

Linguistic embodiment of affect:
Influence of valence, arousal, and dominance on cognitive and motor processes

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December 2019

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of
Doctor of Philosophy

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ABSTRACT

Unlike discrete emotions and action-related words, general affective concepts of valence, arousal, and dominance and linguistic concepts of abstractness/concreteness have not been systematically investigated from the bodily-grounded perspective, which bridges the processing of subtle linguistically encoded information and reflex physiological responses in the human body. The current project examined linguistic embodiment of valence, arousal, dominance, and concreteness during lexico-semantic processing in two different non-word contexts that were tailored to elicit different levels of task engagement, which may be directly proportional to different levels of cognitive arousal, while skin-surface electromyographic (EMG) measurements were recorded from several facial muscles during a lexical decision task. Study 1 (Experiment 1, Experiment 2) used phonotactically English-like pseudowords, which made a lexical decision task harder but also more engaging, and found strong support for the embodiment of valence and arousal and some support for the embodiment of concreteness. Study 2 (Experiment 3, Experiment 4) used consonant-string non-words, which made the lexical decision task much easier but also less engaging, and found strong support for the embodiment of valence and concreteness, while also suggesting dependence of the affective concept of arousal on the level of participants' engagement in the task. In addition, Study 2 found some support for the embodiment of the concept of dominance. These findings suggest that subtle, linguistically encoded concepts of valence, arousal, dominance, and concreteness are embodied during lexico-semantic processing, that the embodiment of arousal qualitatively differs from that of valence, dominance, and concreteness, and that non-emotionally laden stimuli and task can consistently elicit reflex bodily-grounded responses.

RÉSUMÉ

Contrairement aux émotions discrètes et aux mots sémantiquement liés aux actions, les concepts affectifs généraux de valence, d'éveil et de dominance et les concepts linguistiques d'abstraction et de concrétude n'ont pas été systématiquement examinés à partir de la perspective fondée sur le corps humain, qui relie le traitement d'informations subtiles codées linguistiquement et de réponses réflexes physiologiques dans le corps humain. Le projet en cours a examiné l'incarnation linguistique de la valence, de l'éveil, de la dominance et de la concrétude lors du traitement lexico-sémantique dans deux contextes non-verbaux différents, conçus pour susciter différents niveaux d'engagement dans la tâche, qui peuvent être directement proportionnels à différents niveaux d'éveil cognitif, tandis que des mesures électromyographiques (EMG) de la surface de la peau ont été enregistrées à partir de plusieurs muscles faciaux au cours d'une tâche de décision lexicale. L'étude 1 (Expérience 1, Expérience 2) a utilisé des pseudo-mots phonotactiquement de type anglais qui rendaient la tâche de décision lexicale plus difficile, mais également plus intéressante, et a trouvé un fort support pour l'incarnation de la valence et de l'éveil et aussi un support pour l'incarnation de la concrétude. L'étude 2 (Expérience 3, Expérience 4) a utilisé des non-mots à chaîne de consonnes, ce qui a rendu la tâche de décision lexicale beaucoup plus facile, mais également moins intéressante, et a trouvé un fort support pour l'incarnation de la valence et de la concrétude, tout en suggérant une dépendance du concept affectif d'éveil au niveau de l'engagement des participants dans la tâche. En outre, l'étude 2 a mis en évidence l'incarnation de concept de dominance. Ces découvertes suggèrent que des concepts subtils de valence, d'éveil, de dominance et de concrétude, codés linguistiquement, sont incarnés lors du traitement lexico-sémantique, que l'incarnation de l'éveil

diffère qualitativement de celle de valence, de dominance et de concrétude, et que les mots et la tâche non-émotionnels peuvent toujours susciter des réponses réflexes physiologiques dans le corps humain.

ACKNOWLEDGMENTS

I would like to thank my supervisor, Dr. Theodore Milner, whose help and encouragement had enormous impact on the creation and progress of this thesis. Thank you very much for setting up the apparatus for the experiments and for writing the Matlab code for stimuli presentation, as well as filtering, processing, and outputting the data. Also, thank you for the editorial help in the methods, results, and discussion sections of this thesis.

I would also like to thank my committee members, Dr. Marc Pell and Dr. Shari Baum, who have provided valuable feedback on the experimental design and organization of this thesis. Likewise, I would like to express my sincere thanks to Dr. Anna Borghi, who enthusiastically agreed to be my external examiner, and to Dr. Aparna Nadig, who graciously agreed to be my internal examiner and provided constructive feedback for the revision of this thesis.

Last but not least, I would like to thank Dr. Rhonda Amsel for invaluable advice regarding statistical analyses, Antoinette Sommer for generous help with administrative issues, my fellow students Alvaro Iturralde Zurita, Daniel James Dunn, and Felipe De Souza Leite for moral support, and all the participants who kindly spared their time and effort helping me with data collection – without you, I would have had no data to analyze!

To all of you, THANK YOU.

CONTRIBUTION TO ORIGINAL KNOWLEDGE

The two studies in this thesis present a set of novel investigations designed to better understand the embodiment of valence, arousal, dominance, and concreteness during online lexico-semantic processing. A novel set of English word stimuli was developed based upon affect (valence, arousal, dominance) and concreteness (abstract, concrete) factors for a lexical decision task in adult native English speakers. In Study 1 (Experiment 1, Experiment 2), a set of phonotactically English-like pseudowords was developed for the lexical decision, whereas in Study 2 (Experiment 3, Experiment 4) a set of consonant-string non-words was used instead of pseudowords. Study 2 was conducted to further examine qualitative differences between the embodiment of the affective concept of arousal (and its potential dependence upon the level of participants' engagement in the task), as compared to the embodiment of valence, dominance, and concreteness concepts. Responses to the lexical decision task both indicated accuracy and served as a measure of attention to the task on the part of naive participants, in order to understand how affect and concreteness are related to facial reflex muscle activity during lexico-semantic processing. The two studies are presented in traditional monograph-style format. At the time of submission of this thesis to McGill University, the results of these studies have not yet been submitted for publication.

CONTRIBUTION OF AUTHORS

This thesis was conceived, designed, and conducted by the first author, Anna Krusanova, under the guidance of her supervisor, Dr. Milner. The project design was significantly shaped by guidance from thesis supervisor Dr. Milner and from thesis committee members Dr. Pell and Dr. Baum. The results were analyzed by the first author, with advice from Dr. Milner and Dr. Amsel. The manuscript was written in full by the first author, with editorial suggestions from Dr. Milner, Dr. Pell, Dr. Baum, and Dr. Nadig.

1. INTRODUCTION

Abstract lexico-semantic concepts have been a major cornerstone (Mahon & Caramazza, 2008) to the theories of the embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Beffara et al., 2012; Pulvermueller, 2013). The critique is summarized as follows: “For abstract concepts there is no sensory or motor information that could correspond in any reliable or direct way to their ‘meaning’. The possible scope of the embodied cognition framework is thus sharply limited up front; at best, it is a partial theory of concepts since it would be silent about the great majority of the concepts that we have. Given that an embodied theory of cognition would have to admit ‘disembodied’ cognitive processes in order to account for the representation of abstract concepts, why have a special theory just for concepts of concrete objects and actions?” (Mahon & Caramazza, 2008). In line with the restricted perspective on embodiment, one of the major assumptions of the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014) is that affect concordant reflex muscle responses are more likely to occur if the task necessitates a somatosensory simulation of the evaluative meaning of the stimuli (Weinreich & Funcke, 2014), given that the psychophysiological responses have been observed for bodily-action-related and emotionally laden words and sentences when using tasks that explicitly alerted participants to the investigated factors of interest (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Carr et al., 2016; Delaney-Busch et al., 2016; Fino et al., 2016).

Previous research provided substantial evidence for bodily-grounded processes in response to concrete facial actions, such as ‘smile’ or ‘frown’, and abstract lexico-semantic concepts closely related to discrete emotions, such as ‘joy’/‘happiness’, ‘anger’/‘disgust’,

‘fear’/‘surprise’, by using facial action-related and emotionally laden stimuli and/or emotional and affective judgment tasks (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015; Carr et al., 2016; Fino et al., 2016). While very informative in their own right, such findings confine reflex psychophysiological responses to language to explicitly biasing contexts, which posits a serious challenge for their generalizability to more implicit lexico-semantic processing situations and to language processing in general. To address these restrictions of the embodied language processing, the current project extends the research on language embodiment to subtle linguistic contexts that do not alert participants to the investigated factors of interest, something that previous research on the embodiment of emotional/affective and abstract lexico-semantic concepts was consistently unsuccessful in demonstrating (Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Delaney-Busch et al., 2016; Fino et al., 2016). We examine facial reflex physiological activity, as indexed by skin-surface electromyography (EMG), in response to general affective (valence (how positive/pleasant or negative/unpleasant something is), arousal (how intense/active or calm/inactive something is), dominance (how controlling/powerful or submissive/powerless something is)) and lexico-semantic (abstractness (e.g. ‘explore’), concreteness (e.g. ‘sleep’)) factors, using semantically subtle words (cf. Appendix E) and a lexical decision task, both of which contribute to an indirect investigation of the factors of interest and could be generalized beyond emotionally salient contexts.

We start by discussing challenges to the embodied cognition and then move on to discussing available evidence for the linguistic embodiment of each of the investigated factors, as well as discussing prior findings from relevant domains, such as linguistic embodiment of

emotional concepts, and the contributions of the current project to research on the embodied cognition.

1.1. CHALLENGES TO EMBODIED COGNITION

The question whether human language is part of an abstract and amodal system or whether it is grounded in physical sensorimotor and limbic systems has been largely debated over the past several decades. According to the classical view, language is an amodal symbolic system (Fodor, 1983), largely reliant on an abstract conceptual domain (Mahon & Caramazza, 2008). Such an established perspective echoes as far back as to the 17th-century French philosopher René Descartes, who posited that the mind and body operate separately, with no interconnection. While the ‘strong’ version of the disembodied cognition denies any role of the sensorimotor system in linguistic processing (Fodor, 1983), the ‘strong’ version of the embodied cognition ascribes immediate and causal role to the motor system in language processing (Neininger & Pulvermueller, 2003; Boulenger et al., 2008). On the other hand, ‘weak’ versions of the disembodied (Mahon & Caramazza, 2008) and embodied (Barsalou, 1999, 2008, 2009) cognition rather emphasize the primacy of either abstract conceptual information or sensorimotor information, respectively, – does the motor system become activated prior to, or only subsequent to, access to an abstract conceptual representation in the linguistic processing? Timing of the activation of the motor system alone may not shed adequate light on this issue, even if it happens as early as within 200 ms of the presentation of an action word referring to a bodily action, e.g. ‘kick’ (cf. Pulvermueller, 2005; Boulenger et al., 2006), as, in order to prove the primacy of the sensorimotor information to language processes, one would also need to know what types of

cognitive processes (e.g. abstract conceptual processing) take place between the perception of the action word and the activation of the motor system (cf. Mahon & Caramazza, 2008). The current project does not concentrate on the timing issue as related to the embodied cognition and uses the terms ‘implicit’ and ‘embodied’ processing to signify reflex muscle activity, which happens spontaneously during lexico-semantic processing and of which participants are not consciously aware (cf. Mahon & Caramazza, 2008, for a similar definition of ‘automatic’ activation of the motor system).

While the question of the order in which different cognitive processes activate during language processing is certainly of relevance to the embodiment debate, another important question is that of causality – does the impairment of the motor system adversely influence linguistic processing? The answer is: yes. Research repeatedly showed that inhibiting facial muscle activity not only disrupts the lexico-semantic processing of relevant facial action, emotional and affective concepts (Feroni & Semin, 2009; Niedenthal et al., 2009; Baumeister et al., 2015; Davis et al., 2015; Baumeister et al., 2016) but also influences emotional states of the participants (Finzi & Wasserman, 2006; Hennenlotter et al., 2009; Lewis & Bowler, 2009; Lewis, 2012, 2018; Wollmer et al., 2012; Hexsel et al., 2013; Dong et al., 2019). Feroni & Semin (2009) found that facial action-related verbs (e.g. ‘smile’, ‘frown’) that refer to emotional expressions elicit relevant facial EMG muscle activity and that subliminally presented verbal stimuli drive muscle activation and shape social judgments, but not when muscle activation is blocked. Niedenthal et al. (2009) reported that blocking selective facial expressions by making participants hold a pen laterally between lips and teeth to prevent smiling and raising upper lip (i.e. preventing ‘joy’ and ‘disgust’ facial expressions) significantly lowers accuracy of judgments

whether a concept is “related to emotion”, while there are no significant ‘pen effects’ on judgments to ‘anger’-related or ‘neutral’ concepts, which suggests that the ‘blocking effects’ are limited to emotions that engage relevant muscles. Likewise, an event-related potential (ERP) study by Davis et al. (2015), where participants read sentences about positive and negative events (e.g. ‘She reached inside the pocket of her coat from last winter and found some [cash/bugs] inside it’) and performed a valence judgment task, while facial muscle activity was manipulated by asking them to hold a chopstick in their mouth using a position that either allowed or blocked smiling, revealed that blocking smiling increased the amplitude of the ‘semantic processing’ N400 ERP component for final words of sentences describing positive events. Since the N400 is generally associated with the retrieval of meaning from semantic memory and is larger in amplitude for items whose meanings are more difficult to access (Kutas & Federmeier, 2011), the finding of the increased N400 when the smiling was blocked suggests that relevant reflex muscle activity facilitates lexico-semantic processing. The reverse has been also demonstrated. Connell et al. (2012) showed that site-specific proprioceptive stimulation results in facilitative processing of words that were semantically related to the stimulation site – proprioceptive stimulation of hands results in facilitated responses to hand-related words and proprioceptive stimulation of feet results in facilitated responses to feet-related words.

The relationship between motor and limbic systems is intimate and manifests itself at neural, psychophysiological, and behavioral levels. People who undergo botulinum toxin (BTX) injections to reduce facial wrinkles near the nose and mouth can no longer move freely their facial muscles involved in smiling and report feeling less happy or more depressed than before due to such a motor impairment (Lewis, 2012, 2018). Alternatively, the same BTX injections on

the forehead in the area between the eyes that freeze the “frowning” muscles have been used to improve depression symptoms by preventing patients from frowning (Finzi & Wasserman, 2006; Lewis & Bowler, 2009; Wollmer et al., 2012; Hexsel et al., 2013; Dong et al., 2019). Hennenlotter et al. (2009) investigated whether facial feedback influences limbic brain responses, by applying BTX type-A (BTX-A) to the “frowning” muscle (corrugator supercilii) to denervate it during intentional imitation of angry and sad facial expressions. fMRI results showed that during imitation of angry facial expressions the reduced “frowning” muscle feedback (due to BTX-A treatment of the corrugator supercilii) attenuated activation of the left amygdala and its functional coupling with brain stem regions that are implicated in the processing of emotions that involve high arousal levels (e.g. ‘anger’). Baumeister et al. (2016) investigated the effect of facial BTX-A injections in the “frowning” muscle (corrugator supercilii), the “brow lowerer” muscle (procerus), and the “Duchenne smile” muscle (orbicularis oculi) on the processing of pictures and sentences that varied on the degrees of emotionality (e.g. ‘neutral’, ‘slightly happy’, ‘very happy’ or ‘neutral’, ‘slightly sad’, ‘very sad’) and found that BTX-A users rated ‘slightly’ emotional sentences and facial expression pictures (but not ‘very’ emotional or ‘neutral’ ones) as ‘less emotional’ after the treatment and that they also became slower at categorizing ‘slightly’ emotional facial expressions under time pressure. Such findings support a causal, rather than simply correlational, role of the reflex muscle activity in visual and lexico-semantic processing of subtle emotional information.

One of the major restrictions on the evidence in favor of the embodied lexico-semantic processing as a *generally occurring* language phenomenon is the fact that most findings were obtained using highly emotionally laden or facial action-related stimuli (Feroni & Semin, 2009,

2013), emotional judgment or affective categorization tasks (Carr et al., 2016), or both (Niedenthal et al., 2009; Davis et al., 2015; Fino et al., 2016), thereby making the generalizability of the findings limited to explicitly biasing contexts. With previous research *not* finding evidence for the embodiment when using non-emotion-specific / non-body-specific stimuli or non-emotional / non-affective tasks (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Fino et al., 2016), the challenges for viewing evidence in favor of the embodied linguistic processing as a general language phenomenon are serious. Niedenthal et al. (2009) had participants judge emotion-evoking (e.g. ‘cuddle’, ‘vomit’, ‘fight’), emotion-denoting (e.g. ‘delighted’, ‘nauseous’, ‘furious’), and neutral (e.g. ‘pocket’, ‘chair’; ‘programmed’, ‘quantified’) words, corresponding to concrete (Experiment 1) and abstract (Experiment 2) concepts, while facial EMG activity was recorded from their cheek (zygomaticus major), brow (corrugator supercilii), eye (orbicularis oculi), and nose (levator labii superioris) muscles. Results of both experiments confirmed greater EMG activity in relevant muscles in response to emotional vs. neutral words in an emotionally focused task (where participants had to indicate whether the referent of each word was associated with an emotion or not) but not in a detection focused task (where participants had to indicate whether each word presented on the computer screen was written in capital or small letters). Foroni & Semin (2009; silent reading task) and Fino et al. (2016; affective judgment task) obtained similar results, where they found greater facial EMG activity in relevant muscles in response to concrete facial action-related words (e.g. ‘smile’, ‘frown’) than to abstract emotional words (e.g. ‘funny’, ‘irritate’), with both significantly differing from the baseline. Weinreich & Funcke (2014) highlight such a limited nature of the embodied cognition by arguing that valence-concordant EMG responses can

be explained “as somatosensory simulation driven by task-dependent processing strategies” rather than “as an unconditional effect of mere stimulus processing”, which suggests that experimentally biasing methods, such as tasks that explicitly alert participants to the affective aspects of the stimuli, may be a *necessity* for eliciting embodied responses to the affective/emotional concepts. If so, the scope of embodied cognition may be indeed “sharply limited up front” (cf. Mahon & Caramazza, 2008).

The main cornerstone to the embodied cognition are non-emotionally salient abstract lexico-semantic concepts (e.g. ‘justice’, ‘patience’, ‘beauty’). As summarized in Mahon & Caramazza’s (2008) claim at the beginning of this thesis, “[f]or abstract concepts there is no sensory or motor information that could correspond in any reliable or direct way to their ‘meaning’”, which implies that theories of embodied cognition “would be silent about the great majority of concepts that we have” and questions that if “an embodied theory of cognition would have to admit ‘disembodied’ cognitive processes in order to account for the representation of abstract concepts, why have a special theory just for concepts of concrete objects and actions?” The question is daunting. Although abstract lexico-semantic concepts have been shown to elicit bodily-grounded responses, the evidence has been so far limited to abstract emotionally laden words (e.g. ‘entertaining’, ‘repelled’, ‘enjoy’; cf. Foroni & Semin, 2009; Niedenthal et al., 2009; Fino et al., 2016). Similar to concrete action- and physical effort-related words, such as ‘bite’, ‘grasp’, or ‘push’, which have been consistently demonstrated to elicit respective somatotopic activations in brain motor areas (Hauk et al., 2004; Pulvermueller et al., 2005; Tettamanti et al., 2005; Aziz-Zadeh et al., 2006), abstract emotionally laden words, such as ‘abandon’, ‘appreciate’, ‘cruel’, ‘inspiring’, or ‘luxury’, have been shown to evoke brain activity within the

limbic system, including the amygdala and prefrontal cortex (PFC), which are primarily responsive to the affective concept of arousal (Adolphs et al., 1999; Kensinger & Schacter, 2006; Lewis et al., 2007; Wilson-Mendenhall et al., 2013; Lai et al., 2015; although see Winston et al., 2005; Anders et al., 2008; Herbert et al., 2009), and orbitofrontal cortex (OFC), which mostly responds to the affective concept of valence (Protopopescu et al., 2005; Lewis et al., 2007; Goodkind et al., 2012; Wilson-Mendenhall et al., 2013), as well as precuneus and cingulate cortex, which activate in response to abstract lexico-semantic concepts (Tettamanti et al., 2008; Moseley et al., 2012; Desai et al., 2013; Saxbe et al., 2013; Tomasino et al., 2014; Vigliocco et al., 2014). It has been also established that abstract linguistic stimuli tend to emphasize emotional or affective information, while concrete words are grounded rather in sensorimotor information (Noppeney & Price, 2004; Desai et al., 2010; Kousta et al., 2011; Moseley et al., 2012; Newcombe et al., 2012; Sakreida et al., 2013; Vigliocco et al., 2014). As such, respective brain activations of the limbic (Tettamanti et al., 2008; Moseley et al., 2012; Desai et al., 2013; Saxbe et al., 2013; Tomasino et al., 2014; Vigliocco et al., 2014) and motor systems (Boulenger et al., 2008; Scorolli et al., 2012; Lauro et al., 2013; Innocenti et al., 2014; Vega et al., 2014), as well as reflex muscle activity (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Gough et al., 2013; Davis et al., 2015; Carr et al., 2016; Fino et al., 2016), supports the embodiment of concrete action-related and abstract emotion-related lexico-semantic concepts.

The fact that the embodiment of abstract lexico-semantic concepts has been so far limited to emotionally salient contexts posits a weighty restriction on the generalizability of embodied cognition to broader language processing domain. Instead of focusing on relating the time course of reflex bodily-grounded responses to the interplay between the motor and abstract processing

systems (cf. Mahon & Caramazza, 2008), the current project focuses instead on the investigation of automatic, unconscious, implicit, spontaneous (thereafter, all of the above are referred to as ‘reflex’) physiological responses to abstract lexico-semantic concepts (i.e. how abstract or concrete a word is, e.g. ‘inspire’ vs. ‘caress’) and general affective categories, such as valence (i.e. how positive/pleasant or negative/unpleasant something is, e.g. ‘joke’ vs. ‘ruin’), arousal (i.e. how exciting/intense or calming something is, e.g. ‘celebrate’ vs. ‘meditate’), and dominance (i.e. how in-control/powerful or submissive/powerless something is, e.g. ‘insist’ vs. ‘owe’). The reasons for our choice are twofold. It is important to establish the extent of the embodied cognition from the linguistic perspective, as reflected by relatively non-biasing stimuli and task, especially given that prior research observed embodied effects *only* when using explicitly biasing experimental conditions (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Fino et al., 2016). Whereas discrete emotion and facial action concepts (e.g. Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Baumeister et al., 2015, 2016; Davis et al., 2015; Fino et al., 2016) may, arguably, induce facial reflex muscle activity simply due to their relatively straightforward relation to facial expressions, it is important to extend the investigation of embodied cognition to more general factors of affect (i.e. valence, arousal, dominance) and concreteness (i.e. abstract/concrete words) to demonstrate that subtle lexico-semantic concepts, which may be more representative of everyday language use, are also capable of systematically resonating within human body. After the current project establishes the outlined objectives, further research might follow up on present studies by examining timing and causality issues (i.e. demonstrating that activation of motor or sensory

information constitutes the semantic analysis of linguistic stimuli) during online lexico-semantic processing.

1.2. EMBODIMENT OF AFFECT

Below, we review research on the embodiment of the affective concepts of valence and arousal (to our knowledge, the embodiment of dominance has not yet been investigated, so we review literature on the embodiment of emotions and facial expressions that may be related to the affective concept of dominance). While theories of emotions postulate discrete emotions (e.g. ‘joy’/‘happiness’, ‘anger’/‘disgust’, ‘fear’/‘surprise’) as analytical primitives, non-decomposable into smaller analytical units (Ekman et al., 1983; Ekman, 1992, 1993), dimensional theories of affect view discrete emotions as unique combinations of more basic general affective categories, such as valence and arousal (Russell, 1980, 2003; Russell et al., 1989; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016), and sometimes also dominance (Russell & Mehrabian, 1977; Knutson, 1996). As related to the current project, the important point is that discrete emotions, similar to facial action-related words, are directly related to specific facial expressions and thus may relatively easily resonate within facial reflex muscle activity (cf. Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015; Baumeister et al., 2015, 2016; Fino et al., 2016), whereas general affective categories are not only much subtler semantic concepts but also less studied phenomena in terms of language embodiment, as reflected by reflex muscle activity (cf. Carr et al., 2016). Since we are interested in examining embodied responses to those subtle, more general semantic factors,

in order to be able to extend the theories of embodied cognition to broader (instead of emotionally confined) language processing domain, we are not concerned with contrasting the theories of affect and the theories of emotion but rather use the findings from the emotion-focused studies as a source of relevant information when discussing the factors of interest pertinent to the current project.

1.2.1. VALENCE

Out of all affective dimensions, valence has been most studied, though its linguistic examination from the reflex muscle activation perspective has been limited to hedonic judgment tasks (cf. Davis et al., 2015; Carr et al., 2016; Fino et al., 2016). Carr et al. (2016) investigated how perceptual fluency of pseudowords influences approach-related voluntary arm movements and found that response times (RTs) to initiate arm flexion are faster in response to perceptually fluent pseudowords when participants had to rapidly classify pseudowords as either ‘good’ or ‘bad’. Such an effect was present only in the affective classification task and not in the animacy distinction task. EMG findings paralleled behavioral results in that fluent pseudowords elicited activity over the “smiling” muscle (zygomaticus major) but, again, only in the affective classification task and not in the animacy distinction task. Similar linguistic processing task-contingent results for valence in the “smiling” muscle (zygomaticus major) were obtained by Davis et al. (2015) and Fino et al. (2016), although their findings were additionally contingent upon the semantically polarized nature of their stimuli, as the authors themselves admit, “to encourage the processing of the sentence’s affect” (Davis et al., 2015) or “to ensure that participants processed the emotional content of target stimuli” and “maximize the chance of

detecting robust emotionally congruent face reactions” (Fino et al., 2016). Such an ‘encouragement’, however, sharply limits the generalizability of the findings to highly salient contexts, which may not be representative of broader language processing, and therefore does not reveal much about the linguistic embodiment of affect beyond artificial experimental boundaries.

Similarly, picture and imagery studies on valence (Cacioppo et al., 1986; Wexler et al., 1992; Witvliet & Vrana, 1995; Dimberg et al., 2002; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Beffara et al., 2012; Bornemann et al., 2012; Tan et al., 2012; Heller et al., 2014; Davis et al., 2017) reported systematic facial reflex muscle activity in response to positive valence in the “smiling” muscles (zygomaticus major, orbicularis oculi) and to negative valence in the “frowning” muscle (corrugator supercilii). However, visual non-verbal stimuli (e.g. pictures) and imagery tasks may be even more explicitly salient in terms of affective and emotional information than emotionally laden words or linguistic affective judgment tasks, which confines the results of picture/imagery studies to overtly biasing contexts even more than the results of linguistic studies that used emotionally laden / facial action-related stimuli or emotional/affective judgment tasks and may not be representative of reflex muscle activity in more subtle / less biasing semantic processing and language processing in general.

Less biased evidence for the embodiment of valence comes from studies that examined bodily-grounded responses to abstract notions of ‘good’ and ‘bad’, which have concrete physical counterparts of ‘right’ and ‘left’. Although idioms in English associate ‘good’ with right (e.g. ‘in your right mind’, ‘do the right thing’) but not with left (e.g. ‘have two left feet’), right- and left-handers implicitly associate positive valence concepts, such as ‘goodness’, ‘intelligence’,

‘attractiveness’, ‘honesty’, etc., more strongly with the side of space on which they themselves can act more fluently with their dominant hands, and negative ideas more strongly with their non-dominant side (Casasanto, 2009). Such a relation between valence and psychophysiological responses concerns the implicit preference for physical handedness rather than non-physical sidedness. Vega et al. (2013) investigated whether the compatibility effect between positive emotional valence and the space surrounding the dominant hand and negative valence and the space surrounding the non-dominant hand holds when hand and side carry incongruent information, and whether it is related to hand or to side. They conducted two experiments that used an incongruent hand/response key assignment, where participants had their hands crossed. Participants were instructed to respond with their right vs. left hand (Experiment 1) or with the right vs. left key (Experiment 2). In both experiments, they found a compatibility effect related to hand, indicating that the association between hand and valence overrides the one between side and valence when hand and side carry contradicting information, again confirming the body-specificity hypothesis and providing evidence for the perceptuomotor basis of even some of the most abstract ideas, such as ‘goodness’ and ‘badness’.

By contrast, both left- and right-handers show the same preference to associate good things with ‘up’ and bad things with ‘down’. For instance, Casasanto & Dijkstra (2010) showed that simple motor actions influence how people produce language with positive and negative emotional valence. Participants were asked to recount positive or negative autobiographical memories while moving marbles upward or downward between two cardboard boxes. They were faster to tell positive memories while moving marbles up and negative memories while moving them down, consistent with linguistic metaphors for positive and negative emotions, such as

‘their spirits rose’ and ‘their hopes fell’. In addition, upward marble movements caused participants to recount more positive events, while downward movements induced more recollections of negative events from their personal experiences, which suggests that seemingly irrelevant marble movements not only influenced how fluently stories could be produced but also made the story-telling more replete by increasing memory access to relevant emotional content.

Physical embodiment of valence is further substantiated by research on causative involvement of the motor processes in the perception of positive and negative concepts. Casasanto & Chrysikou (2011) found that right-handers’ tendency to associate ‘good’ with right and ‘bad’ with left can be reversed as a result of both long- and short-term changes in motor fluency. They examined patients who were right-handed prior to a unilateral stroke and found that those with disabled left hands associated ‘good’ with right, but those with disabled right hands associated ‘good’ with left, as natural left-handers do. They also found a similar pattern in healthy right-handers whose right or left hand was temporarily handicapped in the laboratory. Even a few minutes of acting more fluently with the left hand was capable of changing right-handers’ implicit associations between space and emotional valence, causing a reversal of their usual judgments, which suggests that motor experience plays a causal role in shaping affective association and abstract thought.

It is important to emphasize that such an association between valence and motor action relates to the egocentric perception of motor fluency. Fuente et al. (2015) investigated whether observing manual actions that are performed with greater or lesser fluency can influence observers’ space-valence associations. In two experiments, they assigned one participant (the actor) to perform a bimanual fine motor task while another participant (the observer) watched.

Actors were assigned to wear a ski glove on either the right or left hand, which made performing the actions on this side of space disfluent. In Experiment 1, observers stood behind the actors, sharing their spatial perspective. After motor training, both actors and observers tended to associate ‘good’ with the side of the actors’ free hand and ‘bad’ with the side of the gloved hand. To determine whether observers’ space-valence associations were computed from their own perspectives or the actors’, Experiment 2 had the observer stand face-to-face with the actor, reversing their spatial perspectives. After motor training, both actors and observers associated ‘good’ with the side of space where fluent actions had occurred from their own egocentric spatial perspectives (if ‘good’ was associated with the actor’s right-hand side, it was likely to be associated with the observer’s left-hand side). These findings suggest that even vicarious experiences of motor fluency can shape valence judgments and that observers spontaneously encode the locations of fluent and disfluent actions in egocentric spatial coordinates.

While the handedness-related research on valence provides a relatively direct evidence of the embodiment of the positivity/negativity concepts, the dependence of the bodily-grounded findings of relevant facial reflex muscle activity on highly biasing stimuli and/or highly biasing tasks (cf. Foroni & Semin, 2009, 2013; Neta et al., 2009; Niedenthal et al., 2009; Gough et al., 2013; Davis et al., 2015; Carr et al., 2016; Fino et al., 2016), undermines the generalizability of the psychophysiological processes in response to general semantic notions of pleasantness/unpleasantness and prompts the investigation of reflex muscle activity in response to valence using rather indirect and subtle means.

1.2.2. AROUSAL

The concept of arousal has not been investigated nearly as extensively as valence within the language processing domain, yet, in contrast to valence, the evidence that substantiates the embodiment of arousal has been obtained using relatively implicit methods and therefore may be more generalizable to broader language processing. Unlike valence, bodily-grounded responses to arousal are not dependent upon the emotional/affective salience of the task, which suggests that valence and arousal act independently during lexico-semantic processing. An ERP study by Delaney-Busch et al. (2016) presented two groups of participants with the same words that varied on the dimensions of valence (pleasant, unpleasant, and neutral, e.g. ‘food’, ‘stingy’, ‘sculpture’) and arousal (high and low, e.g. ‘alien’, ‘feminine’) and found that the task made a substantial contribution to how valence and arousal modulated the late positive complex (LPC) ERP component, which is thought to reflect sustained emotional and evaluative processing. When participants performed a semantic categorization task (where they were told to identify ‘animal’ words) in which emotion was not directly relevant to task performance, the LPC showed a larger amplitude for high-arousal than for low-arousal words, but no effect of valence. In contrast, when participants performed an overt valence categorization task, the LPC showed a large effect of valence (with unpleasant words eliciting the largest positivity), but no effect of arousal. Since automatic brain responses to arousal are not dependent on the task that explicitly alerts participants to the intensity/calmness semantic scale (i.e. animal detection task does not draw participants attention to the concept of arousal), whereas automatic brain responses to valence emerged only when participants were overtly exposed to the positivity/negativity

classification task, such a dichotomy suggests that not all affective dimensions have similar processing limitations, at least as evidenced by relevant brain activity.

From a non-linguistic embodiment perspective, however, reflex muscle activity in response to the concept of arousal revealed inconsistent results, with some studies finding support for its embodiment in the “smiling” (zygomaticus major), “frowning” (corrugator supercilii), and “squinting” (orbicularis oculi) muscles (Cacioppo et al., 1986; Witvliet & Vrana, 1995; Bradley & Lang, 2000; Zhang et al., 2011; Tan et al., 2016) while others not (Simons et al., 1999; Tan et al., 2012). Notably, all of these three muscles semantically relate to valence, the positivity/negativity concept, rather than to arousal, the intensity/calmness dimension. With the bulk of research on the embodiment of arousal concentrating on measuring heart rate, pupil dilatation, and skin conductance responses (Vrana et al., 1986; Vrana, 1993; Witvliet & Vrana, 1995; Simons et al., 1999; Reagh & Knight, 2013; Latham et al., 2017), persistent inconsistencies in reflex muscle activation in response to the concept of arousal continue to posit a gap in our understanding of the embodiment of the intensity/calmness dimension. The reason for the lability of reflex muscle activity as related to arousal could lie in the fact that this affective concept has been examined for the muscles that do not semantically relate to the notions of intensity/calmness. Simons et al. (1999) used two presentation modes for emotion-eliciting pictures and found that, while valence was unresponsive to stimulus motion, there was an interaction between high arousal and picture motion in the corrugator supercilii, the “frowning” muscle, which is generally associated with negative valence and negative emotions (cf. Cacioppo et al., 1986; Hess et al., 1992; Wexler et al., 1992; Vrana, 1993; Witvliet & Vrana, 1995; Simons et al., 1999; Dimberg et al., 2000, 2002; Yartz & Hawk, 2002; Hu & Wan, 2003;

Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Beffara et al., 2012; Bornemann et al., 2012; Dimberg & Thunberg, 2012; Tan et al., 2012; Kret et al., 2013; Carr et al., 2014; Heller et al., 2014; Davis et al., 2015; Latham et al., 2017; Barrett et al., 2019). Importantly, moving picture presentation implies sustained attention to the stimulus (Simons et al., 1999), which, in turn, may be correlated with increased cognitive arousal levels.

Should there be a directly proportional relation between the affective concept of arousal and bodily-grounded psychophysiological processes, such a relation could be informative for the current project in terms of reconciling inconsistent reflex muscle activation findings for arousal. Kever et al. (2015) examined whether various levels of physiological arousal interact with the processing of emotional words and found that categorization accuracy of high-arousal words (e.g. ‘passion’, ‘terror’) improved after a cycling session (increased physical arousal), while categorization accuracy of low-arousal words (e.g. ‘patience’, ‘fatigue’) improved after a relaxation session (reduced physical arousal), with neutral words (e.g. ‘bench’, ‘fork’) remaining unaffected by physiological arousal conditions. Furthermore, Kever et al. (2017) revealed faster RTs for low-arousal words after the relaxation session but no such treatment effect for high-arousal and neutral words. The fact that congruence was observed for the lexico-semantic processing of low and high arousal words and corresponding physical states suggests that actual levels of physiological arousal modulate cognitive access to the affective concept of intensity/calmness. Although the evidence for the embodiment of arousal from the reflex muscle activation perspective revealed inconsistent results (cf. Simons et al., 1999; Tan et al., 2012; vs. Witvliet & Vrana, 1995; Bradley & Lang, 2000; Zhang et al., 2011; Tan et al., 2016), the existence of such a direct psychophysiological proportionality (Simons et al., 1999; Kever et al.,

2015, 2017) may be particularly helpful for reconciling the inconsistencies in reflex muscle activity in response to the affective concept of arousal; we return to this point in section 2 where we motivate the two studies for the current project.

1.2.3. DOMINANCE

As opposed to the affective concepts of valence and arousal, which have received attention within the literature on embodied cognition, the affective concept of dominance (i.e. how in-control/powerful vs. submissive/powerless something is) has been generally regarded as a higher cognitive process of ‘control’ and was therefore excluded from the set of primary affective dimensions (Russell, 1980, 2003; Russell et al., 1989; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016). Yet, early versions of dimensional affect theories, such as the valence-arousal-dominance theory of emotion (Russell & Mehrabian, 1977; Knutson, 1996), did recognize the importance of dominance due to the fact that this affective dimension distinguishes between some of the basic emotions, such as ‘anger’ and ‘fear’, both of which have negative valence and high arousal characteristics but differ in terms of dominance, with ‘anger’ exhibiting a ‘controlling’ trait and ‘fear’ featuring a ‘submissive’ component. Given the absence of literature on the embodiment of dominance, in the remaining discussion we concentrate on evidence for the embodiment of emotions that are rated ‘low’ and ‘high’ on the dominance scale.

Differential discrimination of facial expressions along the axis of dominance has been repeatedly reported in literature (Knutson, 1996; Montepare & Dobish, 2003; Hess et al., 2004;

Hareli & Hess, 2010; Hareli et al., 2009; Gill et al., 2014; Jack et al., 2014; Jack & Schyns, 2015; Rot et al., 2017). Behavioral studies showed systematic classification of emotional facial expressions of ‘happiness’, ‘anger’, ‘surprise’, and ‘disgust’ as being rated ‘high’ on the dominance scale, while emotional facial expressions of ‘fear’, ‘sadness’, and ‘shame’ consistently receiving ‘low’ dominance ratings (Knutson, 1996; Montepare & Dobish, 2003), with neutral facial expressions being rated dominant for men but not for women (Hareli et al., 2009). Physiological correlates of dominance, as manifested by the activation of facial muscles around the lips, nose, and brows (Knutson, 1996; Gill et al., 2014; Jack et al., 2014; Jack & Schyns, 2015), which have been reported in facial classification tasks as perceptual cues to whether someone looks dominant or submissive, could be particularly relevant to the investigation of the embodiment of the concept of dominance, because these findings may provide a measurable way to infer reflex muscle responses to stimuli that are rated high and low on dominance dimension. For instance, Gill et al. (2014) found that participants rated facial expressions that showed wrinkling nose and snarling lips as ‘high’ on dominance, which suggests that a more dominant look can be achieved by wrinkling the nose and raising the upper lip so that the mouth is slightly open. In turn, muscles that have been consistently reported as indicators of ‘disgust’, an emotion that is generally rated ‘high’ on the dominance scale, include corrugator supercilii, which is involved in “frowning” facial expressions, levator labii superioris, which is involved in “raising upper lip”, and orbicularis oculi, which is involved in “squinting” (Vrana, 1993; Yartz & Hawk, 2002; Hu & Wan, 2003; Wolf et al., 2005; Niedenthal et al., 2009). On the other hand, ‘low’ dominance has been associated with raising and lowering eyebrows, showing

dimples, stretching lips, and lowering chin (Knutson, 1996; Gill et al., 2014; Jack et al., 2014; Jack & Schyns, 2015).

As related to the current project, the examination of dominance aims to explore whether the general affective concept of ‘control’/‘submission’, despite being disregarded by research on the embodied cognition and by research on affect, may be put on par with the other two traditionally discussed affective dimensions of valence and arousal. Similar to the investigation of valence and arousal, we aim to do so via relatively subtle and indirect experimental means in order to avoid introduction of explicit stimuli-based or task-based biases that may limit the generalizability of the findings.

1.3. EMBODIMENT OF CONCRETENESS

Since abstract lexico-semantic concepts pose a major challenge for the embodiment theories (cf. Mahon & Caramazza, 2008), investigating reflex muscle activity in response to concreteness (i.e. abstract/concrete words) is vital for pushing the boundaries of the embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Beffara et al., 2012; Pulvermueller, 2013). While bodily-grounded processes have been firmly established within the literature on language embodiment for concrete action-related words (Noppeney & Price, 2004; Tettamanti et al., 2005, 2008; Aziz-Zadeh et al., 2006; Desai et al., 2010; Liuzza et al., 2011; Willems et al., 2011; Foroni & Semin, 2013; Sakreida et al., 2013; Sidhu et al., 2014; Tomasino et al., 2014), including facial action-related words and sentences (Foroni & Semin, 2009, 2013; Fino et al., 2016), the evidence supporting the embodiment of abstract lexico-semantic concepts is currently limited to emotionally laden

abstract words (Foroni & Semin, 2009; Niedenthal et al., 2009; Moseley et al., 2012; Saxbe et al., 2013; Vigliocco et al., 2014; Fino et al., 2016).

It is well established that concrete and abstract words are processed differently by the brain (Tettamanti et al., 2008; Kousta et al., 2011; Liuzza et al., 2011; Scorolli et al., 2011, 2012; Newcombe et al., 2012; Sakreida et al., 2013; Tomasino et al., 2014; Vigliocco et al., 2014). Scorolli et al. (2011) found that homogenous (i.e. abstract-abstract and concrete-concrete) verb-noun combinations are processed faster than heterogeneous (i.e. abstract-concrete and concrete-abstract) verb-noun combinations, suggesting that abstract and concrete concepts form part of different processing systems. Unlike concrete words, lexico-semantic processing of abstract words seems to be tightly linked to their emotional and affective characteristics. Kousta et al. (2011) found that the processing advantage for abstract words was due to differences in emotional valence between concrete and abstract words (i.e. whether the words had positive, negative, or no emotional association). When Kousta et al. (2011) included the entire range of concreteness and valence ratings as a predictor, the effects of concreteness (i.e. faster responses for abstract than concrete words) disappeared, which suggests that the response time (RT) advantage for abstract words was mediated by their greater affective associations. Stronger support for the claim that abstract concepts may be rooted in the neural systems, which mediate processing of emotional information, comes from functional magnetic resonance imaging (fMRI) studies that examined interrelations between emotional and abstract words and site-specific brain activity. In a semi-structured emotion induction interview task, Saxbe et al. (2013) used open-ended verbal responses to ‘admiration’- and ‘compassion’-provoking narratives and subsequently examined blood-oxygen-level-dependent (BOLD) activity to the same narratives

during fMRI scanning. They found that during emotion trials greater use of affective (e.g. ‘happy’, ‘inspiring’, ‘crying’, ‘abandon’, ‘cruel’) relative to cognitive (e.g. ‘think’, ‘know’, ‘assume’, ‘should’, ‘acknowledge’) words predicted more activation in somatosensory areas SI and SII, middle anterior cingulate cortex, and insula, which suggests that both sensory and limbic systems are involved in processing emotionally laden abstract lexico-semantic concepts. Similarly, Vigliocco et al. (2014) found greater engagement of the rostral anterior cingulate cortex during abstract word processing, a brain area that is associated with emotion processing (cf. Etkin et al., 2006). For abstract words, activation of this area was modulated by the degree of positive or negative affective association of the stimuli, which supports the view that engagement of the limbic system (known for emotional processing) is essential for processing abstract words. As such, concrete and abstract semantic representations differ in terms of whether sensory, motor, or affective information has the greatest weight, with sensorimotor information being more important for concrete lexico-semantic concepts and affective information playing a greater role for abstract concepts. However, it is still unclear whether non-bodily-action-related concrete words and non-emotionally laden abstract words that vary on ratings of different affective dimensions (i.e. valence, arousal, dominance) systematically resonate within psychophysiological processes, such as reflex muscle activity, an involuntary motor response that occurs spontaneously, without participants being aware of it.

1.4. ELECTROMYOGRAPHY AS A GATEWAY TO LANGUAGE EMBODIMENT

While there are many ways to approach the investigation of language embodiment, the current project uses skin-surface electromyography (EMG) as means to examine reflex

involvement of facial muscles in response to words that vary on the dimensions of valence (i.e. how pleasant/positive or unpleasant/negative something is), arousal (i.e. how intense/exciting or calm/inactive something is), dominance (i.e. how in-control/powerful or submissive/powerless something is), and concreteness (i.e. how concrete or abstract something is). Previous research already established the effectiveness of EMG in discerning facial reflex muscle responses to emotional and facial action-related words (Wexler et al., 1992; Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015, 2017; Fino et al., 2016) and pictures (Dimberg, 1982, 1986; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Heller et al., 2014; Latham et al., 2017). It is, however, unclear whether EMG could be successful in discerning less salient concepts, such as affect (valence, arousal, dominance) and concreteness (abstract/concrete lexical semantics), in words that are not emotionally laden and in a task that does not explicitly involve emotional or affective processing. The current project thereby extends the applicability of the EMG methodology to a novel investigation of the embodiment of affect and concreteness during real-time lexico-semantic processing.

The idea behind the use of EMG as an objective measure of facial expressions has emerged mainly through a de-emphasis on inferring the ‘meaning’ of the expression and an increase in emphasis on direct description (Rinn, 1984; Cohn et al., 2007). That is, one can objectively describe facial expressions by simply listing the position and movements of various lines, wrinkles, folds, and facial landmarks, without regard to the semantic or emotional meaning(s) expressed. Yet, for more subtle facial activity, description in terms of muscles is a more direct reflection of the actions of the nervous system than is movement of the skin, as it allows a more revealing description of the behavior than is permitted by accounts of skin

movement (Rinn, 1984; Cacioppo et al., 1986). Cacioppo et al. (1986) showed that facial EMG activity can reliably differentiate both valence and arousal characteristics of affective facial reactions, which could not be successfully done by independent judges who viewed video recordings of the participants' facial displays and failed to discern whether a positive or negative stimulus had been presented or whether a mildly or moderately intense stimulus had been presented.

EMG muscle descriptions may be made interpretable via their associations with stimuli and task designed to elicit particular unconscious facial responses (Wexler et al., 1992; Dimberg et al., 2000, 2002; Bornemann et al., 2012), on the one hand, and with concurrent brain activity (Heller et al., 2014; White et al., 2014; Rymarczyk et al., 2019), on the other. Such associations provide a relatively direct measure of the embodied cognitive processes that resonate not only in the brain but also in the face or body. In fact, facial EMG has been reliably shown to measure reflex muscle activity in naive participants during visual (Cacioppo et al., 1986; Dimberg et al., 2000, 2002; Larsen et al., 2003; Bornemann et al., 2012) and auditory (Cacioppo et al., 1986; Wexler et al., 1992; Bradley & Lang, 2000; Larsen et al., 2003) cognitive processing. Although the responsiveness of individuals to EMG could be dependent upon their empathy level (Dimberg & Thunberg, 2012; Rymarczyk et al., 2019), reflex muscle activation is tightly intertwined with brain activity and therefore can serve as an objective measure of both conscious and unconscious cognitive processing (Hennenlotter et al., 2009; Gothard, 2014; Heller et al., 2014; White et al., 2014; Rymarczyk et al., 2019).

Tight interconnections between the limbic (i.e. emotional processing) brain system and facial reflex muscle activity have been demonstrated by studies that combined fMRI and EMG

methodologies. Heller et al. (2014) showed that trial-by-trial EMG increases in the “frowning” muscle (corrugator supercilii) activity in response to negative pictures were associated with greater amygdala activity and a concurrent decrease in ventromedial PFC activity, which highlights the reciprocal relation between amygdalar and ventromedial PFC in the cognitive processing of valence, on the one hand, and facial reflex muscle activity, on the other. Similar findings have been reported in neuroscientific investigation of discrete emotions. Rymarczyk et al. (2019) found that pictures of both ‘fear’ and ‘disgust’ faces induced activity in the “frowning” muscle (corrugator supercilii), with the perception of ‘disgust’ also inducing facial activity in the “upper lip raiser” muscle (levator labii superioris), and that there was a correlation between EMG responses and brain activity in the anterior insula and the amygdala, which may constitute the neural correlates of automatic facial mimicry for ‘fear’ and ‘disgust’, thereby reflecting spontaneous emotional processing at cognitive and motor levels.

Importantly, EMG is sensitive enough to detect reflex muscle activity in response to lexico-semantic processing both for muscle activation and muscle inhibition, which occurs depending upon the meaning of the linguistic stimulus. Foroni & Semin (2013) exposed participants to affirmative and negation sentences while the “smiling” muscle (zygomaticus major) activity on the left side of the face was continuously measured via EMG. Sentences were descriptions of emotional expressions that mapped either directly upon the zygomaticus major muscle (e.g. ‘I am smiling’) or did not (e.g. ‘I am frowning’). Reading sentences involving the negation of the activity of the zygomaticus major (e.g. ‘I am not smiling’) led to the inhibition of this muscle, whereas reading sentences involving the affirmative form (e.g. ‘I am smiling’) led to the activation of the zygomaticus major. Reading sentences describing an activity that was

irrelevant to the zygomaticus major (e.g. ‘I am frowning’ or ‘I am not frowning’) produced no muscle activity whatsoever. Such changes in the facial reflex muscle activity are gradient – the “frowning” muscle (corrugator supercilii) activity increases incrementally with negative valence ratings, regardless of the particular affective state described by the participant, while the “smiling” muscle (zygomaticus major) activity increases incrementally with positive valence ratings (Dimberg, 1982; Cacioppo et al., 1986; Lang et al., 1993).

As far as the investigation of the embodiment of affect (valence, arousal, dominance) and concreteness (abstract/concrete words) is concerned, the only factor of interest in response to which facial reflex muscle activation has been systematically elicited is valence (Wexler et al., 1992; Dimberg et al., 2000, 2002; Bornemann et al., 2012), even though brain activation research is extensive for both valence and arousal (Adolphs et al., 1999; Keil et al., 2001; Winston et al., 2005; Kensinger & Schacter, 2006; Lewis et al., 2007; Herbert et al., 2009; Posner et al., 2009; Colibazzi et al., 2010; Viinikainen et al., 2010; Delaney-Busch et al., 2016; Marchewka et al., 2016). While previous literature on facial reflex muscle activity has concentrated on the use of emotionally laden pictures (Dimberg, 1982, 1986; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Heller et al., 2014; Davis et al., 2017; Latham et al., 2017) or emotionally laden words (Wexler et al., 1992; Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015; Fino et al., 2016), often in contexts of emotional judgment or affective categorization tasks (Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Fino et al., 2016; Davis et al., 2015, 2017), the applicability of the EMG to less salient or less biasing contexts is unclear. This could be particularly worrisome for the extent of the linguistic embodiment of affect, because previous research revealed reflex muscle activity *only* when using either body-specific

and emotionally laden words and/or emotional or affective judgment tasks, not finding evidence for the embodiment of emotions or affect when employing non-emotion-specific / non-body-specific words or non-emotional / non-affective judgment tasks (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Fino et al., 2016; with an exception for the affective concept of arousal at the neural processing level – Delaney-Busch et al., 2016). Embodiment of affect, investigated via EMG responses to non-emotionally laden abstract and concrete words during non-explicitly emotional lexico-semantic processing, may shed light not only on the particulars of the interrelations between muscle-specific activation and affective/concreteness concepts but also on the extent to which EMG can be used as a gateway to objective investigation of abstract lexico-semantic concepts, which continue to pose serious challenges for theories of embodied cognition (cf. Mahon & Caramazza, 2008).

2. MOTIVATION FOR STUDY 1 AND STUDY 2

Before proceeding to the description of the experiments of the current project, it is important to explain why we decided to conduct two studies – Study 1 (Experiment 1, Experiment 2) and Study 2 (Experiment 3, Experiment 4) – that used same word stimuli and lexical decision task but varied in terms of non-word contexts in which valid English words appeared (pseudowords in Study 1 and consonant-string non-words in Study 2).

Out of all the investigated factors of interest in the current project (i.e. valence, arousal, dominance, concreteness), the concept of arousal may stand apart by being particularly responsive to the cognitive levels of participants' (dis)interest or (dis)engagement in the task. Prior research reported potential dependence of the embodiment of arousal on focused attention (Simons et al., 1999) and physiological levels of excitement (Kever et al., 2015, 2017). Given that the level of physical arousal has been reported to influence behavioral and motor responses to linguistic stimuli that vary on the arousal dimension (Kever et al., 2015, 2017), two different kinds of non-word contexts, one that potentially induces more engagement in the task and another one that does not necessarily induce participants' engagement in the task, could influence embodied responses to the affective dimension of arousal due to the excitatory nature of the concept of intensity/calmness. Other investigated factors of interest (i.e. valence, dominance, concreteness) may not necessarily be dependent upon participants' levels of (dis)interest or (dis)engagement in the task, because the concept of cognitive or physiological 'intensity' or 'activation' is specific to the concept of arousal (cf. Russell, 1980; Barrett & Russell, 1998; Russell & Barrett, 1999; Yik et al., 1999; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Lindquist et al., 2016). As such, if participants happen to dislike a more dull / less engaging task,

the embodiment of valence should not be affected, as the muscles specific to negative facial expressions could activate, thereby still reflecting the embodiment of (negative) valence.

When the levels of cognitive arousal are high, as in the emotions of ‘joy’ or ‘anger’ (cf. Figures 1a and 1b), there tends to be more facial muscle activity (e.g. ‘joy’: “smiling” muscle *zygomaticus major*, “squinting” muscle *orbicularis oculi*, and “nose wrinkling” muscle *levator labii superioris alaeque nasi*; ‘anger’: “frowning” muscle *corrugator supercilii*, “chin lifting” muscle *mentalis*, “lip tightening” muscle *orbicularis oris*, and “nostril expansion” muscle *levator labii superioris*) than when the levels of cognitive arousal are low, as in the emotional expression of ‘boredom’ or ‘apathy’ (cf. Figure 1c), which involves a relatively relaxed facial musculature (Rinn, 1984; Barrett et al., 2019).

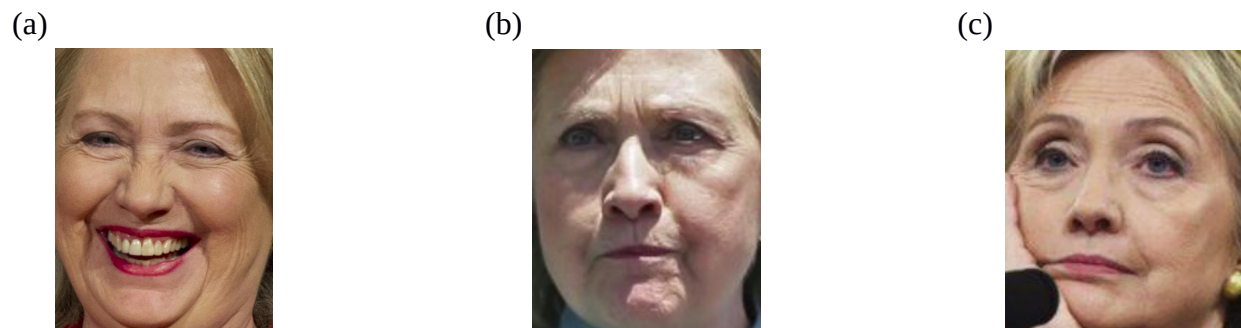


Figure 1. *Facial expressions of (a) ‘joy’, (b) ‘anger’, and (c) ‘boredom’ or ‘apathy’.*

Increased task demands are known to lead to greater focal-task engagement and may even shield against task distracting effects (Engelmann et al., 2009; Mather & Sutherland, 2011; Halin et al., 2014). In order to disentangle the particulars of the embodiment of valence, arousal, dominance, and concreteness during lexico-semantic processing, the current project manipulated

factors not only for word stimuli but also for non-word contexts in which valid English words appear. For the lexical decision task, Study 1 (Experiment 1, Experiment 2) used phonotactically English-like pseudowords, which require more concentration on the task and potentially make the lexical decision more challenging and engaging, whereas Study 2 (Experiment 3, Experiment 4) used consonant-string non-words, which can be easily identified as obvious non-words and potentially make the lexical decision considerably duller as compared to pseudowords in Study 1. As such, Study 1 was designed with an expectation that it would reveal main effect(s) of arousal, while Study 2 was designed with an expectation that the effect(s) of arousal for the same English words that were used in Study 1, would be reduced, because the consonant-string non-word context in Study 2 would qualitatively influence participants' levels of task engagement and cognitive arousal. While we did not have a direct measure for the levels of participants' task engagement or focused attention, lexical decision errors for consonant-string non-words in Study 2 were assumed to indicate some level of participants' inattentiveness to the task, as it is highly unlikely that native English speakers would genuinely confuse consonant sequences of a type 'bklgd' for valid English words. In turn, response time latencies (RTs) to consonant-string non-words in Study 2 were assumed to indicate participants' level of engagement (e.g. shorter RTs) or disengagement (e.g. longer RTs) in the task, as it is highly unlikely that native English speakers would require long RTs to decide that a consonant sequence 'tprsk' is not a valid English word.

3. QUESTIONS AND HYPOTHESES

The major questions of the current project investigate how the embodiment of valence, arousal, dominance, and concreteness factors is manifested by facial reflex muscle activity during word-level lexico-semantic processing that does not explicitly alert participants to the experimental factors of interest. In particular:

- (1) Are general concepts of valence, arousal, dominance, and concreteness, which are not overtly related to discrete emotions or facial actions, embodied at the level of reflex muscle activation during relatively implicit language processing?
- (2) Can language embodiment, as reflected by reflex activity in relevant muscles, be observed in tasks that do not explicitly alert participants to the investigated factors of interest?
- (3) Is it possible to account for the inconsistencies in prior EMG findings for the embodiment of the affective concept of arousal?

To answer the first question, the current project used non-emotionally explicit verbs that were selected based on normalized ‘low’ and ‘high’ ratings for each of the investigated factors of interest (stimuli characteristics are described in detail in the Methods section). To answer the second question, we used a lexical decision task, where participants were to think of the meaning of a word in general, without being asked to concentrate on any particular aspect of the word meaning, which does not artificially divert participants’ attention to any particular aspects of the stimuli, as opposed to emotional judgment or feature detection tasks. Finally, to answer the third question, Study 1 (Experiment 1, Experiment 2) presented valid English words in a context of phonotactically English-like pseudowords, which are harder to identify in a lexical decision task but which potentially make the task more engaging, whereas Study 2 (Experiment 3, Experiment

4) used consonant-string non-words, which are much easier to identify but which potentially reduce participants' engagement in the task due to decreased concentration or focused attention levels. Since the affective concept of arousal is delineated along the excitement/calmness axis, it could be particularly responsive to the level of participants' (dis)engagement in the task, unlike valence or dominance, which are delineated along the positivity/negativity and control/submissiveness axes and should not necessarily be dependent upon the level of task engagement.

For consistency in referring to the extremes for each of the investigated dimensions (i.e. valence, arousal, dominance, concreteness), we refer to the endpoints of each dimension as Low and High (e.g. Low Valence / High Valence, Low Arousal / High Arousal, Low Dominance / High Dominance, Low Concreteness / High Concreteness). Although the concept of valence is usually referred to along the bipolar axes (e.g. Barrett & Russell, 1998; Barrett & Bliss-Moreau, 2009) of positive/negative or pleasant/unpleasant (instead of a single positivity axis with low- and high-end extremes), the Low / High references in the current notation simply denote normalized ratings on the lower and higher ends of a rating scale for a given factor of interest (Warriner et al., 2013; Brysbaert et al., 2014), so that traditional notation of 'negative' valence is referred to as Low Valence and 'positive' valence as High Valence. The same holds for other investigated dimensions: 'calm' = Low Arousal, 'intense' = High Arousal, 'submissive' = Low Dominance, 'controlling' = High Dominance, 'abstract' = Low Concreteness, 'concrete' = High Concreteness.

We expect to find systematic differences in reflex EMG activity in muscles that are involved in facial expressions, which prior literature reported to be perceptually associated with

positive and negative valence, high and low arousal, high and low dominance, and discrete emotions, such as ‘joy’, ‘anger’, ‘disgust’, and ‘fear’, as these emotions are rated on the extremes of more general affective dimensions of valence, arousal, and dominance. Our predictions regarding each of the investigated factors are as follows:

(1) For Low Valence, we expect to find: (a) a main effect in the “frowning” muscle (corrugator supercilii) and (b) a main effect in the “chin lifting” muscle (mentalis).

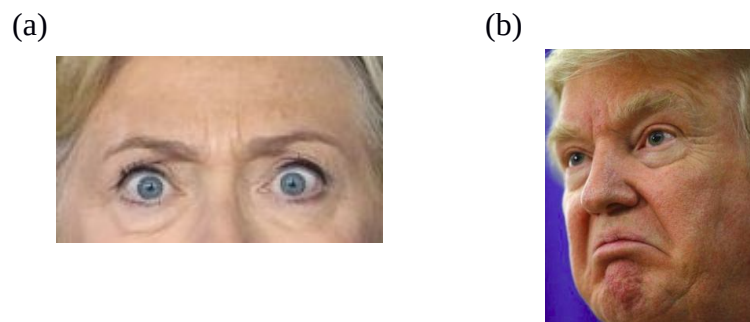


Figure 2. *Facial expressions of ‘negativity’ (a) by frowning and (b) by lifting chin.*

(2) For High Valence, we expect to find: (a) a main effect in the “smiling” muscle (zygomaticus major) and, due to the ‘emotional’ grounding of abstract lexico-semantic concepts (cf. Kousta et al., 2009, 2011; Moseley et al., 2012; Vigliocco et al., 2014), we expect (b) an interaction between Valence * Concreteness in the “squinting” / “Duchenne smile” muscle (orbicularis oculi) and in the “nose wrinkling” muscle (levator labii superioris alaeque nasi), with High Valence Low Concreteness > Low Valence Low Concreteness.

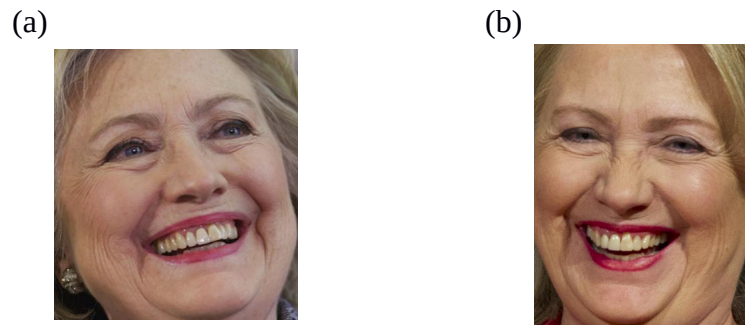


Figure 3. *Facial expressions of ‘joy’ (a) by smiling (pulling lip corners and slightly squinting) and (b) by exaggerated smiling (pulling lip corners, squinting, and wrinkling nose).*

(3) For Low Dominance, we expect to find: (a) a main effect in the “lip tightener” muscle (orbicularis oris) and (b) a main effect in the “outer brow raiser” muscle (occipitofrontalis).

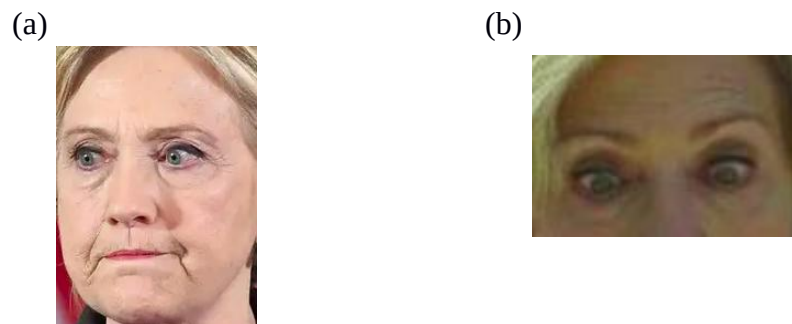


Figure 4. *Facial expressions of (a) ‘contempt’ (by tightening lips) and (b) ‘surprise’ (by raising eyebrows).*

(4) For High Dominance, we expect to find: (a) a main effect in the “frowning” muscle (corrugator supercilii), (b) a main effect in the “upper lip raiser” muscle (levator labii superioris), and (c) a main effect in the “nose wrinkler” muscle (levator labii superioris alaeque nasi).

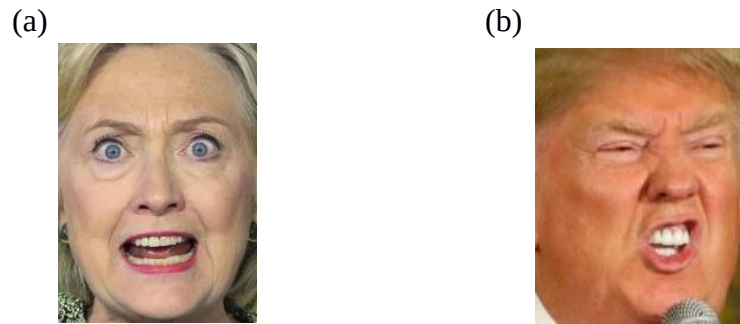


Figure 5. *Facial expression of a ‘controlling character’ (a) by frowning and lifting upper lip and (b) by frowning, raising upper lip, and wrinkling nose.*

(5) For Study 1 (higher task engagement), High Arousal is expected to elicit greater EMG activity in the “nostril expansion” (levator labii superioris) muscle, which is active when people breathe deeply or intensely. In particular, we expect to find: (a) a main effect of High Arousal in the “nostril expander” muscle (levator labii superioris).

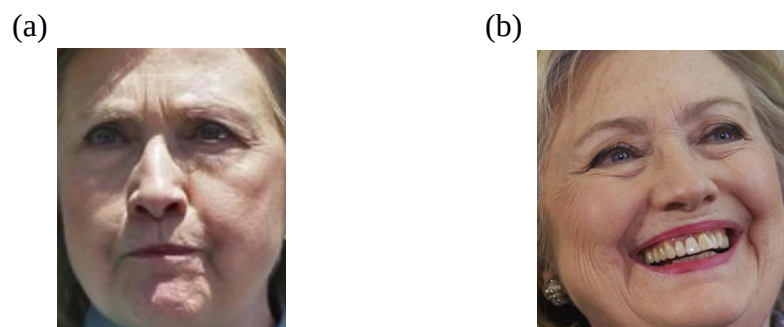


Figure 6. *Facial expression of ‘intensity’ by expanding nostrils in both (a) negative and (b) positive emotional states.*

(6) For Study 2 (lower task engagement), we expect to find interactions between Arousal and major muscles involved in High Valence and High Dominance. In particular, we expect to find: (a) an interaction between Valence * Arousal in the “smiling” muscle (zygomaticus major), with High Valence High Arousal > High Valence Low Arousal (cf. Figure 3), and (b) an interaction between Dominance * Arousal in the “upper lip raiser” muscle (levator labii superioris), with High Dominance High Arousal > High Dominance Low Arousal (cf. Figure 5).

(7) For Low Concreteness, we expect to find: (a) a main effect in the “frowning” / “thinking” muscle (corrugator supercilii) and (b) interactions in the “squinting” muscle (orbicularis oculi) between Valence * Arousal * Concreteness, with High Valence Low Arousal Low Concreteness > Low Valence Low Arousal Low Concreteness and High Valence Low Arousal Low Concreteness > High Valence Low Arousal High Concreteness, and between Dominance * Arousal * Concreteness, with High Dominance Low Arousal Low Concreteness > Low Dominance Low Arousal Low Concreteness and High Dominance Low Arousal Low Concreteness > High Dominance Low Arousal High Concreteness.



Figure 7. *Facial expression of ‘thinking’ (by frowning and squinting).*

4. METHODS

4.1. PARTICIPANTS

A total of 20 native English speakers (10 males, 10 females) between the ages of 19-43 years old participated in Study 1 (Experiment 1, Experiment 2) and a total of 34 native English speakers (21 males, 13 females) between the ages of 21-42 years old participated in Study 2 (Experiment 3, Experiment 4). None of the participants had facial surgery, botulinum toxin or similar kind of muscle-inhibiting treatments; males were clean-shaven and females did not wear any skin makeup.

4.2. MATERIALS

4.2.1. STUDY 1

Study 1 investigated the relation between Valence, Arousal, and Concreteness (Experiment 1) and Dominance, Arousal, and Concreteness (Experiment 2) during a lexical decision task including valid English words and pseudowords that obeyed English phonotactic constraints. We had to test Valence and Dominance separately, because word ratings for Valence and Dominance have a high positive correlation (Pearson's $r=0.717$, $R^2=0.518$, linear coefficient = 0.974; Warriner et al., 2013), which introduces a confound.

Words were selected based upon the normalized ratings from the lower and higher ends of the respective rating scales for Valence, Arousal, Dominance (Warriner et al., 2013; <http://crr.ugent.be/archives/1003>) and Concreteness (Brysbaert et al., 2014;

<http://crr.ugent.be/archives/1330>). Part-of-speech classifications were taken from the English Lexicon Project (<http://ellexicon.wustl.edu/WordStart.asp>) and lexical frequency counts were taken from the Hyperspace Analogue to Language (HAL) frequency norms (Balota et al., 2007; Brysbaert & New, 2009). HAL norms are based on the HAL corpus, which consists of approximately 131 million words from conversational texts gathered across 3,000 Usenet newsgroups during February 1995 (<http://ellexicon.wustl.edu/userguide.pdf>) and is superior to standard corpora, such as Kucera & Francis (1967) or Francis & Kucera (1982), because it is based on a much larger number of words (cf. Delaney-Busch et al., 2016). Out of all parts of speech, we chose verbs, because there is some evidence that verbs induce greater muscle activation than nouns or adjectives (e.g. Foroni & Semin, 2009, vs. Niedenthal et al., 2009; Connell et al., 2012; Gough et al., 2012, 2013), possibly because they intrinsically relate to action concepts. We selected verbs on the lower end of the frequency range for our stimuli (hereafter referred to as ‘Low Frequency’), because prior literature suggested that behavioral measures (e.g. RTs) for affective variables were dependent on lexical frequency – whereas valence and arousal largely influenced lexical decision and naming RTs in low-frequency words, their effects were practically absent in high-frequency words (Larsen et al., 2006; Kuperman et al., 2014; Sheikh & Titone, 2015). Since raw word frequencies in HAL corpus range from < 100 to > 20,000,000 (Balota et al., 2007), we operationalized words as having lower-end frequency if their HAL raw frequency was < 50,000 and their HAL log frequency was < 11. Pseudowords were created based on real words, in a sense that each pseudoword had the same number of letters and a loosely similar syllable structure to the real word on which it was based (frequency

could not be measured for pseudowords, because pseudowords were created ‘from scratch’ instead of being taken from a normalized pseudoword database).

In Experiment 1, Valence, Arousal, and Concreteness were varied based on the Low and High ends of each rating scale, respectively, while Dominance ratings were kept constant by being selected only from the High end of the Dominance rating scale (Warriner et al., 2013; Brysbaert et al., 2014). In Experiment 2, Dominance, Arousal, and Concreteness were varied based on the Low and High ends of each rating scale, respectively, while Valence ratings were kept constant by being selected only from the Low end of the Valence rating scale (Warriner et al., 2013; Brysbaert et al., 2014). We chose to control Dominance as High Dominance in Experiment 1 and Valence as Low Valence in Experiment 2, because due to the high positive correlation between Valence and Dominance (Pearson’s $r=0.717$; Warriner et al., 2013) there are very few words in English lexicon that are rated as High Valence / Low Dominance (cf. Warriner et al., 2013). This resulted in eight permutations of the variables of interest in each experiment, with four combinations being the same for both experiments (i.e. the ones that had Low Valence and High Dominance).

Experiment 1 had the following combinations (enumerated below by condition number):

Table 1. *Stimuli condition classifications for Experiment 1 (Study 1).*

CONDITION	VALENCE	AROUSAL	DOMINANCE	CONCRETENESS
1	High (i.e. positive)	High (intense)	High (controlling)	Low (abstract)
2	High	High	High	High (concrete)
3	High	Low (calm)	High	Low
4	High	Low	High	High
5	Low (i.e. negative)	High	High	Low
6	Low	High	High	High
7	Low	Low	High	Low
8	Low	Low	High	High

The summary statistics for conditions in Experiment 1 are as follows:

Table 2. *Means and standard deviations for Valence, Arousal, Dominance, and Concreteness word ratings, mean Word Length, and Raw Frequency from HAL corpus for Experiment 1 (conditions 1-8, cf. Table 1).*

CONDITION	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concreteness (1-5 scale)	SD	Word Length	Raw Frequency HAL
1. High Valence High Arousal Low Concreteness	7.35	1.51	5.58	2.45	6.48	1.93	2.29	1.23	6.9	5395
2. High Valence High Arousal High Concreteness	7.22	1.58	5.43	2.61	6.31	2.19	3.86	1.17	5.4	6477
3. High Valence Low Arousal Low Concreteness	7.15	1.64	3.91	2.42	6.45	2.02	2.24	1.2	7.1	6450
4. High Valence Low Arousal High Concreteness	6.92	1.59	3.83	2.36	6.19	2.1	3.94	1.15	4.95	5983
5. Low Valence High Arousal Low Concreteness	2.99	1.58	5.39	2.31	5.3	2.46	2.29	1.25	6.6	6931
6. Low Valence High Arousal High Concreteness	3.24	1.8	5.41	2.39	5.21	2.46	3.86	1.12	4.85	6686
7. Low Valence Low Arousal Low Concreteness	3.35	1.47	3.86	2.3	5.04	2.55	2.26	1.2	7.2	6195
8. Low Valence Low Arousal High Concreteness	3.66	1.49	3.81	2.29	5.27	2.32	3.95	1.19	5.25	4306

In turn, Experiment 2 had the following permutations of the manipulated factors (first set of numbers in the “condition” column represents condition numbering 1-8 for Experiment 2, while, in parentheses next to each 1-8 number, “=” signifies that word stimuli came from the corresponding condition numbers in Experiment 1, “E.1” is an abbreviation for “Experiment 1”,

“~” represents condition numbering if one numbers conditions for Experiment 2 continuing with “c5” from “E.1” instead of starting condition numbering for Experiment 2 at “1”):

Table 3. *Stimuli condition classifications for Experiment 2 (Study 1).*

CONDITION	VALENCE	AROUSAL	DOMINANCE	CONCRETENESS
1 (=c5 in E.1)	Low (negative)	High (intense)	High (controlling)	Low (abstract)
2 (=c6 in E.1)	Low	High	High	High (concrete)
3 (=c7 in E.1)	Low	Low (calm)	High	Low
4 (=c8 in E.1)	Low	Low	High	High
5 (~c9)	Low	High	Low (submissive)	Low
6 (~c10)	Low	High	Low	High
7 (~c11)	Low	Low	Low	Low
8 (~c12)	Low	Low	Low	High

The summary statistics for conditions in Experiment 2 are as follows:

Table 4. Means and standard deviations for Valence, Arousal, Dominance, and Concreteness word ratings, mean Word Length, and Raw Frequency from HAL corpus for Experiment 2 (conditions 5-12, cf. Table 3).

CONDITION	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concreteness (1-5 scale)	SD	Word Length	Raw Frequency HAL
1. High Dominance High Arousal Low Concreteness	2.99	1.58	5.39	2.31	5.3	2.46	2.29	1.25	6.6	6931
2. High Dominance High Arousal High Concreteness	3.24	1.8	5.41	2.39	5.21	2.46	3.86	1.12	4.85	6686
3. High Dominance Low Arousal Low Concreteness	3.35	1.47	3.86	2.3	5.04	2.55	2.26	1.2	7.2	6195
4. High Dominance Low Arousal High Concreteness	3.66	1.49	3.81	2.29	5.27	2.32	3.95	1.19	5.25	4306
5. Low Dominance High Arousal Low Concreteness	2.53	1.6	5.48	2.37	3.53	2.28	2.35	1.27	7.15	5876
6. Low Dominance High Arousal High Concreteness	2.16	1.41	5.74	2.5	3.25	2.21	3.78	1.26	6.4	6136
7. Low Dominance Low Arousal Low Concreteness	3.01	1.62	3.78	2.17	3.69	2.19	2.3	1.24	6.94	4986
8. Low Dominance Low Arousal High Concreteness	3.32	1.68	3.8	2.32	3.64	2.2	3.65	1.22	5.42	5227

As may be seen in Tables 1 and 3, conditions 5-8 in Experiment 1 and conditions 1-4 in Experiment 2 have the same permutations of the manipulated variables. Given that each condition in the tables above had 20 words and 20 pseudowords, we wanted to minimize the overall time that participants had to spend for the experiments (as Experiment 1 and Experiment

2 were presented in one testing session), so we reduced the total number of conditions for both experiments from 16 (8 conditions in Experiment 1 and 8 conditions in Experiment 2) to 12 by using the same stimuli for the overlapping conditions (i.e. the stimuli for conditions 5-8 in Experiment 1 served as conditions 1-4 in Experiment 2, cf. Table 2 and Table 4). However, when we conducted the analyses, we separated the stimuli into a Valence block (conditions 1-8 in Table 1) and a Dominance block (conditions 5-12 in Table 3) and analyzed the two sets separately.

Pseudowords were used for the purposes of the lexical decision task, but responses to them were not included in the analyses of reflex muscle activity for the factors of interest. Pseudowords consisted of orthographically legal English letter strings and were matched to experimental stimuli for standard psycholinguistic measures, such as word length, number of syllables, and syllable structure. Pseudowords could not be matched for frequency because they were created ‘from scratch’ and not taken from a normalized database. Lexical decision was chosen as a task because it provides a means to investigate online lexico-semantic processing without overtly alerting participants to the factors that are being examined. Stimuli for each experiment varied on only three factors at a time: Valence / Arousal / Concreteness for Experiment 1 (Dominance was held constant at High Dominance) and Dominance / Arousal / Concreteness for Experiment 2 (Valence was held constant at Low Valence). There were 20 word items in each experimental condition (cf. Tables 1-4), along with matching pseudowords.

To ensure that Low and High ratings differed within each manipulated dimension, we conducted a series of two-sided Student t-tests, and to see whether there were confounds between any of the manipulated and controlled variables in each experiment, we conducted a series of 2 x 2 x 2 ANOVAs. Effect sizes were calculated using Cohen’s d for t-tests and eta squared (η^2)

for ANOVAs. Sample R code for each type of statistical analysis can be found in Appendix D. These analyses were conducted to examine potential limitations of the current experimental design (they are unrelated to the analyses of behavioral and EMG outcome measures that are described in section 4.5). Even though, due to the nature of the EMG signal, the analyses in the Results section were based on participant average responses to conditions (e.g. mean response to correct lexical decision trials for words per each condition in Table 1 for Experiment 1 and in Table 3 for Experiment 2) and not on participant raw responses to individual words within those conditions, we conducted stimuli analyses below at the word-rating level to get a more detailed view of potential confounds within the stimuli, as the stimuli analyses may not yield sufficient statistical power if conducted at the condition-average level (cf. Table 2 and Table 4).

For the words in Experiment 1, where we manipulated Low and High ratings for Valence, Arousal, and Concreteness and controlled all other variables, two-sided Student t-tests showed that Low and High ratings were significantly different from each other for each of the manipulated variables: Valence ($t(150)=-58.22$; $p<0.0001$; Cohen's $d=-9.2$), Arousal ($t(151)=-19.84$; $p<0.0001$; Cohen's $d=-3.13$), and Concreteness ($t(139)=-23.72$; $p<0.0001$; Cohen's $d=-3.75$). $2 \times 2 \times 2$ ANOVAs revealed unexpected significant differences between the controlled dimension of Dominance and the manipulated dimension of Valence ($F(1,156)=205.54$; $p<0.0001$; $\eta^2=0.56$) and between the controlled dimension of Word Length and the manipulated dimension of Concreteness ($F(1,156)=55.46$; $p<0.0001$; $\eta^2=0.26$). As expected, there were no significant differences for Frequency (all p-values > 0.43 for both raw and log frequency) between any of the manipulated variables in the stimuli for Experiment 1.

Table 5. *Summary statistics for the manipulated and controlled variables in Experiment 1 (rating scales: Valence 1-9, Arousal 1-8, Concreteness 1-5; Dominance 1-8).*

Exp. 1	Low Valence	High Valence	Low Arousal	High Arousal	Low Concrete ness	High Concrete ness	High Domi nance	Word Length	log Frequency HAL
Mean	3.31	7.16	3.85	5.45	2.27	3.9	5.78	6.03	7.9
SD	(0.46)	(0.36)	(0.45)	(0.55)	(0.34)	(0.5)	(0.77)	(1.8)	(1.39)

For the words in Experiment 2, where we manipulated Low and High ratings for Dominance, Arousal, and Concreteness and controlled all other variables, two-sided Student t-tests showed that Low and High ratings were significantly different from each other for each of the manipulated variables: Dominance ($t(158)=-24.29$; $p<0.0001$; Cohen's $d=-3.84$), Arousal ($t(143)=-19.53$; $p<0.0001$; Cohen's $d=-3.08$), and Concreteness ($t(152)=-23.01$; $p<0.0001$; Cohen's $d=-3.63$). $2 \times 2 \times 2$ ANOVAs revealed unexpected significant differences between the controlled dimension of Valence and all the manipulated dimensions: Dominance ($F(1,156)=112.45$; $p<0.0001$; $\eta^2=0.25$), Arousal ($F(1,156)=126.97$; $p<0.0001$; $\eta^2=0.28$), and Concreteness ($F(1,156)=47.46$; $p<0.0001$; $\eta^2=0.1$). There was also unexpected significant difference between the controlled dimension of Word Length and the manipulated dimension of Concreteness ($F(1,156)=31.21$; $p<0.0001$; $\eta^2=0.16$). As expected, there were no significant differences for Frequency (all p-values > 0.08 for both raw and log frequency) between any of the manipulated variables in the stimuli for Experiment 2.

Table 6. *Summary statistics for the manipulated and controlled variables in Experiment 2 (rating scales: Dominance 1-8, Arousal 1-8, Concreteness 1-5; Valence 1-9).*

Exp. 2	Low Domi nance	High Domi nance	Low Arous al	High Arousal	Low Concrete ness	High Concrete ness	Low Valence	Word Length	log Frequency HAL
Mean	3.52	5.2	3.81	5.5	2.31	3.81	2.72	6.23	7.62
SD	(0.43)	(0.43)	(0.45)	(0.62)	(0.37)	(0.45)	(1.16)	(1.89)	(1.5)

While full descriptive statistics for the stimuli for the original 12 conditions are provided in Tables 2 and 4 and for the manipulated factors of interest in Tables 5 and 6 above, Appendix E additionally presents raw stimuli for all conditions to illustrate the kind of words (Study 1 and Study 2), pseudowords (Study 1), and non-words (Study 2) that were used in the current project.

4.2.2. STUDY 2

As outlined in the Motivation section, we were interested in examining whether the level of cognitive arousal, which is potentially directly proportional to the levels of participants' focused attention and concentration on the task, influences the embodiment of the concept of arousal (Simons et al., 1999; Kever et al., 2015, 2017) as opposed to the embodiment of valence or dominance concepts, thereby qualitatively setting arousal apart from other affective dimensions. For that purpose, we designed Study 2, using the same English words as in Study 1 but presenting them within a context of consonant-string non-words instead of phonotactically English-like pseudowords. Consonant-string non-words are much easier to identify as not valid

English words, in contrast to pseudowords that potentially induce more uncertainty and therefore require more concentration and focused attention on the task. As such, consonant-string non-words were expected to reduce participants' engagement in the task, which could decrease their cognitive level of arousal and qualitatively influence the embodiment of the concept of arousal. Since we did not have a direct measure for participants' engagement or attention levels, we assumed that lexical decision errors for consonant-string non-words in Study 2 could indicate some level of participants' inattentiveness to the task, as it is highly unlikely that native English speakers would genuinely confuse consonant sequences of a type 'bklgd' for valid English words. Similarly, we assumed that response time latencies (RTs) for consonant-string non-words in Study 2 could indicate participants' level of concentration/engagement (e.g. shorter RTs) or disinterest/disengagement (e.g. longer RTs) in the task, as it is highly unlikely that native English speakers would require long RTs to decide that a consonant sequence 'tprsk' is not a valid English word.

Similarly to Study 1, Study 2 investigated the relation between Valence, Arousal, and Concreteness (Experiment 3) and Dominance, Arousal, and Concreteness (Experiment 4) during a lexical decision task between valid English words and consonant-string non-words. The only difference between Study 1 (Experiment 1, Experiment 2) and Study 2 (Experiment 3, Experiment 4) was that Study 2 used consonant-string non-words of a type "bgkl" or "rtpxw" (instead of pseudowords that were used in Study 1). Consonant-string non-words were created loosely based on real words, so that each consonant-string non-word had the same number of letters as the real word on which it was based. Otherwise, the procedure in Study 2 was the same as in Study 1.

4.3. PROCEDURE

After arriving at the laboratory, participants were led to a quiet room, where the study procedure was explained to them and where they signed a consent form (cf. Appendix A), if they chose to participate. The task required participants to make a lexical decision between valid English language words vs. pseudowords (Study 1) or between valid English words vs. consonant-string non-words (Study 2) by tapping an accelerometer located next to the dominant hand if it was a valid English word or an accelerometer located next to the non-dominant hand if it was not a valid English word. We did not alternate the tap response based on handedness, because we followed prior research on language embodiment that has successfully used similar non-alternating hand response approaches (Noppeney & Price, 2004; Buccino et al., 2005; Boulenger et al., 2006; Sato et al., 2008; Volta et al., 2009, 2014; Dam et al., 2010, 2014; Tomasino et al., 2010; Kousta et al., 2011; Oosterwijk et al., 2011, 2015; Rodriguez-Ferreiro et al., 2011; Santana & Vega, 2011; Aravena et al., 2012, 2014; Gough et al., 2012, 2013; Newcombe et al., 2012; Tremblay et al., 2012; Bartoli et al., 2013; Cacciari & Pesciarelli, 2013; Trumpp et al., 2013; Zubicaray et al., 2013; Innocenti et al., 2014; Schomers et al., 2014; Sidhu et al., 2014; Spadacenti et al., 2014; Vega et al., 2014; Vigliocco et al., 2014; Davis et al., 2015; Filik et al., 2015; Gianelli & Volta, 2015; Huang & Tse, 2015; Moreno et al., 2015; Repetto et al., 2015; Carr et al., 2016). The rationale for using accelerometers instead of keyboard buttons was that accelerometers can be used to measure not only accuracy and RTs but also the tap amplitude, which is proportional to tap force. This additional behavioral measure may potentially provide richer information than accuracy and RTs alone.

First, participants had to read a linguistic stimulus displayed on a notebook computer screen and respond as quickly as possible by tapping the appropriate accelerometer if it was a valid English word or not. If the stimulus was a valid English word, participants were to think about its meaning for the remainder of time that the stimulus was displayed. If the stimulus was not a valid English word, participants were to wait for the next trial after making the lexical decision. Participants were informed that, if they felt that they made a mistake after making the lexical decision, they could correct their response by tapping the appropriate accelerometer with more force. After hearing the instructions and indicating that they understood, participants performed 20 practice trials, while the experimenter stood nearby in order to respond to any questions that might have arisen. Stimuli were displayed on a 14-inch screen located approximately 50 cm from the participant. To reduce eye strain, we used 48-point SansSerif font, black background color, and light cyan text color. A trial started with a fixation asterisk “*” displayed in the center of the screen for 2.5 s, immediately followed by the linguistic stimulus for the next 5.5 s. The screen then went blank for 3.5 s after which the next trial automatically began. The experiment, including setup, took approximately 2.5 hours. The session was divided into blocks of 20-30 stimuli, selected randomly from the list. Stimuli consisted of 240 words and 240 pseudowords for Study 1 (Experiment 1, Experiment 2) or 240 words and 240 consonant-string non-words for Study 2 (Experiment 3, Experiment 4). Each stimulus was presented once during the testing session. After each block, there was a rest break; the length of each break was determined by the participants and varied between few seconds to few minutes. Study 1 and Study 2 were conducted separately, on separate groups of participants, and for each study stimuli from both experiments pertaining to that particular study (i.e. 240 words and 240 pseudowords

for Experiment 1 and Experiment 2 in Study 1; 240 words and 240 consonant-string non-words for Experiment 3 and Experiment 4 in Study 2) were presented in a random order in a single testing session.

The primary measure in both Study 1 and Study 2 was the skin-surface electrical activity (electromyogram or EMG) of facial muscles during an interval of approximately 5 s following the appearance of the word or pseudoword (Study 1) / consonant-string non-word (Study 2). We chose a such a long stimulus presentation time period based on prior research on the linguistic embodiment of emotions (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015; Carr et al., 2016; Fino et al., 2016) and because we wanted a measure that would be sensitive enough to detect statistically significant changes in reflex muscle activity, given that participants had to provide a lexical decision response *during* stimulus presentation, via a hand motor action that has been reported to introduce considerable noise into the facial EMG (cf. Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Davis et al., 2015; Carr et al., 2016; Fino et al., 2016). The face was scrubbed with alcohol after which 8 small (14 mm x 21 mm) bipolar electrodes with 3 mm circular contacts separated by 10 mm were affixed over 8 facial muscles with double-sided medical grade hypoallergenic tape (3M®). Due to the small contact surface area (3 mm diameter) and close contact spacing (10 mm), these electrodes were quite selective to the electrical potentials originating from specific muscles and recorded electrical potentials originating predominantly from nearby muscle fibers (de la Barrera & Milner, 1994). The electrodes were placed over the following muscles: zygomaticus major (lifts lip corner), occipitofrontalis (raises eyebrow), corrugator supercilii (pulls eyebrow inward), mentalis (lifts chin), levator labii superioris alaquae nasi (wrinkles nose), orbicularis oris (tightens lips), levator

labii superioris (raises upper lip and expands nostrils), orbicularis oculi (raises cheeks). The electrodes for zygomaticus major, occipitofrontalis, mentalis, and orbicularis oculi were placed on the left side of the face, while the electrodes for corrugator supercilii, levator labii superioris alaeque nasi, orbicularis oris, and levator labii superioris were placed on the right side of the face, because it was not possible to put all electrodes on one side of the face due to the fact that the separation distance between some of the muscles was less than the size of the electrodes. We followed prior EMG research when we decided not to alternate placement of the electrodes on different sides of the face between participants, as many prior EMG studies did not alternate the left/right sides of the face or body for electrode placement between participants (Hess et al., 1992; Morsella & Krauss, 2005; Foroni & Semin, 2009, 2013; Gomez et al., 2009; Niedenthal et al. 2009; Stins & Beek, 2013; Kunecke et al., 2014; Repetto et al., 2015; Davis et al., 2015, 2017; Carr et al., 2016). A patch ground electrode was placed either on the back of a shoulder or on the back of an ankle. The EMG and acceleration signals were continuously sampled at 1000 Hz using a custom Matlab script, which also controlled the display.

4.4. DATA PROCESSING

A custom Matlab script was created to screen raw EMG data for excessive noise. The noise was attributed to suboptimal contact between the electrodes and the skin, suboptimal grounding, or movement artifact. Excessive noise was identified by conducting spectral analysis on the EMG from which abnormally high spectral content in the low frequency (movement artifact) and high frequency (poor contact) bands could be visualized. Spikes in the EMG spectrum at harmonics of the power line frequency (60 Hz) indicated suboptimal grounding. The

60 Hz harmonic noise was removed by applying dual pass, digital fifth order Butterworth bandstop filters with bandwidths of 58-62 Hz, 118-122 Hz and 178-182 Hz using the `filtfilt` function in Matlab. High frequency noise could sometimes be eliminated by low-pass filtering with a cutoff frequency of 240 Hz (fifth order Butterworth digital filter). The `filtfilt` function filters the data in the forward and reverse directions, thereby eliminating the phase shift that would be introduced by filtering in one direction only. Only EMG activity during the 5.5 s stimulus presentation time window was analyzed, although the EMG was recorded continuously throughout the testing session. Trials for which noise was too prominent to be reduced to acceptable levels by filtering were eliminated from the analysis, which amounted to approximately 3% of the data. In addition to filtering, a visual inspection of all trials for each participant was performed, and trials where more than half of electrode channels showed excessive simultaneous activity were eliminated from subsequent analyses, as they are suggestive of irrelevant facial movements, such as yawning or sneezing. Sample raw EMG response to a valid word and to a non-word, as well as descriptive statistics for accuracy, RTs, tap amplitude, and overall timing delay in the EMG response (ms) for combined muscles for the factors of interest in each experiment, can be found in Appendix B, whereas descriptive statistics for the normalized maximum rms EMG (V) for each muscle relevant to the factors of interest in each experiment can be found in Appendix C.

4.5. DATA ANALYSIS

A custom Matlab script was created to compute behavioral (accuracy, RT, tap amplitude) and EMG (normalized maximum root mean square (rms), timing onset delay) outcome measures,

which were subsequently analyzed with R. Accuracy was defined as the number of correct responses out of a maximum of 240 for words or pseudowords / consonant-string non-words. Reaction time (RT) was defined as the time interval between the onset of the stimulus presentation and the time of occurrence of the acceleration peak created by tapping the accelerometer. The tap amplitude was defined as the amplitude of the acceleration peak. The rms EMG was calculated in a 250 ms moving window starting from the time at which the stimulus was presented until the end of the stimulus presentation period. The 250 ms interval during the stimulus presentation period for which the rms EMG was maximum was then determined and the time of occurrence of this interval was taken as the EMG timing delay. The rms EMG in the 500 ms window prior to presentation of the stimulus was used as a background reference. The background reference value was subtracted from the maximum rms EMG to calculate the maximum change in rms EMG relative to background. Normalization for each subject was performed by dividing this value by the overall maximum determined over the entire experimental session for each muscle. Given that we used a 250 ms moving time window in the 5.5 s stimulus presentation period to detect the maximum EMG activity in relevant muscles, we do not make any claims regarding the timing of the EMG response (i.e. prelexical, lexical, or postlexical processing stages) as related to the embodiment debate. Rather, we use the term ‘implicit processing’ to refer to facial reflex muscle activity that happens spontaneously and of which participants are unaware, regardless of whether it occurs early or late in the lexico-semantic processing.

Statistical analyses comparing the outcome measures between the manipulated factors were carried out in R using two-sided paired t-tests, repeated-measures 2 x 2 x 2 ANOVAs, and

planned comparisons using pairwise t-tests (with Holm correction, if there was more than one comparison for a given muscle). We chose to do planned comparisons instead of post-hoc tests because we were interested only in specific pairwise differences that were relevant to our hypotheses (cf. section 3). Effect sizes were calculated using Cohen's d for t-tests and generalized eta squared (η^2) for ANOVAs. Sample R code for each type of statistical analysis can be found in Appendix D. We chose to do paired t-tests for comparisons of the responses to words vs. pseudowords (Study 1) and words vs. consonant-string non-words (Study 2) and repeated-measures 2 x 2 x 2 ANOVAs for comparisons of the responses to the manipulated variables of interest to reflect the within-subject design of our experiments. Even though stimuli analyses in section 4.2.1 showed that the controlled dimension of Dominance was confounded with the manipulated dimension of Valence in Experiment 1 and that the controlled dimension of Valence was confounded with the manipulated dimensions of Dominance, Arousal, and Concreteness in Experiment 2, we did not do ANCOVAs because Valence and Dominance are highly correlated (Pearson's $r=0.717$; Warriner et al., 2013) and therefore cannot be treated as covariates due to ANCOVA's fundamental assumption regarding the independence of the covariate and treatment effect (Miller & Chapman, 2001; Field et al., 2012). Repeated-measures 2 x 2 x 2 ANOVAs tested for all main effects and interactions for the factors of interest for each of the relevant muscles and were conducted for the variables of interest for valid words only in both Study 1 and Study 2, while paired t-tests were done between responses to all words ($n=240$) vs. all pseudowords ($n=240$) in Study 1 and between responses to all words ($n=240$) vs. all consonant-string non-words ($n=240$) in Study 2. Trials with incorrect responses were excluded from the analyses.

First, we conducted a series of paired t-tests for behavioral (accuracy, RTs, tap amplitude) and EMG (normalized maximum rms for the zygomaticus major muscle) measures to determine whether there were differences in the processing of words vs. pseudowords (Study 1) and words vs. consonant-string non-words (Study 2). The reason for comparing the EMG response to words vs. pseudowords (Study 1) and words vs. consonant-string non-words (Study 2) was mainly to establish that reflex muscle activity was not identical for words vs. pseudowords (Study 1) and words vs. consonant-string non-words (Study 2). Since many participants in Study 1 reported that pseudowords seemed “funny” to them, the most likely response to pseudowords would have been ‘amusement’ and one of the strongest tests of a difference in the reflex response to words vs. pseudowords would be to examine the response of the “smiling” muscle (zygomaticus major). Therefore, we selected the zygomaticus major muscle for the comparisons of the normalized maximum rms EMG response to words vs. pseudowords (Study 1) and words vs. consonant-string non-words (Study 2).

Then, we conducted repeated-measures 2 x 2 x 2 ANOVAs for the factors of interest on the normalized maximum rms EMG in the relevant muscles for words in each experiment: Valence sets (Experiments 1 and 3: zygomaticus major, corrugator supercilii, mentalis, levator labii superioris alaeque nasi, levator labii superioris, orbicularis oculi) and Dominance sets (Experiments 2 and 4: occipitofrontalis, corrugator supercilii, levator labii superioris alaeque nasi, orbicularis oris, levator labii superioris, orbicularis oculi). We analyzed all outcome measures for Valence / Arousal / Concreteness and Dominance / Arousal / Concreteness stimuli sets for each experiment separately because words could not be independently varied on Valence / Dominance due to a high positive rating correlation between them (Pearson’s $r=0.717$;

Warriner et al., 2013). Repeated-measures 2 x 2 x 2 ANOVA analyses were performed on the normalized maximum rms EMG of each relevant muscle separately, because each muscle represented a separate dependent measure. To justify the treatment of each muscle as a separate measure, we tested whether the normalized maximum rms EMG for any of the muscles was dependent between any two muscles. Hoeffding's D test for independence of two continuous variables (where $-0.5 < D < 1$) was performed in R using `hoeffd()` function in library(Hmisc) and showed no evidence for dependence between the muscles in either Study 1 or Study 2 (the highest $D=0.13$ between the levator labii superioris and levator labii superioris alaeque nasi in Study 2). As such, there was no compelling evidence to pool data from different muscles.

5. RESULTS

The Results section presents all statistically significant findings ($p < 0.05$) for the relevant muscles in each experiment, whereas full descriptive statistics for the factors of interest are presented in the tables in Appendices B and C. While the Results section only presents the findings of statistical tests, the Discussion section contains interpretation of the findings for each experiment, and the General Discussion section situates the findings within broader literature.

5.1. STUDY 1

5.1.1. BEHAVIORAL AND EMG FINDINGS FOR THE LEXICAL DECISION TASK

First, we tested for the overall behavioral differences in the processing of valid English words vs. pseudowords by performing a series of two-sided paired t-tests between responses to valid English words vs. pseudowords in Study 1 ($N=20$) on each behavioral measure (accuracy, RTs, tap amplitude) and found that responses to valid English words significantly differed from responses to pseudowords in RTs, with valid English words being identified more quickly ($t(19) = -2.33$; $p = 0.03$; Cohen's $d = -0.2$; words: $M = 1194$ ms, $SD = 366$ ms; pseudowords: $M = 1272$ ms, $SD = 389$ ms) than pseudowords. Words were identified overall less accurately than pseudowords (words: $M = 95.52\%$ (i.e. 229.25 out of 240), $SD = 5.65\%$ (13.58/240); pseudowords: $M = 97.6\%$ (234.25/240), $SD = 2.42\%$ (5.81/240)), although the difference was not statistically significant ($p = 0.14$). Differences in tap amplitude between words ($M = 0.26$ V, $SD = 0.12$ V) and pseudowords ($M = 0.25$ V, $SD = 0.12$ V) in Study 1 were also not statistically significant ($p = 0.31$).

Then, we conducted a two-sided paired t-test on the normalized maximum rms EMG for the zygomaticus major muscle between responses to valid English words vs. pseudowords in Study 1 (N=20) to determine if there was a difference in the response to valid English words compared to pseudowords at the reflex muscle activation level. As expected, we found that EMG activity in response to valid English words significantly differed from pseudowords ($t(19)=2.11$; $p=0.04$ Cohen's $d=0.43$), with words ($M=0.43$ V, $SD=0.18$ V) inducing greater EMG activity than pseudowords ($M=0.35$ V, $SD=0.19$ V).

5.1.2. MUSCLE-SPECIFIC EMG FINDINGS FOR THE FACTORS OF INTEREST

To examine the embodiment of the factors of interest, we performed repeated-measures $2 \times 2 \times 2$ ANOVAs on the normalized maximum rms EMG for relevant muscles in response to correct lexical-decision trials for valid English words (pseudowords were not included in the analyses) to determine main effects of Valence / Arousal / Concreteness (Experiment 1) and Dominance / Arousal / Concreteness (Experiment 2) as well as interactions between these factors in each experiment. In Experiment 1, there was a main effect of Valence in the zygomaticus major ($F(1,19)=28.97$; $p=0.00003$; generalized $\eta^2=0.11$), the “smiling” muscle, where High Valence ($M=0.57$ V; $SD=0.21$ V) induced greater EMG activity than Low Valence ($M=0.38$ V; $SD=0.19$ V).

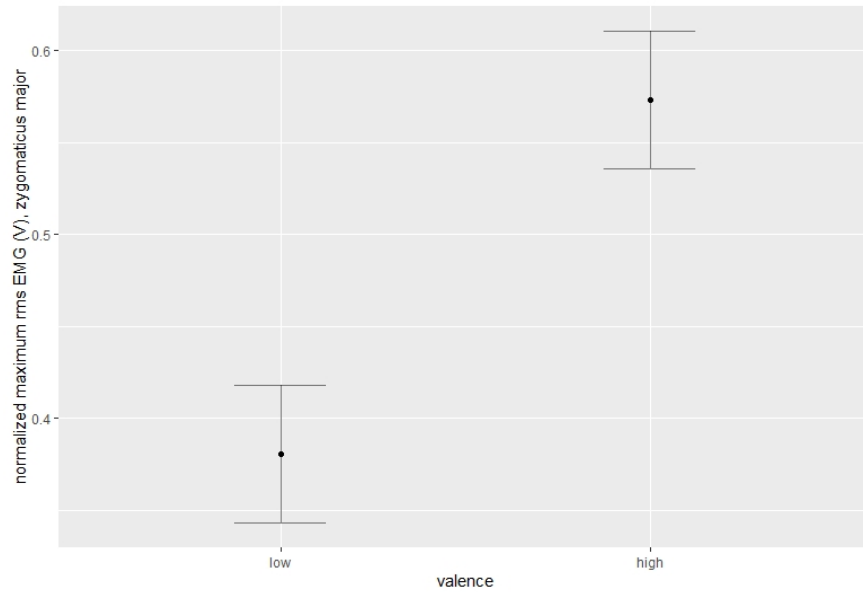


Figure 8. *Mean normalized maximum rms EMG (V) in the zygomaticus major in response to Low Valence and High Valence in Experiment 1 (with standard error bars).*

There was also a main effect of Valence in the corrugator supercilii ($F(1,16)=9.66$; $p=0.006$; generalized $\eta^2=0.06$), the “frowning” muscle, where Low Valence ($M=0.58$ V; $SD=0.17$ V) induced greater EMG activity than High Valence ($M=0.46$ V; $SD=0.19$ V).

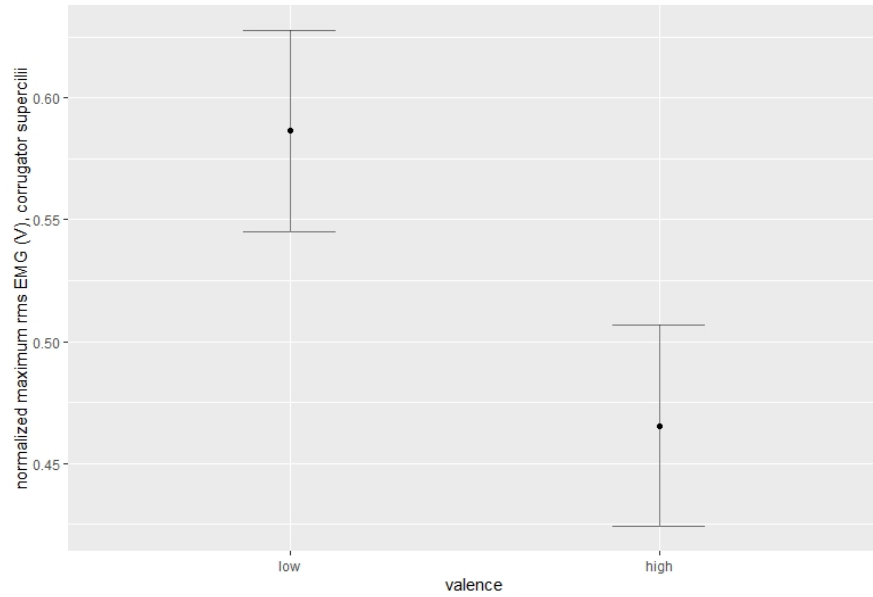


Figure 9. *Mean normalized maximum rms EMG (V) in the corrugator supercilii in response to Low Valence and High Valence in Experiment 1 (with standard error bars).*

Experiment 1 revealed a main effect of Arousal in the levator labii superioris ($F(1,18)=5.87$; $p=0.02$; generalized $\eta^2=0.03$), the “upper lip raiser” / “nostril expander” muscle, where High Arousal ($M=0.62$ V; $SD=0.15$ V) induced greater EMG activity than Low Arousal ($M=0.54$ V; $SD=0.17$ V).

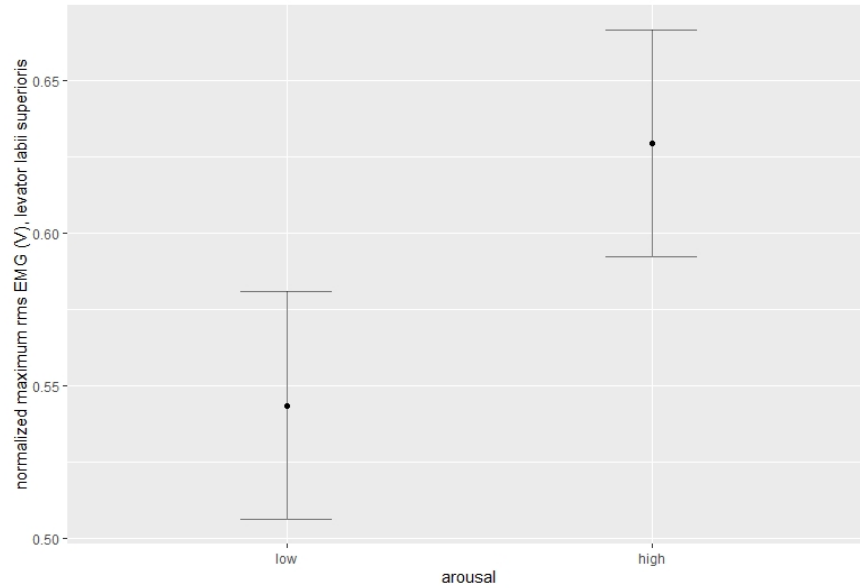


Figure 10. *Mean normalized maximum rms EMG (V) in the levator labii superioris in response to Low Arousal and High Arousal in Experiment 1 (with standard error bars).*

Although there was an overall significant interaction between Valence * Arousal * Concreteness in the orbicularis oculi ($F(1,18)=7.37$; $p=0.01$; generalized $\eta^2=0.02$), the “squinting” / “Duchenne smile” muscle, the planned comparisons between High Valence Low Arousal Low Concreteness ($M=0.66$ V, $SD=0.18$ V) vs. Low Valence Low Arousal Low Concreteness ($M=0.59$ V, $SD=0.24$ V) and High Valence Low Arousal Low Concreteness ($M=0.66$ V, $SD=0.18$ V) vs. High Valence Low Arousal High Concreteness ($M=0.65$ V, $SD=0.22$ V) were not statistically significant (Holm p -values > 0.26). No other main effects or interactions were statistically significant in Experiment 1 (all p -values > 0.06); descriptive statistics for the normalized maximum rms EMG for each muscle relevant to the factors of interest in Experiment 1 can be found in Appendix C (cf. Appendix B for muscle abbreviations).

Table 7. *Summary of EMG findings for main effects and interactions (H=High, L=Low; V=Valence, A=Arousal, C=Concreteness) in Experiment 1 (N=20).*

MUSCLE	FUNCTION(S)	FINDINGS
zygomaticus major	smile	Valence HV > LV
corrugator supercilii	frown	Valence LV > HV
levator labii superioris	raise upper lip, expand nostrils	Arousal HA > LA
orbicularis oculi	squint	Valence * Arousal * Concreteness HV LA LC > LV LA LC (ns.) HV LA LC > HV LA HC (ns.)

In Experiment 2, there were no statistically significant main effects or interactions (all p-values > 0.05); descriptive statistics for the normalized maximum rms EMG for each muscle relevant to the factors of interest in Experiment 2 can be found in Appendix C (cf. Appendix B for muscle abbreviations).

5.2. STUDY 2

5.2.1. BEHAVIORAL AND EMG FINDINGS FOR THE LEXICAL DECISION TASK

First, we performed a series of two-sided paired t-tests between responses to valid English words vs. consonant-string non-words in Study 2 (N=34) on each behavioral measure (accuracy, RTs, tap amplitude) and found that responses to valid English words significantly differed from responses to consonant-string non-words in accuracy and RTs, with words being identified more accurately ($t(33)=3.1$; $p=0.003$; Cohen's $d=0.6$; words: $M=99.45\%$ (i.e. 238.7 out of 240), $SD=0.61\%$ (1.48/240); non-words: $M=98.9\%$ (237.38/240), $SD=1.07\%$ (2.59/240)) and more slowly ($t(33)=2.05$; $p=0.04$; Cohen's $d=0.1$; words: $M=1265$ ms, $SD=548$ ms; non-words: $M=1208$ ms, $SD=503$ ms) than consonant-string non-words. There was no statistically significant difference in tap amplitude between words ($M=0.27$ V, $SD=0.11$ V) and consonant-string non-words ($M=0.27$ V, $SD=0.11$ V) in Study 2 ($p=0.47$).

Then, we conducted a two-sided paired t-test on the normalized maximum rms EMG for the zygomaticus major muscle between responses to valid English words vs. consonant-string non-words in Study 2 (N=34) to determine if there was a difference in the response to valid English words compared to consonant-string non-words at the reflex muscle activation level. As expected, we found that EMG activity in response to valid English words significantly differed from consonant-string non-words ($t(33)=2.88$; $p=0.006$; Cohen's $d=0.5$), with words ($M=0.42$ V, $SD=0.17$ V) inducing greater EMG activity than consonant-string non-words ($M=0.34$ V, $SD=0.15$ V).

5.2.2. MUSCLE-SPECIFIC EMG FINDINGS FOR THE FACTORS OF INTEREST

To examine the embodiment of the factors of interest, we performed repeated-measures 2 x 2 x 2 ANOVAs on the normalized maximum rms EMG for relevant muscles in response to correct lexical-decision trials for valid English words (consonant-string non-words were not included in the analyses) to determine main effects of Valence / Arousal / Concreteness (Experiment 3) and Dominance / Arousal / Concreteness (Experiment 4) as well as interactions between these factors in each experiment. In Experiment 3, there was a main effect of Valence in the zygomaticus major ($F(1,33)=16.07$; $p=0.0003$; generalized $\eta^2=0.06$), the “smiling” muscle, where High Valence ($M=0.51$ V, $SD=0.24$ V) induced greater EMG activity than Low Valence ($M=0.37$ V, $SD=0.17$ V).

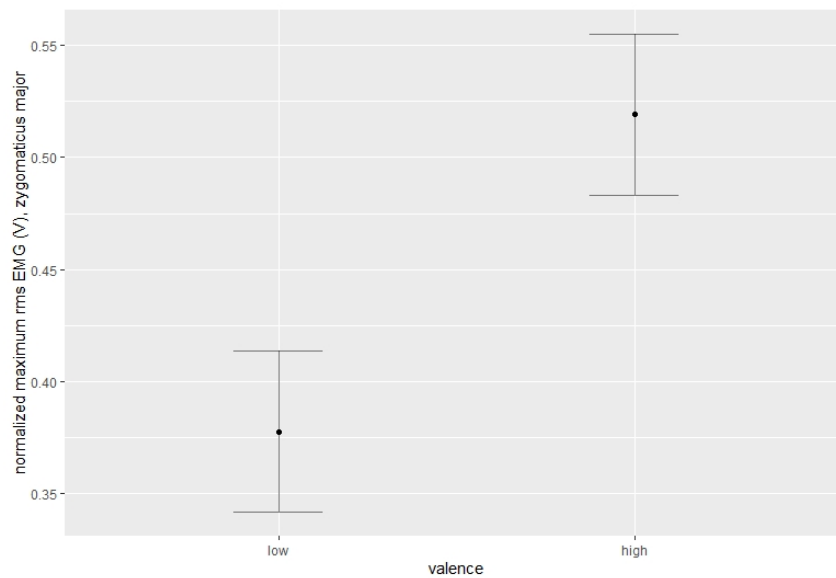


Figure 11. *Mean normalized maximum rms EMG (V) in the zygomaticus major in response to Low Valence and High Valence in Experiment 3 (with standard error bars).*

There were also main effects of Valence in the corrugator supercilii ($F(1,32)=21.4$; $p=0.00005$; generalized $\eta^2=0.05$), the “frowning” muscle, where Low Valence ($M=0.63$ V, $SD=0.15$ V) induced greater EMG activity than High Valence ($M=0.52$ V, $SD=0.18$ V), and in the mentalis ($F(1,31)=6.97$; $p=0.01$; generalized $\eta^2=0.02$), the “chin lifter” muscle, where Low Valence ($M=0.58$ V, $SD=0.14$ V) induced greater EMG activity than High Valence ($M=0.52$ V, $SD=0.15$ V).

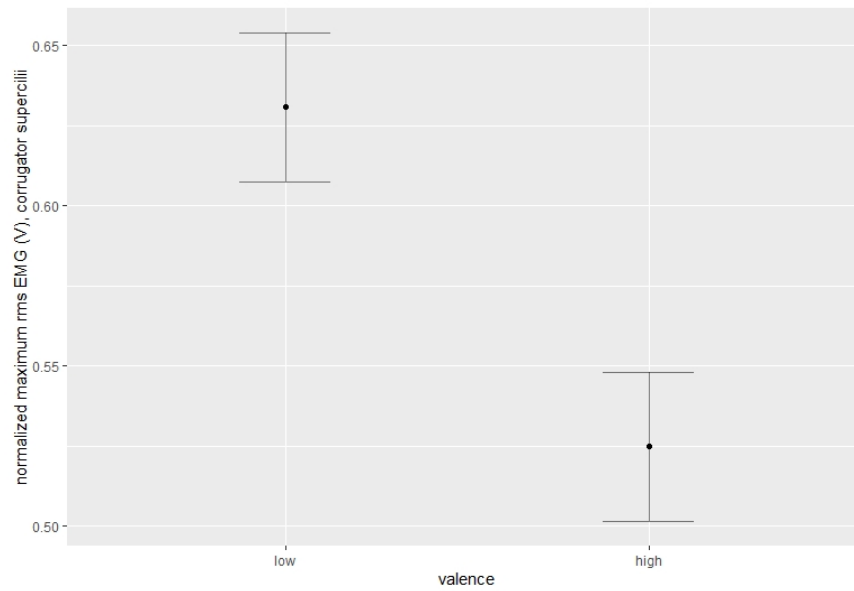


Figure 12. *Mean normalized maximum rms EMG (V) in the corrugator supercilii in response to Low Valence and High Valence in Experiment 3 (with standard error bars).*

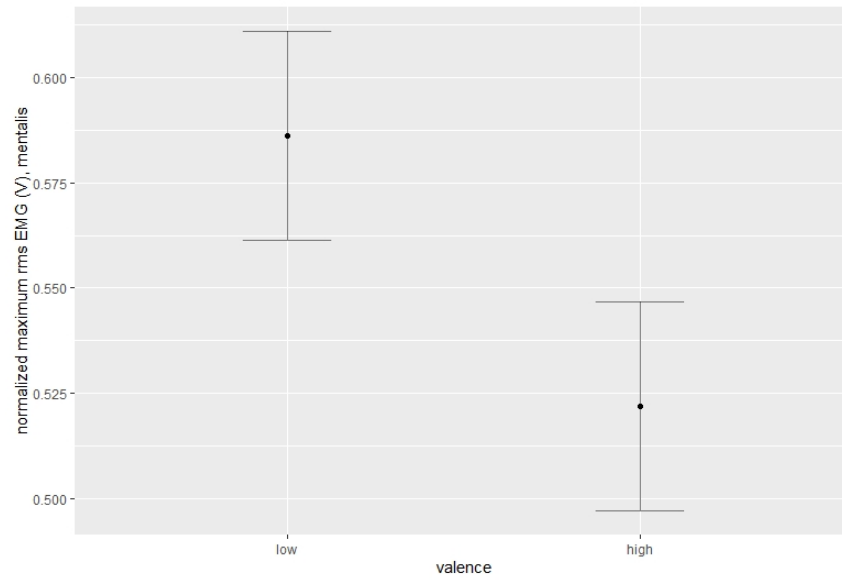


Figure 13. *Mean normalized maximum rms EMG (V) in the mentalis in response to Low Valence and High Valence in Experiment 3 (with standard error bars).*

There was an interaction between Valence * Arousal ($F(1,33)=7.19$; $p=0.01$; generalized $\eta^2=0.01$) in the zygomaticus major, the “smiling” muscle, where the planned comparison between High Valence High Arousal ($M=0.56$ V, $SD=0.26$ V) vs. High Valence Low Arousal ($M=0.47$ V, $SD=0.26$ V) was significant ($p=0.002$).

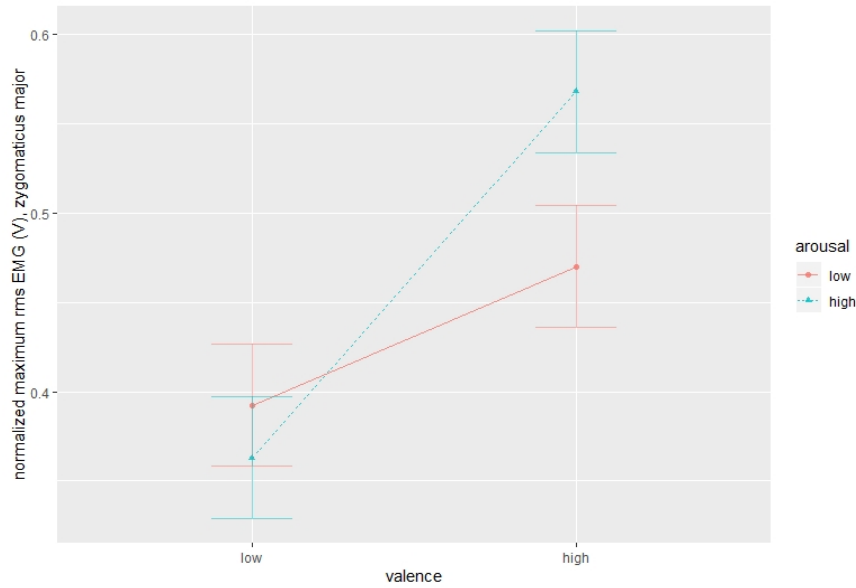


Figure 14. *Mean normalized maximum rms EMG in the zygomaticus major for the interaction between Valence and Arousal in Experiment 3 (with standard error bars).*

There was also an interaction between Valence * Concreteness ($F(1,33)=5.57$; $p=0.02$; generalized $\eta^2=0.004$) in the levator labii superioris alaeque nasi, the “nose wrinkling” muscle, where the planned comparison between High Valence Low Concreteness ($M=0.58$ V, $SD=0.19$ V) vs. Low Valence Low Concreteness ($M=0.53$ V, $SD=0.18$ V) was significant ($p=0.04$).

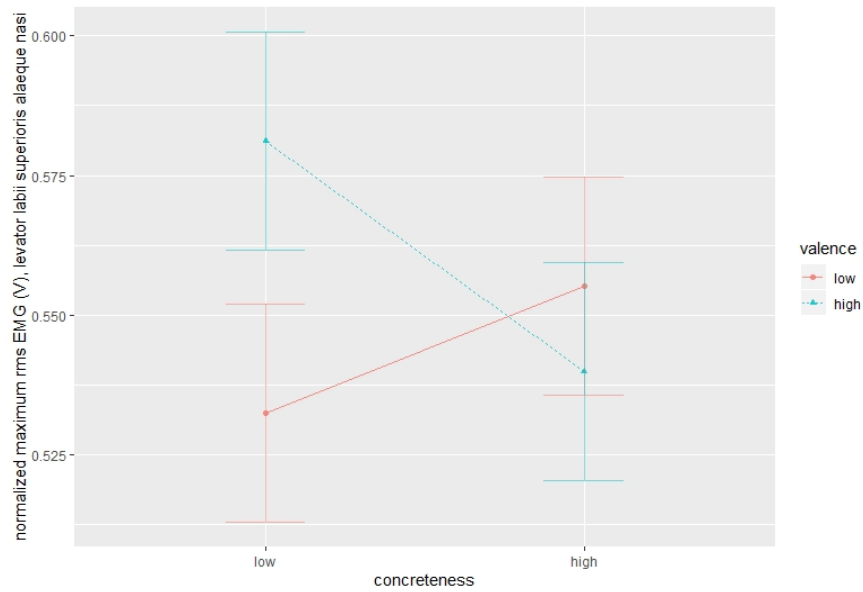


Figure 15. *Mean normalized maximum rms EMG in the levator labii superioris alaeque nasi for the interaction between Valence and Concreteness in Experiment 3 (with standard error bars).*

There was a main effect of Concreteness in the corrugator supercilii ($F(1,32)=4.93$; $p=0.03$; generalized $\eta^2=0.009$), the “frowning” / “thinking” muscle, where Low Concreteness ($M=0.59$ V, $SD=0.14$ V) induced greater EMG activity than High Concreteness ($M=0.55$ V, $SD=0.17$ V).

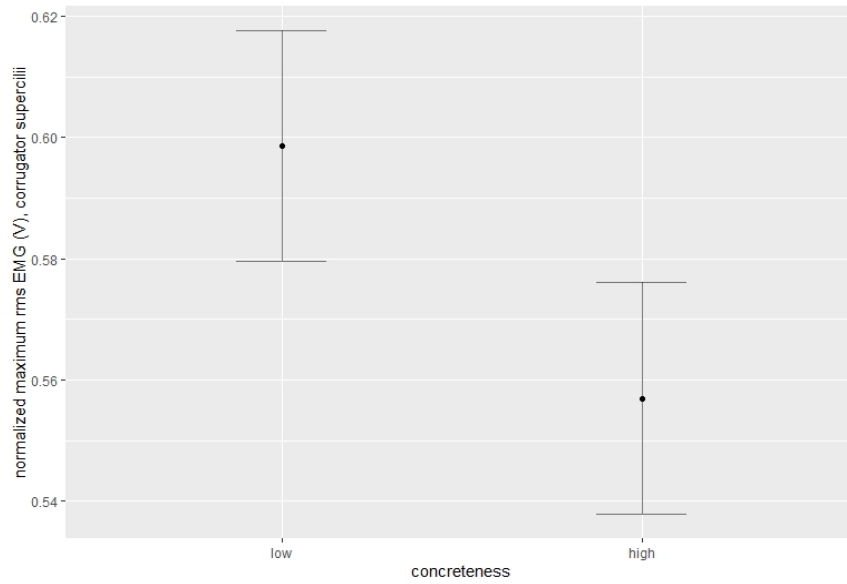


Figure 16. *Mean normalized maximum rms EMG (V) in the corrugator supercilii in response to Low Concreteness and High Concreteness in Experiment 3 (with standard error bars).*

No other main effects or interactions were statistically significant in Experiment 3 (all p-values > 0.12); descriptive statistics for the normalized maximum rms EMG for each muscle relevant to the factors of interest in Experiment 3 can be found in Appendix C (cf. Appendix B for muscle abbreviations).

Table 8. *Summary of EMG findings for main effects and interactions (H=High, L=Low; V=Valence, A=Arousal, C=Concreteness) in Experiment 3 (N=34).*

MUSCLE	FUNCTION(S)	FINDINGS
zygomaticus major	smile	Valence HV > LV Valence * Arousal HV HA > HV LA
corrugator supercilii	frown	Valence LV > HV Concreteness LC > HC
mentalis	lift chin	Valence LV > HV
levator labii superioris alaeque nasi	wrinkle nose	Valence * Concreteness HV LC > LV LC

In Experiment 4, there was an interaction between Dominance * Concreteness ($F(1,32)=5.6$; $p=0.02$; generalized $\eta^2=0.01$) in the corrugator supercilii, the “frowning” / “thinking” muscle, where the planned comparison between High Dominance Low Concreteness ($M=0.67$ V, $SD=0.17$ V) vs. High Dominance High Concreteness ($M=0.59$ V, $SD=0.2$ V) was significant (Holm $p=0.01$) but the planned comparison between High Dominance Low Concreteness ($M=0.67$ V, $SD=0.17$ V) vs. Low Dominance Low Concreteness ($M=0.61$ V, $SD=0.17$ V) was not statistically significant (Holm $p=0.07$).

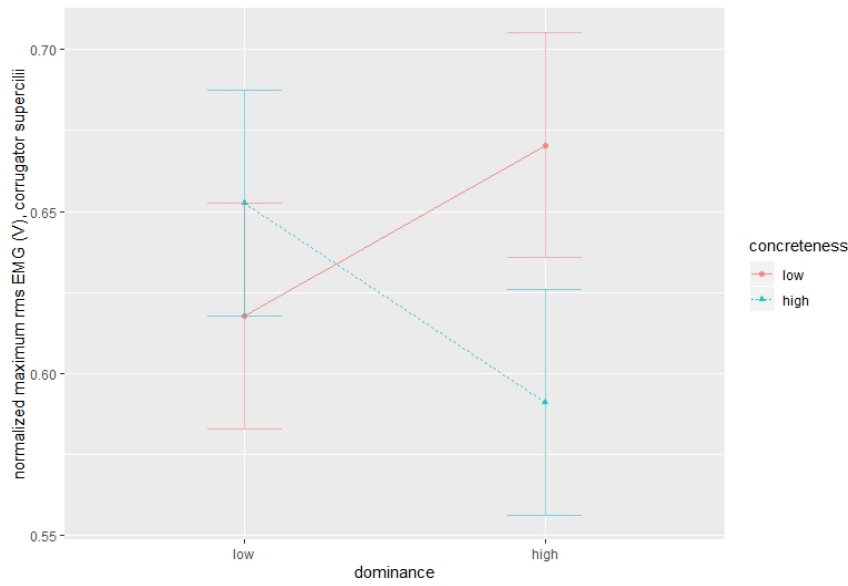


Figure 17. *Mean normalized maximum rms EMG in the corrugator supercilii for the interaction between Dominance and Concreteness in Experiment 4 (with standard error bars).*

Although there was an overall significant interaction between Dominance * Arousal * Concreteness in the orbicularis oculi ($F(1,33)=4.21$; $p=0.04$; generalized $\eta^2=0.008$), the “squinting” muscle, the planned comparison between High Dominance Low Arousal Low Concreteness ($M=0.59$ V, $SD=0.24$ V) vs. High Dominance Low Arousal High Concreteness ($M=0.51$ V, $SD=0.21$ V) was not statistically significant (Holm $p=0.06$) and the planned comparison between High Dominance Low Arousal Low Concreteness ($M=0.59$ V, $SD=0.24$ V) vs. Low Dominance Low Arousal Low Concreteness ($M=0.53$ V, $SD=0.21$ V) was not statistically significant either (Holm $p=0.09$). No other effects or interactions were statistically significant in Experiment 4 (all p -values > 0.07); descriptive statistics for the normalized

maximum rms EMG for each muscle relevant to the factors of interest in Experiment 4 can be found in Appendix C (cf. Appendix B for muscle abbreviations).

Table 9. *Summary of EMG findings for main effects and interactions (H=High, L=Low; D=Dominance, A=Arousal, C=Concreteness) in Experiment 4 (N=34).*

MUSCLE	FUNCTION(S)	FINDINGS
corrugator supercilii	frown	Dominance * Concreteness HD LC > HD HC HD LC > LD LC (ns.)
orbicularis oculi	squint	Dominance * Arousal * Concreteness HD LA LC > HD LA HC (ns.) HD LA LC > LD LA LC (ns.)

6. DISCUSSION

In the Discussion section, we interpret behavioral and EMG findings for each study, relating them to previous research, whereas in the General Discussion section we situate the findings within broader literature on the embodiment of affect and discuss theoretical implications.

6.1. STUDY 1

6.1.1. BEHAVIORAL AND EMG FINDINGS FOR THE LEXICAL DECISION TASK

Behavioral findings in Study 1 (Experiment 1, Experiment 2) suggest overall processing differences between valid English words vs. pseudowords. Unexpectedly, we found significant differences only in RTs but not in accuracy for words vs. pseudowords. Perhaps, due to the fact that we used words on the lower end of HAL frequency range, overall accuracy for words was less than accuracy for pseudowords and between-participant variability was greater in responses to words than to pseudowords, which suggests that participants were, on average, less sure when responding to low-frequency words, likely due to their limited lexicon. On the other hand, the fact that RTs for words were, on average, 100 ms shorter than for pseudowords and that there was a weak negative correlation of -0.2 between RTs and accuracy in Study 1 suggests that participants had less doubt in making lexical decision when they knew the word meaning. It is unlikely that there was a speed-accuracy trade-off, because the correlation between RTs and accuracy was inversely proportional and because participants knew that they could correct their

responses by tapping the appropriate sensor with more force, if they felt that they had made a mistake after they initially tapped for the response.

Similarly to relatively long lexical-decision RTs (~1200 ms), the average timing of the onset of the maximum EMG response in Study 1 was also quite late (~2000 ms), cf. Appendix B. This could be either due to the overall dull and repetitive nature of the study, or it could be an artifact of the task, as participants first had to decide if a stimulus was a valid English word and only then they were to think of its meaning, which may have prompted task-dependent processing strategies. Even though many participants reported that pseudowords seemed “funny” to them, there was a significant difference in the normalized maximum rms EMG activity in the zygomaticus major, the “smiling” muscle, for words vs. pseudowords, with words eliciting greater EMG response than pseudowords. The fact that reflex activity in the muscle that was least likely to show a difference between words and pseudowords was observed suggests that participants were implicitly processing the lexical decision task as expected.

6.1.2. MUSCLE-SPECIFIC EMG FINDINGS FOR THE FACTORS OF INTEREST

Findings on muscle-specific EMG activity in Experiment 1 provide solid evidence for the embodiment of Valence and Arousal and some evidence for the embodiment of Concreteness. As predicted, Experiment 1 revealed that the “smiling” muscle (zygomaticus major) was activated to a greater extent when processing High Valence (positive) than Low Valence (negative) words, while the “frowning” muscle (corrugator supercilii) was activated to a greater extent when processing Low Valence (e.g. ‘ruin’) than High Valence (e.g. ‘joke’) words. This suggests that participants’ facial micro-expressions tended to reflect smiling in response to positive words and

frowning in response to negative words. These findings are consistent with previous EMG research on valence that used picture viewing and imagery tasks and reported increased activity in the zygomaticus major in response to High Valence and positive-emotion stimuli and increased activity in the corrugator supercilii in response to Low Valence and negative-emotion stimuli (Witvliet & Vrana, 1995; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Heller et al., 2014; Latham et al., 2017; Lucas et al., 2019).

Also in line with our predictions, Experiment 1 revealed greater EMG activity for the “nostril expansion” muscle (levator labii superioris) in response to High Arousal (e.g. ‘desire’) than to Low Arousal (e.g. ‘retire’) words. That is, in their facial micro-expressions, participants tended to expand their nostrils more in response to words with ‘intense’ rather than ‘calm’ meaning, exhibiting a physical action that commonly occurs when people breathe deeply or rapidly. This finding is not only consistent with previous research on arousal in picture viewing and imagery tasks that reported increased heart rate, skin conductance, and pupil dilatation in response to High Arousal stimuli (Vrana et al., 1986; Vrana, 1993; Witvliet & Vrana, 1995; Simons et al., 1999; Reagh & Knight, 2013), but it also extends prior EMG findings on arousal that were based on picture viewing and imagery tasks (Dimberg, 1982, 1986; Cacioppo et al., 1986; Witvliet & Vrana, 1995; Simons et al., 1999; Bradley & Lang, 2000; Zhang et al., 2011; Tan et al., 2012, 2016) to the language processing domain, for the first time grounding the affective concept of arousal in the reflex activity of the semantically relevant “nostril expansion” muscle, levator labii superioris.

Prior picture-viewing EMG studies on the embodiment of arousal focused primarily on the zygomaticus major and corrugator supercilii muscles (Witvliet & Vrana, 1995; Simons et al.,

1999; Bradley & Lang, 2000; Zhang et al., 2011; Tan et al., 2012, 2016), even though these muscles are involved in smiling and frowning, respectively, and therefore are more reflective of the concept of valence (i.e. positivity/negativity, pleasantness/unpleasantness). Whereas some of the picture/imagery studies on the embodiment of valence and arousal only obtained significant results for valence (Simons et al., 1999; Tan et al., 2012), others did find effects of arousal in the zygomaticus major and corrugator supercilii (Witvliet & Vrana, 1995; Bradley & Lang, 2000; Zhang et al., 2011; Tan et al., 2016). However, they overlooked examining muscles that are involved in nostril expansion (e.g. levator labii superioris), a motor action that is correlated with deep or rapid breathing, even though it would seem logical to investigate such muscles if one is examining the embodiment of the concept of arousal (i.e. intensity/calmness). The observed interaction between Valence * Arousal * Concreteness in the orbicularis oculi, the “squinting” / “Duchenne smile” muscle, in Experiment 1 is also a novel finding. However, since none of the planned comparisons were statistically significant, it is hard to draw any definitive conclusions regarding the interrelation between these three factors of interest.

Our findings for valence effects in the zygomaticus major and corrugator supercilii muscles parallel prior research on the embodiment of positive and negative emotion-denoting and emotion-evoking words (Niedenthal et al., 2009; Fino et al., 2016) and facial action-related words (Foroni & Semin, 2009, 2013; Fino et al., 2016) and establish the embodiment of general affective concept of valence in lexico-semantic processing. Our finding for an effect of arousal in the levator labii superioris is novel and, for the first time in the embodiment literature, grounds the affective concept of arousal at the reflex activity level of the muscle that is semantically relevant to the intensity/calmness dimension. Together, these findings provide solid support for

the linguistic embodiment of the two traditionally discussed affective dimensions of valence and arousal, which have been the basis of two-dimensional theories of affect, such as the circumplex model (Russell, 1980, 2003; Russell et al., 1989; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016).

6.2. STUDY 2

6.2.1. BEHAVIORAL AND EMG FINDINGS FOR THE LEXICAL DECISION TASK

Behavioral findings in Study 2 (Experiment 3, Experiment 4) suggest that the consonant-string non-word context facilitated the lexical decision task but also reduced participants' engagement in the task, which was already relatively low as evidenced by long RTs in Study 1. Consonant-string non-words made the lexical decision task in Study 2 much easier than did pseudowords in Study 1, thereby potentially inducing even more disinterest and reducing participants' engagement in the lexical decision, which was suggested by errors for *both* words and consonant-string non-words, as it is extremely unlikely that native English speakers would genuinely misidentify consonant strings, such as 'bkgdl', for valid English words. Despite the ease of making the lexical decision in Study 2, RTs were quite long (>1200 ms) for *both* words and consonant-string non-words, which suggests that the participants in Study 2 were less engaged in the task than the participants in Study 1, because it is very unlikely that native English speakers would require, on average, 1200 ms to decide that a consonant string, such as 'bkgdl', is not a valid English word.

Similar to quite long lexical-decision RTs (>1200 ms), the average timing of the onset of the maximum EMG response in Study 2 was also rather late (~2200 ms), ~200 ms later than in Study 1, cf. Appendix B. Such an increase in the delay of the EMG response, in concatenation with marginally longer RTs, is suggestive of the decreased task engagement in Study 2 as compared to Study 1. Similar to Study 1, there was a significant difference in the normalized maximum rms EMG activity in the zygomaticus major, the “smiling” muscle, for words vs. consonant-string non-words, with words eliciting greater EMG response than consonant-string non-words, which suggests that participants were implicitly processing the lexical decision task as expected.

6.2.2. MUSCLE-SPECIFIC EMG FINDINGS FOR THE FACTORS OF INTEREST

Findings on muscle-specific EMG activity in Experiment 3 provide solid evidence for the embodiment of Valence, Arousal, and Concreteness, while the EMG results of Experiment 4 provide evidence for the embodiment of Concreteness and some evidence for the embodiment of Dominance. As predicted, Experiment 3 revealed that the “smiling” muscle (zygomaticus major) was activated to a greater extent when processing High Valence (positive) than Low Valence (negative) words, whereas the “frowning” (corrugator supercilii) and “chin lifting” (mentalis) muscles were activated to a greater extent when processing Low Valence (negative) than High Valence (positive) words. Similar to Experiment 1, participants’ micro-expressions tended to reflect smiling in response to pleasant words but frowning in response to unpleasant words. However, these findings provide a more expansive description of the embodiment of Low Valence (negative words) than Experiment 1, since we found activation of the “chin lifting”

muscle (mentalis), which can be involved in negative facial expressions (cf. Figure 2b) but has not been investigated in prior EMG research that focused primarily on the zygomaticus major and corrugator supercilii muscles in relation to valence (Witvliet & Vrana, 1995; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Heller et al., 2014; Latham et al., 2017; Lucas et al., 2019). Our findings also suggest that EMG responsiveness of the mentalis to Low Valence may be less frequent than that of the corrugator supercilii, because we obtained this finding only when we had a larger sample size and because the effect size for the mentalis in our data was less than the effect size for the corrugator supercilii. Another novel finding of Experiment 3 is the interaction between Valence * Concreteness in the levator labii superioris alaeque nasi, which suggests the involvement of the “nose wrinkling” muscle in the embodiment of High Valence and Low Concreteness, by revealing that at Low Concreteness levels there was greater EMG activity in response to High Valence (positive) than to Low Valence (negative) words.

While our findings for valence effects in the zygomaticus major and corrugator supercilii, again, parallel prior research on the embodiment of emotion-denoting and emotion-evoking words (Niedenthal et al., 2009; Fino et al., 2016) and facial action-related words (Foroni & Semin, 2009, 2013; Fino et al., 2016), the findings for valence in the mentalis and levator labii superioris alaeque nasi are novel and suggest that facial micro-expressions that are reflective of the negativity/positivity dimension can manifest themselves in more complex ways than it was previously suggested (Witvliet & Vrana, 1995; Simons et al., 1999; Hu & Wan, 2003; Larsen et al., 2003; Neta et al., 2009; Zhang et al., 2011; Beffara et al., 2012; Tan et al., 2012; Balconi & Canavesio, 2016). As such, our findings for valence in Experiment 3 not only ground the embodiment of general affective concept of valence in lexico-semantic processing, but they also

reveal the embodiment of valence during online linguistic processing at a more nuanced reflex muscle activation level.

The interaction between Valence * Arousal in the “smiling” muscle (zygomaticus major) in Experiment 3 revealed that at High Valence levels there was more EMG activity in response to High Arousal (e.g. ‘celebrate’) than to Low Arousal (e.g. ‘relax’) words. That is, participants tended to have smiling facial micro-expressions in response to High Valence High Arousal words (e.g. ‘prosper’) as compared to High Valence Low Arousal words (e.g. ‘enlighten’). The absence of a main effect of Arousal in Experiment 3, in contrast to Experiment 1, but the presence of an interaction between Valence * Arousal in the muscle that is specific to the valence dimension (i.e. smiling semantically relates to the positivity/negativity rather than intensity/calmness concepts) may be related to the longer RTs in Study 2 as compared to Study 1. If long RTs in the task that is very easy to perform are indicative of participants’ disengagement or disinterest, which could be classified as Low Arousal states (cf. Simons et al., 1999; Kever et al., 2015, 2017), then the response to words that target the arousal dimension might have been attenuated in Study 2 compared to Study 1, making it less likely to detect differences in muscle activity in response to High Arousal vs. Low Arousal. Since participants’ attention levels have been linked to the physiological correlates of arousal (e.g. Simons et al., 1999; Kever et al., 2015, 2017), the shallower findings on arousal in Study 2, where participants’ engagement could have been reduced by a duller task, are in line with previously observed lower physiological responses to the dimension of arousal at lower sustained attention levels (Simons et al., 1999). The differences in the results between Experiment 1 and Experiment 3 suggest that the effects of arousal, unlike the effects of valence, may be dependent upon the participants’ levels of engagement in the

lexical decision task, which was expected, given the excitatory/calming nature of the concept of arousal.

The fact that we found an interaction between Valence * Arousal in the zygomaticus major in Experiment 3 but not in Experiment 1 parallels prior EMG research on the embodiment of arousal, because prior picture viewing and imagery task EMG studies were just as inconsistent in finding effects of arousal in the zygomaticus major and corrugator supercilii muscles (e.g. Simons et al., 1999; Bradley & Lang, 2000; Tan et al., 2012, 2016; vs. Witvliet & Vrana, 1995; Zhang et al., 2011), even though they used visual stimuli that were more salient in terms of arousal than our word stimuli and thus were more likely to elicit differential EMG activity in response to Low and High Arousal. This suggests an unstable nature of the effect of arousal in the zygomaticus major and corrugator supercilii, which is not surprising, given that these two muscles mostly relate to facial expressions of positivity/negativity or pleasantness/unpleasantness and therefore are more likely to be responsive to the dimension of valence. Specifically, the effects of valence and positive/negative emotions, such as “joy”/“happiness” and “anger”/“disgust”, in the zygomaticus major and corrugator supercilii, respectively, have been replicated numerous times both in picture/imagery studies (Hess et al., 1992; Vrana, 1993; Simons et al., 1999; Larsen et al., 2003; Neta et al., 2009; Beffara et al., 2012; Tan et al., 2012, 2016; Heller et al., 2014; Weinreich & Funcke, 2014) and in studies on the embodiment of language (Niedenthal et al., 2009; Foroni & Semin, 2013; Carr et al., 2016; Fino et al., 2016).

Overall, our findings for Valence and Arousal in Experiment 3 are in line with previous valence and arousal EMG research on picture viewing and imagery tasks that reported increased

EMG activity in the zygomaticus major in response to High Valence and High Arousal stimuli (Hess et al., 1992; Vrana, 1993; Witvliet & Vrana, 1995; Zhang et al., 2011; Latham et al., 2017; Lucas et al., 2019). They also extend prior EMG research on valence and arousal that used picture viewing and imagery tasks (Witvliet & Vrana, 1995; Simons et al., 1999; Zhang et al., 2011; Tan et al., 2012, 2016) to the language processing domain and provide solid ground for the linguistic embodiment of general affective concepts of valence and arousal.

Another revelation of Study 2 are muscle-specific embodied responses to abstract (i.e. Low Concreteness) and ‘in-control’ (i.e. High Dominance) concepts. Experiment 3, where all words were rated on the higher end of the dominance rating scale, showed an effect of Concreteness in the corrugator supercilii, the “frowning” / “thinking” muscle, with greater EMG activity in response to Low Concreteness (abstract words, e.g. ‘comprehend’) than High Concreteness (concrete words, e.g. ‘clench’). In turn, Experiment 4, where all words were rated on the lower end of the valence rating scale, revealed an interaction between Dominance * Concreteness in the corrugator supercilii muscle, where High Dominance Low Concreteness words (e.g. ‘insist’) induced greater EMG activity than High Dominance High Concreteness words (e.g. ‘bite’). The fact that we found consistent greater EMG activity in the relevant muscle for Low Concreteness (abstract) words is in line with research that reported Low Concreteness (i.e. abstract lexico-semantic concepts) to be embodied within the limbic system (Kousta et al., 2009, 2011; Moseley et al., 2012; Vigliocco et al., 2014), which is tightly linked to facial expressions, whereas High Concreteness (i.e. concrete lexico-semantic concepts) have been reported to be embodied within the motor system (Hauk et al., 2004; Pulvermueller et al., 2005; Tettamanti et al., 2005; Aziz-Zadeh et al., 2006), which is linked to limb motion.

Although the corrugator supercilii is mostly known in the embodiment literature as the “frowning” muscle, which has been traditionally associated with Low Valence (negative) concepts (Wexler et al., 1992; Bradley & Lang, 2000; Dimberg et al., 2000, 2002; Foroni & Semin, 2009, 2013; Tan et al., 2012; Davis et al., 2015; Carr et al., 2016), “frowning” is not the only function of the corrugator supercilii and it is not exclusively associated with negativity (Dimberg, 1986; Hu & Wan, 2003; Cohn et al., 2007; Barrett et al., 2019). It can be also associated with being unsure about something, such as reflecting on the different outcomes of a scenario, which would be more consistent with an abstract concept than a concrete concept, as one is more likely to reflect on an abstraction than on something concrete, which is easier to visualize. Given that the corrugator supercilii is involved in both horizontal and vertical brow movements by pulling the eyebrow downward and medially (Cohn et al., 2007; Niedenthal et al., 2009; Dimberg & Thunberg, 2012; Gill et al., 2014; Jack et al., 2014; Jack & Schyns, 2015) and that the processing of abstract concepts potentially implies higher uncertainty and metacognitive awareness of inadequacy than the processing of concrete concepts (Shea, 2018), one could be more likely to move eyebrows when reflecting on abstract rather than concrete words (e.g. Rinn, 1984).

In addition, linguistic processing under higher uncertainty levels may not be limited to the eyebrow micro-movements. Some support for the embodiment of concreteness was also found for the “squinting” muscle (orbicularis oculi). Similar to Experiment 1 where there was an overall significant interaction between Valence * Arousal * Concreteness in the orbicularis oculi, Experiment 4 revealed an overall significant interaction between Dominance * Arousal * Concreteness in the orbicularis oculi, although none of the planned comparisons were

statistically significant. This suggests that while the involvement of the “squinting” muscle in the embodiment of concreteness could be considered provisional, the primary muscle involved in the embodiment of abstract concepts is the corrugator supercilii, the “frowning” / “thinking” muscle. Overall, our findings situate the concept of concreteness within the embodiment debate (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Beffara et al., 2012; Pulvermueller, 2013) by demonstrating that Low Concreteness (i.e. abstract concepts) consistently resonates within the reflex activity of relevant muscle(s) during relatively implicit lexico-semantic processing.

Lastly, Experiment 4 also provided some support for the linguistic embodiment of dominance, as suggested by an interaction between Dominance * Concreteness, where at High Dominance levels there was greater EMG activity in the “frowning” muscle (corrugator supercilii) in response to Low Concreteness (e.g. ‘insist’) than High Concreteness (e.g. ‘bite’) words, and by an overall significant interaction between Dominance * Arousal * Concreteness in the “squinting” muscle (orbicularis oculi). Although our findings for dominance are likely to be dependent on Low Concreteness (i.e. abstract lexico-semantic concepts), as suggested by the interactions between Dominance and Concreteness, they nevertheless provide a tentative evidence that dominance, which has been generally excluded from the dimensional theories of affect (Russell, 1980, 2003; Russell et al., 1989; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016), *may* be examined within the context of language embodiment similar to the traditionally examined dimension of valence (Davis et al., 2015, 2017; Carr et al., 2016; Fino et al., 2016), especially since the “frowning”

muscle (corrugator supercilii) has been implicated in facial expressions related to the concept of dominance, the ‘submissive’/‘controlling’ dimension of affect, as suggested by emotions, such as ‘fear’ (Dimberg, 1986; Hess et al., 1992; Witvliet & Vrana, 1995; Hu & Wan, 2003; Montepare & Dobish, 2003; Hareli et al., 2009; Zhang et al., 2011; Rymarczyk et al., 2019) and ‘anger’ (Hess et al., 1992; Vrana, 1993; Dimberg et al., 2000, 2002; Yartz & Hawk, 2002; Hu & Wan, 2003; Neta et al., 2009; Niedenthal et al., 2009; Beffara et al., 2012; Dimberg & Thunberg, 2012; Kret et al., 2013; Gill et al., 2014; Heller et al., 2014; Jack et al., 2014; Jack & Schyns, 2015; Davis et al., 2017), with ‘fear’ being rated low and ‘anger’ being rated high on the dominance dimension (Knutson, 1996; Dryer, 1998; Montepare & Dobish, 2003; Hess et al., 2004, 2005; Hareli et al., 2009; Gill et al., 2014; Jack et al., 2014; Jack & Schyns, 2015). Further research is needed to disentangle the particulars of the linguistic embodiment of dominance and its relation to abstract lexico-semantic concepts.

6.3. STUDY 1 VS. STUDY 2

Before proceeding to the General Discussion, it is important to address differences in findings between Study 1 and Study 2, and, more specifically, between Experiment 1 and Experiment 3. The observed differences between the two studies could be due to differences between the participants in Study 1 and Study 2, but, importantly, they could be due to different contexts in which valid English words appeared (pseudoword context in Study 1 vs. consonant-string context in Study 2) and which may have influenced participants’ levels of task engagement and lexical decision processing strategies, as English words were the same in both studies. Differences in task performance and processing between the two studies are particularly apparent

in RTs and accuracy. When valid English words were presented in the pseudoword context, RTs in response to words were significantly shorter, but when the words were presented in the consonant-string non-word context, RTs in response to words were significantly longer. Notably, accuracy in response to words vs. pseudowords showed a higher error rate for words (though this difference was not statistically significant), but an opposite pattern was observed for accuracy in response to words vs. consonant-string non-words, where there was a higher error rate for consonant-string non-words, which is suggestive of reduced task engagement. While the overall increase in accuracy in Study 2 is not surprising given the obvious nature of consonant-string non-words, the longer RTs in Study 2 suggest that the obviousness of consonant-string non-words may have qualitatively affected participants' performance by reducing their engagement in the task as compared to Study 1. Otherwise, it is extremely unlikely that native English speakers would require >1200 ms to decide that a consonant string, such as 'bkgdl', is not a valid English word and that they would genuinely misidentify such consonant strings for valid English words.

Despite the observed context-dependent differences in behavioral measures between Study 1 and Study 2, native English speakers' EMG responses were consistent in Experiment 1 and Experiment 3 (Valence sets, cf. Table 7 vs. Table 8) for major muscles that are involved in the expression of the positivity (zygomaticus major) - negativity (corrugator supercilii) dimension (Foroni & Semin, 2009, 2013; Niedenthal et al., 2009; Carr et al., 2016; Fino et al., 2016). The fact that we found evidence for the involvement of the "chin lifter" muscle (mentalis) in the processing of Low Valence and of the "nose wrinkler" muscle (levator labii superioris alaeque nasi) in the processing of High Valence and Low Concreteness in Experiment 3 but not in Experiment 1 might be explained by a lower frequency of activation of these muscles, as

suggested by the smaller effect size for the mentalis as compared to the corrugator supercilii. Given that Experiment 3 had more participants (N=34) than Experiment 1 (N=20), the greater statistical power is likely responsible for revealing the involvement of the mentalis and levator labii superioris alaeque nasi in the processing of valence in Experiment 3 but not in Experiment 1. Same reasoning applies for the findings for concreteness in the corrugator supercilii, the “frowning” muscle, which showed responsiveness to Low Concreteness (i.e. abstract lexico-semantic concepts) in Experiment 3 but not in Experiment 1.

Our findings are inconclusive with respect to the observed trends in the data that showed the predicted directionality but did not reach statistical significance for some or all of the planned comparisons. Specifically, this concerns planned comparisons for the interactions between Valence * Arousal * Concreteness in the orbicularis oculi in Experiment 1, between Dominance * Concreteness in the corrugator supercilii and Dominance * Arousal * Concreteness in the orbicularis oculi in Experiment 4. These interactions need to be further examined in future research. Also, a series of our hypotheses were not supported by the data. For instance, we did not find evidence for greater EMG activity in the levator labii superioris and levator labii superioris alaeque nasi in response to High Dominance, nor did we find evidence for greater EMG activity in the occipitofrontalis and orbicularis oris in response to Low Dominance. The lack of predicted effects could be due to a fairly small number of participants in both Study 1 (N=20) and Study 2 (N=34), large variability in the EMG signal given that participants had to provide a hand motor response during the stimulus presentation time interval, and the use of low-frequency words, which may have reduced participants’ level of certainty regarding some of the word meanings and, by this, contributed to even larger variability in the data. Further research

might mediate these shortcomings by increasing the number of participants and by using higher frequency words to avoid potential shortcomings of the current project.

7. GENERAL DISCUSSION

To our knowledge, this is the first study to systematically examine how abstract concepts and general affective dimensions of valence, arousal, and dominance are embodied during lexico-semantic processing. The goal of this project was to provide ground for the embodiment of subtle, linguistically encoded semantic notions of valence (positivity/negativity), arousal (intensity/calmness), dominance (control/submissiveness), and concreteness/abstractness in a context of a task that does not explicitly make participants aware of the investigated factors of interest. We deemed this objective important because prior research, regardless of whether it was related to language or picture processing, was unable to demonstrate reflex psychophysiological responses to the affective concepts *without* alerting participants to the experimentally relevant factors, either through explicitly salient stimuli (Foroni & Semin, 2009, 2013), explicitly biasing task (Weinreich & Funcke, 2014; Carr et al., 2016) or both explicitly salient stimuli and explicitly biasing task (Niedenthal et al., 2009; Delaney-Busch et al., 2016; Fino et al., 2016). For instance, even though Niedenthal et al. (2009) and Delaney-Busch et al. (2016) used emotionally and affectively laden words, they were able to detect facial reflex EMG responses only when using emotional judgment or affective classification tasks, not when using letter caption detection or animal identification tasks, perhaps because the latter diverted participants' attention from 'regular' lexico-semantic processing to selectively attending to very particular aspects of the words. Such a dependence on biasing strategies led to theories, such as the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014), which suggest the necessity of artificial 'encouragement' means for the occurrence of the

embodied responses to emotional/affective concepts (Weinreich & Funcke, 2014; Davis et al., 2015; Fino et al., 2016), thereby imposing a serious restriction on the scope of the embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Pulvermueller, 2013) and on the generalizability of the findings on the linguistic embodiment of affect and emotions to more general language processing that may not necessarily involve highly biasing contexts. The bodily grounding has been even more inadequate for abstract lexico-semantic concepts, because they have been used as an incentive to dismiss the theory of embodied cognition altogether for reasons that “there is no sensory or motor information that could correspond in any reliable or direct way to their ‘meaning’”, which makes the theory of embodied cognition “at best [...] partial” and “silent about the great majority of the concepts that we have” (Mahon & Caramazza, 2008).

The current project attempted to break the above shackles of the embodied cognition. While we did not concentrate on the timing of reflex muscle responses, as without knowing what types of cognitive processes (e.g. abstract conceptual processing) take place between the perception of the target word and the reflex muscle activation, it is impossible to distinguish between the ‘weak’ versions of the embodied and disembodied cognition theories (cf. Mahon & Caramazza, 2008), we did demonstrate that ‘encouraging’ strategies (cf. Weinreich & Funcke, 2014; Davis et al., 2015; Fino et al., 2016) are not necessary for the elicitation of systematic reflex activity in relevant muscles even for subtly encoded general concepts of valence, arousal, dominance, and abstractness/concreteness during a lexico-semantic processing task that does not explicitly alert participants to the factors of interest. By that, we loosened the restriction on the generalizability of the physiological responses to linguistic information and presented an

alternative to one of the major assumptions of the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014), which predicts that affect concordant EMG is more likely to occur if the task *necessitates* a somatosensory simulation of the evaluative meaning of stimuli (Niedenthal et al., 2009; Weinreich & Funcke, 2014; Davis et al., 2015; Fino et al., 2016). While no one disputes the assertion that, if the task necessitates emotional or affective processing, there would be a higher chance of obtaining significant facial EMG results, the question of the generalizability of the results of such an ‘encouragement artifact’ approach is worrisome. Although we did explicitly ask participants to think of a word meaning after making the lexical decision, we did not ask them to concentrate on any particular aspect of the word meaning and they were free to think of the meaning of a word as they would have ‘normally’ thought of it.

The fact that the words in our experiments were presented in a rather impoverished and disjoint context (i.e. in isolation, one at a time) but nevertheless elicited systematic reflex responses in relevant muscles weakens the ‘encouragement artifact’ assumption of the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014) and suggests a fairly intimate interrelation between subtly encoded affective concepts and facial reflex muscle activity, which itself is a product of the brain processes in motor and limbic systems (Hennenlotter et al., 2009; Havas et al., 2010; Heller et al., 2014; White et al., 2014; Rymarczyk et al., 2019). The fact that we observed reflex muscle activity quite late in lexico-semantic processing (between ~2000 ms and ~2200 ms post-stimulus onset) indicates that the embodied responses in our studies occurred during explicit semantic processing, within ~800 ms - ~900 ms of the lexical decision that occurred ~1200 ms post-stimulus onset, when

participants started to think of the word meaning after making the lexical decision. This echoes the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014) claim that EMG activity reflects an embodied part of the evaluation process (Weinreich & Funcke, 2014), although the findings of the current project suggest that it is not explicit emotional/affective evaluation process (Niedenthal et al., 2009; Weinreich & Funcke, 2014; Carr et al., 2016; Delaney-Busch et al., 2016) that elicits facial reflex activity in relevant muscles but rather that reflex muscle activity and emotional/affective processing are part of a more general semantic processing.

With the notion of ‘core affect’ (Russell & Barrett, 1999) being usually defined as the most elementary consciously accessible affective feelings and their neurophysiological counterparts (e.g. a sense of ‘pleasure’ or ‘displeasure’, ‘tension’ or ‘relaxation’, ‘depression’ or ‘elation’) and dimensional theories of affect (Russell & Mehrabian, 1977; Russell, 1980, 2003; Russell et al., 1989; Knutson, 1996; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009; Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016) providing a coordinate space for systematic relations between different affective factors, our findings validate the axes for valence and arousal at the level of reflex muscle activity, as evidenced by the effects of valence in the zygomaticus major (the “smiling” muscle), corrugator supercilii (the “frowning” muscle), and mentalis (the “chin lifter” muscle), and by the effect of arousal in the levator labii superioris (the “upper lip raiser” / “nostril expansion” muscle), which is in line with the two-dimensional theories of affect (Russell, 1980, 2003; Russell et al., 1989; Barrett & Russell, 1998; Russell & Barrett, 1999; Russell & Carroll, 1999; Posner et al., 2005; Barrett & Bliss-Moreau, 2009;

Colibazzi et al., 2010; Wilson-Mendenhall et al., 2013; Lindquist et al., 2016). At the same time, our findings do not exclude candidacy of dominance for serving as the third dimension of affect (Russell & Mehrabian, 1977; Knutson, 1996), as suggested by the interactions for dominance in the corrugator supercilii (the “frowning” muscle) and orbicularis oculi (the “squinting” muscle). Further research is needed to explore this possibility.

Perhaps, the most important contribution of the current project is that we were able to challenge one of the major objections to the theories of embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Pulvermüller, 2013), in which Mahon & Caramazza (2008) claimed that abstract lexico-semantic concepts have “no sensory or motor information that could correspond in any reliable or direct way to their ‘meaning’” and that theories of language embodiment “would be silent about the great majority of the concepts that we have”. With the terms ‘implicit’ and ‘embodied’ processing signifying systematic reflex activity that happens spontaneously in relevant muscles during lexico-semantic processing and of which participants are not consciously aware, our findings speak contrary to the above claim. These were abstract (i.e. Low Concreteness) words that systematically induced greater EMG reflex activity in the corrugator supercilii, the “frowning” / “thinking” muscle, and, notably, they did so during a relatively implicit lexico-semantic processing task that did not explicitly alert participants to the investigated factors of interest, thereby exemplifying an alternative to the ‘task bias’ assumption of the Embodied Simulation Emotion Account (Niedenthal, 2007; Niedenthal et al., 2009, 2010, 2014). By demonstrating that relevant reflex muscle activity in response to Low Concreteness words occurs spontaneously during lexico-semantic processing, we attested that abstract concepts may no longer be viewed as

a cornerstone to the theories of embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Niedenthal et al., 2005; Casasanto, 2009; Pulvermüller, 2013).

8. CONCLUSION

Returning to the quote cited at the beginning of this thesis, Weinreich & Funcke (2014) argued that affect-concordant EMG responses should be explained “as somatosensory simulation driven by task-dependent processing strategies.” The current project demonstrated the opposite. We showed that spontaneous reflex muscle responses to relatively subtle, linguistically encoded general concepts of affect and abstractness do not require artificial biases for either the stimuli or task. We also provided evidence for distinct muscle-specific activity in response to each of the factors of interest (i.e. valence, arousal, dominance, concreteness), which respectively grounds them within the theories of embodied cognition (Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Casasanto, 2009; Pulvermueller, 2013). Lastly, we demonstrated that abstract lexico-semantic concepts are not a challenge for language embodiment (cf. Mahon & Caramazza, 2008; vs. Barsalou, 1999, 2008, 2009; Gallese & Lakoff, 2005; Casasanto, 2009; Pulvermueller, 2013).

Despite being revealing regarding the embodiment of affective and abstract concepts during lexico-semantic processing, the current project also had important limitations. Since the timing of the onset of the maximum EMG response occurred fairly late in our findings (~2000 ms in Study 1 and ~2200 ms in Study 2), the current project can only substantiate the involvement of the investigated factors in the lexico-semantic processing at the post-lexical-access processing stage and not during the initial lexical processing. It is possible that the nature of the lexical decision task, which required participants to first respond whether a stimulus was a valid English word and only then to think of its meaning, may have delayed reflex physiological responses, as reflected by the timing onset of the maximum EMG (cf. Foroni & Semin, 2009; Weinreich & Funcke, 2014; Davis et al., 2017). It is also possible that the delay in the timing of

the onset of the EMG response in our studies was due to the overall high levels of task disengagement among the participants, as suggested by long RTs in Study 1 (~1200 ms) and even slightly longer RTs in Study 2 (>1200 ms). Further research might try to come up with a way to make the task less repetitive or more interesting, as well as to expand the investigation of the embodiment of affect to other populations, such as non-native speakers of English, in order to examine how robust the observed reflex muscle response patterns are and how consistent they are with those in the current project.

9. BIBLIOGRAPHY

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10. APPENDICES

APPENDIX A

IRB Study Number A06-B36-16B

CONSENT FORM

Title

“Linguistic Embodiment of Affect: Influence of Valence, Arousal, and Dominance on Cognitive and Motor Processes”

Supervisor: Dr. Theodore Milner

Doctoral student investigator: Anna Krusanova

Institution: McGill University

Funding source: Dr. Milner’s research grant

Introduction

This study is being conducted to investigate sweat gland activity during reading. This issue is important, because it would help us gain deeper understanding of some of the biological processes involved in language reading. In order to answer this question, we need people to volunteer as participants. Participation in the study is voluntary, and participants have a right to withdraw from the experiment at any time.

Study Procedures

After arriving at the laboratory, participants will be led to a quiet room, where the study procedure will be explained to them and where they will sign an informed consent form, if they choose to participate. Electrodes will then be attached over the muscles on the face, hands, and legs. After that, participants will be left for several minutes to habituate to the room and the electrodes. The experimenter will then provide instructions for the task. After hearing the instructions and indicating understanding, participants will perform 20 practice trials, while the experimenter will stand nearby in order to respond to any questions that might arise.

During the test phase, stimuli will be presented in a random order. Stimuli will be displayed on a 14-inch monitor located approximately 20 inches from the participant. In Experiments 1-3, a trial will start with a fixation star sign “*” shown in the center of a computer screen for 2.5s, immediately followed by the language stimulus for another 5.5s, at which point participant will respond using a tap sensor. After the answer, a blank screen will be shown for 3.5s, and the next trial will automatically begin. In Experiments 4 and 5, participants will have to provide a response after the stimulus presentation, when a hashtag sign “#” appears on the screen for 2.5s.

Experiments 6 and 7 will be similar to Experiments 1 and 4, respectively, but, in addition to placing skin-surface electrodes on various parts of face, hands, and legs, transcranial direct current stimulation will be applied to the surface of the scalp. This procedure involves application of a small electrical current of about 1-2 mA to the scalp through a pair of surface electrodes. The current is so small that participants rarely perceive it.

Each experiment, including setup, will take approximately 2.5 hours, and, due to experimental time length, each experiment will be conducted on a separate date in order to reduce cognitive load on participants. Participants may choose to participate in one or more experiments in the study. After each experiment, participants will be able to wash their hands and face to remove any residue on the skin.

Benefits and Risks

There are no direct benefits to participants. There are also no known risks associated with electromyography or transcranial direct current stimulation procedures for individuals with no history of facial surgery, neurological diseases, substance abuse or dependence, or use of medication affecting the central nervous system.

Participation in the study would benefit research on the interaction between language and electrodermal activity, thereby enriching our understanding of how language processing interacts with our physical bodies and potentially helping develop innovative interventions for clinical populations with language impairments.

Withdrawal from the Study

Participant may withdraw from the study at any point during the experiment. In this case, the collected data will be deleted.

Cost / Insurance

There is no cost or insurance to participants.

Compensation

Participants will not receive compensation for participation in the study.

Subject Rights

Participants have the right to ask questions at any time, and their participation in the study is voluntary. They have the right to discontinue participation at any time without penalty or loss of benefits to which they are otherwise entitled. Refusal to participate will involve no penalty or loss of benefits to which participants are otherwise entitled.

Confidentiality

Electronic and paper records will be stored in Dr. Milner's laboratory. All participants will be assigned a random code, which will be used instead of their identifying information. Data will be maintained on a password-protected computer in Dr. Milner's lab and used for research purposes only. Only the primary investigator (Anna Krusanova) and her supervisor (Dr. Milner) will have access to the data. Data will be kept for 7 years after publication of the results. Members of the McGill Institutional Review Board (IRB) or persons designated by the IRB may access the study records to verify the ethical conduct of this study.

Contact

Participants should contact the primary investigator via email anna.krusanova@mail.mcgill.ca with any questions about the study. Participants can also contact

the Institutional Review Board Ethics Officer Ms. Ilde Lepore at ilde.lepore@mcgill.ca or (514) 398-8302 for questions about the rights of research participants or for complaints.

Signature

The study has been explained to me and my questions have been answered to my satisfaction. I agree to participate in this study. I do not waive any of my rights by signing this consent.

Name: _____

Signature: _____

Date: _____

APPENDIX B

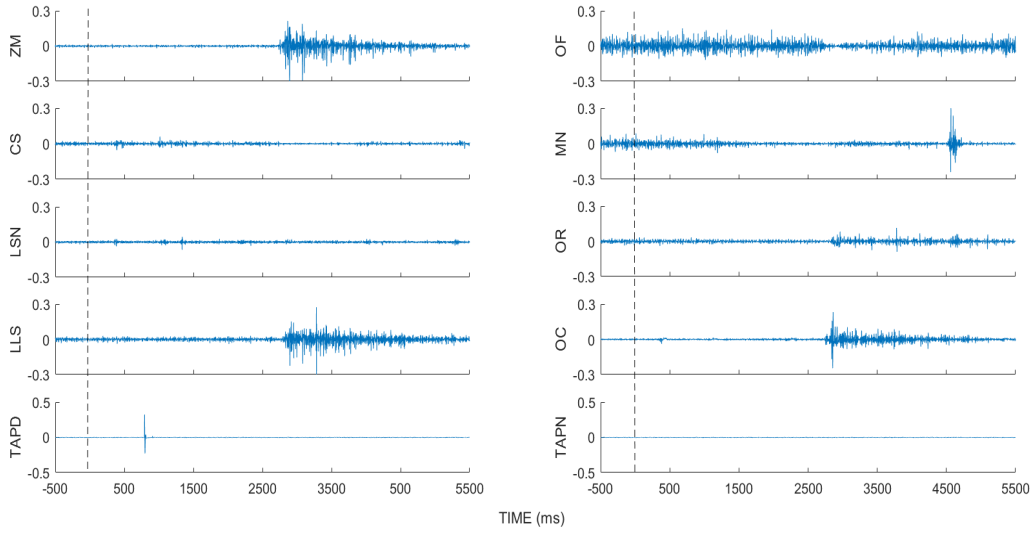


Figure 18. Sample raw EMG response to a valid word. ZM-OC are the abbreviations for 8 muscles. TAPD signifies tap with a dominant hand in response to a word. ZM=zygomaticus major, OF=occipitofrontalis, CS=corrugator supercilii, MN=mentalis, LSN=levator labii superioris alaeque nasi, OR=orbicularis oris, LLS=levator labii superioris, OC=orbicularis oculi

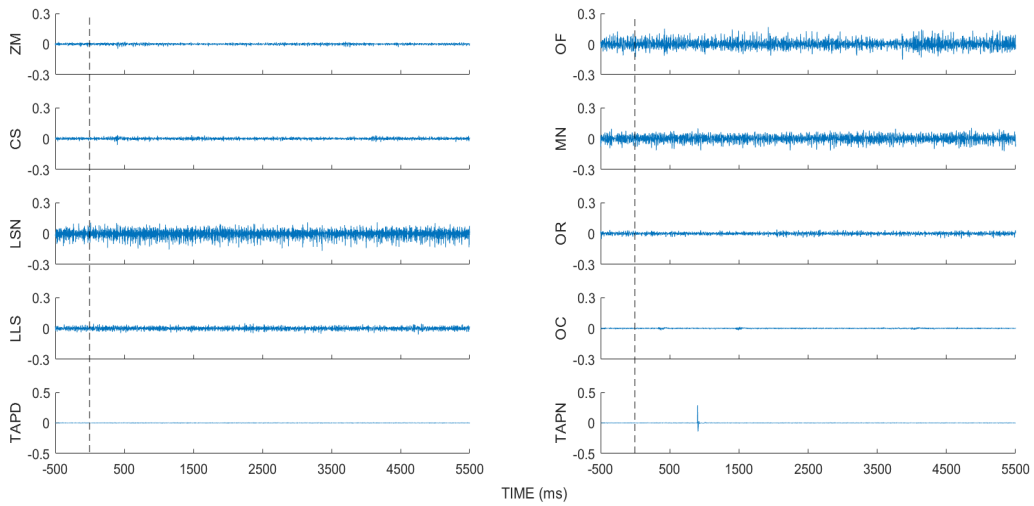


Figure 19. Sample raw EMG response to a non-word. ZM-OC are the abbreviations for 8 muscles. TAPN signifies tap with a non-dominant hand in response to a non-word.

Table 10. Means and standard deviations for accuracy (%), RTs (ms), tap amplitude (V), and overall delay in the EMG response (ms) for combined muscles in Experiment 1 (Study 1, N=20).

EXPERIMENT 1	Accuracy (%)	SD	RT (ms)	SD	Amplitude (V)	SD	EMG delay (ms)	SD
Low Valence	90	(9.53)	1216	(368)	0.26	(0.12)	2023	(275)
High Valence	98.12	(3.25)	1181	(391)	0.26	(0.13)	2031	(224)
Low Arousal	93.75	(7.9)	1222	(396)	0.27	(0.13)	2044	(253)
High Arousal	96.62	(4.42)	1176	(363)	0.26	(0.12)	2009	(242)
Low Concreteness	96.43	(3.65)	1198	(385)	0.26	(0.12)	2018	(223)
High Concreteness	93.93	(8.94)	1199	(372)	0.27	(0.13)	2036	(270)

Table 11. Means and standard deviations for accuracy (%), RTs (ms), tap amplitude (V), and overall delay in the EMG response (ms) for combined muscles in Experiment 2 (Study 1, N=20).

EXPERIMENT 2	Accuracy (%)	SD	RT (ms)	SD	Amplitude (V)	SD	EMG delay (ms)	SD
Low Dominance	96.18	(5)	1185	(349)	0.26	(0.12)	2008	(224)
High Dominance	92.25	(9.53)	1216	(368)	0.26	(0.12)	2023	(275)
Low Arousal	92.43	(9.14)	1202	(365)	0.26	(0.13)	2013	(251)
High Arousal	96	(5.41)	1200	(350)	0.26	(0.12)	2018	(241)
Low Concreteness	97.29	(4.86)	1208	(370)	0.26	(0.12)	2001	(240)
High Concreteness	93.12	(9.82)	1193	(348)	0.26	(0.13)	2030	(261)

Table 12. Means and standard deviations for accuracy (%), RTs (ms), tap amplitude (V), and overall delay in the EMG response (ms) for combined muscles in Experiment 3 (Study 2, N=34).

EXPERIMENT 3	Accuracy (%)	SD	RT (ms)	SD	Amplitude (V)	SD	EMG delay (ms)	SD
Low Valence	99.26	(1.19)	1263	(547)	0.26	(0.11)	2224	(210)
High Valence	99.59	(0.79)	1262	(567)	0.27	(0.12)	2214	(227)
Low Arousal	99.22	(1.15)	1272	(575)	0.26	(0.11)	2210	(212)
High Arousal	99.63	(0.65)	1253	(540)	0.27	(0.11)	2229	(224)
Low Concreteness	99.44	(0.82)	1263	(549)	0.26	(0.11)	2232	(204)
High Concreteness	99.41	(1.11)	1262	(565)	0.27	(0.11)	2207	(223)

Table 13. Means and standard deviations for accuracy (%), RTs (ms), tap amplitude (V), and overall delay in the EMG response (ms) for combined muscles in Experiment 4 (Study 2, N=34).

EXPERIMENT 4	Accuracy (%)	SD	RT (ms)	SD	Amplitude (V)	SD	EMG delay (ms)	SD
Low Dominance	99.52	(0.81)	1270	(538)	0.27	(0.11)	2237	(216)
High Dominance	99.26	(1.19)	1263	(547)	0.26	(0.11)	2224	(210)
Low Arousal	99.33	(1.07)	1263	(526)	0.27	(0.11)	2219	(222)
High Arousal	99.44	(0.82)	1270	(562)	0.27	(0.11)	2242	(206)
Low Concreteness	99.44	(0.88)	1274	(563)	0.26	(0.11)	2237	(190)
High Concreteness	99.33	(1.11)	1259	(523)	0.27	(0.11)	2224	(244)

APPENDIX C

Cf. Figure 18 in Appendix B for muscle abbreviations.

Table 14. *Means and standard deviations for the normalized maximum rms EMG response (V) for the relevant muscles in Experiment 1 (Study 1, N=20).*

EXPERIMENT 1	ZM SD	CS SD	MN SD	LSN SD	LLS SD	OC SD
Low Valence	0.38(0.19)	0.58(0.17)	0.54(0.21)	0.56 (0.24)	0.56 (0.18)	0.62(0.2)
High Valence	0.57(0.21)	0.46(0.19)	0.52(0.16)	0.51 (0.23)	0.61 (0.16)	0.66(0.14)
Low Arousal	0.44(0.19)	0.55(0.18)	0.53(0.19)	0.53 (0.22)	0.54 (0.17)	0.64(0.16)
High Arousal	0.5 (0.21)	0.5 (0.17)	0.53(0.17)	0.55 (0.26)	0.62 (0.15)	0.63(0.17)
Low Concreteness	0.45(0.2)	0.53(0.19)	0.55(0.19)	0.53 (0.24)	0.56 (0.15)	0.61(0.15)
High Concreteness	0.5 (0.21)	0.51(0.15)	0.51(0.17)	0.54 (0.23)	0.6 (0.15)	0.66(0.19)

Table 15. *Means and standard deviations for the normalized maximum rms EMG response (V) for the relevant muscles in Experiment 2 (Study 1, N=20).*

EXPERIMENT 2	OF SD	CS SD	LSN SD	OR SD	LLS SD	OC SD
Low Dominance	0.54(0.21)	0.6 (0.16)	0.54 (0.23)	0.43(0.17)	0.55 (0.14)	0.58(0.21)
High Dominance	0.51(0.17)	0.58(0.17)	0.56 (0.24)	0.47(0.18)	0.56 (0.18)	0.62(0.2)
Low Arousal	0.51(0.2)	0.6 (0.17)	0.53 (0.21)	0.47(0.16)	0.55 (0.16)	0.59(0.2)
High Arousal	0.55(0.19)	0.58(0.17)	0.57 (0.26)	0.43(0.2)	0.56 (0.17)	0.6 (0.2)
Low Concreteness	0.53(0.16)	0.61(0.19)	0.57 (0.22)	0.44(0.17)	0.55 (0.19)	0.59(0.21)
High Concreteness	0.53(0.21)	0.57(0.14)	0.53 (0.25)	0.46(0.19)	0.56 (0.16)	0.6 (0.19)

Table 16. *Means and standard deviations for the normalized maximum rms EMG response (V) for the relevant muscles in Experiment 3 (Study 2, N=34).*

EXPERIMENT 3	ZM SD	CS SD	MN SD	LSN SD	LLS SD	OC SD
Low Valence	0.37(0.17)	0.63(0.15)	0.58(0.14)	0.54 (0.16)	0.5 (0.15)	0.56(0.17)
High Valence	0.51(0.24)	0.52(0.18)	0.52(0.15)	0.56 (0.18)	0.54 (0.19)	0.6 (0.19)
Low Arousal	0.43(0.19)	0.58(0.16)	0.56(0.15)	0.55 (0.17)	0.53 (0.16)	0.57(0.17)
High Arousal	0.46(0.19)	0.57(0.15)	0.53(0.15)	0.54 (0.17)	0.51 (0.18)	0.58(0.17)
Low Concreteness	0.44(0.2)	0.59(0.14)	0.55(0.14)	0.55 (0.17)	0.52 (0.15)	0.59(0.17)
High Concreteness	0.45(0.18)	0.55(0.17)	0.54(0.14)	0.54 (0.17)	0.52 (0.18)	0.56(0.18)

Table 17. *Means and standard deviations for the normalized maximum rms EMG response (V) for the relevant muscles in Experiment 4 (Study 2, N=34).*

EXPERIMENT 4	OF SD	CS SD	LSN SD	OR SD	LLS SD	OC SD
Low Dominance	0.52(0.16)	0.63(0.14)	0.55 (0.15)	0.45(0.18)	0.47 (0.15)	0.57(0.16)
High Dominance	0.5 (0.17)	0.63(0.15)	0.54 (0.16)	0.47(0.19)	0.5 (0.15)	0.56(0.17)
Low Arousal	0.5 (0.17)	0.61(0.15)	0.55 (0.16)	0.46(0.17)	0.5 (0.15)	0.56(0.17)
High Arousal	0.51(0.16)	0.64(0.14)	0.54 (0.16)	0.47(0.18)	0.47 (0.17)	0.57(0.17)
Low Concreteness	0.52(0.17)	0.64(0.14)	0.54 (0.16)	0.47(0.17)	0.48 (0.16)	0.57(0.17)
High Concreteness	0.5 (0.17)	0.62(0.15)	0.54 (0.16)	0.45(0.17)	0.49 (0.15)	0.56(0.17)

APPENDIX D

Sample R code

Below is sample R code for different types of statistical tests performed in the current project. For conciseness, there is one example of the code for each type of statistical test, even though the same type of statistical test was done on different dependent and independent variables, as described in the Methods and Results sections.

1. *Two-sided Student t-test (comparing ratings for Low vs. High Valence stimuli in Experiment 1)*
`t.test(e1lowvalence$valence, e1highvalence$valence, alternative="two.sided")`

2. *Effect size for Student t-test*
`library(effsize)`
`cohen.d(e1lowvalence$valence, e1highvalence$valence)`

3. *2x2x2 ANOVA (testing stimuli in Experiment 1 for confound with Dominance ratings)*
`summary(aov(e1$highdominance ~ as.factor(e1$valence) + as.factor(e1$arousal) + as.factor(e1$concreteness)))`

4. *Effect size for 2x2x2 ANOVA*
`library(sjstats)`
`eta_sq(aov(e1$highdominance ~ as.factor(e1$valence) + as.factor(e1$arousal) + as.factor(e1$concreteness)))`

5. *Two-sided paired t-test (comparing RTs for words vs. pseudowords in Study 1)*
`t.test(s1words$rt, s1nonwords$rt, paired=TRUE, alternative="two.sided")`

6. *Effect size for paired t-test*
`library(effsize)`
`cohen.d(s1words$rt, s1nonwords$rt, paired=TRUE)`

7. *2x2x2 repeated-measures ANOVA (EMG response for muscle #1 (zygomaticus major) in Experiment 1)*
`library(ez)`
`ezANOVA(data=e1m1, dv=(normmax), wid=(subject), within=(valence, arousal, concreteness), within_full=(valence, arousal, concreteness), type=3, return_aov=TRUE)`

8. *Two-sided paired pairwise t-test with Holm correction (testing planned comparison for the interaction between Dominance * Concreteness in muscle #3 (corrugator supercilii) in Experiment 4)*
`pairwise.t.test(e4m3comparisons$normmax, e4m3comparisons$concreteness, paired=TRUE, p.adjust.method="holm", alternative="two.sided")`

APPENDIX E

Condition 1 (Tables 1 and 2)

Word	Valence (1-9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
joke	7.88	1.44	5.73	2.37	5.79	1.86	2.9	1.52	4	20262	9.92
celebrate	7.84	1.3	6.73	1.83	6.12	2.07	2.9	1.42	9	3175	8.06
achieve	7.75	1.16	4.7	2.96	6.61	2.44	2.29	1.3	7	15544	9.65
prosper	7.67	1.91	6	2.6	5.11	2.18	2.27	1.17	7	1652	7.41
praise	7.65	1.31	5.45	2.04	6.57	1.8	2.61	1.37	6	5984	8.7
accomplish	7.45	1.15	5.16	2.81	7.27	1.52	2.33	1.37	10	7794	8.96
energize	7.43	1.33	6	2.16	6.55	2.2	2.46	1.17	8	167	5.12
inspire	7.42	1.71	5.9	2.64	7.11	1.98	1.74	0.98	7	1440	7.27
adore	7.37	1.38	5.96	2.33	6.26	1.73	2.34	1.37	5	1059	6.97
admire	7.35	1.27	5	2.27	7.33	1.65	2.04	1.1	6	3160	8.06
amaze	7.24	2	5	2.25	5.83	2.37	2	1.22	5	803	6.69
flourish	7.21	1.58	5.22	2.33	6.17	1.92	2.1	0.99	8	924	6.83
entertain	7.21	1.81	5.19	2.86	6.7	1.72	2.55	1.06	9	2531	7.84
discover	7.18	1.44	5.7	3.01	6.79	2.04	2.37	1.19	8	11099	9.31
rejoice	7.14	1.98	5.56	2.57	7.68	1.29	2.17	1.31	7	878	6.78
cheer	7.1	1.5	5.33	2.47	6.37	2.23	2.77	1.42	5	1904	7.55
amuse	7.1	1.37	5.17	1.99	6.8	1.64	2.57	1.23	5	644	6.47
satisfy	7.09	1.6	5.53	2.67	6.33	1.96	2.04	1.09	7	5617	8.63
desire	7.05	1.75	6.2	2.33	6.07	1.92	1.7	1.26	6	23188	10.05
fascinate	7	1.4	6.1	2.52	6.32	2.17	1.75	1.11	9	88	4.48

Pseudowords: ciroglate esdrite plazber pleise assandrish emiglize imflire azure atmire avaze froolish emfilbain rojaice choor anuse sobisfy fitsebate

riamite obilgome soutece avouse impent

Non-words: jdkf kfjdswwsf hijpsfwj trpklij qdfklj rtjlhksdcx wrmnlksf hgfpsf rjdsf qjpfjd pfsjl hvnlzxfj hfglksdpq cxsdwjlk sjljwfm sjlcp rwkld bnkmpfd
sfdklxm kcmdwvxgf

Condition 2 (Tables 1 and 2)

Word	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
hug	8.23	0.87	4.85	2.95	6.8	2.21	4.14	1.21	3	3801	8.24
award	7.86	1.15	5.85	2.89	6.9	1.92	4.14	1.01	5	15755	9.66
kiss	7.78	1.64	6.05	3.03	6.52	2.43	4.48	1.02	4	12848	9.46
laugh	7.56	2.64	6.62	1.91	7.39	1.54	4.21	1.1	5	13449	9.51
reward	7.47	1.35	5.58	2.74	6.33	2.25	3.41	1.4	6	5347	8.58
brighten	7.37	1.42	5.32	2.64	6.77	1.82	3.41	1.12	8	329	5.8
dance	7.27	1.49	5.48	2.62	6.28	2.3	4.32	1.22	5	26125	10.17
shine	7.27	1.39	5.19	2.4	5.96	2.14	3.85	1.23	5	3206	8.07
bake	7.2	1.61	5	2.87	6.83	2.38	4.21	0.92	4	2528	7.84
mate	7.18	1.76	5.95	2.74	6.79	2.02	4.34	1.01	4	5179	8.55
chuckle	7.1	1.79	5.3	2.7	5.71	2.78	3.82	1.25	7	1569	7.36
hire	7.09	1.97	5.65	2.41	6.42	2.41	3.11	1.52	4	11829	9.38
marry	7.09	2.2	5.52	2.96	5.67	2.33	3.03	1.5	5	7832	8.97
blossom	7.05	1.5	4.75	2.79	5.64	2.55	4.26	1.35	7	890	6.79
rescue	7.04	1.65	5	2.54	5.94	2.27	3.17	1.17	6	11324	9.33
embrace	7	1.45	5.82	2.58	6.58	2.32	3.38	1.63	7	3151	8.06
caress	6.82	1.45	4.6	2.7	6.38	1.86	4.14	0.95	6	1125	7.03
flirt	6.73	1.41	5.93	2.37	5.8	2.43	3.26	1.26	5	467	6.15
applaud	6.7	1.17	5.05	1.75	5.91	2.02	3.8	1.21	7	1303	7.17
grill	6.64	1.71	5.26	2.79	5.62	2.01	4.86	0.44	5	1495	7.31

Pseudowords: heg geddle glin royerd bleighden snooch pirk shune chiggle morry brannom entlace coless fwert aggraud irranemate grevden slent erufate leck cambledurate rissorge

Non-words: tqp kpdfs tmcn sdpkf ghsklj spsfrtmn ghdsf pjklis mqnv skaj plksdnf mltp bcxdf ljpsfvz hwpdfs pkljdsf mnvcds lpkdf kljdsqw twljpsg

Condition 3 (Tables 1 and 2)

Word	Valence (1-9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
relax	7.82	2.04	2.38	2.13	6.94	2.15	2.86	1.46	5	5905	8.68
nourish	7.5	1.47	3.85	2.15	7.06	2.1	2.26	1.16	7	192	5.26
educate	7.48	1.36	4.36	2.4	6.79	2	2.12	1.21	7	4500	8.41
dream	7.43	1.8	4.37	2.81	5.4	2.36	2.6	1.52	5	32423	10.39
enlighten	7.38	1.12	3.23	2.49	6.3	2.25	1.48	0.65	9	3100	8.04
fulfill	7.33	1.74	3.67	2.37	6.2	2.02	1.78	0.85	7	3844	8.25
relieve	7.25	1.59	3.9	2.31	6.62	2.14	2.47	1.31	7	2005	7.6
encourage	7.16	1.26	4.38	2.42	6.2	2.25	2.61	1.34	9	16191	9.69
nurture	7.14	2.03	4.12	2.3	6.29	1.9	2.24	1.12	7	961	6.87
befriend	7.14	1.93	4.25	2.53	6.32	2.64	2.36	1.45	8	130	4.87
inherit	7.11	1.71	4.35	2.48	4.76	1.9	2.04	1.29	7	1968	7.58
secure	7.08	1.86	3.6	2.5	7	2.18	2.69	1.41	6	14198	9.56
forgive	7.06	2.1	3.62	3.11	6.44	2.43	1.92	1.21	7	8912	9.1
explore	7	1.45	4.05	2.55	6.52	2.38	2.9	1.26	7	10339	9.24
approve	7	1.92	4.09	2.29	7.26	1.41	1.85	1.2	7	4965	8.51
earn	7	1.2	4.35	3.12	6.75	1.78	2.39	1.17	4	11987	9.39
replenish	6.9	1.45	3.5	2.06	6.36	1.93	2.18	1.31	9	398	5.99
reconcile	6.84	1.57	4	2.32	5.63	1.77	1.79	0.83	9	1178	7.07
organize	6.75	1.62	4.05	2.19	6.95	1.39	2.72	1.24	8	5155	8.55
cherish	6.75	1.65	4.14	1.88	7.32	1.45	1.73	1.04	7	661	6.49

Pseudowords: ruwax nealish etovate embethden forzill rowieve dowlteam neldure borliend cannend abblove rubramish olhemize chulish sebor ronemisce
roplesh roteblapate canblagend riochure aldehorate albire

Non-words: psdjl wqsfldj trhikdl mbdsf pmdsklwaj zcxmkjs kwdsfmq lkstdfspgh prjsklv shfkjpvz nmlijspwq trklsf bvxsfpk hlsfpkx nvmbwtr cxkl
kjlsfmnw rhsipkvmz dfsrklj phlgfrwd

Condition 4 (Tables 1 and 2)

Word	Valence (1-9 scale)	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concreteness (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
cuddle	7.6	3.83	2.96	6.65	2.03	3.83	1.17	6	595	6.39
bathe	7.5	3.15	2.23	6.5	1.79	4.19	1.11	5	670	6.51
sing	7.5	4.1	2.49	6.67	1.88	4.34	1.17	4	10917	9.3
heal	7.41	4.32	2.54	5.18	2.59	3.03	1.55	4	4319	8.37
sleep	7.22	3.6	2.57	5.3	2.58	4.44	1.15	5	25606	10.15
shower	7.19	4.15	2.72	7.47	1.68	4.89	0.42	6	6874	8.84
breathe	7.17	2.6	2.19	6.22	2.67	4.07	1.13	7	3117	8.04
cook	7.12	4.33	2.47	6.25	2.63	4.32	1.02	4	13551	9.51
camp	7	4.14	2.26	5.89	2.05	4.35	1.06	4	15938	9.68
sail	6.84	3.74	2.65	6.37	1.77	4.59	0.69	4	3552	8.18
hike	6.68	4.32	2.61	5.69	2.18	4.14	0.95	4	2398	7.78
lunch	6.64	3.57	2.01	6.44	2.19	4.31	0.89	5	11094	9.31
rub	6.63	4.35	2.37	6.78	1.63	4.33	1.18	3	4231	8.35
dine	6.6	4	2.08	6.05	1.84	3.37	1.47	4	570	6.35
rhyme	6.58	3.59	2.4	6.09	2.02	3.29	1.58	5	1630	7.4
highlight	6.58	3.8	2.42	6.25	2.53	3.11	1.34	9	3207	8.07
pray	6.57	3.25	2.27	6.58	2.67	3.21	1.5	4	9582	9.17
brunch	6.57	4.09	2.07	5.64	1.73	4.41	1.02	6	347	5.85
mend	6.53	3.76	1.95	5.83	1.67	3.5	1.26	4	357	5.88
revive	6.53	3.92	2	6.11	2.04	3.13	1.38	6	1113	7.01

Pseudowords: coggle buthe hool bleethe huke rab dane heirheight mund robive mytedate froat rodire ropeild bosk rufolve monch tugulate nupple slender
irretslate sorute

Non-words: qwsdfk kjwls pgnv lmwq hdpri jhrwqg jlpbnz tbnd mchj pqxc swmk hspif bdf zmjs kswql fdljsjvwxz czld jfxl lfsj bzjcw

Condition 5 (Tables 1 and 2) ~ Condition 1 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
ruin	2.32	1.36	5.4	2.52	5.16	2.65	2.59	1.22	4	7182	8.88
criticize	2.41	1.26	5.27	2.39	4.7	2.36	2.03	0.98	9	3505	8.16
aggravate	2.55	1.19	5.9	2.19	4.85	2.56	2.26	1.29	9	321	5.77
shame	2.62	2.11	5.4	2.64	5.21	2.8	2.24	1.46	5	11304	9.33
loathe	2.68	1.92	5.18	2.26	4.77	2.62	2.04	1.32	6	783	6.66
intimidate	2.84	1.3	5.27	2.53	5.75	2.56	1.75	0.97	10	1152	7.05
disagree	2.84	1.17	4.9	2.07	5.45	2.26	2.77	1.42	8	25581	10.15
curse	2.9	2.17	5.2	2.38	5.15	2.37	2.39	1.34	5	7687	8.95
revoke	2.95	1.32	5	2.26	5	2.21	2.85	1.41	6	552	6.31
sin	3.08	1.85	5.82	2.04	5.74	2.21	1.85	1.2	3	17449	9.77
complain	3.1	1.52	5.18	1.99	5.1	2.34	2.6	1.4	8	12433	9.43
argue	3.15	1.53	6.67	2.61	4.77	2.49	2.75	1.27	5	20857	9.95
prosecute	3.15	1.42	4.62	2.78	5.12	2.7	2.44	1.15	9	1287	7.16
manipulate	3.21	1.36	4.76	1.92	5.74	2.96	2.55	1.35	10	3907	8.27
provoke	3.3	1.3	6.72	2.16	5.23	2.42	2.39	1.4	7	1557	7.35
beware	3.3	1.98	5.24	2.14	5.32	2.5	2	1.14	6	5609	8.63
coerce	3.32	1.16	5.45	2.39	5.87	2.36	2.04	1.02	6	542	6.3
ban	3.38	2.2	5.2	2.44	5.86	2.35	2.37	1.5	3	11740	9.37
regret	3.41	2.17	4.9	2.36	5.63	2.69	1.8	1.06	6	4990	8.52
impeach	3.45	1.43	5.74	2.14	5.71	1.93	2.11	1.19	7	198	5.29

Pseudowords: roin cledetize ammoy amher acklopate luathe impallacate impenecate colse rusoke doveive dodeest pladogute ameggerate memabirate
plaroke cundrelate cuarec dercust axodate indeach doflupt

Non-words: glsf dslijfgzcx kxzsfldpw slkdf hxkjsz lsfdxtczpk kqjlpdvx fscpz hpdjisk hkl kzspdfwq ktpxv jslrxwprfd hqkfxpdwzc nwkfzdp grwdlf rvmprfd
dqk tpwrtdt prhklsf

Condition 6 (Tables 1 and 2) ~ Condition 2 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
bury	1.95	1.21	5.55	2.09	4.79	2.84	3.82	1.19	4	2411	7.79
lie	2.39	1.43	4.81	2.8	4.72	2.91	3.11	1.42	3	21911	9.99
slay	2.63	1.54	4.9	2.28	5.39	2.86	3.1	1.4	4	555	6.32
crack	2.68	1.86	5.25	2.53	5.42	2.59	4.53	0.82	5	9519	9.16
gang	2.71	2.15	6.55	1.82	5.37	3.04	4.43	0.63	4	7821	8.96
quarrel	2.84	1.21	5.39	2.75	4.76	1.81	3.32	1.39	7	631	6.45
creep	2.95	2.2	4.78	2.26	4.63	2.09	3.38	1.18	5	1793	7.49
slap	2.95	1.43	4.59	2.3	4.78	2.52	4.72	0.59	4	3098	8.04
punch	3.27	2.07	5.8	2.82	5.26	2.83	4.39	0.79	5	9481	9.16
scorch	3.45	2.09	4.9	2.66	5.59	1.82	4.08	0.98	6	189	5.24
screech	3.5	1.57	6.05	2.84	4.88	2.29	3.77	1.41	7	383	5.95
shoot	3.5	2.37	6	2.47	4.67	2.54	3.97	1.22	5	23531	10.07
bite	3.52	2.09	5.1	2.31	6.58	2.14	4.44	1	4	8162	9.01
drag	3.68	1.73	4.81	1.94	5.52	1.9	4.17	0.97	4	11908	9.38
hoard	3.7	1.75	4.82	2.3	5.24	2.21	3.33	1.39	5	529	6.27
chase	3.77	2.29	6.6	2.72	4.68	2.77	3.48	1.21	5	9066	9.11
hunt	3.84	2.01	5.1	2.57	5.3	2.79	3.81	1.27	4	15346	9.64
flee	3.84	1.5	4.95	2.25	5	2.43	3.67	1.47	4	1506	7.32
alarm	3.86	1.98	6.85	2.39	6.58	2.73	4.47	0.78	5	5599	8.63
dissect	3.95	1.63	5.43	1.85	5.16	2.19	3.21	1.45	7	283	5.65

Pseudowords: bory smurl sray bogger quothel srap giuge spawl shidder sforch bote blowl harrer huard jeb arolm dozzect snuck coss deflose pake borch

Non-words: sxvz mvq pwjl kmpdl nxks xzwpcql hfsdp pqkb mxfrw nbpdfs ldsprw msfgh hklk pdgw thdqf rdpk lpjd vxhg nghpd kjgfrws

Condition 7 (Tables 1 and 2) ~ Condition 3 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concrete- ness (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
grudge	2.86	1.46	4.2	2.67	5.18	2.44	2.14	1.21	6	733	6.6
displace	2.89	1.29	3.8	2.59	4.65	2.01	2.57	1.19	8	369	5.91
hassle	2.95	1.63	3.83	2.33	4.83	2.46	2.18	1.25	6	3923	8.27
detain	3	1.38	4.25	2.36	4.86	2.9	2.74	1.46	6	304	5.72
rumor	3.14	1.82	3.85	2.41	5.36	2.89	2.15	1.2	5	6853	8.83
discriminate	3.18	1.87	4.05	2.29	5.05	3.04	2.54	1.23	12	2008	7.6
dislike	3.25	1.55	4.27	2.6	5.81	2.37	1.7	0.95	7	5309	8.58
caution	3.29	1.27	4	2.45	4.86	2.67	2.04	1.1	7	4352	8.38
ignore	3.33	1.03	3.8	2.07	4.83	2.66	2.22	1.28	6	27790	10.23
inflict	3.35	2.03	3.71	2.37	4.6	2.4	2.75	1.43	7	1204	7.09
distort	3.38	1.32	3.62	2.7	4.7	2.56	2.66	1.2	7	1351	7.21
gripe	3.42	1.77	4.24	1.89	5	2.18	2.15	1.01	5	1429	7.26
patronize	3.48	1.78	3.15	2.39	5.73	2.51	1.79	0.98	9	344	5.84
disapprove	3.55	0.94	3.81	2.4	5.21	2.78	1.89	1.15	10	725	6.59
contradict	3.58	1.22	4.25	2.17	4.83	2.72	2.24	1.35	10	2475	7.81
cancel	3.61	1.2	4.29	2.17	5.83	2.53	2.41	1.21	6	20643	9.94
obstruct	3.61	1.14	4.29	1.74	4.7	2.58	2.46	1.23	8	306	5.72
breach	3.67	1.77	3.46	2.64	4.76	2.59	2.48	1.36	6	2604	7.86
lack	3.68	1.38	2.24	1.18	5.46	2.3	2.04	1.32	4	41016	10.62
misbehave	3.79	1.55	4.28	2.59	4.65	2.55	2.07	0.94	9	172	5.15

Pseudowords: glodge deldrace hophle dydain derglenimate defrike imprict degdort glipe podlamize detuphlove camblotict opsfluct imbict blooch guat
merpogave ruthind derginnect ammul apyrish camlound

Non-words: npdfgs krtjlpds trsjfl mwqkpd rpkts htukpldfwmcvj rjkdjlp gfplds q nvplfd srthgkl brdpsf fgklp dksplrwitq qrwtpxjdlv wvpxsghqij knvdp
hrtjkdps mzpghj kghd wtpvdsklr

Condition 8 (Tables 1 and 2) ~ Condition 4 (Tables 3 and 4)

Word	Valence (1- 9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
litter	2.58	1.43	3.8	1.99	5.7	2.68	4.47	0.78	6	3353	8.12
ditch	3.2	1.32	3.81	1.97	5.42	2.09	4.5	0.9	5	1735	7.46
sneer	3.3	1.92	4.36	2.36	5	2.13	3.65	1.29	5	555	6.32
inject	3.32	1.45	4.14	2.44	4.74	2.03	4.28	0.92	6	1057	6.96
dim	3.37	1.38	3.55	2.31	4.83	2.1	3.31	1.32	3	4289	8.36
pinch	3.5	1.32	4.44	2.59	4.77	2.36	4	1.2	5	1992	7.6
dent	3.52	1.21	3.46	2.75	4.95	2.27	4.63	0.81	4	2465	7.81
grunt	3.68	1.42	3.86	2.34	4.91	2.27	3.56	1.56	5	1108	7.01
glare	3.7	1.59	4.05	2.5	5.53	2.17	3.83	1.42	5	908	6.81
seize	3.79	0.98	4.06	2.53	5.18	2.65	3.97	1.16	5	1925	7.56
drain	3.8	1.67	2.94	1.98	5.17	2.55	4.61	0.83	5	14860	9.61
blob	3.9	1.74	3.57	2.42	5.44	2.36	4.06	1.21	4	1170	7.06
pluck	3.9	1.7	4.16	1.95	5.73	2.31	4	1.02	5	532	6.28
groan	3.9	1.59	4.17	2.55	5.5	2.4	4.09	1.17	5	1014	6.92
pawn	3.9	1.73	4.29	2.08	5.16	2.91	3.9	1.42	4	1542	7.34
bypass	3.95	1.86	3.41	2.36	5.59	2.35	3.5	1.45	6	2733	7.91
crawl	3.95	1.54	3.62	1.83	4.95	1.85	4.27	1.11	5	3131	8.05
conceal	3.95	1.12	3.74	2.73	6.05	2.24	3.19	1.57	7	1524	7.33
partition	4	1.49	3.1	1.89	5.39	1.95	3.72	1.24	9	21415	9.97
delete	4	1.52	3.71	2.24	5.39	2.84	3.48	1.5	6	18824	9.84

Pseudowords: lupper spold pleck dotch smour horl imbect blibe paut flawn plawl spoff pemch dunt neb glunt crinch spockle saize snoor srauch prock

Non-words: fhpksl nsfld lkpfq drsfpb gpq khlpv xskp jgdfs qkpfq dpbnw kdvlg mklp bgtdf twrpk bklq zvkpdf bhgpr rlnfjm xczmqijgh qhkpvd

Condition 9 (Tables 3 and 4) ~ Condition 5 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
abuse	1.53	1.07	6.21	2.17	2.9	2.17	2.71	1.27	5	25915	10.16
harm	1.91	1.11	5.9	2.29	3.95	2.66	2.62	1.21	4	12379	9.42
neglect	2.16	1.21	4.72	2.49	3.69	2.53	2.26	0.98	7	1923	7.56
bullshit	2.33	1.85	7	2.19	3	1.81	2.96	1.4	8	9071	9.11
dishonor	2.37	1.57	4.82	2.44	3.79	2.33	1.72	1.11	8	223	5.41
abduct	2.42	1.61	5.9	2.57	2.75	2.13	2.88	1.51	6	180	5.19
slander	2.45	1.36	5.68	2.58	3.62	1.96	2.33	1.35	7	2098	7.65
disqualify	2.47	1.07	4.7	1.84	3.45	1.74	2.39	1.26	10	473	6.16
betray	2.52	1.92	5.33	2.51	3.86	2.61	2.17	1.32	6	771	6.65
blackmail	2.59	1.51	5.44	2.28	3.98	2.92	2.78	1.45	9	927	6.83
humiliate	2.6	1.74	5.05	2.52	3.96	2.35	2.07	1.33	9	442	6.09
enslave	2.67	2.13	5.35	2.28	4.08	2.81	2.36	1.16	7	639	6.46
endanger	2.67	1.85	4.72	2.37	3.95	2.5	1.96	0.96	8	708	6.56
accuse	2.68	1.63	5.32	2.08	4	2.32	2.25	1.29	6	3798	8.24
malfunction	2.68	1.49	4.62	2.4	2.92	2.08	2.74	1.35	11	765	6.64
incriminate	2.84	1.57	5.95	1.91	3.75	2.11	2.07	1.3	11	139	4.93
punish	2.86	2.2	5.85	2.35	3.81	2.46	2.66	1.45	6	3339	8.11
blame	2.94	1.92	4.81	2.84	3.33	2.2	2.06	1.18	5	17326	9.76
harass	2.95	1.47	6.1	2.45	3.58	2.06	2.67	1.58	6	2648	7.88
doom	3	1.76	6.17	2.92	2.42	1.89	1.5	1.03	4	33765	10.43

Pseudowords: aptuct bliamyash morvampton ove byg roblenand glueve derglirify foss sromber sepadage defown jiaboltize nocrect implunemate

deframor pemish bodlay imblude embinxer impult hinereate

Non-words: dvpkl bxcl kbpqtr hmpjgnxv rklpvmwf tckpmr gbcvpls qtnbvyptmsz lhgpvw mpfsrwpqj bmdpjtsxl fwjpktr strvpmby dtwrmp hbmptqsgfj
kvsrpfdwmbc dmgyvr kjlp fhmgz znpf

Condition 10 (Tables 3 and 4) ~ Condition 6 (Tables 3 and 4)

Word	Valence (1- 9 scale)	SD	Arousal (1- 8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
murder	1.48	0.81	6.24	2.76	3.38	2.28	3.61	1.55	6	19075	9.86
massacre	1.77	1.57	6.68	2.49	3.33	2.45	4	1.08	8	3496	8.16
hijack	1.84	1.5	6.1	2.23	3.06	2.28	3.33	1.47	6	240	5.48
foreclose	2	1.08	6	2.35	2.92	1.85	3.04	1.4	9	54	3.99
mutilate	2	1.21	4.96	2.75	2.91	2.37	3.86	1.19	8	292	5.68
assault	2.05	1.45	6.8	2.11	3.49	2.71	3.41	1.32	7	10485	9.26
rob	2.1	1.21	5.54	2.86	3.57	2.78	3.48	1.31	3	21934	10
amputate	2.1	1.45	5.43	2.37	3	2.37	3.9	1.23	8	121	4.8
poison	2.16	1.46	6.01	2.31	3.38	2.37	4.27	1.01	6	5095	8.54
kidnap	2.19	1.29	5.59	2.75	2.37	2.02	3.83	1.28	6	626	6.44
perish	2.22	1.22	5.19	2.34	3.35	2.31	3.22	1.55	6	1128	7.03
crucify	2.26	1.52	5.6	2.54	3.11	1.41	3.45	1.64	7	487	6.19
arrest	2.33	1.37	6.86	2.24	3.11	2.05	3.93	1.22	6	6567	8.79
slaughter	2.33	1.85	5.77	2.36	3.57	2.28	3.68	1.36	9	2785	7.93
drown	2.33	1.53	5.35	2.69	2.65	1.87	3.93	1.25	5	1415	7.25
pickpocket	2.35	1.27	6	2.73	3.6	2.44	4.03	1.27	10	59	4.08
choke	2.42	1.92	5.3	2.74	3.74	2.33	3.97	1.35	5	2959	7.99
hurt	2.45	1.47	4.72	2.34	3.73	2.12	3.61	1.5	4	28018	10.24
bomb	2.47	1.65	5.71	2.82	3.14	2.19	4.84	0.37	4	15377	9.64
bleed	2.47	1.43	5	2.31	3.75	1.87	4.4	0.97	5	2526	7.83

Pseudowords: ketmap dyown flethden modurate felogrose exbrode antodate metvire shefer huxack clozify bolly dodemate powish puefon indleton
hombstuff clemge sroophder pethbaphet aubit currotise

Non-words: kwrpkl crqd zplwmq xjspmthgf dqpfmwhg dwqxmht zbj xpgwmhsd fzpvxt gwspnz wzkprt hzgmpds klwqpm vbpwhfsqz tspvd smbpdqnxfh
fpjkw gsmz xqhm bsnvg

Condition 11 (Tables 3 and 4) ~ Condition 7 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concreteness (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
flunk	1.95	1.07	3.72	2.07	4.23	2.78	2.4	1.1	5	222	5.4
depress	2.47	2.01	3.14	1.46	3.67	2.41	2.29	1.27	7	464	6.14
belittle	2.7	2.18	4.05	2.01	2.92	1.78	2.1	0.94	8	584	6.37
alienate	2.79	1.62	4.27	1.88	3.71	1.68	1.83	1.2	8	565	6.34
abandon	2.84	1.54	3.73	2.43	3.32	2.5	2.54	1.45	7	3761	8.23
infect	2.84	1.68	4	2.02	3.7	2.1	2.88	1.48	6	1088	6.99
distrust	2.95	2.28	4.05	2.77	3.32	2.44	1.44	0.8	8	1099	7
discourage	3.05	1.16	3.73	2.35	3.71	1.95	1.9	0.98	10	2760	7.92
burden	3.05	2.09	3.96	2.16	3.14	1.82	2.63	1.33	6	7831	8.97
dismay	3.1	1.07	2.85	1.79	3.95	1.89	2.29	1.27	6	987	6.89
atrophy	3.16	1.83	3.86	2.12	4	2.62	2.86	1.43	7	434	6.07
expire	3.16	1.34	4	2.15	3.8	2.26	2.73	1.36	6	2626	7.87
decline	3.19	1.4	3.6	2.5	3.71	2.12	2.76	1.3	7	6068	8.71
distress	3.25	1.37	4	3.16	3.9	2.2	2.66	1.54	8	2032	7.62
impair	3.26	1.42	3.9	1.51	4.12	2.18	1.73	1	6	441	6.09
doubt	3.28	1.93	4.33	2.42	3.06	2.04	1.79	1.18	5	48652	10.79
deprive	3.37	1.3	3.72	2.19	4.24	2.61	2.21	1.34	7	1086	6.99
disappoint	3.38	1.76	3.91	2.04	4.07	2.35	1.89	1.09	10	975	6.88
delay	3.45	1.76	3	2.29	3.68	2.01	2.79	1.54	5	13068	9.48
blacklist	3.45	1.47	4	2.29	3.21	2.23	2.96	1.43	9	485	6.18

Pseudowords: boreddle balten brophrist apomton derdlust meflead pread lynent derbolage bramter dobles dugwease imvect dogrine dergielage aruamate
 elbire dype derdwess aplophy felvake defubboint

Non-words: gqpl fghpvz zwdjqpn dlijksfwh ckjpsb gnprfd mghkwjjs vnpsgqhkwx fjsmt hjkqv bclpdhm gkistq hstrgmw hjstbnqz gvxxpw nzhvm
 qphgdm bsqpgxvmz nbvdp gkpfsbwth

Condition 12 (Tables 3 and 4) ~ Condition 8 (Tables 3 and 4)

Word	Valence (1-9 scale)	SD	Arousal (1-8 scale)	SD	Dominance (1-8 scale)	SD	Concretene ss (1-5 scale)	SD	Word Length	Frequency HAL	Log Frequency HAL
cripple	2.47	1.61	4.05	2.79	2.61	1.62	3.78	1	7	929	6.83
paralyze	2.52	1.78	4.47	2.37	3.05	2.61	3.41	1.12	8	1665	7.42
clog	2.95	1.93	3.23	1.9	3.58	1.82	3.47	1.41	4	836	6.73
clot	2.95	1.8	4.17	2.37	3.71	2.26	4.2	1.19	4	271	5.6
confine	3	1.45	3.96	2.7	3.83	2.66	3.07	1.05	7	754	6.63
shove	3.1	1.14	3.83	3.06	4.41	2.43	4.04	1.29	5	2255	7.72
collide	3.1	1.64	4.33	1.99	3.95	2.01	4	1	7	670	6.51
deport	3.14	1.71	3.84	2.36	3.73	2.76	3.41	1.31	6	261	5.56
bruise	3.24	1.34	4.04	2.84	3.78	2.26	4.73	0.52	6	456	6.12
ache	3.27	2.01	4.3	2.26	4	2.72	3.43	1.45	4	846	6.74
bloat	3.4	1.1	3.78	2.34	3.86	1.64	3.04	1.37	5	564	6.34
sag	3.58	1.98	3	2.35	3.54	1.53	3.27	1.37	3	869	6.77
disable	3.58	1.71	3.6	1.7	4.04	2.72	3.42	1.24	7	7620	8.94
hiss	3.65	2.11	4.29	2.55	3.32	2.17	3.6	1.38	4	1134	7.03
clutter	3.67	1.88	3.68	2.4	3.19	2.04	3.68	1.36	7	1435	7.27
empty	3.78	1.77	2.25	1.65	3.61	2.06	3.43	1.5	5	19261	9.87
fall	3.89	2.31	4.24	2.17	3.83	2.35	4.04	1.08	4	46059	10.74
lisp	3.9	1.89	3.78	2.24	3.5	2.23	3.86	1.33	4	9350	9.14
shrink	4	0.89	3.42	2.1	3.7	2	3.55	1.35	6	4085	8.32
faint	4	1.48	3.74	2.22	3.5	1.92	3.74	1.02	5	2513	7.83

Pseudowords: clebble peleryze inteund crodder hess foint sog crog monple shwink crot dibort bleise camvine broat strepper curride ashe dofable shwurel meck clondle

Non-words: dspgvb jkpsgbvw hvgl lkpd hgpfwmq hcjvt nfhpqwj jwkmtr grkpgj sjhg bnpqd dlk zgkwthr jhgd spgkhmv bwjpd hmqg jtps bxcptz nvxpf