body weight/shape words whose meaning we learn from daily social exposure and experience to admire or reject.

Emotional adjectives, neutral adjectives and body shape/weight related adjectives were presented together with nouns referring to concrete parts of the upper or lower body as well as with neutral nouns related to objects. It is well known that, besides the preferences of neural networks for the processing of features of words, faces or objects, there are neurons in the ventral visual processing stream that selectively respond to visual presentations depicting body parts. This preference for body parts has been located in body sensitive areas of the so called fusiform body area (Schwarzlose et al., 2008), and selective processing has been shown to occur as early as in the N100 time window in studies comparing the processing of non-linguistic body part stimuli and non-body stimuli (Taylor et al., 2010). A recent study using ERP methodology and intracranial ERP methodology found that nouns denoting facial body parts (mouth, nose, etc.) elicit N170 like ERPs in the visual face processing network during a semantic decision task compared to nouns referring to non-facial body parts (García et al., 2020). In the present study, no such early preference for the processing of body part related nouns compared to neutral nouns was found in neither of the two task- or language conditions (L1 or L2). However, akin to the body shape/weight related adjectives, the processing of the nouns with references to upper or lower body parts elicited significantly larger amplitudes in the EPN time window compared to the neutral nouns but only in the L1. The EPN modulation by L1 nouns referring to body parts is in line with the results of a previous study that examined startle reflex modulation in healthy women during reading of body nouns and neutral nouns that were presented in the L1 of the participants. In this study, body-related nouns significantly modulated the acoustically elicited startle reflex suggesting activation of motivational defensive systems during reading of body nouns related to the lower body, especially in women reporting higher body dissatisfaction than the average of the all-female-sample (Herbert et al., 2013). Theoretically, EPN modulation by body nouns is commensurable with the motivational priming hypothesis, suggesting that emotional stimuli are appraised for their emotional valence and bodily arousal before calling the organism to arms (Lang et al., 1998). The latter (activation of approach and avoidance) may then occur specifically for words eliciting a negative connotation in the reader, and especially in women at risk of eating disorders (Herbert et al., 2013). However, the modulation of the EPN by body part nouns seems to be specific to the L1 and the language dominant hemisphere. This L1-restricted processing effect for concrete words (nouns) compared to adjectives may be explained by studies on word acquisition. These studies suggest that emotionally valenced words that are often also more abstract words are learned earlier in childhood compared to concrete words and this earlier acquisition seems to hold even for the L2 (e.g. Ponari et al., 2015; Vigliocco et al., 2014).

L1 and L2: memory effects, ratings, and EEG-ERPs

Words were equally remembered in both languages, the L1 and the L2. Especially emotionally positive adjectives were better remembered than neutral adjectives in the L1 and the L2 supporting the positivity bias during word processing. In addition, the body adjectives related to an overweight body size/shape were better remembered than the neutral adjectives in the L1 and the L2. In addition, body nouns related to lower body parts were better remembered than the neutral nouns in L1. The results cannot be explained by carry over effects between the L1 and the L2 words or by cognitive switch because the German L1 words and the English L2 synonyms were presented in different randomised blocks. Similar results of no memory advantage for emotional words in the L1 and even stronger L2 memory effects were reported by Ayçiçegi-Dinn and Caldwell-Harris (2004) during a shallow encoding task. In addition, a memory advantage in the L1 only was reported in another study using a deep encoding task (Ayçiçegi-Dinn & Caldwell-Harris, 2009). In the present study, RSVP designs, specifically triggering conceptual short term memory (Potter, 1984) in combination with a silent reading task or a word counting (shallow encoding) task were used which might have prevented one language to benefit more than the other from a more effortful and deeper conceptual (probably top-down) processing.

Whether the present results are in support of selective activation and retrieval of L1 and L2 stimuli as proposed by the Revised Hierarchical Model (RHM) (for an overview see Kroll et al., 2010) cannot be answered by the present study but should be investigated in future studies using shallow as well as deep encoding tasks and L2 words comprising both, L1 synonyms and new L2 words. Consensus may exists that quantitative differences between a speaker's or a perceiver's word lexicon related to the L2 and the native language (L1) exist, especially if the L2 is learned late in life and constitutes the foreign language rather than the second language used and spoken in parallel to L1. In the present study, participants had good proficiency of the L2 as was additionally indicated by the vocabulary test performance yielding an 80% accuracy of choosing the correct L1 word translation. Regarding the processing of emotions in the L1 and the L2 much previous evidence converges on the view that for late learners of a second language, the L2 feels like the emotionally detached or disembodied language (e.g. Pavlenko, 2008, 2012). The results of the present study do not lend strong support for this thesis, when looking at the self-report measures and the modulation of the early brain potentials. The English (L2) words were rated in a pilot study by a sample of $N = 208$ women and men who were not participating in the EEG study but who had similar language and sociodemographic background and language proficiency as the participants of the EEG study. The participants of the pilot study rated the emotional and body-related adjectives and nouns in the L2 as more unpleasant or pleasant and as more arousing than the neutral L2 adjectives or the neutral L2 nouns. In addition and as discussed already above, the participants taking part in the EEG study remembered emotional adjectives and body shape/weight adjectives even better or equally well in both languages.

Yet, "language" (L1 vs. L2) effects were found to modulate the N100 and EPN amplitudes. The first language effect was related to a main effect of the factor "language", i.e. the extent to which the amplitudes of the early brain potentials were overall more pronounced during word processing in L1 versus L2. The second language effect observed was related to the extent to which emotional versus neutral or body-related versus neutral processing occurred bilaterally or was more pronounced in the parieto-occipital electrode cluster of the left hemisphere. The language specific interaction effects of emotion by hemisphere that were observed in the time windows of the N100 or the EPN were valence-specific and concerning words with a negative or a positive connotation rather than the neutral words (i.e. the nouns referring to objects or the adjectives referring to neutral traits or states). Modality specific laterality is well described in early auditory speech processing, showing segmental processing in the left occipito-temporal cortex and processing of the suprasegmental features in the right temporal cortex (STG), (Kotz et al., 2003). Similarly, early hemisphere-related modality dependent visual processing has been described in time windows preceding the EPN suggesting that left-hemisphere specific neurons in the ventral visual processing stream are more excitable by lexical stimuli than by non-lexical stimuli, whereas processing of non-lexical stimuli (faces or visual objects) is more pronounced in the right ventral visual processing stream or accompanied by bilateral activation. Whether valence-specific lateralised or bilateral processing in the N100 or EPN time windows as a function of the L1 or the L2 reflects similar differences should be investigated in future studies, ideally using normalised EEG-data for hemisphere comparisons (e.g. Herbert et al., 2008). Regarding the N100 early effects preceding the EPN, in the present study, the participants' use of the L2 language as a "warm language" that is used for daily conversation seemed to have influenced the emotion effects in the L2, – in line with the general assumption of embodiment.

Conclusion, limitations and future outlook

Early and embodied?

Previous neuroscientific research including EEG-ERP studies using action words, concrete perceptual/sensory words or concrete body-related words have accumulated evidence in support of an embodied account of word processing by showing that concrete words and action words elicit modulation of early brain potentials known to be indicators of the processes involved in modality-specific feature processing of e.g. faces, bodies, actions or specific bodily somatosensory sensations (for an overview and a discussion see e.g. Pulvermüller et al., 2009). Emotional words are significantly more abstract compared to action or perception words even when instead of adjectives, nouns or verbs are used as word classes (Vigliocco et al., 2014). The present EEG-ERP study does not imply differential involvement of motor cortex regions in the processing of emotional words or body words. Such an involvement has recently been found for the processing of emotional action words (Moseley et al., 2012). Theoretically, emotions serve the purpose of bodily activation of defense and approach, of rapid appraisal of valence and arousal and feelings of pleasure or displeasure (Lang, 1995). These processes are obligatory steps of emotion processing and, therefore, they should modulate emotional word processing if word processing is embodied. Modality-preferential processing related to action simulation as for example found and reported in some previous studies might apply only to certain emotional stimuli that include the simulation of specific actions and perceptions in their approach or avoidance repertoire (such as action words, Moseley et al., 2012). For emotion processing in the brain, the embodied processes necessary for bodily approach or defense might occur via high- and low cortical and subcortical routes established between primary and secondary visual/auditory cortices and subcortical emotion structures such as the amygdala (Amaral et al., 1992; for words e.g. Herbert et al., 2009; for a discussion, e.g. Lang et al., 1997; Vuilleumier & Driver, 2007).

In the present study, the modulation of early brain potentials, specifically the EPN, was found across word categories, the EPN being enhanced during the processing of emotional adjectives connoting emotional feelings and during the processing of body-related adjectives related to body image traits or nouns related to body parts. The fact that EPN modulation was found across word categories in accordance with ratings of valence and arousal speaks to the idea that the EPN modulation is not specific to the processing of emotional words but reflects the processing stage at which probably any stimulus input is appraised for valence and arousal. Especially, when viewed from a temporal word processing perspective, it is likely that valence and arousal appraisals co-occur at the stages of visual processing at which early and first possible lexico-semantic access has been empirically and theoretically expected, i.e. around 200–300 ms respectively (for an overview, e.g. Dien, 2009).

The idea that the EPN as a brain potential might indicate both, emotional appraisal and lexico-semantic access does not exclude the assumption that the emotional appraisal processes by themselves are non-verbal, implicit and pre-reflective, especially when EPN effects are elicited bilaterally in the language dominant and the language intuitive right hemisphere. Moreover, the EPN by emotion effects emerged irrespective of the task, and therefore, seem not to require or be dependent on semantic categorisation processes. This is interesting because previous EEG-ERP studies using emotional scenes or words and RSVP designs in combination with a selective attention task or passive viewing or reading task report a relative invariance of the EPN emotion effects to manipulations of selective attention including repetition of runs in RSVP designs (e.g. Herbert et al., 2008; Kissler et al., 2009; Schupp et al., 2003, 2006). However, further studies found the EPN emotion effects to be sensitive to manipulations of low-level stimulus features such as stimulus size, font size or stimulus contrast (Bayer et al., 2012; Schindler et al., 2018) or to tasks requiring no lexico-semantic access (Hinojosa et al., 2010). Regarding the present RSVP study, there was little evidence for an interaction of the tasks (blocks of passive reading vs. blocks of word counting) with the selective processing of the words. Task as a main factor significantly influenced the amplitude modulation of all early ERP potentials (P1, N1, and EPN) in almost all word category comparisons and sometimes interacted with the language (L1 vs. L2), confirming that the task at hand plays a general role during early word processing. It is unlikely that the free recall memory examination performed after the runs contributed to these task effects. If so, one would expect that the memory examination intensified word processing in both, the passive reading and the active counting blocks as a possible anticipatory effect of the repeated surprise free recall test. Nevertheless, in the statistical analyses, the tasks never interacted with the emotionality or the body-reference of the presented words as the two distinctive semantic-affective dimensions along which emotional and body-related adjectives and nouns differed from neutral adjectives and neutral nouns during the repeated blocks of word processing.

Furthermore, the EPN emotion effects are found for non-verbal stimuli (emotional pictures and scenes) which paves the way for questions about the specificity and functionality of the EPN as a brain potential occurring during word processing temporally prior to the N400 (the indicator of semantic processing), but temporally after ERP potentials that are more selectively responding to differences in perceptual or sensory modality features of a stimulus (e.g. N100), e.g. Binder et al., 2009; Binder & Fernandino, 2015. In summary, among all different embodied and modality preferential theories, the present results support best a domain-specific embodiment account for the processing of emotional information in opposition to a perceptual-motor (sensory/functional) account (e.g. see Adorni & Proverbio, 2009). According to the accounts of domain specificity, words belonging to certain word categories are processed in specialised and functionally dissociated neural circuits in the brain due to their evolutionary advantage (e.g. see Adorni & Proverbio, 2009). The modulation patterns of the N100 and the EPN by the emotionality of the word might fit to this theoretical notion. However, these interpretations definitively require further proof from future studies. In addition, further investigations of the present observations that the self-referentiality, the social relevance of the content conveyed by the words and the use of the second language as a warm language might constitute experiental and situated factors that can facilitate early visual word processing across the L1 and the L2, should be further investigated to validate the assumptions of embodied cognition accounts that are proposing context and situatedness as two important embodied factors influencing information processing in general (Barsalou, 2010; Barsalou et al., 2008) and emotion processing in particular. Extending the findings of the present study to other languages could provide further understanding of the individual and the contextual factors that drive early facilitated processing of emotional words and body-related words and should be investigated in further studies preferably combining electrophysiological measures with other methods such as functional magnetic resonance imaging methods but also including peripheral-physiological measures such as heart rate or facial muscle activity to examine further the degree of embodied word processing across languages (L1 or L2).

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This study is basic research with no potential clinical applications and no harm or risk that would go beyond the risk of daily living. As described in the manuscript, the study followed ethical guidelines for psychological research (e.g. DGPs, 2018) including the debriefing of the participants about the purpose of the study, the methods (EEG recording), and the inclusion and exclusion criteria before the study. The study participation was voluntary, participants could opt out the study at any time of the study without undue request, they were debriefed about the inclusion and exclusion criteria before the start of the study and could ask questions, no vulnerable groups were investigated (all healthy volunteers), the EEG recordings were done in a scientific and standardised lab environment, the data was pseudonymised and the recorded data was treated according to data privacy policies. The volunteers had to give written informed consent prior to study participation.

Disclosure statement

No potential conflict of interest was reported by the author.

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