Minding the matter: The influence of bodily arousal on emotional information processing

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Nothing is less in our power than the heart
And far from commanding we are forced to obey it.
Jean-Jacques Rousseau

Chapter 1

General introduction

General introduction

Since time immemorial, philosophers, scientists, and laymen have been intrigued by the complex relationship between mind and matter. Especially the question whether body and mind should either be considered as independent or interacting entities has been the source of recurring speculations and debates. In the 17th century, René Descartes put forward the idea that body and mind are radically different substances, able to exist independently of each other. According to his dualistic approach, the body is a complex machine, subjected to the laws of physics, while the mind is the immaterial seat of the soul (Vieillard-Baron, 1991). Over time, however, alternative perspectives rejecting the body-mind dichotomy have gained prevalence, not least in the areas of psychology and neuroscience. In the last decades, researchers have indeed made a concentrated attempt to study bodily and mental processes as inseparable, interwoven dimensions of human life. In this context, particular focus has been put on William James' famous but controversial definition of emotions as the consequence of the perception of bodily changes (1884). Whereas common sense says that if we encounter a bear in the woods, we get frightened, start trembling, and run, James states that the sequence is the opposite: the emotional stimulus of the bear produces the reactions of trembling and fleeing, which consequently generate the feeling of fear (1890). In his view, emotional feelings are rooted in the perception of visceral feedback stemming from facial expressions (e.g., frowning), expressive behavior (e.g., postures), and the activation of the autonomic nervous system (e.g., arousal responses such as increased heart rate and galvanic skin response) (James, 1884). Shortly after, the Danish physiologist Carl Lange (1985) introduced a similar model, advocating the same causal sequence regarding the nature of emotion. Given the analogy between both frameworks, we traditionally speak of the James-Lange theory of emotion, known for focusing on the peripheral (i.e., autonomous and somatic) rather than the central nervous system. Although not without critics (e.g., Cannon, 1987), the James-Lange theory has been a catalyst for the work of numerous contemporary psychologists, attempting to provide a general definition of the emotion construct. In the 1960s, for instance, the social psychologist Stanley Schachter proposed a cognitive theory of emotion. According to him, emotions are elicited by (1) a non-specific arousal response (i.e., sympathetic activation indexed by accelerated heart rate, trembling, face flushing), whose perception triggers (2) a series of cognitions allowing to interpret the immediate situation. For example, the arousal state caused by seeing a person with a knife is interpreted based on knowledge about the potential harmfulness of knifes, and is consequently labelled "fear" (Schachter, 1964). Subsequent theoretical perspectives, however, defined emotions as complex processes necessitating more than two factors to arise. One of the best-known examples is probably Nico Frijda's componential approach to emotions (1986). Starting point of his framework is the perception of an (antecedent) event, which is appraised in terms of its relevance for the individual's concerns. If evaluated as relevant, the organism changes into a state of action readiness and activates a series of emotional responses, consisting of expressive behaviors (i.e., facial expressions, posture, and prosody), physiological changes (e.g., arousal responses), and cognitive changes (e.g., attentional biases). The awareness of some (or all) of those processual components then leads to the subjective experience or feeling of emotions. A comparable model has been proposed by Klaus Scherer (2000, 2005), who argued that motor expressions, physiological changes, and subjective feelings are the three major components constituting the response triad of emotions. Overall, it thus appears that (1) motor expressions in face, body, and voice; (2) physiological reactivity referred to as arousal (e.g., increased heart rate, respiration rate, blushing); and (3) subjective feelings (i.e., emotional experience) are considered central components in recent emotion models.

In line with this view, a growing body of evidence suggests a dynamic relationship between bodily responses, emotion, and cognition. Hence, our physiological state affects emotional experiences, as well as the way in which emotional information is represented, encoded, and interpreted. When reviewing the existing literature, one can find numerous studies highlighting the role of motor expressions (e.g., facial, postural) in emotional processing, whereas systematic investigations on the interplay between physiological arousal and emotional processes seem comparatively sparse. This shortcoming might be partly due to the fact that the theoretical aspects of the arousal construct present a source of confusion across the scientific community. The term arousal is used to describe a variety of phenomena, while it remains partially unclear what it specifically refers to (Norman, 2016). Over the years, arousal has been thought of as drive (Hull, 1943), energy mobilization (Duffy, 1957), activation (Feldman Barrett & Russell, 1999), or tension (Thayer, 1978), to name but a few examples. In addition, it appears that the concept of arousal is also employed to denote one of the two major dimensions of subjective feelings. The latter are typically defined as varying along the dimensions of valence (i.e., positivity - negativity) and arousal (i.e., calm - excitement) (Feldman Barrett & Russell, 1999; Russell, 2003).

In this first chapter, we aim at introducing the key components of the emotion response (i.e., motor expressions, physiological arousal, and subjective feelings), while clarifying their respective influences on the processing of emotional information. We start by taking a closer look at the subjective feeling[1] component and its valence and arousal dimension. We then focus on motor expressions in face and body and review evidence for their role in emotional information processing. Subsequently, we place special emphasis on the impact of arousal responses in this respect. We first highlight the challenges resulting from existing inconstancies regarding the conceptualization of the arousal construct, before providing an outline of current findings on the role of arousal in emotional processing.

[1] In what follows, the terms “subjective feelings” (Scherer, 2005), “emotional experience” (Frijda, 1986), and “affect” (Russel, 1980) will be used in an interchangeable manner given that they refer to a (fairly) similar phenomenon. Even though today’s literature sometimes differentiates between those concepts (e.g., Ekkekakis & Russell, 2013), an overall consensus on the terminology seems to be lacking, which has led us to use them as synonyms.

1. The subjective feeling component of emotion: valence and arousal dimension

Since the beginning of psychology, the emotional side of human nature has presented many puzzles, placing it in the focus of numerous lines of research. Especially the question of the structure of affect has been intensively and controversially discussed. While early theories have put the emphasis on valence, later approaches have mainly focused on the arousal dimension of affect. First, there was Freud who claimed that the instinctive seeking for pleasure and for avoiding pain is the primary drive that guides the Id (i.e., the pleasure principle) (In Laplanche & Pontalis, 1988). In the same vein, introspectionist psychologists such as Titchener and Wundt (1910; 1924) considered the pleasure-displeasure dimension as the fundamental component of conscious feeling. Later on, the concept of arousal slowly moved into the spotlight, with alternative approaches underlining the importance of different activation levels when reporting experienced affect (e.g., Duffy, 1957; Hebb, 1955; Schachter & Singer, 1962). Nowadays, however, two-dimensional models, including both valence and arousal, dominate the affect literature. The most prevalent is probably Russell's circumplex model of affect (1980), stating that all affective states can be understood as a combination of valence and arousal. Happiness, for example, can be defined as the result of intense pleasure and moderate arousal, and sadness as a highly negative state involving low arousal.

According to Russel, the valence and arousal dimensions are orthogonal (independent), and the resulting affect structure can best be summarized in a circular order (see Figure 1). Despite differing descriptive labels, further research has supported the idea of a two-dimensional affective space. Larsen and Diener (1992), for instance, chose activation and pleasure as focal dimensions of their model, while Watson and Tellegen (1985) distinguished between high and low positive and negative affect (see Figure 1).

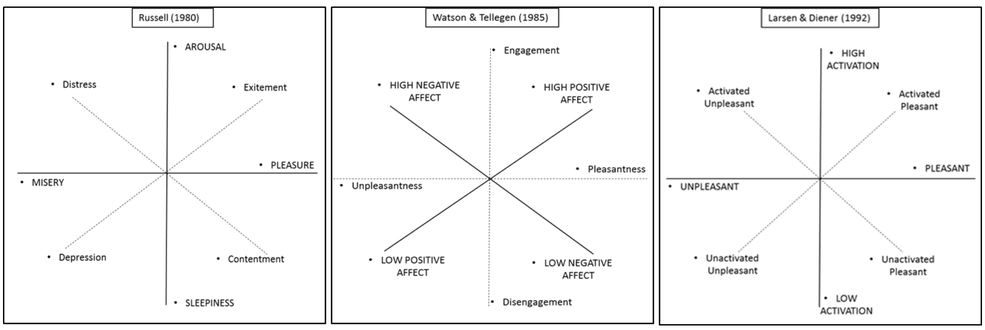

Figure 1. Circular map of core affect after Russell (1980), Watson and Tellegen (1985), and Larsen and Diener (1992). The main dimensions are written in capital letters. The remaining variables are not independent but help defining the quadrants of the space. All three models contain a valence and arousal dimension referred to by different labels.

Importantly, the valence and arousal dimensions did not only emerge in the context of reported affect, but also when investigating emotional judgments. Pioneering work was done again by Wundt (1896) who traced differences in the affective meaning among stimuli (words, objects, pictures, situations) back to the dimensions of pleasure, tension, and inhibition (for an extensive review, see Reisenzein, 1992). Subsequent work has led to consistent findings, suggesting that the dimensions of valence, arousal, and dominance (i.e., high control, agency vs submission, resignation) are prevalent when assessing emotional stimuli. For example, Osgood and colleagues (1952; 1957) asked participants to rate words on 50 different bipolar scales (e.g., hot-cold, fast-slow, black-white). Factor analyses showed about 50% of the observed variance in ratings could be explained by three factors that they named evaluation, activity, and potency. Similarly, Bush (1973) instructed participants to judge the similarity or difference of nearly 200 pairs of adjectives spanning the domain of feelings. Supporting Osgood's findings, results revealed that the dimensions of (un)pleasantness, level of activation, and level of aggression accounted for 20-60% of the total variation in judgments. Interestingly, further studies suggested that the same dimensions apply to nonverbal stimuli such as paintings, emotional facial expressions (Osgood, 1966; Osgood et al., 1957), bodily movements and postural positions (Mehrabian, 1970). Finally, when presented with texts describing common human scenarios, participants' semantic judgments revealed the same 3-factor solution, providing supplementary evidence on the structure of affective language (Mehrabian & Russell, 1974).

To date, researchers seem to widely agree that both the pleasantness (i.e., valence) and activation (i.e., arousal) dimension must imperatively be taken into account when studying affective stimuli. The potency (or dominance) dimension, however, appears to play a more subsidiary role. For most current research, Bradley and Lang's (1994) work on the self-assessment manikin has been used as a directive. The authors created a pen-and-paper instrument (i.e., the Self-Assessment Manikin – SAM) to assess the pleasure, arousal, and dominance associated with an encountered stimulus.

For the pleasure dimension, SAM ranges from a smiling, happy figure to a frowning, unhappy figure, and for the arousal dimension it ranges from an excited to a relaxed figure (see Figure 2). The dominance dimension is represented by a SAM changing in size, with a large figure representing maximal control.

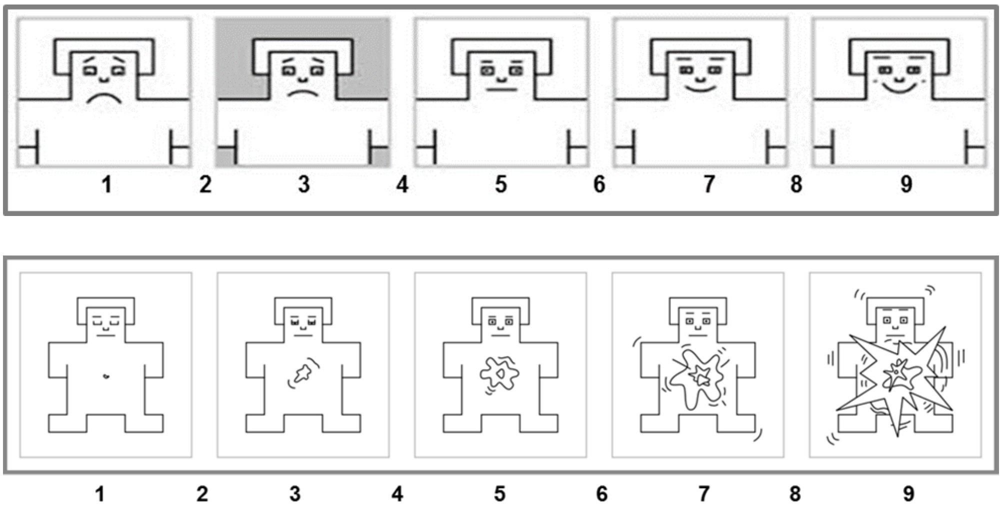

Figure 2. Bradley and Lange's (1994) pen-and-paper version of the Self-Assessment Manikin (SAM) used to evaluate the affective dimension of valence (top panel) and of arousal (bottom panel). Participants can either place an "x" on any of the 5 figures or between two figures, resulting in a 9-point rating scale.

Earlier studies successfully used an interactive computer-version of the SAM (Lang, 1980) to measure emotional responses to pictures (e.g., Lang, Greenwald, Bradley, & Hamm, 1993), sounds (Bradley, 1994), and painful stimuli (McNeil & Brunetti, 1992). In their present study, Bradley and Lang (1994) selected 21 pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999), varying in pleasantness. In a first step, 60 participants were instructed to provide semantic differential ratings for each picture (Mehrabian & Russell, 1974). Therefore, 18 bipolar adjective pairs were presented (e.g., happy-unhappy, relaxed-stimulated, despairing-hopeful), for each of which they chose the adjective that corresponded best to their reaction to the picture. Factor analyses including each rating for each picture from each participant revealed that the dimensions of valence, arousal and dominance accounted for 24%, 23%, and 12% of the variance, respectively. In a second step, these ratings were compared to the SAM ratings for the same 21 pictures. Results revealed strong correlations (> .94) between semantic differential ratings and SAM ratings for both the valence and arousal factor. For the dominance factor, however, correlations were not significant. These findings suggest that the dimensions of valence and arousal are primary when it comes to the assessment of emotional materials. Consequently, one can assume that each emotional stimulus (picture, word, object, event) can be situated within a 2-dimensional affective space, allowing to easily and clearly differentiate between affective categories (Bradley & Lang, 1994; Lang et al., 1993).

In the current literature, distinguishing between the valence and arousal dimension of emotional materials has become a prerequisite for valid and reliable research, and this all the more since neuroscience has provided new insights into the neural circuits of valence and arousal. Valence processing, for instance, has been projected onto several neural substrates, such as the basolateral amygdala (BLA), the prefrontal cortex, the striatum, and the lateral hypothalamus (Tye, 2018). The probably most studied circuit node is the amygdala, which has been identified as a critical hub for the processing of both positive and negative stimuli, (even though research has hyper-focused for a long period on its role in fear, e.g., LeDoux, 2003; Phelps & LeDoux, 2005; Phelps et al., 2001). For instance, causal manipulations of valence-responsive cells in the basolateral amygdala (BLA) showed that the latter are necessary to elicit both innate and learned appetitive and aversive responses (Gore et al., 2015; for a detailed description of the BLA structure, see Kim, Pignatelli, Xu, Itohara, & Tonegawa, 2016). Furthermore, the BLA complex (including lateral, basal, and basomedial cell groups) was identified as important for assigning emotional significance to environmental cues and for the plasticity of positive as well as negative associations in Pavlovian conditioning (e.g., Beyeler, 2016; Rumpel, LeDoux, Zador, & Malinow, 2005; Tye, Stuber, de Ridder, Bonci, & Janak, 2008). Recent findings thus support the idea that amygdala networks play a key role in the processing of positive and negative information, notably due to the presence of valence-selective neurons in the BLA structures (for review, see Janak & Tye, 2015; Tye, 2018). Of interest too, earlier studies also suggest an implication of the amygdala in processing arousal in response to emotional stimuli. The amygdala-hippocampal network, for example, appears to contribute to the enhanced recognition of arousing words (compared to neutral and non-arousing words) (e.g., Dolcos, LaBar, & Cabeza, 2004; Kensinger & Corkin, 2004), and neural activation in the insula, basal ganglia, and amygdala varies in function of word arousal (e.g., P. A. Lewis, Critchley, Rotshtein, & Dolan, 2007). Other neural systems, however, seem to specifically subserve either valence or arousal. For instance, the experience of unpleasant emotions (e.g., sadness), was accompanied by increased blood-oxygen-level (BOLD) responses in the dorsal cortical and mesolimbic areas, while highly arousing emotions (e.g., anger) were associated with increased BOLD signals in the midline and medial temporal lobe structures (Colibazzi et al., 2010). Similarly, data from functional magnetic resonance imaging (fMRI) suggested that distinct brain systems underlie the processing of valence and arousal in affective pictures (Nielen et al., 2009), as well as the ratings of valence and arousal during the presentation of emotional words (Posner et al., 2009) and emotional facial expressions (Gerber et al., 2008). Although further research seems necessary to clarify which brain areas specifically account for the processing of valence and arousal, findings indicate the involvement of partly distinct neural networks in the processing of the latter, supporting the assumption that both valence and arousal present distinctive key factors in emotion research.

Further insight into how valence and arousal affect cognitive processing comes from behavioral data. Findings suggest, for instance, that that under conditions of limited attentional resources (e.g., very brief presentation of several subsequent stimuli), highly arousing words benefit from a privileged attentional status, and this independently of their valence (e.g., Anderson, 2005; Anderson & Phelps, 2001; Arnell, Killman, & Fijavz, 2007; Keil, Ihssen, & Heim, 2006; Kever, Grynberg, et al., 2015; Mathewson, Arnell, & Mansfield, 2008). Concretely, several studies relied on an attentional blink paradigm, in which two targets (T1 and T2) have to be detected from a stream of distractors in a rapid serial visual presentation (RSVP). After the successful report of T1, the detection of T2 is typically impaired if the latter appears 200-500ms after T1 (i.e., the attentional blink effect) (Raymond, Shapiro, & Arnell, 1992). Key results stem, inter alia, from a well-controlled set of experiments indicating that highly arousing T2 words are significantly better detected than low arousing T2 words. Positive and negative words (of the same arousal level), however, are equally well reported (Anderson, 2005). Further findings showed delayed attentional disengagement from highly-arousing compared to low-arousing emotional materials (Mather & Sutherland, 2011; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). These observations converge to the notion that highly-arousing stimuli capture and hold attention more easily, facilitating their entry into awareness. Of interest too, Recio and colleagues (2014) recorded response times (RT) and event-related-potentials (ERP) while participants realized a lexical decision task with words presenting varying valence (positive, negative, neutral) and arousal levels (low, medium, high). RTs were significantly faster for positive words (compared to negative and neutral) and for words of high arousal (compared to medium and low). Besides, negative highly-arousing words were faster recognized than negative words with low or medium arousal, indicating that arousal alone (independently of valence) speeds visual word processing.

Consistently, ERP data indicated earlier processing of the arousal compared to the valence dimension, suggesting that high arousal triggers the mobilization of attentional resources, possibly to optimize consequent behavior (Recio et al., 2014). Similar findings were recently reported by Delanaye-Busch and collaborators (2016) who observed larger ERP responses for highly-arousing compared to low-arousing words in a semantic categorization task, without an effect of word valence. Finally, with respect to memory, research indicates that memory retrieval is more sensitive to differences in the arousal than the valence level of previously encoded stimuli (Bradley, Greenwald, Petry, & Lang, 1992). That is, highly-arousing pictures were significantly better recognized than low-arousing pictures in both immediate and delayed (1 year later) recall. Picture valence, however, had no effect on recognition performance, with pleasant and unpleasant stimuli (presenting the same arousal levels) being equally well recalled. The authors propose that the better memory for highly-arousing information could be related to the physiological reaction (e.g., heightened skin conductance responses) engendered when encountering these information. Findings also revealed slower forgetting for highly-arousing compared to neutral words. While recognition for neutral words decreased over time, recognition for arousing words stayed the same or even improved (Sharot & Phelps, 2004). Furthermore, fMRI data indicate greater successful encoding activity in the prefrontal cortex for arousing compared to neutral pictures (Dolcos, LaBar, & Cabeza, 2004; see also, LaBar & Phelps, 1998). The underlying mechanisms relaying arousal to memory are potentially multiple and still partly unclear. While certain authors claim that neurophysiological factors play a key role in facilitating memory performances for arousing materials (e.g., glucocorticoide release; Roozendaal, Okuda, de Quervain, & McGaugh, 2006), others suggest that elaboration might be a sufficient explanatory factor. That is, stimuli rated as highly arousing have been shown to produce larger psychophysiological responses (e.g., skin conductance, cardiovascular activity, facial electromyography) than non-arousing stimuli (e.g., Greenwald, Cook, & Lang, 1989; Lang et al., 1993). These physiological response information then encourage the individual to process the stimulus in more detail, leading to a more elaborate encoding and eventually to better memory performances (Bradley et al., 1992; Buchanan, Etzel, Adolphs, & Tranel, 2006; Lang, 1979). Overall, the finding seems robust that the arousal level of an encountered stimulus affects its processing, with highly arousing stimuli benefiting from a processing advantage compared to low arousing stimuli.

Research on the effects of valence (while statistically controlling for potential arousal effects), however, has yielded more mixed results. On the side of perception, some results suggest that less exposure or stimulus input is needed to detect unpleasant compared to pleasant stimuli. In agreement with this, several studies showed faster automatic capture of attention for fear-related pictures (e.g., Öhman, Flykt, & Esteves, 2001), threatening faces (e.g., Fox, Russo, Bowles, & Dutton, 2001; Vuilleumier & Schwartz, 2001), and negative words (e.g., Nasrallah, Carmel, & Lavie, 2009) compared to positive materials. Furthermore, findings suggest that negative stimuli cause greater reaction time interferences (e.g., McKenna & Sharma, 1995; Pratto & John, 1991) as well as larger ERP responses in an emotional Stroop paradigm (Thomas, Johnstone, & Gonsalvez, 2007). Likewise, negative stimuli withhold attention longer than positive and neutral stimuli (Fox et al., 2001), leading to slower responses in a variety of cognitive tasks (e.g., word naming: Algom, Chajut, & Lev, 2004; lexical decision: Estes & Adelman, 2008). Further support for the preferential processing of negative information comes from neurophysiological studies. For example, negative words elicited larger ERP amplitudes (Bernat, Bunce, & Shevrin, 2001; Holt, Lynn, & Kuperberg, 2009), and led to enhanced skin conductance responses (Silvert, Delplanque, Bouwalerh, Verpoort, & Sequeira, 2004) compared to positive and neutral words. In sum, whenever a negative stimulus is encountered, it quickly and easily attracts attention and benefits from a more elaborated processing than other stimuli – a phenomenon termed “negativity bias” (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Ito & Cacioppo, 2005). The negativity bias is generally explained by the high relevance of negative stimuli as potential threats for the organism. The earlier those stimuli grab attention, the greater the chances of survival, and the longer they are processed, the greater the chances to react in an appropriate way (Dijksterhuis & Aarts, 2003).

However, other studies showed an overall processing advantage for emotionally significant compared to neutral information. For example, findings revealed faster response times for both positive and negative words compared to neutral words in a lexical decision task (e.g., Kousta, Vinson, & Vigliocco, 2009; Zeelenberg, Wagenmakers, & Rotteveel, 2006). In line with this, research points towards partial overlaps between the neural circuits involved in positive and negative affect, notably with respect to amygdala contributions (for review, see Kim et al., 2016).

Even more importantly, there is amassing evidence for a positivity bias in information processing, suggesting easier and faster classification of positive compared to negative information. This pattern has been found in numerous studies evaluating the processing speed of valenced stimuli (for review, see Unkelbach, 2012; Unkelbach, Fiedler, Bayer, Stegmüller, & Danner, 2008). For instance, Bargh and colleagues (1992) observed a negative correlation between word valence and evaluation latencies. The more positively participants rated a word (on a scale from -5 to 5), the faster they classified it as “good” or “bad”. Snodgrass and Harring (2004) relied on a lexical decision task in which they asked participants to classify very briefly presented stimuli as valenced words or random letter strings. They observed greater sensitivity (d’) to positive than negative words, indicating a positivity advantage even when attention is not directed towards the valence dimension of the stimulus. Evidence supporting this assumption has been provided, amongst others, by Fazio et al. (1986) and Unkelbach et al. (2010; 2008). Importantly, further findings indicate that the valence effect is not only due to the higher frequency of positive information in the environment. In fact, Unkelbach et al. (2010) observed faster classification times for positive compared to negative words even after controlling statistically for word length and frequency. The authors propose the density concept as potential underlying mechanism for the positivity advantage in processing speed (Unkelbach, 2012; Unkelbach et al., 2008). Concretely, they assume greater resemblance between different positive information than between different negative information. This higher similarity translates into greater density of positive information within a multidimensional space. In other words, “happy” and “lovely” are more similar than “sad” and “ugly”, and consequently, are located more closely together when represented in a graphical model (e.g., Russell’s two-dimensional model of affect (1980), see also, Bradley & Lang (1994)). In a classification task, this leads to the following sequence: a stimulus enters the cognitive system and is, based on memory, classified as positive/good or negative/bad. Given the higher density of the cluster, a positive stimulus activates a greater number of other positive stimuli than a negative stimulus would (e.g., “happy” will activate “lovely” while “sad” will not activate “ugly”), which then leads to faster response latencies (Unkelbach, Fiedler, et al., 2008). Additionally, findings from event-related potentials (ERPs) allowed to further investigate the relative contributions of emotional valence to word processing. While some studies supported the assumption of a negativity bias, others reported an advantage for positive content. For instance, enhanced ERP amplitudes suggest a processing advantage for positive compared to negative stimuli in both a simple reading and a lexical decision task (Bayer, Sommer, & Schacht, 2012; Palazova, Mantwill, Sommer, &

Schacht, 2011). Furthermore, results from functional magnetic resonance imaging (fMRI) showed enhanced activation in the left amygdala and the left visual cortex during the silent reading of positive adjectives (compared to negative and neutral adjectives). Visual processing seems thus biased towards positive materials and involves the amygdala, casting doubt upon the notion that the latter preferably detects threat-related information (for a more detailed discussion, see Kim et al., 2016; Lewis et al., 2007; Murray, 2007; Sabatinelli, Lang, Keil, & Bradley, 2006).

Overall, the current state of research supports the idea that valence and arousal are not only conceptually and psychologically different, but that they are also dissociable at a neurocognitive, physiological, and behavioral level. Consequently, both dimensions need to be taken into account when conducting studies involving emotional materials. With respect to the arousal dimension, findings provide strong evidence for the preferential processing of highly arousing over low arousing stimuli. For the valence dimension, however, no such consensus has yet been reached. While some results point towards a negativity bias, others indicate a processing advantage for positive information.

After expanding on the characteristic features of the subjective feeling component of emotion, we will now turn our attention to its motor expression component. In a first section, we present a range of findings clarifying the effects of facial expressions on the processing of emotional information. Subsequently, we focus on the role of bodily expressions (i.e., movements, posture) in that respect. We thus provide a non-exhaustive overview of the state of research regarding the interplay between motor expressions (in face and body) and emotional processing.

2. The motor expression component of emotion

2.1 Facial expressions in emotional processing

According to facial feedback theories, facial muscle activation can modulate emotional experiences and influences the perception and understanding of emotional information (e.g., Havas, Glenberg, & Rinck, 2007; McIntosh, 1996; Tourangeau & Ellsworth, 1979). For instance, participants displaying Duchenne smiles reported increased positive affect when exposed to pleasant and funny videoclips compared to those displaying lip pressing or non-Duchenne smiles (Soussignan, 2002). Similarly, participants prevented from frowning (by botulium toxin A injections) reported reduced negative mood compared to a control group (receiving other cosmetic treatments) (Lewis & Bowler, 2009). Furthermore, it has repeatedly been shown that facial muscle activation plays a functional role within the understanding of emotional language (e.g., Havas, Glenberg, Gutowski, Lucarelli, & Davidson, 2010; Havas et al., 2007; Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009). Havas and colleagues (2010) observed that temporal paralysis of the muscle involved in frowning (i.e., corrugator supercilii) lead to increased reading times for angry and sad, but not for happy sentences, providing strong evidence for a causal role of facial expressions in emotional processing. Likewise, preventing participants from facial mimicry (i.e., by holding a pen horizontally between the teeth) impaired their ability to detect transitions from happy to sad emotional expressions, and interfered with the recognition of happiness (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman, Winkielman, & Ramachandran, 2007). Also noteworthy, findings revealed that Botox-induced selective denervation of facial muscles reduces mimicry of others' facial expressions together with an attenuated activation in the left amygdala (Hennenlotter et al., 2009).

Importantly, when taking a closer look at the numerous findings in the field, one notices that specific muscle activation patterns seem to be tied to valence representations. For instance, evaluating the emotionality of concrete and abstract words leads to emotion specific somatic responses. Concretely, judgments about concepts typically evoking joy (e.g., sun, cuddle) were accompanied by facial electromyographic (EMG) activity in the zygomaticus and orbicularis oculi muscles, both involved in smiling. Likewise, the processing of concepts eliciting anger (e.g., fight, murderer) caused activation in the corrugator supercilii, involved in frowning (Niedenthal et al., 2009). Similarly, results showed that facial muscles responded in an emotion-congruent way while reading angry, happy, and sad sentences (Havas et al., 2010). Interestingly, distinct positive and negative emotional facial response patterns can even be observed when emotional stimuli are presented too quickly to allow conscious perception (Dimberg & Thunberg, 2000). Given the evidence that specific facial expressions relate to positive and negative valence, it can be assumed that cognitive processing is facilitated when the valence of the facial expression matches that of the to-be-processed stimulus (i.e., a congruency effect). Research has indeed shown that manipulations of facial expressions affect participants' response patterns in an autobiographical memory task. Participants who practiced facial expressions associated with happiness recalled more life events with content rated as happy, while participants who previously expressed anger recalled more angry information (Schnall & Laird, 2003). In the same vein, findings revealed that spontaneous facial responses predict memory biases for emotionally-congruent stimuli. That is, ambiguous faces encoded as "happy" led to enhanced zygomaticus activation, which in turn was positively correlated with recognition performances when re-viewing the faces (Halberstadt, Winkielman, Niedenthal, & Dalle, 2009). Furthermore, reading and judgment times for pleasant sentences were significantly faster when participants were smiling (congruent-combination) than when they were frowning (incongruent-combination) (Havas et al., 2007). Research also indicates that the inhibition of congruent facial expressions (e.g., by Botox-injections) significantly impairs the understanding of emotional language (e.g., Havas et al., 2010; Havas & Matheson, 2013) and the ability to read others facial emotions (e.g., Neal & Chartrand, 2011). Finally, facial feedback has been shown to affect impression formation when interacting with a hostile or friendly person. Openly displaying ones facial expressions shifts the impression to the emotionally-congruent direction (e.g., smiling to a friendly person leads to a particularly positive impression) (Ohira & Kurono, 1993). Research thus provides substantial evidence for a congruency-effect between facial expressions and information with matching hedonic value, such that congruent stimuli benefit from enhanced or facilitated processing.

2.2 Posture and movements in emotional processing

In addition to facial expressions, the assumption of a relationship between bodily and affective states has been supported by research focusing on posture and body movements. For example, adopting postures characteristic of anger, fear, and sadness has be shown to increase emotion-specific feelings (e.g., Duclos et al., 1989; Riskind & Gotay, 1982). Furthermore, generating words associated with the feeling of disappointment leads to greater decreases in posture height than generating words related to pride (Oosterwijk, Rotteveel, Fischer, & Hess, 2009). In the same vein, positive feedback following an achievement task causes greater self-reported pride when received in an upright rather than in a slumped position (Stepper & Strack, 1993). Likewise, participants holding an upright posture when confronting a stressful situation report higher self-esteem, reduced fear and more positive emotion than participants in a slumped position (Nair, Sagar, Sollers, Consedine, & Broadbent, 2015). Of interest too, adopting a bodily posture expressing power (i.e., an expansive position with open limbs) leads to higher feelings of power, higher risk tolerance, increased testosterone and lowered cortisol levels, compared to a contracted posture (Carney, Cuddy, & Yap, 2010).

Of particular interest, just as with facial expressions, research indicates the presence of congruency-effects between posture/movements and emotional stimuli. Based on the notion that the evaluation of stimuli on a valence dimension (positive-negative) is closely linked to specific motor actions (e.g., approach-withdrawal), findings revealed processing advantages for stimuli whose valence is congruent with that of the motor expression. For instance, the memory of valenced words is facilitated by a congruent motor action at the time of encoding. Participants who nodded during the encoding phase (i.e., a movement associated with agreement) were more likely to recognize positive words whereas those who shook their heads (i.e., a movement associated with disagreement) were more likely to recognize negative words (Neumann & Strack, 2000). By the same token, results revealed that autobiographical memories are better recalled when the body position adopted during retrieval is congruent with the body position in the original event than when it is incongruent (e.g., retrieving a dentist memory when lying down vs standing up) (Dijkstra, Kaschak, & Zwaan, 2007). Further investigations demonstrated that participants were faster to press a button using arm flexion (i.e., an approach movement) when viewing happy compared to angry faces, while the opposite was true when the button press required arm extension (i.e., an avoidance movement) (Rotteveel & Phaf, 2004). Converging results were found when participants were provided with the impression of moving either towards (approach) or away from the computer screen (avoidance) (Rotteveel & Phaf, 2004). Moreover, power-related words (e.g., authority, win) become more accessible (i.e., greater interference in a Stroop color naming task) for participants who make a fist (a behavior related to body force) than for those who make a neutral gesture (e.g., a “scissor” hand gesture) (Schubert, 2004). Of interest too, fluent arm movements (i.e., movement to the right for right-handers) lead participants to evaluate neutral words more positively whereas non-fluent arm movements (i.e., movement to the left for right-handers) lead to more negative evaluations of neutral words (Milhau, Brouillet, & Brouillet, 2013; see also; Cacioppo, Priester, & Berntson, 1993;

Deuter, Best, Kuehl, Neumann, & Schächinger, 2014). Compatibility of the processed information with motor actions thus facilitates memory performances, processing speed, and affective judgments.

In sum, there is broad evidence that motor expressions in face and body influence the processing of emotional information. More precisely, numerous findings can be understood as so-called congruency effects given that stimuli matching the emotional-value of the facial expression/movement/posture displayed by the individual are processed more easily and efficiently than emotionally-incompatible stimuli. However, in view of these evidence, two substantial questions arise: (1) At a theoretical level, which accounts have been offered to explain congruency-effects? (2) Can similar effects be observed when focusing on the third component of emotion, i.e., autonomic arousal responses?

2.3 Congruency effects and underlying mechanisms

When searching the literature in an attempt to find theoretical models accounting for congruency-effects, one inevitably comes across the concept of mood-congruency, which started attracting researchers' attention in the early 1980's. According to the mood congruency hypothesis, information that is consistent with an individual's mood benefits from a processing advantage over mood-incongruent information (Bower, 1981; Bower & Cohen, 1982; Fiedler, 1990; Forgas, 1994b). These so called mood-congruency effects have first been observed in memory tasks, with positive stimuli being better remembered under positive mood and negative stimuli being better remembered under negative mood (for review, see Ellis & Ashbrook, 1989; Mayer, Gayle, Meehan, & Haarman, 1990). For instance, depressed psychiatric patients showed a pronounced bias to recall depression-related and negative words compared to control subjects (e.g., Denny & Hunt, 1992; Moritz, Gláscher, & Brassen, 2005; Watkins, Mathews, Williamson, & Fuller, 1992). Likewise, depressed participants exhibited enhanced recognition for negative compared to positive facial expressions (Gilboa-Schechtman, Erhard-Weiss, & Jeczemien, 2002). Moreover, findings suggest better memory for autobiographic events matching ones prevailing mood (Miranda & Kihlstrom, 2005).

Congruency effects are, however, not confined to memory but also extend to processing speed, social judgments, and attributions. For instance, participants made faster lexical decisions for mood-congruent stimuli (e.g., "sad" words like despair or regret following sadness induction) (Niedenthal & Setterlund, 1997, 1994) and showed faster response times when evaluating mood-congruent pictures (e.g., categorizing a slide displaying flowers as positive when feeling elated) (Hermans, De Houwer, & Eelen, 1996). Furthermore, research indicates that a person's mood considerably influences self- perceptions and social-thinking. While positive mood leads to more optimistic thinking, negative mood occasions pessimism (for review, see Forgas & Vargas, 2000). Hence, participants reported greater overall happiness and satisfaction with their lives when in a positive mood compared to a negative mood (Schwarz & Clore, 1983). Likewise, studies focusing on self-perceptions of achievement showed that students experiencing positive mood anticipated greater success in an upcoming exam than students in a bad mood (Detweiler-Bedell, Detweiler-Bedell, &

Salovey, 2006), and people in a bad mood blame themselves more for conflicts in their close relationships than those in a good mood (Forgas, 1994a).

With regard to the issue of underlying mechanisms, most authors seem to rely on associative network theories (e.g., Anderson, 1976; Bower, 1981; Collins & Loftus, 1975; Isen, Shalker, Clark, & Karp, 1978). The probably best-known model stems from Bower (1981), who states that the human memory can be modelled as an associative network of concepts (or knowledge-units) that are used to form a proposition. Within this network, concepts relating to a same event or experience are connected by associative linkages. For example, following “a sunny holiday in Miami” a link between the different concepts of this proposition (i.e., sunny, holiday, Miami) has been created, which also extends to associated concepts (e.g., travel, beach, sunscreen). Consequently, when the concept “Miami” is activated, activation spreads to its associated concepts, facilitating their retrieval. In the same vein, Bower proposes that mood states are represented as nodes in an associative network. For instance, a given emotion, say happiness, is represented as a node surrounded by its associated expressive behaviors, autonomic reactions, evoking situations, and verbal labels. Being in a certain mood state then means that the corresponding node is activated. This activation spreads to the closely related, neighbouring nodes first (e.g., positive words or pictures), such that those stimuli come faster and more easily to mind (Bower, 1981).

Despite its popularity, the associative network model has been called into question in recent years. In fact, alternative accounts propose that knowledge about an emotion concept is not reducible to an abstract description node, but involves partial reactivation of the bodily state that occurred when one actually experienced that emotion (the “embodied emotion” account, e.g., Niedenthal, 2007; Niedenthal et al., 2009). For instance, when remembering a sad personal moment, we partly reproduce the feeling of sadness. In view of this, it can be assumed that the initial emotional experience or perception of an emotional stimulus leads to bodily responses that are partially recorded and stored in the brain. Later, when cognitive processes require information about this emotional event, the associated pattern of neural states is partially reactivated, facilitating the access to emotion knowledge (Damasio, 1994; Niedenthal et al., 2009). Even if these reenactments (or simulations) are not as marked as the original emotional states, they are more than simply by-products of thinking about past events. On the contrary, they seem to be crucial to the understanding and interpretation of emotional concepts, language, and social interactions (Niedenthal et al., 2009; Winkielman, Niedenthal, Wielgosz, Eelen, & Kavanagh, 2015). The above-mentioned explanatory theories will be addressed in more detail in the discussion section of the present dissertation.

Let us now turn to the second open question, namely whether congruency-effects can also be observed when focusing on arousal responses. Given that arousal responses are a key component of the emotional response triad (Scherer, 2005), and that each stimulus can be rated on an arousal dimension (Bradley & Lang, 1994; Russell, 1980), it seems rather obvious to test for potential “arousal-congruency” effects. However, when reviewing the current literature, it appears that the arousal construct has attracted only scant interest, leading to a limited number of studies exploring its interplay with emotional stimulus processing.

3. The complex case of the arousal component

While research findings provide consistent evidence for a link between motor expressions and emotional processes, it seems that the physiological component of the emotion response has been largely overseen. Even if it is widely acknowledged that the latter constitutes an essential dimension of emotion (e.g., Frijda & Mesquita, 1998; Kreibig, 2010; Scherer, 2005), the relationship between arousal responses and emotional processing has been a topic of debate over the last decades. Much of the discussion stems from discrepancies regarding the definition of the arousal construct, with the same term being used to refer to a variety of different phenomena in neuroscience, psychophysiology, and psychology research. Besides, it remains partly unclear what components of the physiological response system (e.g., electrodermal, cardiac, vascular, pupillary) constitute the most sensitive measures of arousal (Norman, 2016). Research on sleep disorders, for instance, mainly relies on pulse transit time (i.e., time it takes the pulse pressure wave to cover a certain distance in the vascular system), and on measures of skin vascular conductance (e.g., fingertip blood flow, finger and ear pulse wave amplitudes) to quantify arousal (e.g., Catcheside et al., 2002; Pèpin et al., 2005; Pitson, Chhina, Knijn, Herwaaden, & Stradling, 1994). Studies investigating the effects of exercise on cognitive performance, however, primarily use heart rate (and sporadically blood pressure) as measure of arousal (for review, see McMorris, 2005; Tomporowski, 2003), while studies focusing on emotionally-induced arousal seem to favour endocrine indices, such as salivary cortisol levels (e.g., Cahill, Gorski, & Le, 2003; Mitchell, MacDonald, & Brodie, 2004; Smeets, Otgaar, Candel, & Wolf, 2008). Furthermore, pupillary dilatation has been put forward as reflecting arousal responses to emotionally salient stimuli (Bradley, Miccoli, Escrig, & Lang, 2008; Mathot, 2018; Wang et al., 2018).

Given these conceptual and methodological challenges, it is hardly surprising that systematic research on the influence of arousal on emotional processing is rather sparse as compared to the extensive literature examining the relation between facial/postural feedback and emotional knowledge.

The following paragraphs are dedicated in the first instance to an overview of existing theoretical approaches and inconsistencies regarding the definition of the arousal construct. Subsequently, we will provide a brief review of current empirical findings on the interactions between arousal responses, emotional experience and emotional information processing. As above-mentioned, studies on the topic are relatively scarce and encompass a wide variety of - sometimes conflicting - theoretical and methodological approaches, emphasizing the need to review existing data and put it into perspective.

3.1 Definitional challenges & arousal models

The concept of arousal has been studied for years in biological and behavioral sciences and has, ever since, be surrounded by controversies (e.g., Duffy, 1962; Humphreys & Revelle, 1984; Levenson, 1983; Thayer, 1978). According to early conceptualizations, arousal refers to a physiological state ranging from vigorous activity, excitement and alertness on one extreme, to calmness, relaxation and sleep on the other (Duffy, 1962). However, the definition becomes less straightforward when taking into account the multifaceted nature of arousal. Arousal indeed encompasses both quite specific states of activation (e.g., increased cardiovascular and brain functioning) as well as more general activation occurring in the whole body when shifting from calmness to activity (e.g., sitting quietly and then rising and start to move) (Thayer, 1989). Moreover, arousal can be induced by diverse external events or internal motivations, which further complexifies its conceptualization (Lee, Sakaki, Cheng, Velasco, & Mather, 2014). Consequently, different theoretical models have used the term arousal to describe different physiological or emotional processes. For instance, Schachter and Singer (1962) conceive arousal as an affectively neutral (i.e., emotionally nonspecific) activity of the autonomic nervous system (ANS), that needs to be actively perceived to elicit an emotional response (Reisenzein, 1983). Other accounts assign an emotional dimension to the term arousal, using it for example when referring to ANS activation following the encounter of an emotional stimulus or event (e.g., Norman, Berntson, & Cacioppo, 2014; see also, Kreibig, 2010).

Interesting contributions to this issue have been made by Thayer's multidimensional model of arousal, suggesting that one can differentiate between energetic arousal and tense arousal (1978). While energetic arousal refers to the psychophysiological changes occurring when performing a physical activity (e.g., cycling or walking), tense arousal typically occurs when encountering an emotionally charged situation (e.g., experiencing a stressful event). Although both arousal types present some overlapping characteristics (e.g., activation of the endocrine system leading to increased metabolic and cardiovascular output), several findings support their two-dimensional conceptualization. For instance, while bodily movements in the energetic arousal condition are rather smooth and ongoing (e.g., when lawn mowing), muscles in the tense arousal condition are typically tight, resulting in jerk and uneven movements (e.g., when walking down the hall to go to an important exam) (Thayer, 1989). Besides, subjective experiences differ considerably depending on the arousal type. While energetic arousal ranges from sleepiness to a feeling of vigour, peppiness, and energy, tense arousal ranges from feeling calm to feeling nervous or even anxious (Schimmack & Reisenzein, 2002; Thayer, 1989; Watson, Wiese, Vaidya, & Tellegen, 1990). Interestingly, the two arousal dimensions can even change in opposite directions. For example, Gold and colleagues (1995) observed that insulin-induced hypoglycemia resulted in a fall in energetic arousal (e.g., low energy scores) and a rise in tense arousal ratings (e.g., an emergency response resulting in high anxiety scores), urging the body to quickly restore blood sugar levels. Thayer's model thus stresses the importance of using the concept of arousal gingerly, especially in view of the fact that it can be elicited by different means and can have diverse, or even opposite, psychophysiological effects.

But, as most novel approaches, Thayer's theory has not been without critics. Alternative views state, for instance, that markers of energetic arousal (awake-tired) and tense arousal (tense-calm) are actually mixtures of valence and a single arousal dimension (i.e., the valence activation hypothesis: Yik, Russell, & Barrett, 1999). According to this perspective, energetic and tense arousal mainly differ due to the fact that they incorporate valence in opposite directions. Energetic arousal increases with valence, whereas tense arousal decreases with valence. The type of activation involved in both dimensions, however, does not seem significantly different (e.g., feeling awake: state of positive valence and high activation vs feeling tense: state of negative valence and high activation). A recently conducted test of this prediction, however, provided unambiguous support for the two-dimensional arousal model (Schimmack & Reisenzein, 2002). In fact, the authors observed no significant correlation between the residuals of energetic and tense arousal after removing their shared variance with valence, underlining the importance of differentiating between arousal types. Supporting this assumption, research on consumer attitudes has shown that treating arousal as a single dimension might result in inaccurate findings and misleading conclusions (Fan, Chang, & Wegener, 2015). Results revealed that energetic arousal mediates the effects of ergonomic product quality (i.e., usability) on consumer attitudes (i.e., positive or negative product rating), while tense arousal mediates the effects of hedonic quality (i.e., originality, aesthetics) on attitudes. These findings thus demonstrate that product characteristics can influence consumer attitudes via two arousal routes, supporting Thayer's two-dimensional arousal conceptualization.

However, when looking at current researches in the field of psychophysiology, it becomes striking that systematic studies on the role of tense and energizing arousal are rather rare, especially with regards to emotional processes. In what follows, we will thus provide an overview of current work investigating the influence of arousal responses on the processing of emotional information, while differentiating between tense (i.e., psychologically-induced) and energetic (exercised-induced) arousal throughout this whole introduction. In view of the above-mentioned findings, investigating the effects of tense and energetic arousal separately seems to be a first important step to organize and clarify the sometimes disparate literature on the topic. Thayer's model convincingly theorizes the indisputable and perceivable differences between both arousal dimensions, such as the smooth vs uneven movements or the feeling of being awake vs tense. Moreover, compelling empirical evidence supports the assumption of a two-dimensional arousal construct, which further underpinned our decision to rely on the proposed distinction between tense (psychologically-induced) and energetic (exercise-induced) arousal.

3.2 Tense arousal and emotional processing

While studies on motor expressions in face and body have mainly focused on their impact on the processing of emotional information, most work on tense (psychologically-induced) arousal has examined its influence on non-emotional neutral materials. Nevertheless, a series of studies revealed an interplay between tense arousal levels and the processing of emotional information, primarily with respect to memory and attentional processes (e.g., Cahill & McGaugh, 1998; Knight & Mather, 2009; McCullough, Ritchey, Ranganath, & Yonelinas, 2015; Smeets et al., 2008; Sutherland & Mather, 2015). Research indeed suggests an impact of tense arousal on the encoding, consolidation and retrieval of emotional and neutral memories. For instance, Smeets and colleagues (2008) made participants memorize lists of emotional and neutral words before (encoding arousal group), directly after (consolidation arousal group), or 24h after (retrieval arousal group) the administration of a cold pressor stress test (CPS). The CPS was performed by immersing the participants' arm into ice-cold water (0-3°C) for as long as possible with a maximum of 3 minutes; a procedure that is known to induce robust and reliable stress responses related to pain monitoring (i.e., increased adrenal stress hormone release) (e.g., Mitchell et al., 2004). Participants in the control condition were instructed to place their arm in warm water (37-40°C) until told to remove it. Results reveal that, compared to the encoding and retrieval condition, the tense arousal induction during consolidation (i.e., directly after memorization) led to an increased recall of emotional, but not neutral words 24h later. On the other hand, tense arousal induction before retrieval (i.e., just before the recall test 24 hours after word memorization,) resulted in reduced recall of emotional words compared to the other experimental conditions. No such effects were found for emotional words in the encoding condition and for overall memory performances on neutral words. These observations indicate that a same source of tense arousal affects the processing of emotional stimuli differently, depending on the memory phase during which arousal levels (i.e., cortisol and salivary alpha-amylase release) are modified. Further findings reveal that post-learning tense arousal inductions enhance long term memory for emotional material (Cahill, Gorski, & Le, 2003). Participants viewed a series of arousing and neutral slides followed by the administration of a CPS (resulting in increased saliva cortisol levels) or a control procedure (i.e. immersing an arm in warm water). After a delay of one week, participants in the CPS condition recalled more emotionally arousing slides compared to those in the control condition, with no differences for neutral slides. Only emotional pictures benefited from the induced tense arousal state, perhaps because the supplementary arousal produced by the encoded stimuli was interpreted as a sign of importance, increasing their memory consolidation (Cahill et al., 2003). By and large, these few examples indicate that the effects of tense arousal on emotional memory depend on the memory phase studied (encoding, consolidation, retrieval). Increased tense arousal during memory encoding and consolidation seems to facilitate the recall of emotional stimuli, whereas it interferes with recall when experienced just before the retrieval phase (for a detailed review on the effects of stress on memory, see LaBar & Cabeza, 2006; Wolf, 2008).

With respect to underlying explanatory factors, research suggests that emotionally arousing events lead to glucocorticoid release (i.e., noradrenaline, cortisol), activating the basolateral amygdala (BLA). Amygdala activity in turn enhances memory consolidation by facilitating neural plasticity and information storage in connected brain regions, including the hippocampus (Hermans et al., 2014; Roozendaal et al., 2006). By contrast, high levels of circulating glucocorticoids have been shown to impair memory retrieval at the time of retention testing, potentially through disturbances in medial temporal lobe and hippocampus function (De Quervain et al., 2003; Roozendaal et al., 2006). Overall, the literature thus supports the assumption that a non-linear, inverted-U shaped curve most accurately represents how tense arousal interacts with cognitive performance (i.e., the Hebbian version of the Yerkes-Dodson law, Boehringer, Schwabe, & Schachinger, 2010; Diamond, Campbell, Park, Halonen, & Zoladz, 2007). Although appealing, these explanations only partially account for the observed findings, leaving open the question why the effects are limited to emotional materials.

An interesting contribution to this issue has been made by alternative frameworks positing that tense arousal modulates selective attention by enhancing the (perceptual) representation of high-salient stimuli and reducing the representation of low-salient stimuli (Sutherland & Mather, 2012, 2015). For example, participants were exposed for 6 seconds to highly arousing negative sounds (e.g., screams, vomiting) or neutral sounds. Subsequently, a letter array comprising high-salient and low-salient letters (i.e., darker versus lighter shade of gray, less versus more numerous) appeared on the computer screen for 200 ms. Participants were instructed to report the letters they saw by using the keyboard. Overall, results revealed better immediate recall for high-salient letters. However, when exposed to negative arousing sounds, the attentional bias for high-salient letters increased, while low-salient letter reports slightly decreased. These observations suggest that tense arousal facilitates the processing of high-salient stimuli and impairs the processing of low-salient stimuli (Sutherland & Mather, 2012). An interesting theoretical account for these findings has been provided by the arousal-biased competition (ABC) model, which posits that arousal modulates mental processing by favoring high-priority stimuli over low-priority stimuli (Mather & Sutherland, 2011). In other terms, tense arousal evoked by emotional events amplifies ongoing perceptive selection processes, leading to the winner-takes-more and the loser-takes-less effects (Mather, Clewett, Sakaki, & Harley, 2015; Mather & Sutherland, 2011).

Further noteworthy contributions have been made by a recent line of research positing that emotional arousal influences thinking and reasoning by providing evaluative cues about an encountered stimulus. According to Clore and Storbeck's (2006) "affect-as-information" model, tense arousal reactions to a given emotional stimulus provide us with information about its valence (positive vs negative), urgency, and importance. These information are consequently used to guide our decisions and judgments and affect cognitive processing. A series of classic experiments have indeed shown that emotionally-induced arousal influences affect-related judgments. The best known example is probably Dutton and Aaron's study (1974), demonstrating that men provided higher attractiveness ratings for an unknown woman after walking over a high suspension bridge. They suggested that the bridge crossing led to an emotionally arousing state, which was mistakenly interpreted as a reaction to the woman, and consequently amplified their feelings of attraction for her. More recent studies revealed that increased tense arousal levels (i.e., after viewing emotionally arousing pictures), lead to an overestimation of the distance from a balcony to the ground (Stefanucci & Storbeck, 2009). Interestingly, a follow-up study showed that participants who were asked to up-regulate their experienced arousal, overestimated the height more than those not regulating or down-regulation their emotional experience (Stefanucci & Storbeck, 2009). Psychologically-induced arousal can thus influence judgments of height, which can even be magnified when increasing arousal levels.

To sum up, a growing body of evidence indicates an influence of tense arousal manipulations on the processing of emotional information, while emphasizing at the same time the complexity and multifaceted nature of this relationship. For instance, in different studies tense arousal has been induced and measured by different means (e.g., cold pressor stress test vs picture viewing; salivary cortisol levels vs self-reports), and proposed underlying processes varied markedly depending on the cognitive nature of the task (e.g., endocrine effects vs. affect as information model). Given that such variations are observed even within the restricted domain of tense arousal research, it seems all the more important to differentiate between tense and energetic arousal for more clarity and better comparability between findings.

3.3 Energetic arousal and emotional processing

In the late seventies, the interplay between energetic (exercise-induced) arousal and emotional experience started attracting the interest of numerous researchers and quickly evolved to a hotly discussed and extensively studied topic. For instance, Zillmann's prominent line of research on excitation-transfer effects elegantly illustrates how energetic arousal can affect subsequent stimulus processing (e.g., Zillmann, 1971; Zillmann, Katcher, & Milavsky, 1972; see also, Bunce, Larsen, & Cruz, 1993; Reisenzein, 1983). His work is based on the fact that physiological arousal decays relatively slowly following the cessation of its eliciting conditions. Therefore, arousal residues from a prior episode of activity can add to the arousal generated by a subsequently encountered stimulus, leading to an intensified emotional reaction (i.e., a misattribution effect) (Zillmann, 1971, 1979). In line with these predictions, residual excitation after a short physical exercise has been found to enhance aggressive behavior in response to a provocation (Zillmann & Bryant, 1974). Likewise, after exercising, participants report enhanced sexual-arousal and more positive evaluations when viewing an erotic film (Cantor, Zillmann, & Bryant, 1975). Besides, energetic arousal has been shown to increase males' judgments of romantic attraction towards an attractive women (White, Fishbein, & Rutsein, 1981), replicating previous findings with tense arousal manipulations (Dutton & Aron, 1974). More recent data indicate that participants who exercised during the completion of a cognitive task showed higher mood improvement when receiving positive feedback on their performance than those who did not exercise (Turnbull & Wolfson, 2002).

In view of the above-mentioned findings, the question arises whether energetic arousal might also play a broader role in the processing of emotional information. While there is ample evidence for arousal misattribution effects (i.e., subjective evaluations of emotional information or behavioral changes), it remains partly unclear whether energetic arousal also influences the cognitive processing of emotional stimuli.

Over the last years, numerous studies have examined the influence of a single bout of exercise on cognitive functions. Meta-analytical results indicate an overall small and positive effect of acute exercise (e.g., a cycling session; during, immediately following, or after a delay) on cognitive performances, which is moderated by the type of cognitive performances assessed, exercise duration and intensity, and participant's level of fitness (Chang, Labban, Gapin, & Etnier, 2012; McMorris, Hale, Corbett, Robertson, & Hodgson, 2015; Tomporowski, 2003). For instance, overall findings suggest positive effects of exercise on visual search, verbal fluency, free recall and Stroop interference tasks (decreased interference), while no effects are observed for verbal working memory, figure learning, and forward digit spans (Chang et al., 2012). With regard to exercise intensity, results differ depending on the timing of test administration relative to exercise. Immediately following exercise, a positive effect on cognitive performances was observed, but only for very light, light, or moderate intensities (not for hard, very hard, maximal intensities). On the contrary, after a delay following exercise, very light exercise resulted in a negative effect on cognitive performance while all other intensity levels lead to positive effects. Lastly, no effect of exercise intensity was observed when the cognitive task was administered during exercise (Chang et al., 2012). When turning to exercise duration, findings reveal that short exercise sessions (<11 min) have a negligible effect on cognitive performance (immediately after exercise) whereas sessions longer than 11 minutes resulted in significantly positive effects. However, when the cognitive task was administered during exercise, exercise for 11-20 minutes had negative effects on cognitive performance and exercise for longer than 20 min resulted in positive effects. Interestingly, meta-analyses suggest that the effects of exercise on cognitive performance are not moderated by the type of exercise (i.e., aerobic, anaerobic, muscular resistance, a combination of different types) (Chang et al., 2012; McMorris et al., 2015). In fact, a multitude of exercise types have been used to manipulate energetic arousal levels successfully, ranging from cycling (e.g., McMorris et al., 2015), to running (e.g., Young et al., 2010), squatting (e.g., Lyons, Al-Nakeeb, & Nevill, 2006), isometric contractions (e.g., Vuillerme, Forestier, & Nougier, 2002), and tennis simulations (e.g., Davey, Thorpe, & Williams, 2002). An example of a study design leading most likely to an increase in cognitive performance would thus be the administration of a visual searching task immediately following a cycling session at light intensity lasting longer than 20 minutes. On the contrary, a figure learning task administered immediately after a short (< 11 min) high intensity exercise session, will very likely have no effects or even negative effects on task performance.

Importantly, when reviewing the literature on energetic arousal and cognitive performance, it becomes striking that most of the studies rely on neutral stimuli, whereas emotional stimuli are hardly used. Research, however, suggests that the processing of emotional and neutral stimuli should not be deemed equivalent. In fact, numerous findings revealed a processing advantage for emotional over neutral information, notably with respect to perception, attention, and memory (for review, see Brosch, Pourtois, & Sander, 2010; Cross, Santamaria, & Kohler, 2018; Yiend, 2010). Furthermore, research has shown that novel and emotional stimuli alter perceiver's bodily states, inducing cardiac, electrodermal, and central (i.e., ERP measured brain activity) changes (for review, see Bradley, 2009).

In view of the above, focusing on the interplay between energetic arousal and the processing of emotional (and not only neutral) stimuli seems to be a highly relevant and promising research area.

Over the last years, several studies have examined the influence of cardiac signals on emotion processing, without, however, modulating energetic arousal levels. A recent line of research has investigated the effects of cardiovisceral feedback on emotional processing, by focusing on the phasic discharge of arterial baroreceptors (pressure sensors in the aortic arch and carotid sinus) (e.g., Fiacconi, Peter, Owais, & Köhler, 2016; Garfinkel et al., 2013, 2014; Pfeifer et al., 2017). Arterial baroreceptors are activated when the heart contracts to eject blood (at systole) and are silent between heartbeats (during diastole). Cardiac feedback is therefore maximal during systole and minimal during diastole. By presenting brief stimuli either at systole or at diastole, one can thus examine how information processing is affected by the strength of cardiovascular feedback. Findings revealed mixed effects of cardiac signals on the processing of emotional stimuli. For instance, brief nociceptive skin stimuli delivered during systole elicited attenuated event-related potentials compared to stimuli delivered during diastole (Edwards, Inui, Ring, Wang, & Kakigi, 2008; Gray, Minati, Paoletti, & Critchley, 2010). Similarly, healthy participants showed a damped nociceptive flexion reflex and weaker autonomic responses when painful stimulation was applied during cardiac systole (Edwards, McIntyre, Carroll, Ring, & Martin, 2002; Gray, Rylander, Harrison, Wallin, & Critchley, 2009). Overall, the effect of cardiac signals on the processing of pain stimuli appears to be largely inhibitory, potentially because baroreceptor firing during systole disrupts attention, causing a short distraction reducing experienced pain (Gray et al., 2010). In contrast, other findings suggest that cardiac feedback facilitates information processing. For example, faces displaying fear are detected more easily and rated as more intense when seen at systole than at diastole. Consistently, amygdala responses to fearful faces are greater when presented at systole relative to diastole (Garfinkel et al., 2014). Comparable results were found for neutral stimuli (i.e., letters, circles), which were detected more easily during systole when presented in a visual search paradigm (Pramme, Larra, Schächinger, & Frings, 2016) or at the threshold of consciousness (Park, Correia, Ducorps, & Tallon-Baudry, 2014). Turning to memory, research shows poorer subsequent recall for words embedded in a stream of distractors when detected during systole as compared to diastole (Garfinkel et al., 2013). Furthermore, faces presented during systole are more likely to be endorsed as previously studied on trials for which participants report impressions of familiarity without conscious recollection (Fiacconi et al., 2016). These findings suggest that cardiac feedback influences memory performance as well as subjective memory-based judgments.

While a growing number of studies examining the impact of baroreceptor signals on emotional processing have appeared over the last years, it seems that the effects of energetic arousal manipulations have received comparatively little attention in current research. To our knowledge, there exist at this time only a modest number of studies that have attempted to address this issue.

3.3.1 Memory processes

With respect to memory, findings revealed that a single bout of resistance exercise during consolidation (i.e., a one-leg knee extension/flexion task) influences emotional episodic memory performances (Weinberg, Hasni, Shinohara & Duarte, 2014). Participants were instructed to classify a set of 180 positive, negative, and neutral pictures ("Would you find this indoors?" yes or no), without being informed that they would be tested on those images. Immediately after the incidental memory encoding they either performed the resistance exercise task or did no exercise (control condition). The physiological response to exercise was measured via salivary biomarkers of norepinephrine, heart rate (HR), and blood pressure (BP). Forty-eight hours later, a remember-know recognition paradigm was administered. Results revealed a main effect of exercise, with better performance for the high arousal exercise group, as well as an effect of picture valence with better recognition for emotional compared to neutral stimuli, but no difference between positive and negative stimuli. Of particular interest, physiological responsiveness modulated memory performances within the exercise group. Response status was determined by averaging the z-scores of each of the physiological measures (salivary biomarkers, HR, BP) and dividing the group by a median split. Only the high responders showed an effect of stimulus valence, with better recognition for emotional compared to neutral items. This observation seems partly consistent with above-mentioned research suggesting that tense arousal can be beneficial for the consolidation of emotional, but not neutral materials (Cahill et al., 2003; Smeets et al., 2008). In line with previous explanations (e.g., McGaugh, 2004; Roozendaal et al., 2006), Weinberg and colleagues (2014) propose that exercise lead to increased epinephrine and cortisol release, facilitating amygdala activity (involved in emotional memory) but disrupting hippocampal function (involved in memory for neutral information).

3.3.2 Attentional processes

Furthermore, a handful of studies examined the potential influence of energetic arousal on the attentional processing of emotional stimuli. Barnes and colleagues (2010), for instance, observed that heightened energetic arousal (i.e., heart rate) improves performance at a modified dot probe paradigm with positive, negative, and neutral stimuli. Concretely, an affective (pleasant or unpleasant) and a neutral picture were displayed above each other, followed by a to-be-detected probe presented at the center location of the upper or lower image. The task was realized either after a 30 minutes cycling session (at 70% of heart rate reserve) or a 30 minutes rest period. Participants showed significantly better reaction times after exercise than after rest, suggesting a broadening of attentional scope, allowing to respond quicker to the probes irrespectively of their valence. Other findings revealed, however, that participants exhibit greater attentional bias to pleasant compared to unpleasant emotional facial expressions (EFE) during moderate-intensity exercise (HR at 45% of peak oxygen consumption (VO2peak)), whereas no shift in attention allocation was observed during high-intensity exercise (HR at 80% VO2peak) and seated rest (Tian & Smith, 2011). In view of this, the authors argue that moderate-intensity exercise primes emotion circuits promoting visual attention networks associated with positive EFE and inhibit those associated with negative EFE. In addition, Shields and colleagues (2011) investigated the effects of rest, moderate - and high intensity exercise (45% and 80% of maximal HR; within-subjects design) on a visual threat detection task. During exercise/rest participants were presented with a series of 3 x 3 picture matrices, containing 9 pictures of a same category (e.g., only flowers or only snakes), as well as discrepant fear-relevant (e.g. a snake located in a background of flowers) and fear-irrelevant pictures (e.g., a mushroom located in a background of spiders). Participants had to decide as quickly and accurately as possible if all the stimuli were the same or if there was a discrepant picture present. Results showed improved visual detection (RT and accuracy) in the moderate- and high-intensity exercise conditions compared to the rest condition, suggesting that increased energetic arousal facilitates the detection of both emotional and neutral information. Overall, it seems that findings regarding the effects of energetic arousal on the attentional processing of emotional stimuli are to date largely inconsistent, making it particularly difficult to draw generalizable conclusions regarding underlying mechanisms.

3.2.3 Subjective judgments

Unfortunately, similarly variable results are found when turning to subjective evaluations and judgments of emotional stimuli. For instance, Smith and O'Connor (2003) observed that emotional responsiveness to aversive and pleasant stimuli remained relatively unaffected during rest, very low (HR at 20% of VO2peak) and low intensity cycling exercise (HR at 40% VO2peak). Each session lasted 20 minutes during which the participants viewed a slideshow with pleasant, unpleasant and neutral pictures. Startle eyeblink responses and electromyographic activity (EMG) of the corrugator supercilii were measured during baseline and picture viewing. While startle and EMG responses were greater during unpleasant compared to pleasant picture viewing, their magnitude remained unaffected by the different exercise conditions, indicating that low intensity exercise does not suffice to significantly alter emotional responsiveness (Smith & O'Connor, 2003). In the same vein, Gable and Harmon-Jones (2013) observed no effects of exercise on valence and arousal ratings of emotional and neutral pictures. Participants either realized a cycling session (at easy-to-moderate speed) or simply rested on a chair while viewing a series of appetitive (delicious dessert) and neutral (rocks) pictures. Arousal changes were quantified via HR measurements (beats per minute), and emotive responses to the pictures were evaluated via event-related potentials (ERP). ERP responses were greater for appetitive compared to neutral pictures but did not differ between the exercise and rest condition. Other findings, however, suggest that energetic arousal manipulations affected the recognition and intensity ratings of emotional facial expressions (EFE) (Brunyé, Howe, & Mahoney, 2013).

Participants realized a 25 minute cycling session (either at low work rate (25-35% of HR peak) or at high work rate (75-85% of HR peak)) followed by a 5 minute cool-down and a 5 minute rest. During exercise, cool-down and rest, participants were presented with morphed animated faces changing from neutral into an affective state (happy, surprise, sadness, anger, disgust) and vice-versa. They were instructed to stop the animation as soon as a face corresponded to an indicated target state (e.g., whenever the face looks happy), and then rate its emotional intensity. Results revealed no effects of energetic arousal on EFE recognition times, but showed reduced intensity ratings for happy, angry, and surprise EFE during high compared to low work rate exercise. Hence, participants became less sensitive to perceived emotional intensity when experiencing states of high physiological arousal. Brunyé and colleagues (2013) suggest that overlapping neural circuits between emotional information processing and sustained exercise (i.e., insula, anterior cingulate, and amygdala) lead to competitive interactions between resources allocated to both processes, which consequently impair the processing of EFE. A table summarizing all above-mentioned studies can be found below.

Table 1
Summary of participant's demographics, exercise type and intensity, physiological markers, administered task, and main results

Authors	N	M/F	Exercise Type	Physiological Marker	Task	Main Result
Weinberg et al. (2014)	46	29 F	Knee extension/flexion During consolidation	Norepinephrine HR BP	Remember-Know paradigm with IAPS pictures 48h post-exercise	Positive effect of exercise on recognition accuracy ($\eta^2 = .271$) High physiological response → impaired recognition of neutral pictures
Barnes et al. (2010)	30	19F	Cycling 30 min, 70% of HRmax	HR	Dot - probe with IAPS pictures Immediately post-exercise	Faster RT post-exercise ($\eta^2_p = .30$) No effects of exercise on response accuracy
Tian et al. (2011)	34	17F	Cycling 45% VO_2max (moderate), 80% VO_2max (intense)	HR	Dot-probe with (un) pleasant EFE During exercise	Greater attentional bias to pleasant EFE at moderate intensity ($\eta^2_p = .219$) No effect of rest and intense exercise
Shields et al. (2011)	30	15F	Cycling 45% HRmax (moderate), 80% HRmax (intense)	HR	Visual threat detection task (pictures) During exercise	Improved detection (accuracy and RT) during exercise (moderate and intense compared to rest) (Acc $\eta^2_p = .451$, RT $\eta^2_p = .552$)
Smith et al. (2003)	24	24F	Cycling 20% VO_2max (very low), 40% VO_2max (low)	HR	Emotional responsiveness (EMG) to (un)pleasant pictures During exercise	No effect of exercise on EMG responses
Gable et al. (2013)	60	23F	Cycling at easy to moderate speed	HR	Emotional responsiveness (ERP) and subjective ratings of appetitive and neutral pictures During exercise	No effect of exercise on ERP responses and subjective arousal/valence ratings
Brunyé et al. (2013)	12	No F	Cycling 25-30% HRmax (low) 75-85% HRmax (intense)	HR	Recognition and intensity ratings of EFE During exercise	No effect of exercise on recognition accuracy Reduced intensity ratings during exercise ($\eta^2 = .57$)

Note. HR = heart rate; BP = blood pressure

Overall, it appears that the relatively small number of studies on the interplay between energetic arousal and emotional processing has issued a rather large number of different, sometimes even conflicting, results. These discrepancies seem partly due to methodological variations, such as differences in arousal levels (e.g., HR during moderate vs low exercise), in stimuli types (e.g., affective pictures displaying objects/animals/everyday scenes vs EFE), and in tasks (e.g., memory vs attention vs evaluation). Importantly, none of the above-mentioned studies reveals findings that could be considered as congruency-effects. However, given that arousal responses are a key component of emotion, and that each stimulus can be rated on an arousal dimension, it seems rather obvious to test for potential "arousal-congruency" effects. But when reviewing the literature, it becomes striking that research has almost exclusively focused on the valence dimension of emotion (e.g., impact of approach/avoidance motor expressions on the processing of positive/negative stimuli). Studies on the influence of arousal on the processing of arousal (in)congruent information (e.g., effects of high/low heart rate on the processing of high/low arousing stimuli), however, seem to be largely lacking.

One of the few studies on the topic has been conducted over 30 years ago by Clark and colleagues (1984). Given the evidence that emotional states differ in arousal levels (e.g., higher overall increases in cardiovascular measures when experiencing anger versus sadness; Kreibig, 2010; Schwartz, Weinberger, & Singer, 1981), Clark et al. investigated whether changes in bodily arousal influenced judgments of other's emotions. Concretely, participants were approached either before or after playing a short tennis match (low arousal condition vs high arousal condition), and were asked to rate a series of positive statements on a 7-point scale ranging from serenity to joy. Results revealed that highly aroused participants were more likely to interpret positive statements as indicating joy (a high arousal emotion) than serenity (a low arousal emotion). Converging evidence was found when rating a set of photographs depicting ambiguous positive facial expression. Findings thus suggest that participants' judgments are biased towards evaluations matching their current level of experienced arousal. Regarding potential explanatory mechanisms, the authors propose that high bodily arousal and positive stimuli combine and cue positive highly-arousing thoughts. These thoughts then become more available than other thoughts (i.e., higher probability that they come to mind) and consequently bias one's judgments. Although the study design is not without limitations (i.e., a lack of reliable physiological and mood measurements), it provides noteworthy preliminary evidence for an arousal-congruency effect in emotional information processing.

In subsequent years, the question of arousal-congruency has remained largely outstanding, with only few insights coming from research on consumer behaviors. Wirtz and colleagues (2007), for example, investigated whether a (mis)match between expected and perceived arousal influences consumer satisfaction and in-store behaviors. Previous research has shown that people enter a consumption experience with a series of expectations of what they would like to happen (e.g., Wilson, Lisle, Kraft, & Wetzel, 1989; Wirtz & Mattila, 2000). For instance, when visiting a spa one expects a low arousal, calm, relaxing atmosphere and when visiting an amusement park one expects a high arousal, exciting, stimulating experience. In the present study, participants' arousal-expectations were manipulated by describing a book (or music) shop as either vibrant and lively or idyllic and relaxing. Subsequently, participants were presented with a more or less arousing video of the book (or music) shop. Music sound, tempo, and lightening where manipulated to create different arousal levels (e.g., slow music and dimmed light for low arousal vs up-beat music and bright light for high arousal). Findings revealed greater consumer satisfaction and more positive in-store behavior in congruent-conditions compared to incongruent conditions. For instance, participants reported more enjoyment during the store visit and spent more time exploring the store when the environment was congruent with the desired level of arousal (Wirtz et al., 2007).

Overall, it appears that arousal-congruency effects remain largely unexplored, thus calling for further research. In a first step, additional studies seem necessary to investigate whether arousal-congruency presents a replicable and stable phenomenon in emotional processing.

Chapter 2

Overview and rationale of the empirical section

Overview and rationale of the empirical section

In the General introduction, we extensively discussed the different components of the emotion response (i.e., subjective feelings, motor expressions, and arousal) and their impact on emotional information processing. Special attention has been devoted to the arousal construct whose conceptualization has been the source of recurring debates and confusion amongst different research fields. In order to provide the clearest overview of the present state of knowledge, we decided to differentiate between tense (i.e., psychologically-induced) and energetic (i.e. exercise-induced) arousal, as proposed by Thayer's two-dimensional arousal model (1989). But the term "arousal" does not only refer to physiological activation levels. It is also used in the context of stimulus description and categorization, where an emotional word or picture is defined as presenting a certain valence and arousal level. Valence refers to the extent to which a stimulus is positive or negative, and arousal to the extent to which it is calming or exciting. Consequently, positive and negative concepts can be judged as either highly arousing (e.g., passion, terror) or lowly arousing (e.g., gentleness, boredom) (Bradley & Lang, 1994; Russell, 1980).

When reviewing the current literature, one can find numerous evidence supporting the assumption that motor expressions in face and body influence emotional information processing. For instance, temporarily preventing participants from displaying facial mimicry impairs their ability to detect emotional facial expressions and to comprehend emotional language (e.g., Havas et al., 2010; Niedenthal et al., 2001; Oberman et al., 2007). Furthermore, motor actions of approach and avoidance (e.g., moving towards or away from the computer screen) have been shown to affect the processing speed of valenced stimuli (e.g., Neumann & Strack, 2000; Rotteveel & Phaf, 2004). Importantly, many of those findings seem to meet the criteria for so-called congruency effects. Congruency effects typically refer to a processing advantage for information whose emotional connotation matches the mood an individual is experiencing or the behavior he/she is displaying at a given moment. For instance, people in a positive mood show better memory for pleasant stimuli, whereas negative stimuli are better remembered when in a negative mood (Ellis & Ashbrook, 1989). In the same vein, stimuli whose valence dimension is congruent with one's motor expression (mimicry, posture, movements) benefit from a processing advantage compared to incongruent stimuli (e.g., Dijkstra et al., 2007; Havas et al., 2010; Rotteveel & Phaf, 2004; Schnall & Laird, 2003).

Although congruency effects present a well-documented phenomenon in psychology research, it seems that previous studies have focused exclusively on the valence dimension of emotional stimuli while neglecting their arousal dimension. So far, there exist, to our knowledge, no consistent line of research addressing the following questions: (1) Can arousal-congruency effects be observed in a highly-controlled experimental setting? (2) If yes, are they confined to specific cognitive processes or do they represent a more general phenomenon? (3) And finally, can they, such as mood-congruency effects, be observed when focussing on more subjective, social evaluations (compared to performance oriented cognitive tasks)? The following dissertation aims at providing initial answers to these questions by presenting a selection of four empirical studies.

In Chapter 3, we examined for the first time whether changes in bodily arousal influence the detection of arousal (in)congruent words. As in all our experiments, we relied on a within-subjects design, allowing to compare two arousal conditions, while minimizing errors associated with inter-individual differences. Participants realized both a short cycling and relaxation session to increase and reduce arousal levels, respectively. We consciously decided to modify (energetic) arousal levels via exercise instead of drawing on an emotional (tense) arousal manipulation (e.g., a cold pressor test, presentation of emotional stimuli). In fact, we aimed at minimizing potential effects of arousal-associated emotional experience, in order to assess the impact of the physiological arousal reaction at its best. Inducing arousal by means of an emotional event carries the risk that the valence dimension (e.g., feeling highly aroused and angry/happy after viewing an emotional video clip) attenuates or blurs potential arousal-congruency effects, maybe even in favour of mood-congruency effects. Consequently, we relied on a cycling session, which appears to be the most commonly used method to manipulate energetic arousal levels (cf. Chapter1, p. 35-38). Based on the assumption that the effects of exercise-induced arousal on cognitive performance follow an inverted-U relationship (Tomporowski, 2003), we chose for an exercise of moderate intensity (target HR at 65% of estimated maximal HR), aiming to avoid impaired task performances due to high intensity exercise. Changes in arousal were quantified via hear rate recordings throughout the entire experiment.

In study 1, each arousal condition was followed by the administration of rapid serial visual presentation paradigm (RSVP), with two target words (T1 and T2) presented briefly after each other within a stream of random symbols. Participants are generally able to identify and report T1 with a high degree of accuracy (Raymond et al., 1992). T2, however, is only rarely identified if it appears 200-500ms after a correctly reported T1. This reduction in performance on T2 is known as attentional blink effect (AB; Raymond et al., 1992). To test for potential arousal-congruency effects, we used target words varying in valence and arousal. Concretely, T1 and T2 were either neutral, high arousal (positive and negative) or low arousal (positive and negative) words. All target words were pre-tested, assuring significant differences in arousal and valence between categories. Moreover, the word sample used in both conditions did not differ in terms of mean arousal, valence, and frequency. Regarding the statistical analyses, we compared each word category (high arousal, low arousal, neutral) in the cycling vs relaxation condition, while one could alternatively have compared high arousal vs low arousal vs neutral words in the cycling and relaxation condition. The decision to rely on this approach was primarily based on the fact that the literature predicted a main effect of word arousal, while hypotheses regarding the effects of a 7-cycling/relaxation session on AB performance were rather vague. Given that our study purpose was to examine potential word arousal-bodily arousal interactions, a comparison of high arousal vs low arousal T2 reports post-cycling and post-relaxation (and the resultant graphical representations) appeared most suitable for our experiments. Overall, this design allowed to examine whether the different arousal conditions (post-cycling, post-relaxation) affect participants' detection accuracy for arousal-(in)congruent target words (e.g., high arousal T2 post-cycling vs high arousal T2 post-relaxation).

Several reasons have led us to use a RSVP task in this initial study. Firstly, the AB effect is very robust and has been demonstrated with a variety of stimuli including words (e.g., Anderson, 2005; Broadbent & Broadbent, 1987), letters (e.g., Raymond et al., 1992), pictures (e.g., Most, Smith, Cooter, Levy, & Zald, 2007; Trippe, Hewig, Heydel, Hecht, & Miltner, 2007), and emotional facial expressions (e.g., Grynberg, Vermeulen, & Luminet, 2014; Maratos, Mogg, & Bradley, 2008) (for review, see Dux & Marois, 2009). Furthermore, findings suggest a high reliability of the AB effect, underlining its methodological eligibility. Recent results indicate very high internal-consistency for both T1 and T2 reports within a 60-minutes experimental session (Dale & Arnell, 2013), as well as good test-retest reliability for RSVP tasks including both non-emotional and emotional target words (Adams et al., 2016; Dale & Arnell, 2013; Kranczioch & Thorne, 2013). Overall, the AB effect has thus been shown to be reliable within session, and over time, such that individual performances on the task are stable enough to yield conclusive results. Secondly, the AB tasks presents an interesting advantage over more basic categorization or detection tasks. Given that participants are simply instructed to report (i.e., type) the target words, their attention is at no point oriented towards the emotional dimensions of the stimulus. In other terms, participants are unlikely to consciously focus on the arousal dimension of the to-be-detected words, reducing the risk of potential biases (e.g., desirability) and strengthening the explanatory power of the results.

Of interest too, we recorded and analyzed participant's heart rate variability (HRV) during completion of the post-cycling and post-relaxation AB trials. HRV is commonly described as the fluctuation in time intervals between heartbeats (Rajendra Acharya, Paul Joseph, Kannathal, Lim, & Suri, 2006). Given that the heart is innervated by the sympathetic and parasympathetic (vagal) branches of the autonomous nervous systems (ANS), HRV represents the continuous interplay between the latter, producing varying degrees of physiological arousal (Porges, Doussard-Roosevelt, & Maiti, 1994; Rajendra Acharya et al., 2006; Thayer & Lane, 2000). Research indicates, for instance, that HRV indices are influenced by changes in the ANS associated with stress (for review, see Kim, Cheon, Bai, Lee, & Koo, 2018). Based on the assumption that a rapidly working ANS allows for greater flexibility in responding to environmental demands (i.e., by adjusting physiological arousal), HRV has recently emerged as a popular index of emotion regulation capacities (Appelhans & Luecken, 2006). A growing body of empirical findings supports the idea of an association between HRV and emotional responding, for instance, by revealing a positive correlations between HRV measures and the use of adaptive coping strategies (e.g., positive self-instruction, social support seeking vs avoidance, repression) (e.g., Geisler, Kubiak, Siewert, & Weber, 2013; O'Connor, Allen, & Kaszniak, 2002; Pauls & Stemmler, 2003). However, although results of our first study suggest a relation between HRV measures and arousal-congruent processing advantages in the AB task, we refrained from collecting HRV data in subsequent studies. In fact, a detailed review of the literature revealed important methodological requirements for the exact and unbiased measurement of HRV indices. For example, the consumption of energizing drinks (e.g., coffee or tea) and food during the 3h preceding the experiment directly affects HRV since viscera are innervated by the autonomic nervous system (for a detailed discussion of methodological issues in HRV measurement, see Heathers, 2014; Quintana & Heathers, 2014). This, together with the fact that the idea of HRV as a proxy for emotion regulation and adaptation seems to require further empirical support to establish itself as reliable variable (e.g., inconsistent results regarding the effects of stress on HRV, Kim et al., 2018), has fed into our decision to not include it in further studies.

In this first study we thus relied on a well-controlled experimental design, allowing to examine whether stimuli matching one's current arousal state benefit from a processing advantage, or not. Based on the assumption that arousal-congruency exist, one would hypothesize increased reports of high arousal words following the cycling session compared to the relaxation session, and increased reports of low arousal words following the relaxation compared to the cycling session. Neutral word reports would remain unaffected by the arousal conditions.

After providing first evidence for an arousal-congruency effect in Chapter 3, we examined in Chapter 4, whether the effect can be replicated when modifying the cognitive requirements of the task. In other words, this second study aimed at examining whether arousal-congruent processing advantages are confined to word detection in RSVP or whether they can also be observed in other paradigms. While findings from our first study suggest that arousal-congruent words enter working memory more easily (see, a boost and bounce theory of the AB effect; Olivers & Meeter, 2008), it remains unclear whether those words can also be more easily retrieved. In order to answer this question, we relied on a constructive recognition task (CRT) requiring active elaboration to access word meaning (Fiedler, Nickel, Muehlfriedel, & Unkelbach, 2001; Unkelbach, Guastella, & Forgas, 2008). In the CRT, a target word is initially hidden by a black mask that slowly dissolves, such that the word becomes gradually recognisable. Visual analysis is thus impeded, inviting for active, knowledge-based inferences to complete or generate the meaning of the emerging word as quickly as possible. These generative features make it an appropriate paradigm to investigate whether arousal-congruency effects can not only be observed under limited attentional resources when information is fully presented (i.e., AB task), but also when information is actively constructed (i.e., CRT) based on previous memory-stored knowledge (retrieval).

However, before using the CRT in the context of an arousal-congruency study, we realized a series of pre-tests to determine the optimum CRT version for our purposes. To avoid potential confounds in our results, we first examined whether different word categorization criteria influenced participants' performances. Concretely, we compared a semantic categorization version and a lexical decision version of the CRT. That is, participants were instructed either to classify the incrementally appearing word as emotional or non-emotional or to decide whether the appearing letter string is an existing word or not. Overall, results indicated similar performances for both CRT versions (cf. Chapter 4, study 2a), leading us to opt for a semantic categorization criterion in the main experiment. Participants were instructed to decide as quickly and accurately as possible whether an appearing word was "associated with an emotional context" or "not associated with an emotional context"; a categorization criteria that had already been successfully used in previous emotion studies (e.g., Baumeister, Rumiati, & Foroni, 2015; Niedenthal et al., 2009). Target words varied again in arousal and valence levels, allowing to differentiate between high and low arousal for positive and negative words. We also relied on the same arousal manipulation as in the first study, namely a short cycling and relaxation session during which participant's heart rate was closely monitored. This combination of proven methodology and an innovative, but well-controlled, paradigm allowed us to test for the first time whether an arousal-congruent recognition (and categorization) advantage can be observed when knowledge-driven processes are needed to construct a word beyond the information given.

The findings presented in Chapter 3 and 4, point towards the presence of arousal-congruency effects in cognitive tasks, involving inhibitory, attentional, and mnesic processes. In view of these results, the question arised whether similar effects can be observed when the depended variable is no objectively quantifiable cognitive performance, but a more subjective evaluation. As mentioned in the introduction section, there is substantial evidence for mood-congruent judgments, such that our affective state influences the way we perceive ourselves and others (e.g., Forgas, 1994a; Forgas & Bower, 1987; Mayer, Gaschke, Braverman, & Evans, 1992). Moreover, expressive behaviors have been shown to guide impressions and judgments in an affect-congruent way. For instance, cartoons are rated as funnier when smiling (Strack, Martin, & Stepper, 1988), objects looked at with a happy expression are liked more than objects looked at with a disgust expression (Bayliss, Frischen, Fenske, & Tipper, 2007), and happy faces are judged more positively (i.e., more approachable and trustworthy) than sad, fearful, disgusted, and neutral faces (Willis, Palermo, & Burke, 2011). Further studies have focused on the influence of bodily movements on judgments, evaluations, and choices (for review, see Reimann et al., 2012). For example, when listening to a persuasive message with strong arguments, nodding leads to more persuasion than shaking one's head does (Briñol & Petty, 2003; Wells & Petty, 1980). Other research in this stream showed that induced nodding led to more favourable evaluations (i.e., desire to buy) of positive products (e.g., Snickers candy bar), while head shaking cause more unfavourable evaluations of negative products (e.g., beef lung) (Förster, 2004). Similarly, arm flexion and extension movements affected participants' attitudes towards neutral, Chinese ideographs (Cacioppo et al., 1993). Findings thus suggest that stimuli whose affective value matches one's facial expression or movements benefit from more favourable judgments and evaluations compared to non-matching stimuli – an observation that has also been made with respect to cognitive performances (cf. General introduction, p. 22-25).

Importantly, however, the question of arousal-congruency in subjective judgments and evaluations, seems to remain outstanding. Consequently, we decided to investigate this question in Chapter 5 of this dissertation. While we relied on previously-used arousal manipulations (i.e., cycling vs relaxation), the choice of the stimuli has been less straightforward. Given that words convey an established meaning (i.e., their semantic component), they leave relatively little room for interpretations and subjective judgments. Therefore, we decided to use pictures, which can be evaluated with regards to various perceptual and content-related criteria whilst presenting the necessary valence and arousal levels. Participants were presented with a set of high and low arousing IAPS pictures (Lang et al., 1999) they thought were taken from various media outlets (e.g., television, newspapers). Their task consisted in reporting subjective feelings of familiarity for several pictures, once after a cycling session and once after the relaxation session. High familiarity ratings equalled high confidence that a picture has been previously seen and thus matches an already existing mental representation (Claypool, Hugenberg, Housley, & Mackie, 2007; Morris, Cleary, & Still, 2008). Interestingly, one can assume that the very low probability of a previous encounter with the pictures increases participants' tendency to rely on external (arousal) cues to guide their familiarity judgments. With regard to memory, findings indeed suggest that congruency-effects occur best when minimal cues are given for retrieval of the targets (recognition vs recall) (Bower, 1981; Fiedler et al., 2001). Consequently, perceived familiarity seems to be a well-suited evaluation criterion for our study purpose.

To sum up, the following chapters will present 4 empirical studies, providing new insights regarding the effects of (exercise-induced) bodily arousal on the processing of emotional information. More precisely, our experimental designs allowed to examine whether arousal-congruent processing advantages can be observed in an attentional blink paradigm (study 1), in a constructive recognition task (study 2a and 2b), and in a task requiring subjective ratings of perceived familiarity (study 3). Altogether, findings from these studies allow us to provide first answers to the question whether arousal-congruency effects present a noteworthy, and reliable phenomenon in psychology research.

Chapter 3

The spontaneous influence of congruent bodily arousal on the awareness of emotional words (Study 1)

The spontaneous influence of congruent bodily arousal on the awareness of emotional words (Study 1)

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Abstract

Nowadays, the idea of a reciprocal influence of physiological and psychological processes seems to be widely accepted. For instance, current theories of embodied emotion suggest that knowledge about an emotion concept involves simulations of bodily experienced emotional states relevant to the concept. In line with this framework, the present study investigated whether actual levels of bodily arousal interact with the processing of emotional words. Participants performed two blocks of an attentional blink task, once after a cycling session (increased arousal) and once after a relaxation session (reduced arousal). Concretely, participants were instructed to detect and report two target words (T1 and T2) presented among a series of non-word distractors. T1 and T2 were either neutral, high arousal or low arousal words. Results revealed that increased bodily arousal led to improved reports of high arousal T2 words, while reduced bodily arousal led to improved reports of low arousal T2 words. Neutral T2 remained unaffected by the arousing conditions. These findings emphasize that actual levels of bodily arousal modulate the cognitive access to arousal (in-)congruent emotional concepts, and suggest a direct grounding of emotion knowledge in our bodily systems of arousal.

1. Introduction

For centuries, philosophers and scientists have focused on the crucial question of whether body and mind should be considered as unrelated, independent entities or whether they interact with each other (Notturno & Popper, 1994). In the recent literature, the idea of a reciprocal influence of physiological and psychological processes seems to be widely accepted. For instance, current theories of grounded (or embodied) cognition suggest that conceptual processing requires partial "as if" reactivation of the sensory-motor systems that are used during interactions with the real world (Barsalou, 1999, 2008; Niedenthal, 2007; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008).

Of particular interest, the grounded cognition approach has also been applied to the area of emotions. Emotions are generally defined as presenting three critical components: expressive behavior (e.g., facial expressions), subjective emotional experience, and bodily arousal (e.g., autonomic responses) (Frijda, 1986). Theories of embodied emotion postulate that knowledge about an emotion concept is not reducible to an abstract description but involves bodily simulations of the experienced emotional states relevant to the concept (Niedenthal, 2007; Niedenthal et al., 2009). In support of this assumption, several studies have demonstrated that manipulations of facial expressions and posture influence the way in which emotional information is processed (e.g., Chen & Bargh, 1999; Havas et al., 2010; Neumann & Strack, 2000; Niedenthal et al., 2009).

However, previous findings reveal that the embodying emotion hypothesis has to date exclusively been tested by focusing on peripheral bodily feedback (i.e., the behavioral component of emotion) without considering the potential impact of internal bodily changes (i.e., the arousal component of emotion) on the processing and representation of emotional concepts. Concretely, the current state of knowledge leaves an essential question unanswered: Is the arousal dimension of emotional concepts grounded in our bodily systems of arousal?

Various studies have shown that novel and emotionally arousing stimuli alter the bodily state of perceivers by increasing their physiological arousal response (e.g., heart rate acceleration, heightened electrodermal activity) (for review, see Bradley, 2009). Nevertheless, there is, to our knowledge, no evidence that physiological arousal reciprocally influences the processing of more or less arousing emotional concepts. In order to fill in this gap, the present study examined whether changes in bodily arousal (i.e., an increase or a decrease in heart rate) affect the access of arousal-congruent and -incongruent emotional words to consciousness. Concretely, we assumed that there is a congruency between actual internal bodily activation and emotional words when physiological arousal is low (high) and the emotional words are low (high) in arousal (i.e., intensity, energizing aspect of the concepts). We relied on an attentional blink (AB) paradigm, in which two targets (T1 and T2) are presented in close succession in a rapid serial visual presentation (RSVP) of distractor items (Raymond et al., 1992). The AB effect refers to the reduced ability to report the second of two targets (T2) if it appears 200 to 500 msec after the first to-be-detected target (T1). In the present study, T1 and T2 were either neutral (e.g., chair, echo), high arousal (e.g., vomit, orgy) or low arousal words (i.e., tear, flower). Bodily arousal was manipulated by means of a short cycling session (increased arousal) and a relaxation session (reduced arousal).

Interestingly, recent research findings indicate that the AB effect can be moderated by the emotional dimensions of the to-be-detected stimuli (Anderson, 2005; Maratos et al., 2008; Vermeulen, Mermillod, Godefroid, & Corneille, 2009). For example, Anderson (2005) observed a diminished AB for highly arousing compared to less arousing emotional T2 words, suggesting that arousal is associated with reduced attentional requirements, leading to enhanced entry into awareness (Anderson, 2005).

These observations lead us to hypothesize that high arousal T2 words would be better reported than low arousal and neutral T2 words. Moreover, regarding the embodiment of the arousal dimension of emotion, we posited the following hypotheses: (1) increased bodily arousal (i.e., following a cycling session) would lead to increased reports of high arousal T2 words, while reduced bodily arousal (i.e., following a relaxation session) would lead to increased reports of low arousal T2 words, (2) reports of neutral T2 words would not be affected by either of the arousal conditions. Furthermore, we examined whether participants' emotion regulation capacities (quantified via heart rate variability measures) influence the embodiment of the arousal component of emotion.

2. Method

2.1 Participants

Seventy-three French-speaking students (39 men, 34 women) from the Université catholique de Louvain (Louvain-la-Neuve, Belgium) took part in our study in return for a monetary reward (10 euro). Their ages ranged from 18 to 29 years (M = 21.80; SD = 2.40). Only healthy participants presenting no contra-indications to the practice of a moderate-intensity physical exercise were recruited. All participants were tested individually and gave informed consent.

2.2 Stimuli

In order to create a battery of neutral, high arousal, and low arousal words, 316 French words were partly selected from previous attentional blink studies (Anderson, 2005; Vermeulen et al., 2009) and partly chosen by means of an online French synonyms dictionary[2]. Subsequently, selected words were rated on valence and arousal value by 32 and 48 independent raters, respectively. Results of the pre-test showed that high arousal words were significantly more arousing (M = 4.92; SE = 0.70) than low arousal words (M = 3.61; SE = 0.90), F (4, 258) = 282.20, p < .001). On the basis of these ratings, 156 pairs of targets (T1-T2), paired for length, were created (cf. Appendix 1 for the complete list of T1-T2 pairs used). In order to hide the aim of the experiment, half the time, emotional targets appeared in the first position (T1), and the other half in the second "blinked" position (T2). More precisely, 3 blocks of 52 trials including the following T1-T2 pairs were created: 10 high arousal T1- neutral T2, 10 low arousal T1 - neutral T2, 10 neutral T1 - high arousal T2, 10 neutral T1 - low arousal T2, and 12 neutral T1 - neutral T2. Distractor items consisted of random strings of symbols and digits of the same length as the targets of each trial (e.g., 2, %,*).

2.3 Procedure and design

Upon their arrival at the laboratory, the moistened belt of the Polar RS800CX heart rate monitor was placed around the participants' chest. Polar watches allow for the precise, non-invasive recording of mean heart rate and inter-beat intervals and present a valid and reliable device for field studies (e.g., Nunan et al., 2008). Next, participants performed an AB training block and were then randomly assigned to either first complete a cycling or a relaxation session (counterbalanced conditions).

2.3.1 Arousal manipulation: Cycling and relaxation

During the cycling session, participants pedaled on a bicycle ergometer (Pro-form 748 by ICON Health & Fitness, Ldt.) for 7:30 min. Target heart rate was set at 65% of estimated maximal heart rate (i.e., 65% of [220 (beats per minute) - age]). The experimenter monitored participant's heart rate by indicating whether the cycling speed should be increased or decreased. During the relaxation session, participants were comfortably seated in an armchair while listening for 7:30 min to a relaxing audio program. After each session participants were

[2] http://dico.isc.cnrs.fr/dico/fr/chercher

instructed to evaluate on a 10-point Likert scale whether they felt “relaxed” (1 = very relaxed) or “activated” (10 = very activated) and whether the session was “unpleasant” (1 = very unpleasant) or “pleasant” (10 = very pleasant). Both sessions were followed by the completion of a new AB block.

2.3.2 Attentional Blink Task

Each AB trial began with a central fixation cross appearing for 500 ms, followed by a blank screen for 240 ms, which was immediately replaced by the RSVP stream of distracters and targets. Between 3 and 5 distractors preceded the appearance of T1, whereas T2 was always followed by two distractors. Within a trial, the same distractor was never repeated. Target words were presented for 67 ms with a stimulus onset asynchrony (SOA) set to 268 ms (3 distractors between T1 and T2) in order to induce a blink of T2. Stimuli were presented using E-Prime 1.1.4.1 on a computer with a 17-inch monitor with a refresh rate of 75 Hz. Each item in the stream was presented in black uppercase letters (i.e., Courier New 18-point bold) on a white background. After each RSVP, participants were instructed to type the first word they saw (T1), followed by the second word they saw (T2). When target identification was not possible, they were instructed to press the spacebar. No feedback was provided and the next trial started 1000 ms after the decision on the second target was made. Performance on each word in the pair was scored separately. Misspelled words and blanks were counted as errors, whereas T1-T2 order reversals were considered as correct (e.g., Davenport & Potter, 2005; Olivers & Meeter, 2008). Correct target reports were scored as 1 and omissions and errors as 0. On the basis of these scorings, the proportion of accurately reported targets was calculated. Target accuracy data were submitted to an analysis of variance with repeated measures (MANOVA) with a 2 (arousal level: cycling vs relaxation) x 3 (T2/T1 arousal value: neutral vs high arousal vs low arousal) design.

2.3.3 Heart rate variability.

Heart rate variability (HRV) data were subjected to a series of regression analyses. HRV corresponds to a measure of the continuous interplay between the sympathetic and the parasympathetic branches of the autonomic nervous system that influences cardiac activity. HRV thus provides information about autonomic flexibility and thereby represents a physiological index of emotion regulation ability (Appelhans & Luecken, 2006). In the present research, HRV was evaluated by one of the most commonly used measures of overall heart rate variability: RMSSD (the root mean square of successive R-R differences) (for review, see Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012).

3. Results

3.1 Heart rate measurements

Table 2 displays participants' mean heart rate during the cycling session, the relaxation session, the post-cycling AB, and the post-relaxation AB.

Table 2
Mean heart rate (beats per minute)

Condition	Mean (*SD*)
Cycling session	119.40 ^{a} *(5.80)*
Relaxation session	74.40 ^{d} *(11.20)*
Post-cycling AB	85.50 ^{b} *(11.50)*
Post-relaxation AB	80.80 ^{c} *(11.80)*

Note. Means with different letters are statistically different at $p < .001$. *SD* = standard deviation.

3.2 T1 and T2 report

Overall, 75.5% of the targets (T1 and T2) were reported accurately. Specifically, results revealed a main effect of target position (i.e., the AB effect), $F(1, 72) = 108.50$, $p < .001$, $\eta^2 p = .60$, with T1 reported more accurately ($M = .88$; $SE = .01$) than T2 ($M = .63$; $SE = .03$). Furthermore, we observed a main effect of T2 arousal value, $F(2, 71) = 23.60$, $p < .001$, $\eta^2 p = .40$, with high arousal T2 reported more accurately ($M = .73$; $SE = .03$) than low arousal T2 ($M = .66$; $SE = .03$), $t(72) = 4.34$, $p < .001$, and neutral T2 ($M = .60$; $SE = .03$), $t(72) = 6.66$, $p < .001$). There was no main effect of the physiological arousal condition (i.e., cycling vs relaxation). Importantly, as shown in Table 3, results revealed a significant interaction between the physiological arousal condition and the type of T2 words reported (i.e., neutral, high arousal, low arousal), $F(2, 71) = 5.23$, $p < .01$, $\eta^2 = .13$. No significant interaction was observed for T1 reports (cf. Appendix 1 for supplementary results).

Table 3
Proportion of accurate T1 and T2 report as a function of target arousal value and physiological arousal condition.

	M (SE)				
T2 Category	Total	Post- Cycling	Post-Relaxation	*t*(72)	*p*
	Proportion of accurate T1 reports				
High arousal	.91 *(.01)*	.92 (*.01*)	.90 (*.01*)	1.62	*ns*
Low arousal	.86 *(.01)*	.87 (*.01*)	.86 (*.01*)	0.89	*ns*
Neutral	.90 *(.01)*	.91 (*.01*)	.91 (*.01*)	0.54	*ns*
	Proportion of accurate T2 reports				
High arousal	.73 *(.03)*	.75 (*.03*)	.71 (*.03*)	1.98	**.052**
Low arousal	.66 *(.03)*	.63 (*.03*)	.68 (*.03*)	2.27	**.028**
Neutral	.60 *(.03)*	.62 (*.03*)	.61 (*.03*)	0.41	*ns*

Note. SE = standard error of mean.

Furthermore, an "interaction magnitude" index was calculated by subtracting incongruent conditions from congruent conditions (i.e., interaction index: [(proportion of high arousal T2 post-cycling minus proportion of high arousal T2 post-relaxation) + (proportion of low arousal T2 post-relaxation minus proportion of low arousal T2 post-cycling)]. Higher scores reflect a more important interaction between the physiological arousal condition and the type of T2 reported, whereas lower scores reflect a smaller interaction effect.

3.3 Heart rate variability

Correlation analyses were conducted in order to clarify whether individual differences in heart rate variability were related to the magnitude of the observed interaction (i.e., level of physiological arousal x type of T2 reported). As shown in Table 4, results reveal a significant, positive correlation between RMSSD measures during the post-cycling and post-relaxation AB and the interaction index.

Table 4
Correlation between the interaction index and RMSSD during the post-cycling and post-relaxation AB.

HRV measure	Interaction Index
RMSSD post-cycling AB	. 39**
RMSSD post-relaxation AB	. 27*

*Note. ** p < .01; * p < .05.*

3.4 Subjective reports of arousal and pleasure

With regard to participants' subjective feelings of activation, it appears that the latter were significantly higher after the cycling (M = 6.70; SD = 1.70), than after the relaxation, (M = 2.70; SD = 1.90), $t(72) = 13.07$, $p < .001$. Correlations between a subjective activation index (i.e., subjective activation post-cycling – subjective activation post-relaxation) and the interaction index were not significant, suggesting that the detection of target words is not influenced by participants' subjective feelings of activation.

Regarding participants' ratings of experienced pleasure during cycling and relaxation, the relaxation session was evaluated as significantly more pleasant (M = 7.30; SD = 1.90) than the cycling session (M = 6.60; SD = 1.80), $t(72) = 2.31$, $p < .03$. However, correlations between experienced pleasure (for both conditions) and the interaction index were not significant, indicating that the observed interaction is not influenced by changes in participant's experienced feelings of pleasure.

4. Discussion

The present research was designed to examine whether physiologically induced arousal modulates the spontaneous access to arousal-congruent and -incongruent emotional stimuli. In other terms, we investigated whether the arousal dimension of emotional concepts is grounded in our bodily systems of arousal. For this purpose, participants performed two blocks of attentional blink trials, once after a cycling session and once after a relaxation session.

Firstly, consistent with our predictions, we found an attenuated AB effect (increased T2 report) for high arousal compared to low arousal and neutral words, which confirms previous findings (Anderson, 2005; Keil & Ihssen, 2004; Mathewson et al., 2008). Hence, concepts pertaining to highly arousing emotional states display a greater resistance to the AB, reflecting an easier access to awareness (Anderson, 2005).

Secondly, and most importantly, our findings revealed a significant interaction between participants' level of physiological arousal (cycling vs relaxation) and the proportion of neutral, high arousal and low arousal T2 accurately reported. As expected, high arousal words were better reported after the cycling than after the relaxation session, while low arousal word reports were better following the relaxation compared to the cycling session. The proportion of neutral word reports did not differ in function of the physiological arousal condition. These findings indicate that experiencing a level of bodily arousal that matches the emotional arousal value of a concept (e.g., being highly aroused while processing a highly arousing word such as "orgasm" or "terror") promotes the awareness of the concept. A possible explanation for the present observation may be that the level of physiological arousal acts as a sort of prime, facilitating the access to prime-congruent stimuli (Vermeulen et al., 2009). That is, if the level of bodily arousal matches the level of emotional arousal of the presented concept, the target benefits from an attentional boost and will therefore be reported more accurately.

Regarding T1 reports (with neutral T2), no significant interaction was observed. In line with this, previous findings showed that sensory-conceptual interactions only arise when report conditions were challenging (i.e., T1 in the lag-1 sparing or T2 in the AB) (Vermeulen et al., 2009). However, in the present study, T1 were easily detected, with report rates up to 90%, suggesting the presence of a ceiling effect. The latter might explain why results reveal no interaction between the T1 arousal value and the cycling/relaxation conditions.

Furthermore, in view of the grounded cognition approach, our findings make a series of highly significant and noteworthy contributions. Firstly, all of the studies conducted so far have investigated the embodied emotion hypothesis by focusing on peripheral bodily feedback, namely postures and facial muscle activation (e.g., Havas et al., 2010; Niedenthal et al., 2009; Schubert, 2004). The present data extend previous research in demonstrating that the processing of emotional concepts is also influenced by changes in heart rate. Our findings are indeed the first to provide evidence that actual levels of physiological arousal modulate the cognitive access to arousal (in-)congruent emotional concepts, suggesting a direct grounding of emotion knowledge in our bodily systems of arousal. Interestingly, the current observations also support and extend earlier theoretical models, such as Antonio Damasio's "somatic marker hypothesis". According to the latter, changes in internal bodily state guide both emotional and cognitive behavior (e.g., decision making) (Damasio, 1994).

Moreover, it should be highlighted that the AB keeps the requirement for emotional processing implicit given that participants were simply invited to report the target words accurately. That is, participants were not instructed to directly process either the arousing value or the emotional content of the to-be-detected stimuli, which strengthens the relevance of the observed effects.

Of interest too, we observed a positive correlation between the interaction index and participants' heart rate variability scores during the AB tasks. Higher levels of HRV are thus associated with better detection of emotionally arousing stimuli that are congruent with ones level of physiological arousal. Interestingly, it has been shown that greater HRV is also related to more adaptive patterns of emotional responding, greater behavioral flexibility, and better self-regulation in emotionally charged situations (Appelhans & Luecken, 2006; Koval et al., 2013; Park, Van Bavel, Vasey, Egan, & Thayer, 2012; Thayer & Lane, 2000). Likewise, it has been argued that emotional embodiment may facilitate the interpretation of others' behaviors and attitudes, which might in turn allow for more adapted interactions with the social world (Barrett, Niedenthal, & Winkielman, 2005). With regard to this, it can be suggested that individuals who present better emotional adaptation (as indicated by higher HRV) also present an improved grounding of the arousal dimension of emotion (indicating better adaptation in social context).

In conclusion, the present research provides first evidence suggesting that the arousal dimension of emotional concepts is grounded in our bodily systems of arousal. Our findings indeed reveal that an increase or decrease in physiological activation facilitates the awareness of emotional words that are congruent in terms of their arousal value. The current observations contribute thus greatly to the advancement of knowledge in the field of body-mind interactions, namely by demonstrating that internal physiological processes, such as changes in heart rate, have the power to influence our awareness of emotional information.

Chapter 4

Arousal & the Constructive Recognition Task

“Passion” versus “patience”: The effects of valence and arousal on constructive word recognition (Study 2a)

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Abstract

Accumulating evidence suggests that emotional information is often recognized faster than neutral information. Several studies examined the effects of valence and arousal on word recognition, but yielded partially diverging results. Here, we used two alternative versions of a constructive recognition paradigm in which a target word is hidden by a visual mask that gradually disappears, to investigate whether the emotional properties of words influence their speed of recognition. Participants were instructed either to classify the incrementally appearing word as emotional or non-emotional (semantic categorization task) or to decide whether the appearing letter string is an existing word or not (lexical decision task). Results from both tasks revealed faster recognition times for highly compared to low arousing words, and for positive compared to negative or neutral words. These findings indicate a recognition advantage for emotionally positive and highly arousing stimuli that persists even when visual word recognition is hampered and participants are encouraged to make more active, semantic inferences to generate the meaning of the emerging word.

1. Introduction

Over the last decades, research has suggested that emotional value influences information processing at various levels, from perceptual analysis (e.g., Öhman et al., 2001) to memory performance (e.g., Doerksen & Shimamura, 2001). Emotional stimuli are typically defined as varying along the dimensions of valence and arousal (Feldman Barrett & Russell, 1998). While valence indicates whether a stimulus is rather positive or negative, arousal indicates whether a stimulus is rather calming or exciting. According to Russel's circumplex model of affect (1980), each emotion is a linear combination of these two dimensions, which are bipolar, orthogonal, and independent from each other. For instance, positive and negative concepts can be judged as either calming (e.g., rest, tear) or exciting (e.g., passion, terror). Studies have indeed indicated separate neural routes for the processing of valence and arousal (e.g., Nielen et al., 2009), and have shown that they can be conditioned independently (Gawronski & Mitchell, 2014).

A growing body of empirical evidence indicates that emotional information captures attention in a manner unlike that of neutral stimuli. For example, studies using an attentional blink paradigm (AB) showed that emotional stimuli are selected preferentially from a temporal stream of verbal information, with particularly highly arousing emotional stimuli enjoying facilitated access to awareness compared to low arousing words (e.g., Anderson, 2005; Kever, Grynberg, et al., 2015). Further research examined the effects of emotion on the semantic categorization of briefly presented or masked stimuli, yielding partially inconsistent results. While some authors report higher categorization accuracy for negative compared to positive words (e.g., Nasrallah et al., 2009), others observed a categorization advantage for positive words (Unkelbach, 2010). Importantly, previous semantic categorization studies mainly focused on word valence whereas potential arousal effects were more sparsely investigated. Of interest too are a series of recent, well-controlled studies that examined the influence of valence and arousal on lexical decision and naming latencies. For instance, Kuperman and colleagues (2014) analyzed lexical decision and naming data from over 12,000 words and observed faster recognition times for positive compared to negative words, and for calming compared to arousing words. Besides, both valence and arousal interacted with word frequency, exerting larger effects on low frequency than on high frequency words, which reveals a presumably lexico-semantic origin of the effects. Other research, however, showed no effects of arousal on lexical decision times (e.g., Kousta et al., 2009) or indicated faster recognition of low arousing compared to highly arousing words (e.g., Larsen, Mercer, Balota, & Strube, 2008).

Despite the noteworthy advances in the field, findings regarding the effects of emotion on semantic categorization and lexical decision remain partially conflicting, leaving parts of the variance in visual word recognition unexplained. Besides, when considering current theories of word recognition, it appears that the importance of lexical and semantic influences represents a widely debated topic. For instance, localist and distributed models of visual word recognition tend to disagree about whether semantic information is required for word recognition. In a typical lexical decision task the involvement of semantic activation seems to depend on the difficulty to discriminate words from non-word foils. The more similar they are in terms of orthographic and phonological properties (e.g., pseudowords), the more that top-down semantic input becomes crucial to achieve accurate visual word recognition (see Carreiras, Armstrong, Perea, & Frost, 2014).

Here, we aimed to extend previous studies by examining the effects of valence and arousal on visual word recognition when participants are encouraged to make active semantic inferences. Therefore, we adapted our tasks following a constructive recognition technique (CRT) that has been put forward in the emotion and object recognition literature (e.g., Fiedler et al., 2001; Unkelbach, Guastella, et al., 2008). In the CRT, an initially masked target stimulus appears gradually. Analogously to the role of discrimination difficulty in a classical lexical decision task, research on object recognition has shown that semantic knowledge is activated under conditions of degraded visual input to enable inferences and resolve ambiguity (Trapp & Bar, 2015). Given that the CRT hampers visual analysis by slowly revealing word fragments, it invites for active, knowledge-based inferences to generate the meaning of the emerging stimulus as quickly as possible (Unkelbach, Guastella, et al., 2008). The CRT thus presents a pronounced top-down component requiring semantic inferences beyond the information given to accelerate word recognition. This should allow us to better understand whether or how the effects of valence and arousal emerge under particular experimental visual word recognition conditions.

We used two alternative versions of the CRT, allowing us to compare recognition times of highly vs low arousing positive or negative words, and neutral words. In the semantic categorization task, participants were instructed to decide as quickly and accurately as possible whether an appearing word was associated with an emotion or not. In the lexical decision task, they had to decide whether an appearing letter string was an existing word or not.

2. Task 1: Constructive semantic categorization

2.1 Method

2.1.1 Participants

Sixty-four volunteers (47 females; M_{age}=23.86 years, SD_{age}=5.17) took part in the study after providing informed consent. Experimental procedures were approved by the research ethics committee of the Université catholique de Louvain (Belgium).

2.1.2 Stimuli and Materials

Targets were 96 French words. Sixty-four were emotion-related (32 positive and 32 negative) words. Within each of these categories, 16 words were classified as high arousal (*e.g., passion, terror*) and 16 as low arousal (*e.g., patience, fatigue*). The remaining 32 words were neutral *(e.g., bench, ceiling)*. The selected words were rated by 112 independent judges (13 men and 99 women; M_{age}=27.1 years, SD_{age}=8.7) on valence and arousal by means of the 9-point SAM (*Self-Assessment Manikin*, (Bradley & Lang, 1994). A 2 (valence: positive, negative) x 2 (arousal: high, low) repeated measures ANOVA with arousal ratings as dependent variable revealed a main effect of word arousal [$F(1,15) = 155.58$, $p < .001$, η^2p = .91] and word valence [$F(1,15) = 23.56$, $p < .001$, $\eta^2p = .61$]. High arousal words were significantly more arousing ($M = 6.01$; $SE = 0.15$) than low arousal words ($M = 4.50$; SE = 0.12), and negative words were overall more arousing than positive words ($M = 5.57$; SE = 0.38; $M = 4.98$; $SE = 0.24$). However, no significant arousal x valence interaction was observed, $F(1,15) = 0.18$, p = *ns.* Analyses also revealed significant valence differences between positive ($M = 7.08$; $SE = 0.15$), negative ($M = 2.90$; $SE = 0.15$), and neutral words ($M = 5.04$; $SE = 0.04$), $F(2,30) = 791.47$, $p < .001$, $\eta^2p = .96$. All word stimuli are matched in terms of length, frequency, summated bigram frequency and orthographic neighborhood size, except for the comparison between the neutral and positive high arousal words, which showed a neighborhood-size advantage for the neutral words (see Table 5).

Table 5
Arousal, valence, length, frequency, summated bigram frequency, number of orthographic neighbors and recognition times per stimulus subgroup.

	Arousal		Valence		Length (number of letters)		Frequency		Summated bigram frequency		Number of orthographic neighbors		Semantic categorization (ms)		Lexical decision (ms)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Neutral	2.76^{e}	0.19	5.50^{b}	0.20	5.50	1.24	50.50	66.78	12777	4620	4.19^{b}	3.53	5278.13^{c}	663.95	5968.26^{c}	595.13
Low Arousal Positive	4.10^{d}	0.50	7.18^{a}	0.41	6.25	1.44	40.48	53.51	15134	7975	2.00^{ab}	2.78	5118.21^{b}	740.19	4914.42^{b}	585.53
High Arousal Positive	5.86^{b}	0.44	7.23^{a}	0.62	6.50	1.21	59.71	67.28	16751	9269	1.06^{a}	1.12	5000.57^{a}	846.54	4823.53^{a}	622.96
Low Arousal Negative	4.77^{c}	0.76	3.09^{c}	0.39	6.25	1.24	28.74	15.99	15093	7914	1.68^{ab}	2.49	5281.97^{c}	790.90	5049.89^{c}	609.21
High Arousal Negative	6.38^{a}	0.36	2.48^{d}	0.58	6.25	1.65	25.76	43.81	17861	9644	2.44^{ab}	3.78	5152.99^{b}	704.66	5001.33^{bc}	651.84

Note. ^{abcde} Superscripts indicating significant difference between means of different word categories at a significant level of $p < .05$. Post-hoc pairwise comparisons-Bonferroni. Means that have no superscript in common are significantly different from each other.

The constructive recognition task consists of an initially masked target word that is progressively uncovered. In the beginning, the target is hidden by a black mask that covers the entire presentation area. The mask then slowly dissolves, whereby small rectangles (of a few square pixels) randomly disappear so that the target becomes gradually recognizable. The complete target is uncovered after 8 seconds on average. The computerized French version of the Positive and Negative Affect Schedule (PANAS), and the Affective Intensity Measure (AIM) were administered to control for potential effects of mood congruency and emotional reactivity.

2.1.3 Procedure

Participants first completed the PANAS and then started the recognition task. Participants were instructed to decide as quickly as possible whether the appearing word was associated with an emotion or not. Participants first engaged in a short training session (5 trails) to familiarize with the task. Words were presented in random order without replacement. Participants started each trial by pressing the spacebar and responded to the target by pressing d or k on the keyboard with their right and left index finger respectively. Response-selection was counterbalanced across participants (d: associated with an emotion, k: non-associated with an emotion and vice-versa). Stimuli were presented using E-Prime 2.0 on a Dell PC with 17-inch monitor and a refresh rate of 75 Hz. Participants were invited to take a short break after the first half of the task. The experiment lasted 20 to 25 minutes. Decisions and reaction times (RTs) were recorded for each trial. Participants then completed the AIM and were debriefed.

2.2 Results

All trials with incorrect decisions and RTs deviating 3 standard deviations (SD) from participants' individual means were excluded (total of 9.3 %). Data were submitted to a repeated measures ANOVA to examine valence (positive vs negative) and arousal (high vs low) effects. Neutral words were included as non-emotional control items when examining the effects of word valence and word arousal separately.

Results reveal a significant effect of word valence, $F(2, 126) = 27.56$; $p < .001$, $\eta^2p = .30$, with faster RTs for positive ($M = 5059.39$; $SE = 96.84$) compared to negative ($M = 5217.48$; $SE = 91.62$), $t(63)=38.25$, $p < .001$, d-Cohen = 0.84, and neutral words ($M = 5278.13$; $SE = 82.99$), $t(63)=36.69$, $p < .001$, d-Cohen = 0.75. Negative words were detected faster than neutral words ($M = 5278.12$; $SE = 78.74$), $t(63) = 4.49$, $p =.038$, d-Cohen = 0.26. (Figure 3).

Results also show a main effect of word arousal, $F(2,126) = 19.90$; $p < .001$, $\eta^2p = .24$, with faster recognition times for high arousal ($M = 5076.78$; $SE = 95.32$) compared to low arousal ($M = 5200.09$; $SE = 93.78$), $t(63)=17.40$, $p < .001$, d-Cohen = 0.51, and neutral words ($M = 5278.12$; $SE = 78.74$), $t(63)=29.19$, $p < .001$, d-Cohen = 0.67, and faster recognition times for low arousal compared to neutral words, $t(63) = 7.22$, $p < .01$, d-Cohen = 0.33. No interaction between valence and arousal was observed, $F < 1$; $p = ns$. (Figure 3).

Furthermore, Pearson's correlations between individual word-recognition times (averaged across categories), PANAS and AIM scores showed that PANAS positive affect was associated with shorter reaction times ($r = -.27$, $p = .034$). The other correlations were not significant ($ps > .55$).

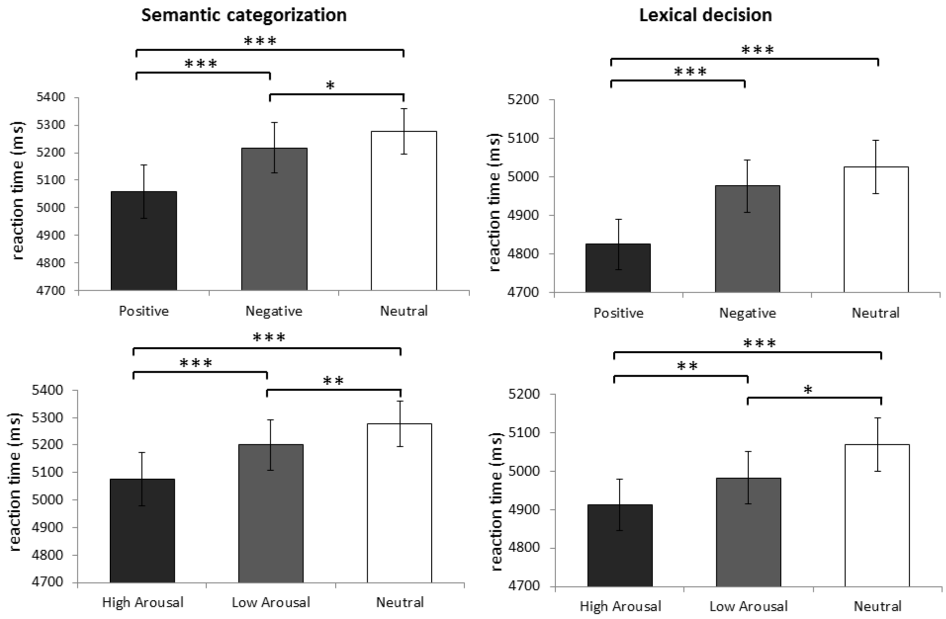

Figure 3. Mean recognition times for positive, negative, neutral, high arousal and low arousal words in the semantic categorization (left) and the lexical decision (right) paradigm.
* $p < .05$; ** $p < .01$; ***$p < .001$; Bars represent standard error of mean (SE).

3. Task 2: Constructive lexical decision

3.1. Method

3.1.1 Participants

Sixty-six volunteers (42 females; $M_{age} = 24.47$ years, $SD_{age} = 8.30$) took part in the study after giving informed consent.

3.1.2 Stimuli and Materials

Targets were 72 words[3] and 36 pseudowords. Forty-eight words were emotion-related (24 positive and 24 negative) words. Within each of these categories, 12 words were classified as high arousal and 12 as low arousal. The remaining 24 words were neutral. Pseudo-words were generated using the WinWordGen program (Duyck, Desmet, Verbeke, & Brysbaert, 2004), which allows to create pseudowords satisfying several (psycho)linguistic constraints. They were easy to pronounce and did not differ from target words in terms of length. As for the semantic categorization paradigm, target words were presented with CRT (Fiedler et al., 2001).

[3] The same as used in Task 1.

3.1.3 Procedure

Participants were instructed to decide as quickly as possible whether the appearing target was an existing French word or a pseudoword (i.e., lexical decision). Again, decisions and response times (RTs) were recorded for each trial. The computerized French versions of the PANAS and AIM were administered at the end of the task.

3.2. Results

All trials with incorrect decisions and RTs deviating 3 standard deviations (SD) from participants' individual means were excluded (total of 6.48 %). The same analysis was used as for Paradigm 1.

Results reveal a significant effect of word valence, $F(2,126) = 20.55$; $p < .001$, $\eta^2p = .25$, with faster RTs for positive ($M = 4825.46$ $SE = 66.04$) compared to negative ($M = 4976.59$; $SE = 68.28$) and neutral words ($M = 5026.04$; $SE = 69.00$), $t(63) = 22.35$, $p < .001$, d-Cohen = 0.60; $t(63)=37.69$, $p < .001$, d-Cohen = 0.83, respectively. The difference between negative and neutral words did not reach significance, $t(63) = 2.23$, $p > .05$; d-Cohen = 0.18 (Figure 3).

As in Paradigm 1, we observe a main effect of word arousal, $F(2,126) = 19.90$; $p < .001$, $\eta^2p = .24$, with faster RTs for high arousal ($M = 4912.43$; $SE = 75.02$) compared to low arousal ($M = 4982.16$; $SE = 70.35$), $t(65) = 6.51$, $p < .05$, d-Cohen = 0.31, and neutral words, ($M = 5068.26$; $SE = 73.26$), $t(65) = 22.43$, $p < .001$, d-Cohen = 0.58. RTs for low arousal words were significantly faster than for neutral words, $t(65) = 8.39$, $p < .01$, d-Cohen = 0.37. Across categories, existing words ($M = 4971.48$; $SE = 70.90$) were detected faster than pseudowords ($M = 5800.87$; $SE = 96.90$; $F(1, 65) = 324.12$; $p < .001$; $\eta^2p = .83$). No interaction between valence and arousal was observed, $F < 1$; $p = ns$. Pearson correlations showed no association between word recognition times, affect (PANAS) and emotional reactivity (AIM) ($ps > .08$).

4. Discussion

The present study examined the effects of valence and arousal on visual word recognition using two alternative versions of the Constructive Recognition Task (Fiedler et al., 2001). Participants were instructed either to classify a slowly appearing word as emotional versus non-emotional (semantic categorization) or to decide whether the appearing letter string is an existing word or not (lexical decision). Results reveal faster recognition of positive compared to negative and neutral words, as well as faster recognition of high-arousing compared to low-arousing words. Consistent with findings from the AB paradigm (e.g., Anderson, 2005), the present results support the assumption that arousal plays an essential role in visual word recognition. Under conditions of degraded visual input requiring increased activation of semantic knowledge, highly arousing words are faster recognized than low arousing words even when deciding on the word's emotional value is not task-relevant (i.e., lexical decision). This finding partially contrasts with previous lexical decision studies reporting no arousal effects (Kousta et al., 2009) or slower response times for high- compared to low-arousing words (Kuperman et al., 2014). Arousal thus appears to have diverging effects on visual word recognition. This presumably depends on the degree to which semantic representations are activated for accurate word recognition (CRT versus classic LDT). Interestingly, earlier findings suggest a lexico-semantic locus for arousal and valence effects and showed that the recall of either emotional or neutral words was affected by their semantic-relatedness with no impact of arousal (e.g., Talmi & Moscovitch, 2004). One could thus tentatively argue that the increase of semantic inferences proper to the CRT paradigm (Fiedler et al., 2001) may reinforce valence and arousal effects and hereby modulate their influence on visual word recognition. This interpretation deserves to be investigated with more detail in future studies.

Regarding valence, our results show that positive words are detected faster than negative and neutral words, supporting recent findings indicating a processing bias towards pleasant words, which was not only evident in RTs (e.g., Schacht & Sommer, 2009) but also in ERPs (e.g., Recio et al., 2014). Of importance too, our results are consistent with findings from previous CRT studies, indicating that participants are faster to detect positive words over same-category negative words. Unkelbach (2010) propose the density hypothesis as a potential explanation, stating that positive information is processed faster because it is more closely related to other positive information (i.e., more neighboring stimuli) compared to the overall similarity of negative information. The present results support this assumption by showing faster recognition times for positive compared to negative words when visual processing is impeded and active top-down semantic inferences are required.

Of interest, previous studies suggest that processing advantages for emotional over neutral information mainly occur when attention is directed toward emotional stimulus dimensions. For instance, affective priming effects have been shown to be more important when participants assign attention to affective stimulus features (e.g., happy vs sad) compared to semantic features (e.g., old vs young) (Everaert, Spruyt, & De Houwer, 2013). In the present study, however, we observed faster recognition times for positive compared to neutral information even when categorization criteria did not require focusing on the emotional word dimension (i.e., lexical decision), suggesting that arousal and valence effects in visual word recognition arise automatically. This is further supported by the lack of finding a significant interaction between task and valence, $F<1$. Further research is necessary to determine whether or not categorization criteria (emotion-oriented or not) influence the processing speed of pictorial and lexical stimuli differently.

Finally, results of both paradigms revealed no interaction effects, supporting the assumption of independent emotion dimensions (Russell, 1980). In line with this, a growing body of evidence suggests independent contributions of valence and arousal in visual word recognition (e.g., Anders, Lotze, Erb, Grodd, & Birbaumer, 2004). Consistent with our results, Recio et al. (2014) observed faster lexical decision times for positive and high arousal words, when independently manipulating valence and arousal. However, despite the widespread use of both dimensions in emotion research, theories and findings are far from unequivocal. Alternative theories, for instance, describe the emotional space under two motivational systems (appetitive vs aversive) for which, within, the arousal dimension reflects the degree of activation, resulting in a U-shaped distribution of stimuli along the valence and arousal axes (Bradley & Lang, 1994).

It is worth mentioning that valence and arousal of words were not fully independent from each other. Indeed, negative words were rated as more arousing than positive words. This limitation has likely influenced the results (i.e., underestimation) such that the speed-advantage for positive words compared to negative words should in reality be larger because the responses for the negative words are additionally speeded by their higher arousal.

Importantly, the present and previous findings demonstrate the complex picture of the role of emotion in word processing. Methodological aspects presumably account for these contradictory results. Previous studies examining emotional word processing have revealed opposite results likely due to heterogeneity in task (e.g., lexical decision, reading), material (e.g., including neutral words), statistical analyses (e.g., Estes & Adelman, 2008) and/or control of lexical and semantic confounds (e.g., Kuperman et al., 2014; Talmi & Moscovitch, 2004; Yao et al., 2016). For instance, Yao et al. (2016) showed that valence interacted with arousal for abstract but not for concrete words. Finally, based on the PANAS, the present results support the likely weakening of inhibition caused by positive affect which then broadens processing style (Vermeulen, 2010). Therefore, there is a need to consider methodological and individual characteristics (such as positive affect) when examining the discrepand findings about the role of emotion in word processing.

Please note that the CRT does not allow us to differentiate effects on initial perception, subsequent semantic evaluation of the target and motor processes. This is important as prominent theories suggest that negative stimuli require a more extensive and time-consuming cognitive analysis than positive stimuli, masking potentially fast perception effects (e.g., Dijksterhuis & Aarts, 2003). Moreover, response preparation in motor networks is less efficient for negative stimuli (vs positive) (Kuhbandner, Spachtholz, & Pastötter, 2016). To disentangle these effects, future research could focus on implementing evoked response potentials that are specific to 1) perceptual or pre-lexical processing (N1; P1, P2; Kissler, Herbert, Winkler, & Junghofer, 2009), 2) rudimentary semantic classification (Early Posterior Negativity; Kissler et al., 2009), 3) semantic relatedness (N400; Kissler & Koessler, 2011), and/or 4) motor electroencephalographic brain oscillations (Kuhbandner et al., 2016). The presentation of weakly vs highly degraded words might allow determining in what extent valence and arousal affect the perceptual, subsequent semantic evaluation of the target word and motor preparation.

To conclude, although further studies are needed to examine the exact time course of emotion effects in the CRT, the present findings join an increasing amount of research highlighting the importance of both valence and arousal in word processing. Our study showed, for the first time, that high arousal and positive words were more rapidly recognized than low arousal and negative words when visual analysis is hampered and semantic activation intensified. Altogether, the present observations emphasize the importance of the arousal dimension in word recognition and support the processing advantage for positive stimuli.

Congruent bodily arousal promotes the constructive recognition of emotional words (Study 2b)

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Abstract

Considerable research has shown that bodily states shape affect and cognition. Here, we examined whether transient states of bodily arousal influence the categorization speed of high arousal, low arousal, and neutral words. Participants realized two blocks of a constructive recognition task, once after a cycling session (increased arousal), and once after a relaxation session (reduced arousal). Results revealed overall faster response times for high arousal compared to low arousal words, and for positive compared to negative words. Importantly, low arousal words were categorized significantly faster after the relaxation than after the cycling, suggesting that a decrease in bodily arousal promotes the recognition of stimuli matching one's current arousal state. These findings highlight the importance of the arousal dimension in emotional processing, and suggest the presence of arousal-congruency effects.

1. Introduction

Do emotional feelings have the power to influence our thinking and behavior? Research seems to indicate that this is the case. Numerous studies indeed provide evidence for interactions between affective and cognitive phenomena. For instance, past research revealed enhanced or facilitated processing of information that matches an individual's current affective state (Bower, 1981; Fiedler, 1990; Forgas, 1994b). These so-called *mood congruency effects* have typically been observed in memory tasks, with positive materials recalled better when experiencing a pleasant mood, and negative materials recalled better when experiencing an unpleasant mood (for review, see Ellis & Ashbrook, 1989; Mayer et al., 1990). Moreover, findings indicate that transient emotional states influence processing speed for affectively loaded stimuli. Participants made faster lexical decisions (word versus non-word) for mood-congruent stimuli (e.g., "sad" words like *despair* or *regret* following sadness induction) (Niedenthal & Setterlund, 1997) and showed facilitated response latencies when evaluating mood-congruent pictures (e.g., categorizing a slide displaying flowers as positive when feeling elated) (Hermans et al., 1996). Emotional congruency effects thus present a well-documented phenomenon in the literature. However, when taking a closer look, it becomes clear that prior studies primarily focus on the most universal, obvious feature of emotion, its valenced character. But emotions involve more than just a positivity-negativity dimension. They also vary along the dimension of arousal, indicating whether an emotional state or stimulus is rather calming or exciting (Feldman Barrett & Russell, 1999; Russell, 1980). According to Russel's circumplex model of affect (1980), each emotion can be understood as a linear combination of these two dimensions, which are bipolar, orthogonal, and independent from each other. Fear, for example, is conceptualized as an affective state involving both negative valence and heightened levels of autonomic arousal. Similarly, positive and negative concepts can be judged as either highly arousing (e.g., *passion, terror*) or lowly arousing (e.g., *gentleness, boredom*).

In support of this model, studies have indicated separate neural routes for the processing of valence and arousal (e.g., Colibazzi et al., 2010; Kensinger & Corkin, 2004; LaBar & Cabeza, 2006; Nielen et al., 2009), and have shown that valence and arousal can be conditioned independently (Gawronski & Mitchell, 2014).

Furthermore, previous research suggest that arousal value might play a critical role in word processing. Findings indeed indicated that highly arousing stimuli benefit from special attentional status (e.g., Anderson, 2005; Schimmack, 2005) and facilitated memory recollection compared to low arousal stimuli (e.g., Ochsner, 2000). Interestingly, findings also suggest that experienced arousal reactions provide information about the importance of an encountered stimulus (e.g., signaling personal relevance) and consequently guide our judgments and decisions (for review, see Storbeck & Clore, 2008). For instance, a series of classic experiments showed that increased arousal intensified judgments of attractiveness (Dutton & Aron, 1974), amusement (Martin, Harlow, & Strack, 1992), and, more recently, perceived height (Stefanucci & Storbeck, 2009).

However, when turning to congruency effects it becomes striking that previous studies have exclusively focused on valence features (i.e., positive/negative mood and processing of positive/negative stimuli), and this despite the undeniable importance of the emotional arousal dimension. Given this gap in the literature, the question rises whether congruency effects can also be observed when stressing the role of arousal in this context. More concretely, it remains largely unclear whether high/low levels of bodily arousal may influence the processing of high/low arousal emotional stimuli.

To date, little research has been undertaken to examine this issue and empirical evidence is correspondingly sparse. In 1984, Clark and collaborators investigated the influence of bodily arousal on judgments of other's emotions. Results revealed that highly aroused participants (i.e., after vs before a tennis match) were more likely to interpret positive statements and facial expressions as indicating joy (a high arousal emotion) than serenity (a low arousal emotion). In other terms, participants' judgments seemed to be biased towards evaluations matching their current level of experienced arousal. Although the results of this study should be interpreted with caution (i.e., given a lack of reliable physiological and mood measurements), they point towards a possible facilitating effect of a congruent arousal state on emotional stimuli processing. In subsequent years, the question of arousal congruency remained largely outstanding, with new insights having only been provided very recently. Current findings indeed suggest that actual levels of bodily arousal modulate the cognitive access to arousal (in)congruent stimuli in an attentional blink paradigm (Kever et al., 2015). The attentional blink paradigm requires the report of two targets (T1 and T2) presented within a stream of distractor items. The ability to report the second target (T2) is typically impaired if it appears 200 to 500 msec after the first to-be-detected target (T1) (Raymond et al., 1992). While early theories attribute the attentional blink effect to capacity limitations or a bottleneck (e.g., Chun & Potter, 1995; for review, see Dux & Marois, 2009), a more recent account assigns it to a gating system that promotes ("boosts") the entrance of relevant information (a target) and hampers ("bounces") the entrance of irrelevant information (a distractor) into working memory (Olivers & Meeter, 2008). Previous results showed that high arousal T2 words were better reported when experiencing increased bodily arousal (i.e., following a cycling session), while low arousal T2 reports improved when experiencing low bodily arousal (i.e., following a relaxation session). It can thus be suggested that arousal-congruent words enjoy facilitated access to the working memory space, increasing the possibility that they get accurately reported (Kever, Grynberg, et al., 2015; Vermeulen, Chang, Mermillod, Pleyers, & Corneille, 2013; Vermeulen et al., 2009).

In view of these promising preliminary findings, further studies are clearly needed to determine more specifically under which conditions arousal congruency effects can be observed. While research suggests that arousal-congruent stimuli enter working memory more easily, it remains unclear whether these stimuli can also be more easily retrieved. In an attempt to solve this issue, the present study examines whether changes in overall bodily arousal influence the recognition and categorization of high and low arousing words when active elaboration is required to access word meaning (Fiedler et al., 2001). Concretely, we relied on a constructive recognition task (CRT), in which a target word is first hidden by a mask and then becomes progressively visible (Fiedler et al., 2001). While the attentional blink paradigm reflects the temporal costs in allocating selective attention (Dux & Marois, 2009), the CRT complexifies visual analysis by slowly revealing word fragments, and consequently invites for active, knowledge-based inferences to complete or generate the meaning of the emerging stimulus (Fiedler et al., 2001). The CRT thus presents a pronounced top-down component requiring to draw semantic inferences beyond the information given. These generative features make it an appropriate paradigm to investigate whether arousal-congruency effects can not only be observed under limited attentional resources when information is fully presented (i.e., attentional blink), but also when information is actively constructed (i.e., CRT) based on previous memory-stored knowledge (retrieval).

Here, participants' level of physiological arousal was modified by means of a short cycling and relaxation session (Kever, Grynberg, et al., 2015). Following each session, participants realized a CRT block, with targets being high arousal (positive and negative), low arousal (positive and negative), and neutral words (non-emotional control items). This way, potential interactions between bodily arousal and word arousal could be determined reliably. Based on the assumption of an arousal-congruency effect, we hypothesize that increased physiological arousal (i.e., post-cycling) leads to faster categorization of high arousal words, while reduced physiological arousal (i.e., post-relaxation) leads to faster categorization of low arousal words. Recognition times for neutral words, however, should not be affected by the physiological arousal conditions.

2. Method

2.1 Participants

Sixty French-speaking students at the Université catholique de Louvain (M_{age} = 20.8 years, SD_{age} = 1.8 years; 8 males) participated in return for course credit or a monetary reward of 10 euros. Recruitment criteria included restrictions against individuals presenting any contra-indications to the practice of a moderate-intensity physical exercise.

2.2 Procedure

2.2.1 Arousal manipulation

After providing informed consent, participants received instructions on how to place the Polar RS800CX strap around their chest. Polar heart rate monitors allow for the precise and noninvasive recording of heart rate (variability) and present a valid and reliable device for field studies (e.g., Nunan et al., 2008; Williams et al., 2016). Once the strap fastened, participants filled out the French version of the Positive Affectivity Negative Affectivity Schedule (Gaudreau, Sanchez, & Blondin, 2006) to examine potential influences of their current affective state, and were then randomly assigned to either a cycling or relaxation session (counterbalanced within-subjects conditions). The cycling session involved pedaling on a bicycle ergometer (Pro-form 748 EKG model produced by ICON Health & Fitness, Ldt.) for 7: 30 minutes. Target heart rate (HR) was set at 65% of the estimated maximal HR (i.e., 65% of [220 (beats per minute) minus participants' age]), corresponding to a moderate-intensity exercise. If needed, the experimenter monitored participant's HR to maintain exercise intensity within the adequate HR zone for each individual. Participants did not get any online feedback on their heart rate during the cycling session.

During the relaxation session, participants were seated in an armchair while listening through headphones to a 7:30 minutes audio program, in which a male voice calmly describes a landscape. After each session, participants completed three 10-point Likert scales evaluating their subjective feelings of activation (1 = very relaxed; 10 = very activated), stress (1 = not stressed at all; 10 = very stressed), and pleasantness (1 = not pleasant at all; 10 = very pleasant). Both sessions were followed by a constructive recognition block (counterbalanced order), including 48 trials each.

2.2.2 Constructive Recognition Task

The constructive recognition task (CRT) consists in the gradual presentation of an initially masked target word (Fiedler et al., 2001; Unkelbach, Guastella, et al., 2008). In the beginning, the target is hidden by a dark mask covering the entire presentation area. The mask then slowly dissolves, whereby small rectangles (of a few square pixels) disappear in a random fashion to render the target progressively visible. The complete target is uncovered after 8 seconds. The CRT calls for making active inferences to generate the meaning of the emerging word from the appearing fragments. Participants are thus required to rely on knowledge-driven top-down processes to actively construct the target word beyond the information given (Fiedler et al., 2001). In the present experiment, participants were instructed to decide as quickly and accurately as possible whether an appearing word was "associated with an emotional context" or "not associated with an emotional context". Similar categorization criteria have already been successfully used in previous studies (e.g., Baumeister et al., 2015; Niedenthal et al., 2009). Words were presented in black letters (i.e., Lucida Sans 96-point) using E-prime 1.1.4.1 on a 17-inch monitor with a refresh rate of 75 Hz.

Participants first engaged in a short training session (5 trails) to get familiarized with the task. They started each trial by pressing the spacebar and responded to the target by either pressing the d or k button on the keyboard (key assignment was counterbalanced). The index fingers of the right and left hand were used for this purpose. Decisions and reaction times (RTs) (for correct answers) for each trial were recorded. Following the second CRT block, participants completed the computerized French version of the Affective Intensity Measure (Mathieu et al., 2014). The latter quantifies the strength or weakness with which one experiences emotion and presents a suitable measure to examine potential effects of emotional reactivity on task performances.

2.2.3. Statistical Analyses

Data of one participant were discarded because of system failure during the task (i.e., N = 59). Response times (RTs) were prepared by eliminating trials with incorrect decisions (3.4 %) and RTs below or above 3 standard deviations (SD) of participants' individual mean. Data were submitted to a series of repeated measures ANOVA's with RTs as dependent variable and physiological arousal (2 levels: post-cycling, post-relaxation), and either stimulus valence (3 levels: positive, negative, neutral) or stimulus arousal (3 levels: high, low, neutral) as factors. Neutral words were included as non-emotional control items when examining the effects of word valence and word arousal separately.

3. Results

3.1. Manipulation check: heart rate

Heart rate data of three participants were excluded because of technical problems during recording (i.e., $N = 57$). As intended, participants' mean heart rate during the cycling session ($M = 125.40$; $SD = 6.65$) was significantly higher than during the relaxation session ($M = 77.26$; $SD = 11.20$), $t(56) = 46.15$, $p < .001$. Furthermore, analyses reveal a significant difference between mean heart rate during the post-cycling CRT block ($M = 88.20$; $SD = 11.20$), and the post-relaxation CRT block ($M = 78.20$; $SD = 10.84$), $t(56) = 14.38$, $p < .001$.

3.2 Constructive Recognition Task

Firstly, results reveal a significant main effect of word valence, $F(2, 57) = 27.20$; $p < .001$, $\eta^2 p = .32$, with faster RTs for positive ($M = 5120$; $SE = 85$) than for negative ($M = 5242.80$; $SE = 77$), $t(58) = 3.72$, $CI_{95\%}$ [57, 188], $p < .01$, $dz = .48$, and neutral words ($M = 5368$; $SE = 76$), $t(58) = 6.64$, $CI_{95\%}$ [173, 322], p < .001, $dz = .86$. Negative words were categorized faster than neutral words, $t(58) = 4.15$, $CI_{95\%}$ [65, 186], $p < .001$, $dz = .54$. Results showed no interaction between physiological arousal (i.e., post-cycling, post-relaxation) and stimulus valence (i.e., positive, negative, neutral), $F(2, 57) = 2.60$, *ns.*

Secondly, results reveal a significant effect for word arousal, $F(2, 57) = 39.79$; $p < .001$, $\eta^2 p = .41$, with faster RTs for high arousal ($M = 5091$; $SE = 82$) compared to low arousal words ($M = 5272$; $SE = 79$), $t(58) = 6.35$, $CI_{95\%}$ [123, 236], $p < .001$, $dz = .83$, and neutral words ($M = 5368$; $SE = 76$), $t(58) = 8.23$, $CI_{95\%}$ [209, 343], $p < .001$, $dz = 1.07$. Low arousal words were categorized significantly faster than neutral words, $t(58) = 3.00$, $CI_{95\%}$ [31,160], $p < .01$, $dz = .39$. (Figure 4).

Importantly, analyses reveal a significant interaction between participants' levels of physiological arousal and stimulus arousal, $F(2, 57) = 12.21$; $p < .001$, $\eta^2 p = .17$. Critically, follow-up paired t-tests show significantly faster RTs for low arousal words in the post-relaxation ($M = 5136$; $SE = 79$) compared to the post-cycling condition ($M = 5408$; $SE = 98$), $t(58) = 3.35$, $CI_{95\%}$ [123,236], $p < .01$, $dz = .44$. RTs for high arousal words (post-cycling: $M = 5058$; $SE = 96$; post-relaxation: $M = 5098$; $SE = 86$) and neutral words (post-cycling: $M = 5394$; $SE = 85$; post-relaxation: $M = 5343$; $SE = 80$) did not differ depending on the physiological arousal conditions, $t(58) = .17$, *ns*; $t(58) = .78$, *ns* (Figure 5). Furthermore, results show no main effect of the physiological arousal condition, $F(2,58) = 2.21$, *ns*, such that participants' RTs post-relaxation ($M = 5192$; $SE = 79$) are not significantly different from those post-cycling ($M = 5296$; $SE = 89$), $t(58) = 1.58$, *ns*. Both the two-way (word valence x word arousal; $F(1, 58) = 0.02$, *ns*) and the three-way interaction (physiological arousal x word valence x word arousal; $F(1, 58) = 0.90$; *ns*) were none significant.

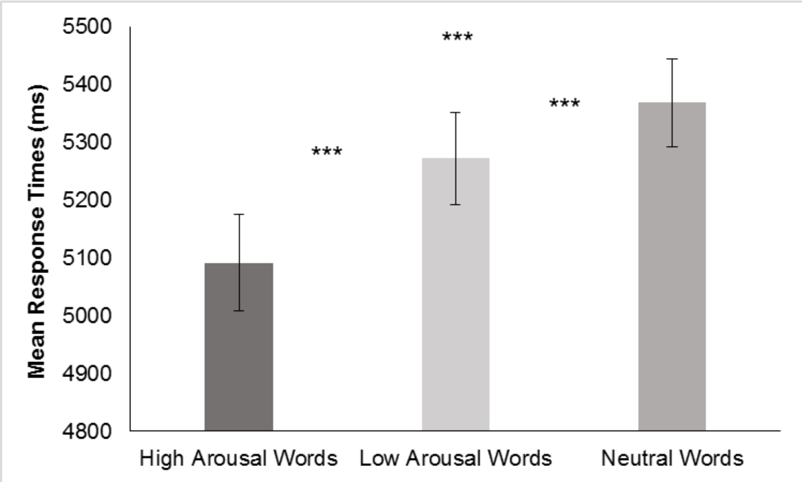

Figure 4. Mean response times (*ms*) for high arousal, low arousal, and neutral words. Error bars depict within subject error (i.e., standard error of mean).
*** $p < .001$

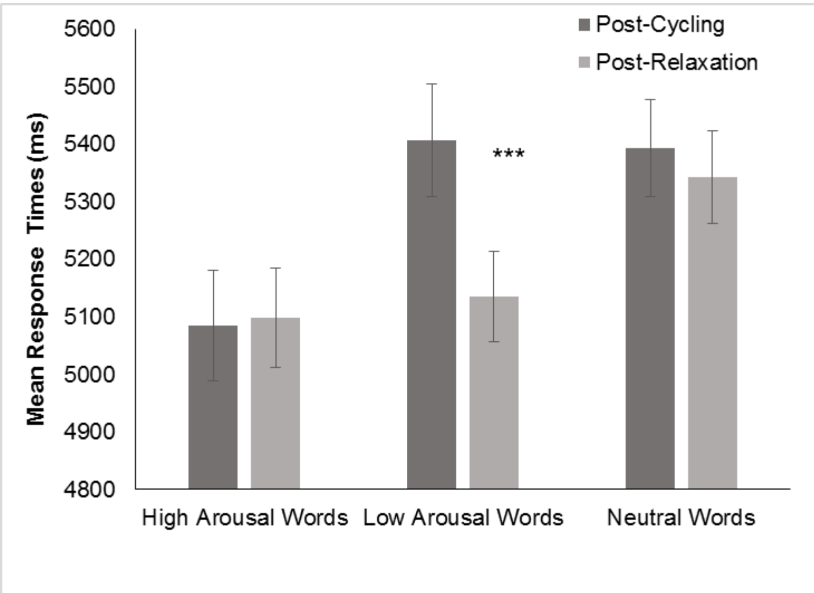

Figure 5. Mean response times (ms) for high arousal, low arousal, and neutral words as a function of participants' level of physiological arousal (post-cycling, post-relaxation). Error bars depict within subject error (i.e., standard error of mean).
*** p < .001

3.3 Control measures

A series of Pearson correlations were conducted to evaluate potential influences of baseline affect (PANAS), and affective intensity (AIM) on CRT RTs. Results showed no significant effect for any of these variables, suggesting that task performances were not influenced by participants' affective states and traits ($p = ns$). Additional analyses evaluating participants' subjective feelings of activation and stress showed that the latter were significantly higher after cycling (Activation: $M = 7.78$; $SD = 1.58$; Stress: $M = 2.65$; $SD = 1.52$) than after the relaxation session (Activation: $M = 2.93$; $SD = 1.76$; Stress: $M = 1.75$; $SD = 1.14$), $t(59) = 16.95$, $p < .001$, and $t(59) = 4.50$, $p < .001$. Moreover, ratings of experienced pleasantness were significantly higher after the relaxation ($M = 7.82$; $SD = 1.94$) than after the cycling ($M = 7.10$; $SD = 1.71$), $t(59) = 2.44$, $p < .01$. However, correlations between self-reported feelings of activation, stress, and pleasantness did neither correlate with CRT performances nor with actual heart rate during cycling, relaxation, and the task.

4. Discussion

Accumulating evidence during the past decades suggest that bodily responses influence affective experience and the processing of emotional information (e.g., Laird & Lacasse, 2014; Niedenthal et al., 2009). To date, however, most research has focused on the influence of facial feedback and expressive behavior on the processing of valenced materials, while the potential influences of autonomic arousal responses have been comparatively little investigated. For instance, previous studies show a processing advantage for valenced information that matches an individuals' affective state (e.g., mood), one's facial expressions or posture (e.g., Havas et al., 2010; Neumann & Strack, 2000). The aim of the present experiment was to investigate whether similar congruency effects can be observed when considering the arousal dimension of the to-be-processed stimulus. Concretely, we examined whether changes in bodily arousal modulate the retrieval of arousal-(in)congruent emotional words when knowledge-based top-down processes are required to generate word meaning (Fiedler et al., 2001). Participants performed two blocks of a constructive recognition task (CRT), once after a cycling session (increased arousal) and once after a relaxation session (reduced arousal). By calling for inferential and generative thinking, the CRT nicely allows to test whether arousal-congruency effects occur when information must to be actively constructed to be recognized and categorized.

Firstly, our results reveal a main effect of word arousal, with high arousal words being faster detected than low arousal and neutral words. These observations are consistent with previous findings indicating that highly arousing information captures attention in a privileged manner and enjoys facilitated access to awareness (e.g., Anderson, 2005; Öhman et al., 2001; Schimmack, 2005). However, inspection of the recent literature reveals a series of discrepancies regarding the presence and direction of arousal effects on word processing. While studies relying on rapid serial visual presentation (Lawrence, 1971) mainly show better identification for high arousal compared to low arousal words (Anderson, 2005; Anderson & Phelps, 2001; Keil et al., 2006; Mathewson et al., 2008), results from lexical decision tasks (LDT) reveal either no effects of arousal (e.g., Estes & Adelman, 2008a; Kousta et al., 2009) or suggest faster recognition of low arousal words (e.g., Kuperman et al., 2014). The present findings complement existing knowledge by indicating a processing advantage for high arousing over low arousing words when one is encouraged to make active top-down inferences to self-generate word meaning. However, further studies seem necessary to disentangle the specific effects of arousal in word recognition depending on experimental and cognitive requirements.

Secondly, results reveal faster response times for positive than for negative and neutral words, which challenges the widespread assumption of a negativity bias in information processing (e.g., Dijksterhuis & Aarts, 2003; Hansen & Hansen, 1988; Nasrallah et al., 2009). According to a functional, evolutionary perspective, negative stimuli automatically attract attention because their detection is particularly critical to survival, and allows to act efficiently when one's well-being is threatened (Pratto & John, 1991; Wentura, Rothermund, & Bak, 2000). However, a substantial body of findings provides evidence for a positivity advantage in processing speed. Data reveal faster classification times (Bargh et al., 1992; Unkelbach, Fiedler, et al., 2008) higher identification rates and faster lexical decision latencies for positive compared to negative words (e.g., Unkelbach, 2010). Unkelbach et al. (2008) propose the density hypothesis as a potential explanation, stating that positive information is processed faster because it is more densely clustered in memory than negative information. The present findings thus support the assumption of a positivity advantage by indicating faster recognition and categorization of gradually presented positive relative to negative words.

Thirdly, and most importantly, our findings show a significant interaction between participants' levels of physiological arousal and the arousal-value of the to-be-processed words. More precisely, results point towards an arousal-congruent recognition advantage, with faster response times for low arousal words following a relaxation session (i.e., low bodily arousal) than following a cycling session (i.e., high bodily arousal). That is, a decrease in physiological arousal seems to promote the recognition of stimuli matching one's current arousal state. Surprisingly, however, no such arousal-congruency effect was observed for high arousal words. Although one would have expected faster recognition times for high arousing words after the cycling session (compared to the relaxation session), the latter did not differ from one condition to another. When having a closer look at the results, it seems that high arousal words benefit from a generalized processing advantage (independently of bodily arousal) while the recognition and categorization of low arousal words seems impeded when experiencing an incongruent arousal state. That is, after the cycling session response times for low arousal words were significantly increased, whereas after the relaxation session they approach the average response times for high arousal words. Interestingly, previous findings revealed a similar response pattern, suggesting that the interactions between physiological and word arousal are driven by differences in low arousal word reports (Kever et al., 2015). Alternatively, one could argue that high arousing stimuli show greater resistance to "unfavorable" processing contexts or that their overall recognition advantage leads to a ceiling effect, restraining the possibility that recognition times further speed up in arousal-congruent processing conditions. Further studies should investigate whether arousal-congruency effects can also be observed for high arousal words when relying on paradigms that bypass their privileged attentional status or that are less associated with a ceiling effect.

Moreover, as predicted, recognition times for neutral words remained unaffected by the arousal manipulations. In fact, when relying on the premise that the arousal dimension specifically relates to emotional information, and does not apply to neutral materials (e.g., Feldman Barrett & Russell, 1999; Watson, Clark, & Tellegen, 1988), no arousal-congruency effects should be expected. Considering neutral words as arousal-lacking control items, these findings further support the assumption that the experienced physiological state makes the cognitive system specifically more sensitive to emotional words that match in arousal level.

Previous research has mainly focused on valence congruency, and to date only one study has shown processing advantages for arousal-congruent words, which enter more easily into working memory (Kever et al., 2015). The present study extends those findings by demonstrating that arousal congruency effects also occur when knowledge-based inferences are made to actively retrieve the meaning of an emerging word. Although further studies are necessary to determine the underlying processes with more certainty, several theoretical approaches seem relevant with regards to our results. Mood congruency effects, for instance, have been mainly explained in terms spreading activation within an associative network, where emotion are stored as nodes and connected by associative linkages (Isen et al., 1978). For instance, a given emotion, say sadness, is represented as a node surrounded by its associated autonomic reactions, expressive behaviors, evoking situations, and verbal labels. In view of this, one could assume the presence of different bodily arousal nodes, which are connected to concepts of similar meaning or with a similar associative history (e.g., nodes for low bodily arousal lie closer to calming, non-arousing concepts than to exciting, highly arousing concepts). Being in a certain arousal state then means that the corresponding node is activated. This activation spreads to the closely related, neighboring nodes first, making arousal-congruent stimuli more likely to enter consciousness than incongruent stimuli. In the same vein, Clark and colleagues (1983) suggested that autonomic arousal cues material from memory, which is associated with a similar level of arousal. Bodily arousal can thus serve the role of a retrieval cue for arousal - congruent information. In other terms, experiencing low arousal (i.e., following a relaxation session) might activate low arousing concepts which will therefore come to mind faster. Although the associative network model provides an appealing explanation for mood- and arousal-congruency effects, it remains somewhat vague regarding the format under which information is represented within the nodes. While connectionist models assume that information is stored as an abstract, amodal code (e.g., Fodor, 1975; Pylyshyn, 1984; Rumelhart & Norman, 1988), alternative embodied cognition accounts view knowledge as grounded in modality-specific systems (e.g., Barsalou, 1999, 2008). According to the latter, knowledge of an emotion concept is not reducible to an abstract, language like description, but involves partial reactivations (or simulations) of the experienced emotional states relevant to the concept. (Niedenthal, 2007; Niedenthal et al., 2009). Consistent with an embodied emotion account, several studies showed that peripheral bodily feedback (i.e., posture and facial expressions) influence information processing (e.g., Neumann & Strack, 2000; Niedenthal et al., 2009). For instance, findings reveal that facial expressions interact with sentence valence during language processing, such that participants reading times for pleasant sentences were significantly faster when they were smiling than when they were frowning. The reverse effect was found for unpleasant sentences, indicating that emotion-congruent facial expressions facilitate language processing (Havas, Glenberg, & Rinck, 2007). Of interest too, further studies suggested that specific bodily manipulations enhance the accessibility of associated (often abstract) concepts. For instance, holding a heavy (vs light) object leads to increased judgments of importance (Jostmann, Lakens, & Schubert, 2009), and a gesture related to bodily force (i.e., making a fist vs a “scissor” hand) activates power-related words (e.g., authority, win) in a Stroop paradigm (Schubert, 2004). Based on the presupposition that concepts are not represented in an amodal manner but contain modality-specific aspects (e.g., facial expressions, movements, posture, sensory states), a modal – priming mechanisms might account for the observed effects (Körner, Topolinski, & Strack, 2015). In other terms, activating a certain bodily state activates related concepts within a multi-modal associative store. This idea seems coherent with research proposing the existence of a shared sensory space used both off-line (during the conceptual representation of sensory properties) and on-line (during the buffering of perceptual information) (Vermeulen, Corneille, & Niedenthal, 2008). Applied to the present findings, it could thus be stated that the recognition advantage for arousal-congruent words suggests a direct grounding of emotion knowledge in our bodily systems of arousal (Kever, Grynberg, et al., 2015). That is, arousing stimuli do not only alter the bodily state of the perceiver (e.g., heart rate acceleration, heightened electrodermal activity) (for review, see Bradley, 2009) but physiological arousal also influences the cognitive accessibility of more or less arousing concepts.

Altogether, the present findings suggest that shifts in bodily arousal affect the processing of arousal-congruent and –incongruent emotional concepts. That is, low arousal words benefit from a processing advantage when being in a low arousal state (post-relaxation) compared to a high arousal state (post-cycling). These findings thus extend existing knowledge regarding body-mind interactions and emotional congruency effects, while underlying the importance of the arousal dimension in that context. Further studies should now investigated in more detail which underlying processes account for arousal-congruency effects. For instance, classic amodal network theories should be confronted with more recent embodiment accounts (e.g., modal-priming effects) in order to shed new light on the mechanisms.

Chapter 5

The influence of physiological arousal on subjective familiarity of novel stimuli (Study 3)

When the body matches the picture: The influence of physiological arousal on subjective familiarity of novel stimuli (Study 3)

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Abstract

Numerous studies show that bodily states shape affect and cognition. Here, we investigated whether incidental physiological arousal impacted perceived familiarity for images that were never actually observed. Participants provided familiarity ratings for high- and low arousal images, once after a cycling session (to increase heart rate) and once after a relaxation session (to reduce heart rate). We observed a novel match-effect between internal (physiological) and external (stimulus) arousal sources, where participants rated highly arousing images as more familiar when bodily arousal was also high (post-cycling vs. post-relaxation). Importantly, the match-effect was greater in participants that scored low on self-report measures of interoception, suggesting that these individuals are less able to correctly perceive bodily changes, and thus are more likely to confuse their physiological arousal with an external source. Overall, our findings underscore the importance of interactions between the mind, body, and stimulus, especially when it comes to subjective judgments of familiarity.

1. Introduction

Emotion theories have long emphasized contributions of bodily arousal to affective experience (James, 1884), and numerous studies have provided evidence for its role in basic perceptual, cognitive, and memory processes (Cahill & McGaugh, 1998; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004). For example, a recent line of research has investigated the effects of cardiovisceral feedback on emotional processing, by focusing on the phasic discharge of arterial baroreceptors (pressure sensors in the aortic arch and carotid sinus) (e.g., Fiacconi et al., 2016; Garfinkel et al., 2013, 2014; Pfeifer et al., 2017). Arterial baroreceptors are activated when the heart contracts to eject blood (at systole) and are silent between heartbeats (at diastole). Findings revealed that, under limited attentional resources, fear faces are more likely to access awareness when presented during cardiac systole (when visceral feedback is maximal) than during diastole (when visceral feedback is minimal; Garfinkel et al., 2014). Similar autonomic-cognitive links extend to memory, where familiar stimuli elicit increased arousal (Morris, Cleary, & Still, 2008), and highly arousing pictures are better remembered (Bradley et al., 1992). Together those results suggest that incidental bodily arousal could influence memory processes. Indeed, memory performance for words presented during systole declines (relative to diastole), especially for low-confidence items (Garfinkel et al., 2013). Consistently, previously studied and novel faces presented around systole are more often endorsed as “old” when participants report impressions of familiarity (know vs remember responses) without conscious recollection (Fiacconi et al., 2016). Cardiac feedback thus influences subjective memory-based judgments, particularly when there is uncertainty about the presented material. Interestingly, such influences seem rather nonspecific, as incidentally related arousal signals (e.g., a low-amplitude vibration on participants’ chair) can also enhance feelings of familiarity (Goldinger & Hansen, 2005).

More broadly, current visceral experience can also affect complex social judgments. For instance, participants are more likely to believe that global warming, desertification, or drought are looming crises when actually feeling warm (Risen & Critcher, 2011). Presumably, these effects reflect the extent to which internal states are deemed plausibly related to the target stimulus (Schwarz, 2015). Similar "visceral fit" effects have been observed when manipulating participants' levels of bodily arousal by means of a short cycling or relaxation session. Concretely, participants detect more high arousal words (e.g., *terror, champion*) when experiencing increased bodily arousal (i.e., post-cycling) and more low arousal words (e.g., *tear, flower*) when experiencing reduced bodily arousal (i.e., post-relaxation) (Kever, Grynberg, et al., 2015). Confirming results were found when performing a constructive recognition task, in which a target word is first hidden by a mask and then becomes progressively visible (Kever, Grynberg, & Vermeulen, 2017).

Building on this research, the present study examines familiarity judgments for novel images, while focusing on the role of a (mis-)match between stimulus arousal and the participant's bodily state. We manipulated participants' bodily arousal through a short cycling and relaxation session (Kever, Grynberg, et al., 2015), then presented high- and low-arousing emotional pictures and collected familiarity ratings. Unlike traditional recognition-memory tasks, participants did not complete an encoding phase, but reported subjective feelings of familiarity for pictures they thought were taken from various media outlets (e.g., television and newspapers). We hypothesized that high arousal images would be rated as more familiar when experiencing high bodily arousal (post-cycling) compared to low bodily arousal (post-relaxation), due to the "match" between external (stimulus) and internal (body) arousal. However, this match-effect should be reduced (if not eliminated) for low arousal stimuli, since high bodily arousal (post-cycling) should also lead to a general misattribution effect and thus higher overall familiarity ratings (regardless of stimulus arousal).

Of interest too, previous studies suggest that individual differences in the ability to sense internal bodily changes (i.e., interoception; Craig, 2003) shape the relationship between physiological responding, emotional experience, and information processing (e.g., Herbert, Pollatos, & Schandry, 2007; Kever, Pollatos, Vermeulen, & Grynberg, 2015; Wiens, 2005). In view of this, we collected measures of participants' interoceptive sensibility (IS; self-report assessments of subjective interoception; Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015) allowing to examine its potential moderating effect on the interplay between arousal and familiarity. Note that the current literature leads to two rather opposite predictions concerning the effect of IS. One alternative is that individuals with high IS better sense their bodily states, increasing the likelihood that they rely on them when judging familiarity (aligning with notions that "gut feelings" are susceptible to arousal manipulations; Goldinger & Hansen, 2005). Consequently, individuals with high IS would show greater overall familiarity ratings as well as greater "match"- effects when in a highly arousing state. Another alternative is that low IS individuals cannot easily decipher the nature and origins of their transient bodily states, and thus more easily conflate their own physiological arousal with an external stimulus (aligning with ideas that low IS individuals are more vulnerable to visceral influences on memory and body ownership; Garfinkel et al., 2013; Tsakiris, Jimenez, &

Costantini, 2011). Consequently, low IS would lead to greater bodily influences on familiarity ratings based on a "misattribution" procedure.

2. Method

2.1 Participants, stimuli, and materials

Sixty University of California, San Diego undergraduates participated for course-credit (M_{age} = 20.2 years, SD_{age} = 1.5 years; 17 males). Sample size was determined by an a priori analysis using the G*Power general power analysis program (Erdfelder, Faul, & Buchner, 1996). Alpha was set at 0.05 with a corresponding power of 0.50 to detect a medium effect size (Cohen, 1988). Accordingly, a sample size of 56 was determined to be adequate.

Stimuli were 96 pictures from the International Affective Picture System (IAPS; Lang et al., 1999). Based on IAPS ratings, pictures were categorized into four groups, according to valence (positive vs negative) and arousal level (high vs low). Thus, positive images (M = 7.17, SD = .66) were more positive than negative images (M = 2.99, SD = .86), $t(47) = 25.76$, $p < .001$, and high arousal images (M = 6.26, SD = .51) were more arousing than low arousal images (M = 3.87, SD = .60), $t(47)=19.41$, $p < .001$. Negative high arousal pictures were slightly more negative (M = 2.47, SD = .72) than negative low arousal pictures (M = 3.38, SD = .75), $t(23) = 4.13$, $p < .001$, and slightly more arousing than positive high arousal pictures (M = 6.39, SD = .45; M = 6.13, SD = .55), $t(23) = 4.42$, $p < .001$. We then created two blocks of 48 stimuli, each including 24 high arousal (12 positive, 12 negative) and 24 low arousal (12 positive, 12 negative) pictures. Blocks did not differ in mean picture valence or arousal. To minimize gender effects and large variability in affective responses to the stimuli, the picture set did not include erotic stimuli or pictures of snakes and spiders.

The Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012) and Body Consciousness Questionnaire (BCQ; Miller, Murphy, & Buss, 1981) measured individual differences in general interoceptive sensibility, private body consciousness (awareness of internal sensations), public body consciousness (awareness of observable body aspects), and body competence (bodily use or application). We have consciously chosen not to rely on the commonly used heartbeat counting task to assess interoceptive accurateness (e.g., Herbert, Muth, Pollatos, & Herbert, 2012; Schandry, 1981; Wiens, 2005), given that the latter has recently been subject to numerous psychometric and theoretical criticisms, questioning its reliability (e.g., Brener & Ring, 2016; Desmedt, Luminet, & Corneille, 2018; Zamariola, Maurage, Luminet, & Corneille, 2018).

2.2 Procedure

After providing informed consent, participants were instructed to place the Polar RS800CX strap around their chest, allowing for the precise and non-invasive recording of heart rate (HR) at 1-Hz frequency (Williams et al., 2016). Once the monitor placed, participants filled out the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), before being randomly assigned to either a cycling or relaxation session (counterbalanced within-subject conditions). During cycling, participants pedaled on a bicycle ergometer for 7 minutes. Target HR was set at 65% of the estimated maximal HR

(65% of [220 (beats per minute) minus age]), corresponding to moderate-intensity exercise. During relaxation, participants were seated in an armchair while listening to relaxing music for 7 minutes. After each session, participants completed three 10-point Likert scales evaluating their subjective feelings of activation, stress, and pleasantness.

Both sessions were followed by a picture-rating task. Participants were told they would see images from television, movies, magazines, newspapers, and advertisements that appeared over the last 20 years. On each block, participants rated their perceived familiarity of the pictures on a horizontal scale from 1 (not at all familiar) to 7 (very familiar). Each trial was preceded by a 1000-ms fixation cross, followed by the 2500-ms picture presentation, and the rating screen. Once both blocks finished, participants completed the paper-version of the BCQ questionnaire, serving as a distraction task. They then completed an “old/new” recognition test on 48 previously presented pictures with an equal number of arousal- and valenced-matched distractors. After each answer, they provided a confidence rating on a 9-point Likert scale (1 = not sure at all, 9 = absolutely sure). Finally, participants filled out computerized versions of the MAIA and BCQ, before being debriefed. HR recordings during this period served as baseline in further statistical analysis. None of the participants questioned the cover story (most thought the study was investigating the effects of sports on memory).

3. Results

3.1 Analysis strategy

We analyzed our repeated-measures data with multilevel models (MLMs), which allow for more effective handling of missing observations, stimulus-level random-effects, and fewer covariance assumptions (West, Galeki, & Welch, 2014). MLMs were generated with the lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2015), using bottom-up model building to achieve the maximal random-effect structure appropriate for the data on both participant and stimulus IDs, allowing for convergence after 10,000 iterations. We used Type III Satterthwaite approximations to obtain p-value estimates, which often result in decimal degrees of freedom (Luke, 2016).

3.2 Heart rates and subjective scale measures (manipulation checks)

Heart rates. We analyzed participants’ percent change from their baseline heart rate (HR), both during cycling/relaxation and after (during their familiarity ratings), using an MLM with Block (2: cycling/relax) x Time (2: during/after) as fixed-effects (see Table 6). All effects were highly significant. A main effect of Block, $F(1,52.36) = 290.72$, $p < .001$, revealed that participants’ HRs were elevated significantly above baseline both during cycling, $t(58.50) = 23.24$, $CI_{95\%}[39.55,47.00]$, $p < .001$, and after cycling, $t(67.40) = 5.61$, $CI_{95\%}$ [4.61,9.72], $p < .001$, whereas HRs were significantly below baseline both during relaxation, $t(80.60) = -2.06$, $CI_{95\%}$ [-4.20,-0.08], $p = .04$, and after relaxation, $t(71.50) = -2.50$, CI95%[-4.88,-0.55], $p = .015$. The main effect of Time, $F(1,63.07) = 269.99$, $p < .001$, only showed that HRs during the block (cycling/relax) were generally greater than HRs after the block (during familiarity ratings).

Finally, the Block x Time interaction, $F(1,102.48) = 427.34$, $p < .001$, demonstrated that while HRs during cycling were significantly higher than HRs after cycling, $t(99.60) = 25.88$, $CI_{95\%}$ [33.34,38.88], $p < .001$, HRs during and after relaxation were not significantly different, $t(103.90) = 0.41$, $CI_{95\%}$ [-2.24,3.40], *ns*.

Table 6
Means and standard deviations for percent change from baseline in heart rate (HR), as a function of Block (cycling vs relax) and Time (during vs after).

	Time	
	During Block	After Block (During Familiarity Ratings)
Block	*M (SD)*	*M (SD)*
Cycling	43.28% (16.02%)	7.21% (7.30%)
Relax	-2.12% (6.95%)	-3.05% (5.45%)

Note. M and *SD* represent mean and standard deviation, respectively.

Subjective activation scales. We also analyzed participants' subjective ratings of activation, stress, and pleasantness by Block (cycling/relax) (see Table 7). Our manipulation had the predicted robust effect on subjective activation, where participants gave higher activation ratings after cycling (vs relaxation), $t(118.00)=18.21$, $CI_{95\%}$[4.11,5.12], $p < .001$. The stress ratings after cycling (vs relaxation) were not significantly different, $t(59.00) = 1.36$, $CI_{95\%}$[-0.15,0.78], *ns*. Finally, participants also gave slightly higher pleasantness ratings after relaxation (vs. cycling), $t(59.00)=2.23$, $CI_{95\%}$[0.08,1.42], $p = .03$.

Table 7
Means and standard deviations for subjective scale measures of activation, stress, and pleasantness, as a function of Block (cycling vs. relax).

	Scale Dimension		
	Activation	Stress	Pleasantness
Block	*M (SD)*	*M (SD)*	*M (SD)*
Cycling	7.05 (1.71)	2.65 (1.60)	6.85 (2.26)
Relax	2.43 (0.96)	2.33 (1.27)	7.60 (2.12)

Note. M and *SD* represent mean and standard deviation, respectively.

Overall, the HR data and subjective scale measures confirmed that participants experienced more objective and subjective physiological activation after cycling (compared to relaxation).

3.3 Familiarity ratings

We analyzed participants' familiarity ratings using an MLM with Block (2: cycling/relax) x Stimulus Valence (2: positive/negative) x Stimulus Arousal (2: low/high) as fixed-effects. Figure 6 displays the key finding. Critically, we observed the predicted Block x Stimulus Arousal interaction, $F(1, 5367.80) = 5.13$, $p = .02$. Participants rated high arousal images more familiar after cycling (vs. relaxation), $t(88.80) = 2.65$, $CI_{95\%}[0.06,0.40]$, $p = .01$, while there was no difference for low arousal images, $t(88.80) = 0.64$, $CI_{95\%}[-0.11,0.22]$, *ns*.

We also observed a marginal main effect of Block, $F(1,57.30) = 3.36$, $p = .07$, demonstrating that cycling led to higher familiarity ratings when collapsing across high- and low arousal stimuli. This aligns with the assumption of a general misattribution effect of post-cycling arousal on familiarity, leading to a significant match-effect for high arousal stimuli (and not low arousal stimuli). Finally, we observed a main effect of Stimulus Valence, $F(1,126.30) = 30.06$, $p < .001$, with positive images being rated as more familiar than negative images.

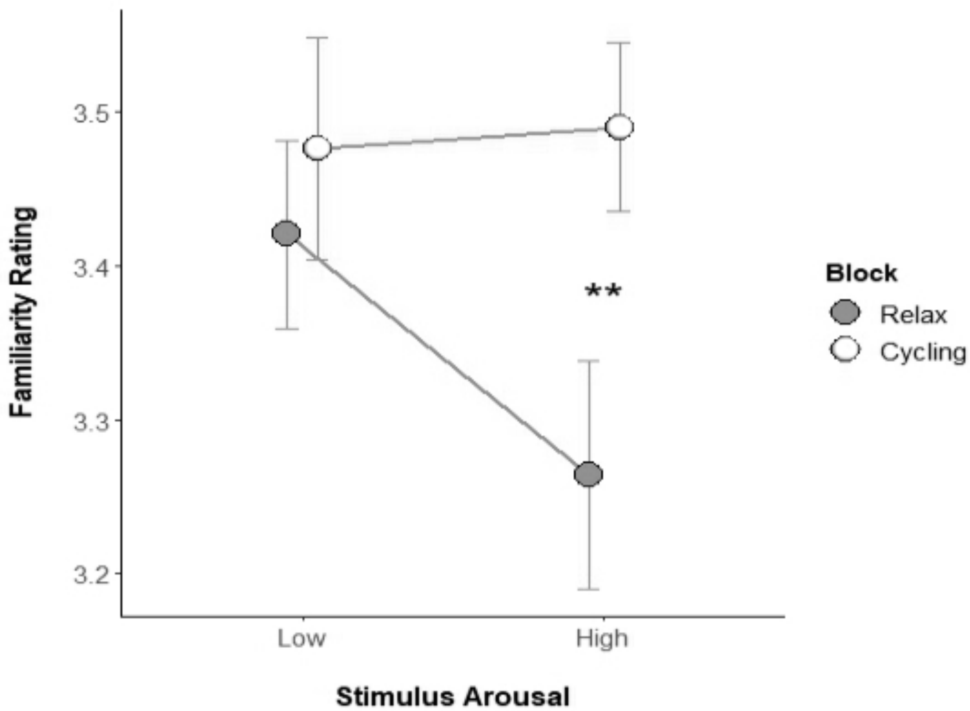

Figure 6. Familiarity ratings by Block (relax vs. cycling) and Stimulus Arousal (low vs. high). Colors indicate Block type. Error bars show ±1 within-subject (repeated-measures) SE. ** $p = .01$

3.4 Individual difference measures

To assess how interoceptive sensibility and bodily awareness measures impacted familiarity ratings, we included total MAIA scores and BCQ subscales as a fourth continuous factor in separate MLMs, along with fixed-effects for Block (2: cycling/relax) x Stimulus Valence (2: positive/negative) x Stimulus Arousal (2: low/high).

MAIA. We observed a MAIA x Block x Stimulus Arousal interaction on familiarity ratings, $F(1,5364.70) = 5.74$, $p = .017$, while the original Block x Stimulus Arousal interaction remained significant, $F(1,5364.90) = 7.69$, $p = .006$. A breakdown of this three-way interaction demonstrated that the familiarity match-effects were localized to participants with lower MAIA scores (see Figure 7).

BCQ. We observed similar three-way interactions for Private BCQ x Block x Stimulus Arousal, $F(1,5131.30) = 7.91$, $p = .005$, and Public BCQ x Block x Stimulus Arousal, $F(1,5130.30) = 4.39$, $p = .036$ (see Figure 7). The Block x Stimulus Arousal interaction also remained significant in both the Private BCQ MLM, $F(1,5127.20) = 10.60$, $p = .001$, and Public BCQ MLM, $F(1,5125.70) = 6.74$, $p = .009$. Once again, the familiarity match-effects occurred more for participants with lower scores on the Private and Public. Interestingly, with the Body Competence BCQ subscale, we did *not* find similar effects. There was no three-way interaction for Body Competence x Block x Stimulus Arousal, $F(1,5091.70) = 1.76$, *ns*, showing that the familiarity match-effects were selective to individual differences on interoception and bodily awareness, rather than to any body-related statements.

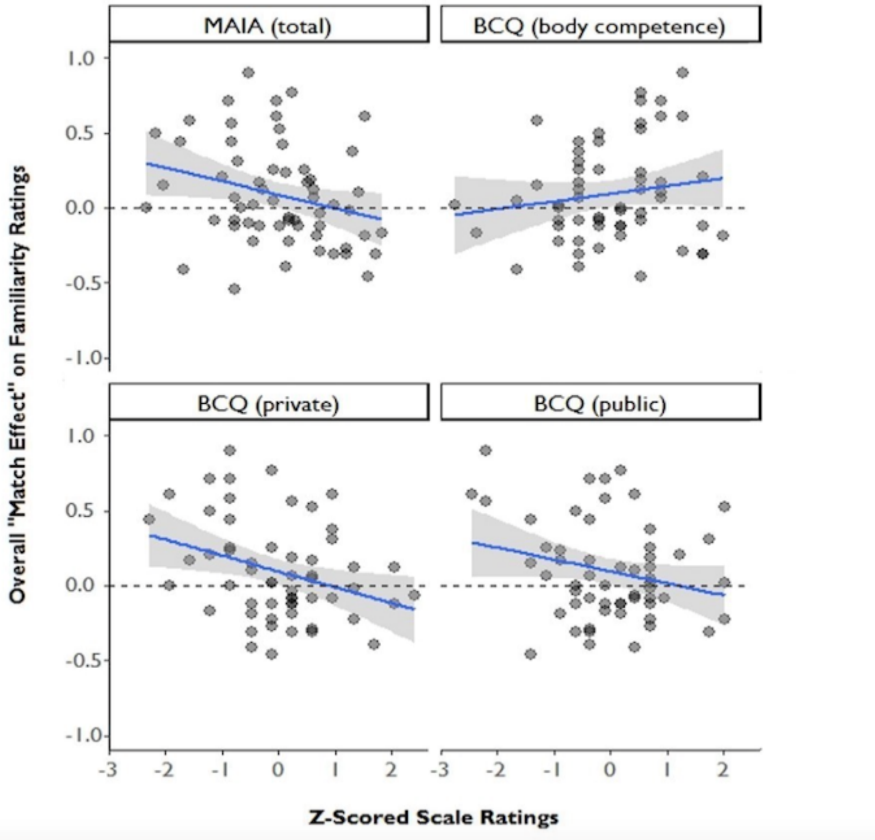

Figure 7. Overall familiarity match-effects collapsed over stimulus arousal (high vs low) and z-scored scale ratings on x-axes (MAIA, BCQ Body Competence, BCQ Private, and BCQ Public). Linear fits are shown in each plot with 95% confidence interval bands. We observed the clearest match-effects between physiology and stimulus arousal on familiarity ratings in participants with low scores on MAIA, BCQ Private, and BCQ Public (but no differences by BCQ body competence).

4. Discussion

To our knowledge, this study offers the first evidence that incidental internal (physiological) and external (stimulus) arousal combine to impact familiarity judgments for novel images. We demonstrated that participants judged highly arousing pictures as more familiar when experiencing higher bodily arousal (post-cycling vs post-relaxation), indicating that subjective stimulus familiarity is augmented when its arousal value matches the physiological state. These match-effects were mainly present in participants with low interoceptive sensibility (IS), supporting our claim that the confusability of bodily signals modulates the impact on familiarity judgments.

Our central findings extend previous research on the link between physiological activity and memory-related judgments. Since the early finding that prosopagnosics show large skin conductance responses when presented with familiar yet unrecognized faces (Tranel & Damasio, 1985), several studies reported physiological arousal responses to previously encountered stimuli (e.g., Morris et al., 2008). Overall, our results seem consistent with ideas of a “visceral fit” (Risen & Critcher, 2011) and excitation transfer theories (Reisenzein, 1983; Schachter & Singer, 1962), which require the simultaneous presence of two elements: bodily arousal and a stimulus that could act as a plausible arousal source. Of interest too, more recent studies revealed significant processing advantages for emotional words matching one’s current arousal states (Kever, Grynberg, et al., 2015; Kever et al., 2017). That is, arousing stimuli do not only alter the bodily state of the perceiver (e.g., heart rate acceleration, heightened electrodermal activity) (Bradley, 2009), but changes in bodily arousal also influence the cognitive accessibility of more or less arousing concepts. The authors rely on an embodied emotion approach to account for their findings, suggesting that concepts are represented together with their modality-specific features (e.g., facial expressions, postures, arousal responses) within a multi-modal associative store (Körner et al., 2015). Experiencing a given arousal level then leads to the activation of arousal-congruent stimuli, which therefore come to mind faster (Clark et al., 1984; Kever et al., 2017).

Note, however, that our match-effect mainly occurred with high arousal stimuli (see Figure 6). This is presumably because cycling also leads to general misattribution of arousal, making all stimuli feel more familiar, even if the effect of the arousal condition was marginal. Relaxation, on the contrary, made high arousal stimuli appear especially *un*familiar. For low arousal stimuli, familiarity is increased to similar levels both after cycling and relaxation, but for different reasons (i.e., a match-effect for relaxation and a general misattribution effect for cycling). On a memory-focused account, one could argue that high arousal stimuli are particularly salient. When in a relaxed state, this salience may further increase (due to the arousal mismatch), leading to a “pop-out” of novelty for high arousal stimuli after relaxation (as seen in Figure 6). Surprisingly, however, results of the administered “old/new” recognition task, did not reveal a memory advantage for high arousal images, challenging the above-mentioned explanation. Given the original character of this study, follow-up studies are clearly needed to provide further insight into the mechanisms underlying the interplay between arousal-congruency and perceived familiarity.

A final outstanding question relates to the role of interoceptive sensitivity (IS) in this context. Previous findings suggest that IS modulates the integration of multi-sensory bodily perceptions (i.e., sense of ownership in the Rubber Hand Illusion; Tsakiris et al., 2011), and that people with low IS show weaker embodiment of weight and softness into social judgments of importance and harshness (Häfner, 2013). The present results, however, revealed more pronounced familiarity-match effects in low IS participants, pointing towards greater influences of bodily processes on subjective judgments. Based on the assumption that low IS individuals cannot easily sense or isolate the physiological condition of their body, they might be more susceptible to attribute their experienced arousal to a plausible external source (e.g., an emotional image) (Garfinkel et al., 2013, 2014), leading to more intense feelings and ratings of subjective familiarity. In support of this assumption, research examining the effects of bodily arousal on height estimates showed that participants who were made aware of the source of their arousal, reduced their height estimations compared to participants who did not receive attribution instructions (Storbeck & Stefanucci, 2014). Similarly, earlier observations suggest that excitation transfer only occurs if the individual does not consciously relate the experienced arousal state to the prior inducing source (Cantor et al., 1975; Zillmann, 1979; Zillmann & Bryant, 1974). In other terms, our findings fit the idea of "source confusion" underlying the moderating effect of IS on body-mind interactions. Nevertheless, further studies should include a broader range of tasks and measures to quantify all dimensions of interoception (Garfinkel et al., 2015; Zamariola et al., 2018), in order to obtain a more complete picture of its role in the interplay between arousal and perceived familiarity.

In conclusion, the present findings contribute to the literature on mind-body interactions and discussions surrounding arousal-familiarity links in the real-world. Our study indeed hints that transient internal states shape subjective beliefs about having witnessed an emotional event, even though no memory trace has been previously encoded.

Chapter 6

General discussion

General discussion

The contributions of bodily states to feelings and thoughts have been debated for many centuries, reaching back from ancient Greek philosophers to contemporary research in psychology and neuroscience. In the present dissertation, we provide new insights into the available knowledge on body-mind interactions by examining whether changes in physiological arousal affect the processing of emotional information. But why did we decide to focus on arousal? Together with behavioral expressions and subjective feelings, arousal responses are considered as one of the central components in recent emotion models (Frijda, 1986; Frijda & Mesquita, 1998; Scherer, 2005). That is, when encountering an emotionally charged stimulus or situation, the organism displays a series of emotional responses, consisting of (1) motor expressions in face, body, and voice; (2) physiological reactivity referred to as arousal (e.g., increased heart rate, respiration rate, blushing); and (3) subjective emotional experience. When reviewing the current state of research, it appears, however, that studies have mainly focused on the motor expression component of emotion while its arousal component has received comparatively little attention. For instance, a large body of evidence suggest that facial expressions, movements, and posture influence the processing of emotional information, and this at various cognitive levels (e.g., detection, categorization, memory, social judgments). Interestingly, many of these findings seem to meet the criteria for so-called congruency effects. Congruency effects typically refer to a processing advantage for information whose emotional connotation matches the mood an individual is experiencing or the behavior he/she is displaying at a given moment. In the general introduction section, we have provided an overview of existing studies revealing processing advantages for stimuli whose valence dimension (positive vs negative) is congruent with one's facial expression (e.g., smiling vs frowning) (e.g., Havas et al., 2010; Niedenthal et al., 2001, 2009), one's (head and arm) movements (e.g., nodding vs shaking) (e.g., Neumann, Förster, & Strack, 2003; Phaf, Mohr, Rotteveel, & Wicherts, 2014; Rotteveel et al., 2015), or one's overall posture (e.g., Dijkstra et al., 2007; Riskind, 1983). In view of these findings, the question arises whether similar effects can be observed when focusing on the arousal component of emotion. Considering that arousal responses play a key role in ancient and current emotion models (James, 1884; Schachter & Singer, 1962; Scherer, 2005), and that emotional stimuli present a valence as well as an arousal dimension (Bradley & Lang, 1994; Russell, 1980), there seems to be a solid theoretical basis to test for potential "arousal-congruency" effects. Surprisingly, however, to date, no consistent line of research has addressed this issue. In an attempt to fil in this gap in the literature, the present dissertation elucidates data of three empirical studies investigating the influence of exercise-induced arousal on the processing of arousal-(in)congruent stimuli.

More precisely, this set of studies aimed at providing first answers to the following outstanding questions: (1) Can arousal-congruency effects be observed in a highly-controlled experimental setting? (2) If yes, are they confined to specific cognitive processes or do they represent a more general phenomenon? (3) And finally, can they, such as mood-congruency effects, be observed when focusing on more subjective evaluations (compared to performance-oriented cognitive tasks)?

1. Summary of our findings

With the above-mentioned questions in mind, we developed an experimental design whose core element consisted of an exercise-induced arousal manipulation. In each of our three main experiments, participants' arousal levels were modified by means of a short cycling and relaxation session, inducing considerable and quantifiable changes in heart rate. In **Study 1**, we examined whether changes in bodily arousal affected participants' detection accuracy in an attentional blink paradigm featuring high arousal (positive and negative), low arousal (positive and negative), and neutral target words (Kever, Grynberg, et al., 2015). Firstly, findings revealed increased reports for high arousal compared to low arousal and neutral T2 words, suggesting that highly arousing materials benefit from an easier access to awareness (e.g., Anderson, 2005; Keil & Ihssen, 2004). Secondly, results indicated a significant interaction between participants' arousal levels (post-cycling vs post-relaxation) and the proportion of high arousal, low arousal, and neutral T2 accurately reported. High arousal words were better reported following the cycling compared to the relaxation, while low arousal words were better reported following the relaxation compared to the cycling. The proportion of neutral word reports did not differ in function of the physiological arousal condition. These findings provide first evidence for the existence of an arousal-congruent processing advantage when stimuli are presented under limited attentional resources. In other terms, the results of our first study support the hypothesis that an arousal-congruency effect can be observed in a paradigm reflecting the temporal costs in allocating selective attention (Dux & Marois, 2009; Olivers & Meeter, 2008).

Motivated through these promising initial findings, we prepared our second study, which aimed at investigating whether arousal-congruency effects are not only confined to an AB paradigm, but can also be observed when different cognitive processes are at hand. We decided to rely on a constructive recognition task (CRT), in which an initially masked item appears gradually (Fiedler et al., 2001; Unkelbach, Guastella, et al., 2008). Given that the CRT calls for active, knowledge-based inferences to retrieve the emerging word from memory, it nicely complements the AB paradigm, which measures, amongst others, stimulus access to working memory (Olivers & Meeter, 2008). The design of Study 2 was equal to that of Study 1 with exception of the CRT replacing the AB task. Importantly, the main study was preceded by a preliminary study (**Study 2a**) comparing a semantic categorization version (i.e., emotional vs non-emotional) to a lexical decision version (i.e., word vs non-word) of the CRT (Kever, Grynberg, Szmalec, Smalle, & Vermeulen, 2019). Results from both tasks revealed faster recognition times for high arousal compared to low arousal words, and for positive compared to negative and neutral words. Those results were replicated in the subsequent **Study 2b**, examining the effects of exercise-induced arousal on CRT performances (Kever et al., 2017). Furthermore, findings showed that low arousal words were categorized significantly faster after the relaxation than after the cycling, suggesting that a decrease in bodily arousal promotes the recognition of stimuli matching one's current arousal state. Study 2 thus provides further evidence for an arousal-congruent processing advantage, namely in a task calling for active inferences to reconstruct information based on previous memory-stored knowledge. Overall, the results obtained in Study 1 and 2 suggest that **(1)** arousal-congruency effects occur in a highly-controlled experimental setting, and **(2)** can be observed in different cognitive paradigms involving selective attention and short term memory storage, as well as active retrieval from semantic memory.

In our final **Study 3**, we shifted our focus from cognitive performance to subjective judgments. More specifically, we investigated whether arousal-congruency effects can be observed when participants are instructed to provide judgments of perceived familiarity for high- and low arousal (positive and negative) pictures they have never seen before. Participants could thus not rely on previously acquired knowledge to evaluate the pictures, leaving them with very little cues to inform their judgments. Consequently, it can be assumed that available bodily cues, such as arousal responses, become increasingly relevant when searching for information to substantiate one's (purely subjective) judgments. Results revealed a main effect of picture valence, with positive pictures being rated as more familiar than negative pictures. Of particular interest, however, results also showed the predicted bodily arousal - stimulus arousal interaction, pointing towards arousal-congruent familiarity judgments. In fact, participants judged highly arousing pictures as significantly more familiar when experiencing higher bodily arousal (post-cycling vs post-relaxation), while judgments of low arousing pictures remained unaffected by differences in bodily arousal. These findings thus indicate **(3)** that arousal-congruency effects are not confined to performance-oriented cognitive tasks, but also occur in the context of subjective judgments.

As mentioned above, the main purpose of our studies was to investigate potential arousal-congruency effects while focusing on the influence of exercise-induced bodily arousal on the processing of emotional stimuli. Our findings, however, did not only provide first answers to this central research question, but also led to series of interesting data regarding the role of valence and arousal in word processing. Before diving into the topic of arousal-congruency, we will thus briefly discuss these findings and confront them with the current state of the literature. Given that 3 out of our 4 studies relied on lexical stimuli, we decided to take a closer look at the effects of arousal and valence on written word processing, instead of focusing on pictorial stimuli.

2. Word processing: Do arousal and valence play a role?

According to Russel's circumplex model of affect (1980), valence describes the extent to which a stimulus is positive or negative, while arousal refers to its degree of intensity or activation, i.e., how calming or exciting a stimulus is. This two-dimensional approach accounts for most of the variance across evaluative ratings of mood states, facial expression, pictures, and words (e.g., Bradley & Lang, 1994; Lang et al., 1993; Osgood, 1966; Russell, 1980). When stimuli are mapped in affective space they typically show a quadratic relationship, whereby extremely valenced stimuli (positive or negative) also tend to be rated as highly arousing, and negative stimuli tend to be rated as more arousing than positive ones (Bradley & Lang, 1999; Citron, Weekes, & Ferstl, 2014b; Lang et al., 1999). Despite this relationship, a growing body of empirical evidence supports the assumption that valence and arousal are distinct affective dimension. In fact, findings suggest that valence and arousal are associated with different physiological and behavioral responses, and are mediated by partially-dissociable neural structures. Startle eyeblink reactions, for instance, are enhanced when confronted with negative compared to positive stimuli, but remain largely unaffected by differences in arousal (Bradley, Cuthbert, & Lang, 1990; Cook, Hawk, Davis, & Stevenson, 1991). Moreover, neuroimaging data suggest that subjective ratings of valence and of arousal evoked by emotional sentences or experiences correlate with activation in distinct neural substrates (e.g., Colibazzi et al., 2010; Lewis et al., 2007; Wilson-Mendenhall, Barrett, & Barsalou, 2013).

2.1. Arousal affects word processing

In the current literature, there is fairly strong evidence that valence and arousal exert independent effects on cognitive processing. As mentioned in the general introduction, numerous studies have shown higher identification rates for highly-arousing compared to low-arousing stimuli when presented within a temporal stream of information (Anderson, 2005; Aquino & Arnell, 2007; Arnell et al., 2007; Keil & Ihssen, 2004; Mathewson et al., 2008). Research indeed suggest that high arousal is associated with diminished attentional requirements for stimulus detection and consolidation, thereby rendering these events more accessible to consciousness (Anderson, 2005). The results we observed in Study 1 support this assumption by showing significantly higher report rates for high arousal compared to low arousal T2 words, and this independently of valence. Our findings thus nicely complement previous findings suggesting that arousing stimuli are less susceptible to the AB, leading to higher accurate report rates. However, even though the privileged attentional status of highly arousing information has been shown repeatedly, a certain unanimity prevails over its underlying mechanisms.

Over the years, different theoretical models have been proposed, most of which attribute the AB to a limited-capacity processing stage or bottleneck (for review, see Dux & Marois, 2009). The two-stage model (Chun & Potter, 1995), for instance, states that the stimulus features of T1 and T2 are processed in parallel before entering a second stage, where they are consolidated into a more durable format able to enter working memory. The second stage, however, presents limited capacities, increasing the probability that the fragile T2 representation gets lost while resources are preoccupied with the processing of T1 (for similar proposals, see also Broadbent & Broadbent, 1987; Jolicoeur & Dell' Acqua, 2000; Potter, Staub, & O'Connor, 2002). Based upon this model, one can thus assume that highly arousing stimuli are less prone to decay, bridging the gap in time where cognitive resources are temporarily unavailable, facilitating their access into awareness (Anderson, 2005). More recently, Olivers and Meeter (2008) have proposed a "boost and bounce" model of temporal attention, attributing the AB to a selection deficit rather than a capacity limitation. In a first step, representations of perceptual features (e.g., shape, orientation) as well as semantic and categorical information are activated for each stimulus. Subsequently, the generated representations attempt to enter working memory. To do so, they have to pass a rapidly responding input filter (or gating system) boosting the entrance of relevant information (i.e., target-like features) and inhibiting (bouncing) the entrance of irrelevant information (i.e., distractor-like features) into working memory. The detection of T2 is thus often difficult because it follows a series of inhibited distractors. In the light of this model, it could be suggested that the pronounced emotional salience of highly arousing stimuli allows the input filter to differentiate more easily between distractor and target, switching more quickly from inhibition into boosting mode, and thus facilitating the entrance of arousing T2 into working memory. Although purely hypothetical in nature, this explanation presents an interesting addition to the classic bottleneck theories, not least because the boost and bounce approach allows to explain findings the capacity-limit framework could difficultly account for (e.g., high performance for T2 when it immediately follows T1; Lag-1 sparing; for a detailed discussion see, Olivers & Meeter, 2008). Of interest too, Anderson and Phelps (2001) observed enhanced AB performance for highly arousing compared to neutral T2 words in healthy participants, while patients with bilateral amygdala damage did not show such enhancement. Especially patients with left amygdala lesions did not show the typical detection advantage for arousing stimuli, even though they exhibit normal subjective and psychophysiological responses when encountering the latter in a memory task (LaBar & Phelps, 1998; Phelps et al., 1998). Accordingly, the amygdala is considered the central neural substrate orchestrating the modulatory influence of arousal on attention. In fact, Anderson and colleagues (2005; 2001) suggest that the special attentional status of both positive and negative high arousal stimuli in the AB is attributable to amygdala activity. Despite these promising findings, further research seems necessary to disentangle the exact neural mechanisms by which the amygdala affects the processing of high arousal information in AB paradigms. A tentative explanation states that the amygdala modulates a larger network of cortical regions involved in information processing, leading to increased perceptual sensitivity to stimuli of potential importance for the organism (e.g., highly threatening), requiring less attentional resources to achieve awareness (Anderson & Phelps, 2001).

Importantly, we did not only observe a processing advantage for high arousal compared to low arousal words in our AB study, but found confirming results in subsequent studies (2a and 2b) using a constructive recognition task (CRT). As explained earlier, the CRT consists in the gradual presentation of an initially masked target, which participants have to categorize as quickly as possible. Given that the CRT asks for active, knowledge-based inferences to generate the meaning of the appearing word, it allows to investigate whether differences in stimulus arousal (and valence) influence retrieval from semantic memory. In both studies, results consistently showed faster categorization times for high arousal compared to low arousal words. In fact, the same arousal-effects were observed in a semantic categorization version (emotional vs non emotional) and a lexical decision version (word vs non-word) of the CRT, leading to three converging findings. Interestingly, these findings are in line with previous CRT results, indicating faster categorization times for threat-related (highly arousing) compared to sadness-related (low arousing) words (Guastella, Kenyon, Unkelbach, Alvares, & Hickie, 2011; Unkelbach, Guastella, et al., 2008).

However, not all findings support the assumption of faster response times for highly arousing compared to low arousing stimuli. In fact, studies relying on lexical decision paradigms (i.e., word vs non-word), have yielded partially diverging results. While some found that exciting words were recognized faster than calming words (Estes & Adelman, 2008a; Larsen et al., 2008), others observed no effect of arousal on lexical decision times (Kousta et al., 2009), and yet others reported faster recognition for low arousal compared to high arousal words (Kuperman et al., 2014). In view of these discrepancies, there is currently no generally accepted framework accounting for the role of arousal in lexical decision. In fact, previous work mainly focuses on the influence of lexical and semantic control variables (e.g., lexical density: orthographic, phonological, and phonographic neighbors), whereas underlying mechanisms for the observed effects remain largely unexplored, calling for further research.

Although no absolute consensus has yet been reached, a large body of evidence suggest that highly arousing stimuli benefit from a cognitive processing advantage. Our findings clearly support this assumption, while emphasizing at the same time that arousal presents a central stimulus dimension that necessarily needs to be controlled for when working with emotional materials. In both the AB paradigm and the CRT, we observed significantly better performances for high arousal compared to low arousal and neutral stimuli.

With respect to the AB, reflecting the temporal costs in allocating selective attention (Raymond et al., 1992), the “boost and bounce” theory (Olivers & Meeter, 2008) provides a particularly appealing interpretation. As above-mentioned, the latter defines the AB as a selection deficit that is not caused by capacity limitations but by a working memory gating system, facilitating/inhibiting the entrance of relevant/irrelevant information, respectively. Considering that high arousal words are particularly salient, one can assume that they pop-out more easily within a stream of distractors (Harris & Pashler, 2004; Lamy, Amunts, & Bar-Haim, 2008), and thus suffer only little from the competition of the surrounding items. More precisely, their pronounced distinctiveness allows the gating system to recognize them more easily, facilitating their entrance into working memory (increased boosting feedback), and leading to higher proportions of correctly reported words. Of interest too, while other models adhere to a amodal, symbolic representation of concepts (e.g., Chun & Potter, 1995; Potter et al., 2002), Olivers and Meeter’s (2008) do not settle clearly the way information is represented (Vermeulen et al., 2009). Consequently, their model does not preclude a modal grounding of (emotional) concepts, which nicely fits our observation of an arousal-congruent processing advantage in the AB.

With respect to the CRT, involving a knowledge-based, active recognition process, convincing explanatory frameworks seem to be lacking. Although we observed faster response latencies for high arousal compared to low arousal and neutral words in both our studies (2a & 2b), further research reports partially diverging results without expanding on potential underlying mechanisms (e.g., Kuperman et al., 2014). Given that the AB and the CRT rely on different cognitive processes (selective attention/short term memory vs retrieval from semantic memory), it seems injudicious to extrapolate the latent mechanisms from one task to another. One could, at most, reconsider the aforementioned idea of a “pop-out” effect, and tentatively hypothesize that highly arousing concepts require less external stimulus input (i.e., less visible word fragments) to be correctly recognized. Nevertheless, it seems at this time premature and presumptuous to make further conjectures regarding the mechanism accounting for the processing advantage of high arousal words in the CRT.

2.2 Valence affects word processing

Other than the effects of arousal on word processing, our findings also shed new light on the role of valence in this context. In both the AB paradigm and the CRT, we observed better performance for positive compared to negative and neutral words. Although unmentioned in the published article, our AB results revealed a main effect of T2 valence, $F(2,71) = 7.43$, $p < .01$; $\eta^2 p = 0.1$, with positive words reported more accurately ($M = .71$; $SE = .03$) than negative ($M = .67$; $SE = .03$), $t(72) = 2.62$, $p < .05$, and neutral words ($M = .62$; $SE = .03$), $t(72) = 5.57$, $p < .001$. Besides, negative words were significantly better reported than neutral words, $t(72) = 3.26$, $p < .01$. With respect to the CRT (study 2a), we observed faster categorization times for positive compared to negative and neutral words in both the semantic and the lexical decision version of the task (Kever et al., 2019). These findings were replicated in our main study (2b), which also revealed faster RTs for positive compared to negative and neutral words (Kever et al., 2017).

In the current literature, a large body of findings corroborates the hypothesis that emotional stimuli benefit from a general processing advantage compared to neutral stimuli (e.g., Kanske & Kotz, 2007; Kousta et al., 2009; Vinson, Ponari, & Vigliocco, 2014). However, the evidence, for an advantage in processing positive versus negative information remains largely inconclusive. Over decades of research, many studies have suggested that negative stimuli benefit from adaptive priority, leading to an early processing advantage – a phenomenon termed *automatic evaluation* (or *negativity bias*) (Flykt, 2006; Öhman et al., 2001; Öhman & Mineka, 2001). Concretely, from an evolutionary standpoint, it seems highly functional for a negative stimulus (e.g., a hungry lion) to be detected as fast as possible, whereas it is less important for a positive stimulus (e.g., a pretty butterfly). Hence, it has been assumed that it requires less input to detect a negative word compared to a positive word (e.g., Dijksterhuis & Aarts, 2003; Nasrallah et al., 2009; Rozin & Royzman, 2001). Several findings indeed suggest that people preferably attend, detect, encode, and retrieve negative information. For instance, negative stimuli have been shown to be less susceptible to the AB effect (e.g., Kihara & Osaka, 2008; Ogawa & Suzuki, 2004), and to be categorized faster than positive words (e.g., Nasrallah et al., 2009).

Other studies, however, have found no asymmetries between positive and negative words, with faster processing for both positive and negative stimuli compared to neutral ones (e.g., Kanske & Kotz, 2007; Kousta et al., 2009; Schacht & Sommer, 2009; Scott, O'Donnell, Leuthold, & Sereno, 2009; Scott, O'Donnell, & Sereno, 2012, 2014; Zeelenberg et al., 2006). From a theoretical perspective, the latter findings support the model of motivated attention and affective states proposed by Lang and colleagues (Lang, 1995; Lang, Bradley, & Cuthbert, 1990, 1997). According to the latter, attention is captured and sustained by motivationally-significant stimuli, regardless of polarity. That is, stimuli which are important for adaptive, preservative, or protective functions are preferentially processed, with no difference between (appetitive) positive and (aversive) negative stimuli.

Of interest too, a growing body of evidence indicates positivity advantages in stimulus processing. Results revealed, for example, greater sensitivity (d') to briefly masked positive compared to negative words (Snodgrass & Harring, 2004), and faster evaluation times (e.g., good vs bad) for positive words compared to negative ones (e.g., Balota et al., 2007; Bargh, Chaiken, Raymond, & Hymes, 1996; Bayer et al., 2012; Palazova et al., 2011; Unkelbach, 2010, 2012; Unkelbach, Fiedler, et al., 2008). In line with these findings, our own experiments revealed higher detection rates for positive compared to negative words (Study 1, AB task) as well as faster categorization times for positive compared to negative words (Study 2a and 2b, CRT).

Although rather unexpected, the preferential detection of positive words in the AB seems in line with previous findings suggesting that romantic and erotic pictures of couples capture attention to a greater degree than other types of stimuli (e.g., fear, disgust, and neutral pictures) (Ciesielski, Armstrong, Zald, & Olatunji, 2010; Most et al., 2007; Piech, Pastorino, & Zald, 2010). Moreover, de Oca and colleagues (2012) observed enhanced reports of pleasant T2 pictures within at set of 3 AB experiments. The authors interpret their findings based on a motivational relevance account, suggesting a processing advantage for stimuli assessed as subjectively relevant (versus "evolutionary" relevant). That is, stimuli related to positive events like parties, relationships, or money might be particularly relevant to a sample of young university students while negatively valenced items are less important to them (see also, Fox, Griggs, & Mouchlianitis, 2007). In the same vein, appraisal theories (Frijda, 1988; Sander, Grafman, & Zalla, 2003) propose that stimuli relating common source concerns are appraised as particularly relevant and are thus granted privileged attentional status. For instance, stimuli referring to offspring caregiving (e.g., *baby*, *cuddle*), reproduction (e.g., *orgasm, love*) achievements (e.g., *diploma*, *win*), and values (e.g., *security*, *friendship*) are defined as generally relevant across individuals, are relatively stable, and easily recognized (Frijda, 2009; Pool et al., 2016). Hence, these affectively relevant stimuli are faster detected than competing neutral and negative stimuli (Pool et al., 2016). Furthermore, research on the neural network of emotional attention suggests that the amygdala detects stimulus' relevance, enhances its cortical perceptual representation, and thus increases its salience and its likelihood to be detected (Brosch, Sander, Pourtois, & Scherer, 2008; Sander et al., 2003). Besides, additional findings defining the amygdala as vital structure of the reward circuit (Murray, 2007) further support the idea of its involvement in positive stimulus processing.

With respect to our findings, further studies seems necessary to investigate whether a relevance-related mechanism might underlie the report advantages for positive compared to neutral and negative T2 words in the AB. That is, follow-up experiments could use positive stimuli relevant to common concerns (e.g., related to nourishment, reproduction, success), as well as stimuli without specific relevance (e.g., related to sports, nature) to disentangle the role of stimulus relevance in emotional attention.

Regarding the CRT, previous studies show partially supporting results, reporting faster RTs for positive words (un)related to happiness (e.g., *virtue*, *elated)* versus negative words (un)related to sadness (e.g., *crime*, *upset*) (Unkelbach, Guastella, et al., 2008), as well as for positive relationship-related words (e.g., *love*) compared to negative relationship-related words (e.g., *hate*) (Guastella et al., 2011). These findings should, however, be interpreted with caution given that measures of word arousal were lacking (see introduction, point1. for a detailed discussion about the importance of arousal in word processing). Regarding the underlying mechanisms of this positivity advantage, an interesting framework has been proposed by Unkelbach and colleagues (2010, 2012; 2008). Their *density hypothesis* is based on the assumption that positive information is more similar to other positive information than negative information is to other negative information (Unkelbach, Fiedler, et al., 2008). If represented within a multidimensional affective space, positive stimuli present more densely clustered representations in memory than negative ones. Consequently, if a positive stimulus enters the cognitive system it will activate a greater number of other positive stimuli than a comparable negative stimulus would (e.g., *happy* will activate *good*, but *sad* will not activate *evil*). This higher overall memory response from a positive stimulus leads to faster response times and fewer errors compared to negative information. In other words, a prompt related to a positive target will activate a large number of associated items, which in turn facilitates the response "*positive*" (Unkelbach, 2010, 2012; Unkelbach, Fiedler, et al., 2008). Although not explicitly mentioned by the authors, their model seems to imply that task instructions play a critical role in the emergence of a positivity advantage in categorization tasks. That is, when instructed to classify words as either positive or negative, the close density of positive stimuli might actually speed up decision times given the initial presence and activation of a positive prompt. In a classic lexical decision task, however, the higher density of positive information seems to be a structural property with no inherent advantages. It thus appears that the density hypothesis presents an interesting model to account for some of our results (i.e., faster categorization of positive words in the semantic categorization version of the CRT), while other results require complementary explanations to be fully elucidated (i.e., positivity advantage in the lexical decision version of the CRT).

On the whole, the literature on the role of valence in word processing appears largely inconsistent, resulting in a lack of generally accepted models and theories (for review, see Brosch et al., 2010). Regarding the AB paradigm, the current state of research does not yet provide a convincing framework accounting for the positivity advantage we observed in the latter. In fact, most studies either do not enlarge upon the underlying mechanisms of their observations, or offer vague, non-specific explanatory approaches (e.g., Anderson, 2005; Ciesielski et al., 2010; Kuperman et al., 2014). At this point, appraisal theories (Brosch, Sander, Pourtois, & Scherer, 2008; de Oca, Villa, Cervantes, & Welbourne, 2012; Frijda, 2009) seem to provide the most compelling - although not entirely satisfactory- explanation for the observed positivity bias. However, before delving more deeply into the issue of underlying mechanisms, it seems necessary to replicate our findings, especially in view of their novel, unexpected character (see de Jong, Koster, van Wees, & Martens, 2009; Kihara & Osaka, 2008; Mathewson et al., 2008; Ogawa & Suzuki, 2004 for results indicating a negativity bias in the AB paradigm). With respect to the CRT, all three of our studies revealed faster categorization times for positive compared to negative and neutral words, supporting the assumption of a ubiquitous positivity advantage in processing speed in classification (Unkelbach, 2012). From a theoretical perspective, the above-mentioned density hypothesis (Unkelbach, 2012; Unkelbach, Fiedler, et al., 2008), appears to be of particular interest when searching for the mechanisms underlying our findings. However, as with the role of arousal in word processing, it seems at this point presumptuous to pretend that we can make strong statements regarding the exact mechanisms accounting for the positivity advantages we observed in both the AB paradigm and the CRT. Within the framework of this research project and dissertation, we remain at a rather speculative level, while (critically) considering existing models and theories.

To finish with, it should be mentioned that none of our studies revealed an interactive influence of valence and arousal on word processing. Contrary to a series of studies reporting faster lexical decision times for high arousal negative compared to low arousal negative words (Bayer et al., 2012; Hofmann, Kuchinke, Tamm, Võ, & Jacobs, 2009; Larsen et al., 2008), our results showed independent effects of both arousal and valence. These observation fit the assumption that valence and arousal present distinct, orthogonal emotion dimensions (Russell, 1980), but do not suffice to draw further conclusions about a potential relationship between valence and arousal. Although our word sample has been pre-tested and we controlled for main lexico-semantic variables (i.e., valence, arousal, frequency, summated bigram frequency, number of letters, orthographic neighbors), it cannot be excluded with absolute certainty that the specific characteristics of our sample have had an influence on the observed results.

3. Arousal-congruent processing advantages

As mentioned above, our research project primarily aimed at investigating whether changes in bodily arousal influence the processing of arousal-(in)congruent stimuli. Overall, our results point towards a processing advantage for information matching an individual's current arousal state – a phenomenon we have termed "arousal-congruency effect". This new evidence, however, also raises new questions. Especially the question of the psychological mechanisms underlying our findings calls for answers. Given the relative novelty of the arousal-congruency effect, there is, to date, no ready-to-use model allowing to account for our findings. However, the literature provides a series of interesting frameworks that we relied on to formulate a tentative explanation for our observations. In what follows, we will expand on *associative network models* and on *embodied cognition (and emotion) theories*, while discussing their respective interest with regards to our research. Furthermore, we will propose a combined *embodied network model* to account for our findings.

3.1 Associative network models

When looking back at research in the mid-twentieth century, it becomes striking that work on the relationship between affect and cognition was predominantly based on models of information storage and retrieval for their explanatory frameworks (e.g., Bower, 1981; Collins & Loftus, 1975; Fiedler, 1990; Fodor, 1975; Forgas, 1999; Isen et al., 1978; Pylyshyn, 1984). Perhaps the most influential model has been the *associative network theory of affect* (Bower, 1981; Isen et al., 1978). Variations of this model hold that knowledge units (or concepts) are represented as nodes within an associative network. These nodes are interconnected by pathways that reflect the strength of their semantic association. That is, connected items (e.g., dog-cat, happy-birthday) lie close to each other and present strong connections, whereas unrelated or dissimilar items (e.g., dog-banana, happy-failure) are characterized by distant nodes and weak connections. When a node is activated, linked nodes are also activated via *spreading activation*. The amount of transported activation, however, decreases with the associative distance from the initially activated node (i.e., the stronger the link between nodes, the greater the probability that they will be activated). The same model applies to affective states, with mood and emotions being represented in memory like any other concept, namely as nodes connected by associative links (Bower, 1981; Carr, Kever, & Winkielman, 2018; Forgas, 1999; Niedenthal, 2008). For instance, nodes representing the events, beliefs, antecedents, behaviors, and physiological patterns associated with anger are closely linked to the network's anger node. Consequently, when an affective state is experienced, the relevant node is activated and activation spreads to associated nodes, facilitating access to those concepts, which, in turn, influences subsequent information processing (Bower, 1981; Niedenthal, 2008).

Network models have typically been applied to account for mood-congruency, a notion that refers to the cognitive processing advantage of information that matches the affective state an individual is currently experiencing (Ellis & Ashbrook, 1989). With respect to memory, findings indeed revealed that participants in an elated mood are more likely to recall positive than negative stimuli, while the opposite effect appears for participants in a depressed mood (e.g., Ellis & Ashbrook, 1989; Fiedler et al., 2001; Kuiken, 1989). When applied to attention, the network model predicts that stimuli congruent with one's affective state are detected with greater efficiency than incongruent stimuli – an assumption supported by numerous empirical findings (e.g., Forgas, Bower, & Krantz, 1984; Niedenthal & Setterlund, 1997, 1994) (see also section 2.3 for further details).

However, despite its large prevalence in the mood literature, the associative network model presents a series of weaknesses. For instance, the anticipated mood-congruency effects appeared to be less robust than initially expected. In fact, several studies failed to replicate mood-depended memory effects (for review, see Blaney, 1986; Bower & Mayer, 1985; Parrott & Sabini, 1990), leading to a certain confusion in the field. The absence of effects was variously explained as due to a lack of sufficiently intense mood manipulations or a missing causal link between mood induction and experimental task (Forgas, 1999). Furthermore, the associative network model appears to be notoriously difficult to falsify. In fact, it seems that most mood-congruency outcomes can be potentially explained in terms of network principles. This problem mainly arises because it is difficult to provide a complete a posteriori statement regarding the exact concepts that will be activated in a given task (Forgas, 1999). Given that the model assumes that some nodes are biologically wired, while others are the result of personal experiences and cultural learning (Bower, 1981), one cannot predict with absolute certainty how certain concepts are (or are not) related. Even more importantly, major difficulties arise from the lack of clarity regarding the grounding of the concepts in network theories. While some models clearly define the nature of their conceptual nodes (Fodor, 1975; Pylyshyn, 1984; Rumelhart & Norman, 1988), others do not provide explicit information in this respect, above all Bower and colleagues (1981, 1987; 1982). This vagueness, has led subsequent researchers to assume that network models inevitably consider concepts as purely non-perceptual redescriptions of the input from the sensory system. More concretely, a given perception (e.g., viewing a chair) is transduced by an amodal symbol system into a completely new, language-like code, that is inherently nonperceptual (e.g., Fodor, 1975). Consequently, these amodal representations bear no correspondence to the perceptual states that caused them and are thus completely arbitrary (Barsalou, 1999; Niedenthal, 2008). In other terms, perception and cognitive representations take place in two separate, non-interacting systems. By this account, the concept of anger or happiness does not comprise any of its characteristics regarding perception, action, and interoception (Niedenthal et al., 2009). Classic amodal network theories thus fail to account for the influence of bodily arousal on emotional information processing. Consequently, we turned towards alternative models to elucidate the processes underlying our findings.

3.2 Embodied cognition theories

In the course of the last decades, researcher have started questioning the sufficiency of amodal network theories, especially with respect to the representation of emotion knowledge. Consequently, alternative frameworks proposed a way to represent (emotion) concepts while preserving their visual, motor, and somatovisceral characteristics. These so-called *embodied (or grounded) cognition theories* rely on the idea that concepts are represented in the same systems as the perceptual states that produce them (Barsalou, 1999, 2008; Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Gallese & Lakoff, 2005). In other terms, the use of a given concept directly depends on simulations in sensory-motor systems that were active when the original entity (or situation) was encountered. For instance, thinking of a lemon leads to partial re-activations in the brain areas involved when viewing, tasting, smelling, and touching an actual lemon. Nowadays, numerous findings support the assumption that sensory-motor systems play a key role in knowledge access. Firstly, results revealed that participants were faster and more accurate in deciding whether a property was a typical feature of a concept (e.g., BLENDER- loud) after verifying a property in the same modality (e.g., LEAVES-rustling) than after verifying a property in a different modality (e.g., BANANA-yellow) (Pecher, Zeelenberg, & Barsalou, 2003; Vermeulen et al., 2008; Vermeulen, Niedenthal, & Luminet, 2007). Importantly, similar switching cost effects were observed in property-verification tasks with positive and negative concepts (e.g., faster RTs for BABY-babbling following LAUGTHER-loud than following SPIDER-black) (Vermeulen et al., 2007). Moreover, after locating an auditory, tactile, or visual concept, participants were faster in verifying the sensory properties of a concept in the same modality than the previously presented concept. For example, the word BROCCOLI (visual), was followed by faster verification times for DIAMOND-sparkles (visual) compared to BEE-buzzes (auditory). Further evidence for sensory-conceptual interactions stems from interference effects. Findings revealed that short- and long-term memory of concepts related to a visual or to an auditory modality (e.g., LIGHT or SONG) are disrupted by sensory interferences in the same modality (e.g., a cross on the screen or a beep sound) (Vermeulen et al., 2013).

Of interest too, neuroimaging studies demonstrated activation in the brains' motor-systems when listening to action-related words and sentences (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Fadiga, & Pulvermüller, 2010; Tettamanti et al., 2005). In the same vein, word related to odors (e.g., cinnamon) activate olfactory brain regions more strongly than control words (González et al., 2006), and different kinds of visual concepts (e.g., animal names, color words) activate specific inferior temporal areas (where auditory language areas and the visual stream for object recognition converge) (Martin, Wiggs, Ungerleider, & Haxby, 1996; Pulvermüller & Hauk, 2006; Simmons et al., 2007). Of interest too, a single case study showed that damage to the auditory association cortex impairs the processing of sound-related everyday objects (e.g., slower lexical decision times for words like "bell" or "telephone" compared to "chair") (Trumpp, Kliese, Hoenig, Haarmeier, & Kiefer, 2013).

Overall, a large body of evidence supports the grounded cognition framework by indicating that perception and conceptual representations share common sensory-motor resources.

In the context of our research, however, the focus has been put on emotional concepts, that is, on positive and negative words presenting different arousal levels. Consequently, the question arises whether affective concepts are also grounded in modality-specific systems. As briefly mentioned in the introduction (section 2.3), Niedenthal and colleagues (2007, 2008; 2009) have extended the embodied cognition account to emotion knowledge. In this view, processing an emotional concept (e.g., HAPPINESS) involves partial reproduction or *simulation* of the motor, somato-sensory and interoceptive states that occurred when one actually experienced that emotion (e.g., zygomaticus activation through smiling). Although these simulations may not be conscious, full-blown physical emotions, they can be sufficient to influence conceptual processing.

Importantly, a large number of findings in the emotion literature seem consistent with an embodied emotion approach. When taking a closer look, it appears that most of these findings refer to some type of congruency effect, revealing processing advantages for valenced stimuli matching ones facial expression or motor state (see also, p. 23-25). For instance, preventing participants from engaging in emotion-specific muscle movements (e.g., blocking the corrugator "frowning" muscle) can impair accuracy and processing times for emotion-congruent stimuli (e.g., an angry facial expression, a sentence with anger-related content) (e.g., Havas et al., 2010; Niedenthal et al., 2001; Oberman et al., 2007; for a recent review, see Wood, Rychlowska, Korb, & Niedenthal, 2016). Similarly, memory for positive words improved when nodding during encoding (Förster & Strack, 1996), and categorization times for negative words were faster when responding with an avoidance-related movement (Alexopoulos & Ric, 2007; Neumann et al., 2003; Rotteveel et al., 2015; Seibt, Neumann, Nussinson, & Strack, 2008). Overall, embodied emotion theories seem to present a rather convincing approach when trying to account for the numerous emotion-congruency effects one can find in the current literature.

In summary, a glance at the literature reveals two, at first sight contradictory, models, accounting for a variety of affective congruency effects. On the one hand, we have the associative network models (Bower, 1981; Bower & Cohen, 1982), and on the other hand, we have the embodied cognition and emotion accounts (Barsalou, 1999; Gallese & Lakoff, 2005; Niedenthal, 2007; Niedenthal et al., 2009). Both models have their strengths and weaknesses, which has lead us to consider a combined model to account for our findings. The attentive reader has probably noticed that we have not always been as diplomatic in our assumptions. In our first study, our rationale was indeed largely based on the idea of an embodied arousal dimension, while alternative explanations were disregarded (Kever, Grynberg, et al., 2015). With growing knowledge, however, we developed a more critical approach, which has led us to formulate assumptions more carefully, while still considering the embodied emotion account as noteworthy and highly captivating.

3.3 A combined model to account for our findings?

As explained earlier, mood congruency effects have been mainly explained in terms spreading activation within an associative network, where emotion are stored as nodes and connected by associative linkages. Although several models clearly state that concepts are amodal (Fodor, 1975; Pylyshyn, 1984; Rumelhart & Norman, 1988), other models remain rather vague about the format under which information is represented (e.g., Bower, 1981). This has led us to propose a combined *embodied network* account, suggesting that emotion concepts are represented as a node within an associative network, but not in an amodal manner. On the contrary, a given emotion concept is stored together with its modality specific characteristics. For instance, the concept of HAPPINESS is represented as a node surrounded by its associated facial expressions, expressive behaviors, autonomic reactions, and evoking situations. Applied to our findings, the following framework could be imagined: Highly arousing concepts are stored together with the corresponding high bodily arousal node, whereas low arousing concepts are accompanied by a low bodily arousal node. Consequently, concepts characterized by a similar arousal level lay close together and present strong associative linkages (e.g., TERROR closer to REVENGE than to BOREDOM) (see Figure 8). Being in a certain arousal state (e.g., increased heart rate following a cycling session), then means that the corresponding node is activated. This activation spreads to the related neighboring nodes first, making arousal-congruent stimuli more likely to come to mind than incongruent stimuli. A comparable assumption has been made in the early eighties by Clark and colleagues (1983). They proposed that when information is stored in memory, subjective feelings and autonomic arousal experienced at the same time are also stored, linked to that information. Hence, changes in bodily arousal may serve the role of a retrieval cue for previously stored, arousal-congruent material.

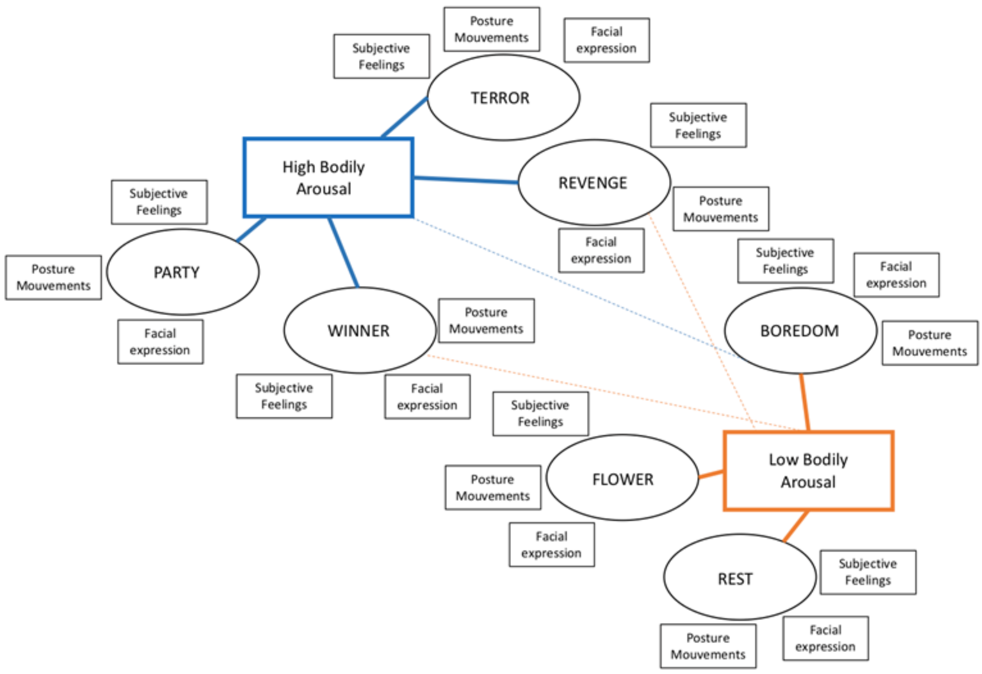

Figure 8. Simplified representation of a small fragment of the associative network containing a series of emotional concept nodes together with their respective embodied features. Bold lines indicate strong linkages, dashed lines indicate weak linkages.

Of interest too, Körner, Topolinski and Strack (2015) recently proposed a series of psychological mechanisms allowing to account for most embodiment effects. Aside from direct state induction and sensorimotor simulation, they referred to *modal priming* as a potential mechanism underlying the influence of bodily states on information processing. In its most basic sense, priming relates to “a procedure that stimulates or activates some stored knowledge” (Higgins, 1996, p.6). Classic views on priming were mainly based on amodal network theories, suggesting that concepts are represented in linguistic forms, such that sematic cues activate other semantically-related concepts (e.g., FAMILY activates MOTHER, SISTER). Multimodal priming accounts, however, state that concepts can also be activated by non-linguistic cues, for instance sensorimotor cues of perceptive experience (Lee, 2016). Research indeed shows that sensorimotor manipulations in different modalities (tactile, olfactory, gustatory) can function as effective primes. A series of findings supporting this assumption comes from studies on emotional language and metaphors. Consider a person you appreciate and that you can confide versus a person you rarely see and with whom you only have few in common – you will probably describe the former as “close” and “warm”, and the latter as rather “distant” and “cold”. Thinking about emotion is thus metaphorically related to the concepts of distance and temperature. In line with this, research revealed that priming participants with the sensations of warmth (by holding a warm coffee mug versus a cold mug) led them to judge an interaction partner as “warmer” (Williams & Bargh, 2008; see also, Kang, Williams, Clark, Gray, & Bargh, 2011).

Similarly, participants recalling a moment of social exclusion estimated the room temperature as lower compared to participants recalling an experience of social inclusion (Zhong & Leonardelli, 2008). Finally, more recent findings indicate that social exclusion may actually lead to lower skin temperature (IJzerman et al., 2012). Comparable results have been found with tactile and kinesthetic experiences of rough vs smooth, or heavy vs light, leading to perceptions consistent with their metaphorically related emotional construct of difficult vs easy (Ackerman, Nocera, & Bargh, 2010), or important vs unimportant (Ackerman et al., 2010; Jostmann et al., 2009; Zhang & Li, 2012).

Overall, multi-modal priming operates similar to classic priming, with the difference that concepts are represented together with their modality-specific features (e.g., facial expressions, movements, posture, subjective feelings, and arousal states). Applied to our findings, one could assume that the arousal manipulation increases the accessibility of associated, arousal-congruent concepts, making them more likely to enter awareness, leading to better reports (in the AB task) and faster categorization times (in the CRT). In other terms, activating a given arousal state (high vs low), leads to the activation of related concepts via spreading activation within a multi-modal store or network. It thus appears that a priming mechanism within a multi-modal, embodied network presents an attractive potential explanation for the arousal-congruent processing advantages we have observed.

Before providing supplementary details about the embodiment and modal-priming accounts, we will devote a few lines to our third study, in which we examined the interplay between bodily arousal and subjective feelings of familiarity. Our findings revealed that participants judged highly arousing pictures as more familiar when experiencing higher bodily arousal (post-cycling vs post-relaxation), indicating that subjective familiarity is augmented if stimulus' arousal matches one's physiological state. In the discussion of our paper, we mainly focused on the positive correlation between bodily arousal and feelings of familiarity (Goldinger & Hansen, 2005; Morris et al., 2008), and only briefly mentioned priming as possible underlying mechanism. Fundamentally, however, nothing seems to speaks against the assumption that a given arousal state facilitates the access to arousal-congruent pictures, always presuming that objects and scenes represented in pictures are, just like concepts, stored as multi-modal representations. In support of this assumption, research has shown that viewing emotional pictures causes physiological responses (skin conductance, startle blink, facial EMG) (e.g., Anders et al., 2004; Lang et al., 1993), which are greater than responses evoked by comparable words (e.g., Larsen, Norris, & Cacioppo, 2003). Furthermore, neuroimaging studies showed that emotionally significant pictures enhanced activity in both the amygdala and the extrastriate visual cortex (Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002; Sabatinelli et al., 2006; Vuilleumier & Driver, 2008). Given that the viewing of a picture is accompanied by bodily reactions, triggering these reactions should have a congruent influence on picture processing. With respect to our findings, one could thus hypothesize that the increase in bodily arousal (post-cycling) primed pictures with highly-arousing content, leading to greater processing ease, referred to as perceptual and conceptual fluency (Schwarz, 1998). The higher fluency, in turn, elicits mild positive feelings (the hedonic fluency model; Winkielman & Cacioppo, 2001; Winkielman, Schwarz, Fazendeiro, & Reber, 2003), leading to enhanced feelings of familiarity. In fact, processing fluency has been shown to have wide-ranging effects on evaluative judgments, including judgments of liking (e.g., Lee & Labroo, 2004; Winkielman & Cacioppo, 2001), trustworthiness (Winkielman, Olszanowski, & Gola, 2015), and familiarity (A. S. Brown & Marsh, 2009; Westerman, Lanska, & Olds, 2015). Concretely, results revealed that increased processing fluency (manipulated by priming or complexity differences) significantly enhanced feelings of familiarity for different types of drawings. In line with the idea of a positivity-familiarity link, earlier studies showed that attractive face are evaluated as more familiar than average ones, and that positive words feel more familiar than negative or neutral ones (Monin, 2003). Even though the modal-priming account only presents a tentative explanation for the arousal-congruency effect in perceived familiarity, the reported sequential link between priming, processing fluency, positive feelings, and increased familiarity provides an interesting base when trying to account for our findings.

Following this brief parenthesis, we are going to discuss the implications the assumption of an embodied modal-priming framework has for further research. More precisely, we address the questions of the testability of the proposed explanatory mechanisms and suggest ways to clarify the boundary conditions of arousal-congruency effects.

3.4 Clarifying underlying mechanisms and boundary conditions

Our research has provided first evidence for arousal-congruency effects in stimulus detection, categorization, and perceived familiarity. As concerns the underlying mechanisms of our findings, we propose an embodied view on modal-priming, which currently, however, must be regarded as merely hypothetical. Consequently, further research is needed to improve our understanding of the role of modal-priming in this context. In what follows, we will first examine the procedural features of the modal-priming account, before recommending possible ways of probing it. Next, we consider ways to better define the characteristics and boundary conditions of arousal-congruent processing advantages. To finish with, we discuss potential biases and limitations of our experimental designs.

Classic semantic priming is considered bidirectional, meaning that two associated concepts prime each other (e.g., *beach* cues *sand* and *sand* cues *beach*) (e.g., Barr, Vieira, & Rovee-Collier, 2002; Carroll & Young, 2005). Similarly, research points towards the bidirectionality of modal priming effects. Findings on embodied metaphors showed, for instance, that the exposure to fishy smells activates the concept of suspiciousness, and that socially induced suspicion enhanced the correct recognition of fishy smells, but not other smells (Lee & Schwarz, 2012).

In the same vein, evaluations of concepts associated with happiness were accompanied by activation in the zygomaticus muscle (Niedenthal et al., 2009), and mimicry involving zygomaticus activation facilitates the processing of positive language and happy facial expressions (e.g., Havas et al., 2010; Soussignan, 2002; for review, see Wood et al., 2016). With respect to arousal-congruency effects, there is convincing evidence that emotional stimuli alter the bodily state of the perceiver (e.g., heart rate acceleration, heightened electrodermal activity) (e.g., Bradley, 2009; Lang et al., 1993; Purves et al., 2001). Conversely, our findings suggest that changes in bodily arousal affect the processing of emotional stimuli, hinting at a bidirectional priming mechanism.

The most obvious way to further test the modal-priming account would be to examine the effects of bodily arousal on concept accessibility, for instance via a lexical decision task (similar to what we did with the CRT), free associations, or a word stem completion task. Furthermore, priming associations can be arbitrary and flexible, such that conditioned links can alter embodiment effects (Körner et al., 2015). More precisely, one could imagine an experimental design, in which a classic conditioning procedure (e.g., association with high pitched, arousing sounds) transforms random, neutral letter sequences or Chinese symbols into high and low arousal conditioned stimuli. If arousal-congruent processing advantages appear despite the initially non-existent association between bodily arousal and stimulus, modal-priming might be involved. If, on the contrary, highly arousing concepts are not activated by an increase in bodily arousal, the sole involvement of modal-priming account seems rather unlikely.

Of interest too, when reviewing the embodiment literature, one comes across numerous studies relying on interference or blocking procedures to examine the bidirectional link between bodily reactions and information processing (Körner et al., 2015). Findings revealed, for instance, that reading sentences leads to sensorimotor simulations of the content (e.g., motor activity for action-related sentences or emotion-related mimicry for affective content) (e.g., Fischer & Zwaan, 2008; Glenberg & Kaschak, 2002; Niedenthal & Setterlund, 1994; Wood et al., 2016), and, conversely, hindrance of these simulations affects information processing (e.g., blocking facial mimicry (via Botox injections) impairs emotion recognition and the understanding of emotional language; Oberman et al., 2007; Havas et al., 2010; e.g., chewing gum impairs pronounciation and reduces advertisement effects; Topolinski, Lindner, & Freudenberg, 2014). It thus appears that the impediment of task specific bodily reactions presents an interesting method to examine the (causal) role of the latter in information processing. Applied to our studies, one would have to prevent participants from experiencing heightened and/or reduced bodily arousal while maintaining a similar experimental design. One option, requiring strict medical surveillance and expertise, would be the administration of a beta blocker drug, known for slowing down heart rate (Bangalore, Sawhney, & Messerli, 2008). Beta blocker are generally recommended for patients suffering from cardiovascular disturbances, such as arrhythmias or increased risks for cardiac attacks due to high blood pressure (e.g., Bangalore et al., 2008; Salles, Cardoso, Fonseca, Fiszman, & Muxfeldt, 2013).

The intake of a beta blocker should lead to a pharmacological reduction of participants' heart rate when engaging in a cycling session. Assuming that significant changes in heart rate are a prerequisite for the occurrence of arousal-congruency effects, beta blocker administration should reduce (or even impede?) the previously observed processing advantage for highly arousing stimuli. Although interesting, the latter procedure only interferes with the high arousal condition, as it does not allow to prevent heart rate reduction during the relaxation session. A second option to examine the necessity of heart rate changes in arousal-congruency, would be the exposure to false cardiac feedback (e.g., Crucian et al., 2000; Ehlers, Margraf, Roth, Taylor, & Birbaumer, 1988; Gray, Harrison, Wiens, & Critchley, 2007). Concretely, participants will hear amplified versions of their heartbeat, which will be significantly slower or faster than their actual heart rate during cycling and relaxation, respectively. Results of this study will help disentangling the role of actual autonomic arousal responses and of the (inaccurate) conscious perception that one is or is not aroused in the emergence of arousal-congruent processing advantages. Alternatively, participants could simply realize a word processing task in the context of true and false auditory feedback of their tonic heartrate. If perceived arousal surpasses actual arousal, one could expect arousal-congruency effects in the absence of any real bodily change. If, on the contrary, heart rate modifications are indispensable, no arousal-congruent processing advantage should be observed in default of the latter.

Overall, the above-mentioned studies allow to better define and circumscribe the prerequisites and boundary conditions of arousal-congruency effects, without, however, providing clear evidence in favor of a specific theoretical model. The embodied network model, for instance, might account for both the absence and presence of arousal-congruency in the case of missing cardiac changes. In line with the assumption that a stimulus elicits a simulation even without any particular sensorimotor state (Körner et al., 2015; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005; Wilson, 2002), one could argue that the simple thought of being in a highly aroused state suffices to activate highly arousing concepts.

In view of the above, it becomes clear that it is yet premature and difficult to make strong predictions about the mechanisms underlying arousal-congruent processing advantages. Given the originality of our observations and the absence of convincing, ready-to-use explanatory models, we reviewed the literature in an attempt to find potentially applicable theories. First input came from mood-congruency research, which relied on an *associative network model* to account for their findings. Additional contributions came from the *embodied cognition* framework, which views knowledge as grounded in the brain's modality-specific systems. Together, these two models have let us to propose an embodied modal-priming account, according to which changes in bodily arousal activate closely associated, congruent concepts, facilitating the processing of the latter. We believe, however, that we are at this point not in a position to provide incontestable evidence for one or the other theoretical model. Nevertheless, we propose a series of studies whose outcomes allow to further detail the necessary and sufficient conditions for the occurrence of arousal-congruency effects.

4. Perspectives and further studies

Given the relative novelty of our findings, a series of follow-up studies should be considered in order to obtain a more complete picture of the interplay between bodily arousal and emotional information processing. From a personal standpoint, further experiments should primarily focus on the following outstanding issues:

Replicability and generalization of the effects. In a scientific world, where the number of publications would be regarded as secondary, and non-significant effects could be easily published, a systematic replication of each conducted study should be a universal procedure. The current scientific system, however, provides only limited incentive to proceed in this manner. This, together with the temporal and financial restrictions accompanying a Ph.D., has led us to refrain from replicating our studies. Although we have put great effort in pre-testing our tasks and stimuli, controlling for potential moderating variables, and correctly defining sample sizes, a replication process would certainly allow to further strengthen the validity of our findings (see, Świątkowski & Dompnier, 2017 for a discussion about the current replicability crisis in psychology).

On a less moralizing note, follow-up studies should also examine whether arousal-congruency effects emerge in alternative cognitive tasks. To complement findings from the AB paradigm, one could, for instance, rely on a visual word search task (e.g., Brown, 1996; Dampure, Benraiss, & Vibert, 2016) or an emotional Stroop paradigm (e.g., Ben-Haim et al., 2016). The latter traditionally shows slower color-naming times for emotional compared to neutral words, suggesting that emotional relevance causes greater attentional capture (Algom et al., 2004; Burt, 2002). In the context of arousal-congruency, one could examine whether naming times for high and low arousal words vary depending on bodily arousal. Moreover, an experiment investigating the effects of bodily arousal on memory would nicely follow-up with our CRT study. Bodily arousal could either be manipulated before the encoding or before the retrieval of arousal-(in)congruent stimuli. Based on the mood-congruency literature, one could expect better memory performances for congruent materials in both conditions (Kuiken, 1989). Interestingly, the choice of the memory task is of crucial relevance in this respect. In fact, several studies have demonstrated the importance of the type of paradigm employed in mood-memory research (for review, see Ellis & Ashbrook, 1989). For instance, participants showed greater mood-congruent recall in an effortful, difficult task compared to an easy task (e.g., Ellis, 1985; Tyler, Hertel, McCallum, & Ellis, 1979). Furthermore, findings suggest that mood effects are most likely observed in unstructured tasks, where minimal cues are given for retrieval of the targets (e.g., Forgas, 1992, 1995). A free recall tasks, asking for active participation and generative thinking, seems thus more suitable to test for mood-congruency than a strongly cued recall or recognition test (Bower, 1981; Bower & Cohen, 1982; Fiedler, 1990). For example, after studying a list of adjective-noun pairs (e.g., dying-dog, rainy-day, fun-party), a strong cue like “dying” will relatively directly retrieve the stored target “dog” because there are no competing associations. Other cues (e.g., bodily or mood states) become thus unnecessary to facilitate the memory search process. In other terms, individuals are unlikely to rely on other search cues, when adequate retrieval cues are provided, reducing the probabilities to obtain mood-congruent memory effects (Bower, 1981; Fiedler et al., 2001). Also noteworthy, it can be assumed that similar criteria apply to other cognitive tasks. Consequently, one should chose for a sufficiently difficult paradigm, requiring active inferences and leaving enough uncertainty to rely on additional cues to generate answers. The AB paradigm, the CRT, and the subjective familiarity task seem to fulfil those requirements, and thus appeared well-adapted to examine arousal-congruent processing advantages.

Underlying mechanisms. As mentioned above, the issue of the mechanism(s) underlying arousal-congruent processing advantages remains largely outstanding. In a nutshell, theories of embodied cognition and emotion seem to provide interesting input when searching for explanatory frameworks. At this point, it seems, however challenging, if not infeasible, to design experiments providing clear-cut evidence for the involvement of specific embodiment-related mechanisms. Consequently, research should in a first instance aim at obtaining a precise picture of the conditions that need to be met for arousal-congruency effects to occur (e.g., actual increase in heart rate?).

Individual differences. Little is known about the role of individual differences in body-mind interaction effects. Most researches have routinely focused on fundamental cognitive processes without taking further interest in potential moderating variables. A handful of studies, however, suggest that interindividual variations in people's thoughts and feelings influence embodied cognition. For instance, findings revealed that the association between morality and cleanness (Zhong & Liljenquist, 2006) is moderated by differences in participants impulsiveness, god-beliefs, and daily pro-social behaviors (Fetterman, 2016; see also, Moeller, Robinson, & Zabelina, 2008; Sherman, Haidt, Iyer, & Coan, 2013 for findings regarding the role of dominance and pro-sociality). Furthermore, research suggests that differences in the perception and processing of internal bodily signals (i.e., interoceptive sensitivity, IS) moderate embodiment (Herbert & Pollatos, 2012). Studies have indeed shown that higher levels of IS are associated with greater subjective and physiological emotional responses (e.g., Herbert et al., 2007; Pollatos, Herbert, Matthias, & Schandry, 2007; Pollatos, Kirsch, & Schandry, 2005; Wiens, 2005), and that IS modulates the integration of multi-sensory bodily perceptions (i.e., sense of ownership in the Rubber Hand Illusion; Tsakiris et al., 2011). Concrete evidence stems from research showing that the embodiment of weight and softness into social judgments of importance and harshness is moderated by differences in IS. That is, people with low IS showed weaker embodiment effects than those with higher IS (Häfner, 2013). In view of our experiments and findings, variables related to bodily perception and awareness seem of particular interest. Therefore, our third study comprises measures of IS and body consciousness, but revealed rather unexpected results (i.e., greater congruency effects for participants with low IS, see Chapter 5 for more details). Hence, it seems all the more essential to consistently include a set of body-related control variables, such as interoception (Valenza, Citi, Lanatá, Scilingo, & Barbieri, 2014), body self-relation (Cash, 2016), body consciousness (Miller et al., 1981), and body perception (Porges, 1993) in further studies.

Moreover, follow-up studies should include measurements of emotional reactivity (e.g., Mehling et al., 2012; Nock, Wedig, Holmberg, & Hooley, 2008; Preece, Becerra, & Campitelli, 2018), to investigate whether variations in emotion sensitivity, intensity, or persistence impact emotional stimulus processing.

Facilitation and impediment. Moderating conditions that hinder of facilitate bodily influences on cognitive processing remain largely unspecified, calling for further research. Nevertheless, the literature reveals a series of findings pointing towards potential boundary conditions. In what follows, we will touch upon a few of those findings, without, however, providing an exhaustive overview. Storbeck and Stefanoucci (2014), for example, investigated conditions under which arousal does and does not affect height estimates. They observed that height estimates increased following a brief, but not a long delay, from the arousal induction. Furthermore, participants who were made aware of the source of their arousal, reduced their height estimations compared to participants who did not receive attribution instructions. This finding supports earlier observations, suggesting that excitation transfer only occurs if the individual does not consciously relate the experienced arousal state to the prior inducing source (Cantor et al., 1975; Zillmann, 1979; Zillmann & Bryant, 1974). Given that the delay between arousal induction and task administration in our studies was very short, further studies could evaluate whether greater delays affect (potentially decrease?) the occurrence of arousal-congruency effects. Regarding the awareness of the arousal source, we assume that most of our participants made no direct connection between bodily arousal and stimulus arousal. Contrary to the well-known and easily discernable valence dimension, individuals are generally unaware of the less obvious arousal dimension. Consequently, follow-up studies could examine whether arousal-congruency effects do or do not emerge when drawing participants' attention to the different arousal levels of the to-be-processed words.

Of interest too, research suggests that one's current frame of mind moderates the interplay between sensorimotor cues and conceptual processing (Maglio & Trope, 2012). Concretely, findings revealed greater influence of contextual bodily states (e.g., wearing a heavy backpack, holding a heavy clipboard) on distance estimates and importance judgments for participants led to think concretely compared to those thinking abstractly. The authors conclude that abstract thought prevents proprioceptive feedback from informing higher order cognition, leading to weaker embodiment effects (Maglio & Trope, 2012). In contrast, recent results showed that focusing participants' attention on the weight of a heavy clipboard eliminated the effects of weight on judgments of importance (Zestcott, Stone, & Landau, 2017). The potential moderating effects of different cognition styles thus presents another interesting route that deserves to be explored in further embodiment studies.

5. Limitations

No research design is perfect and free from any potential bias – our experiments are no exception to this. What could thus be optimized in further studies? A first point concerns our stimulus selection and categorization. Although the valence and arousal of our stimuli have been evaluated by not less than 100 independent judges, there might remain a part of variance our pre-tests could not account for. While most people would agree that the word “terror” is more arousing than “tear”, there are always exceptions to the rule. Ideally, each participant would thus provide personal arousal and valence ratings for each stimulus, and analyses would be conducted based on the resulting, individual word categories. However, given the large expenditure of time such an approach would require, a pre-test seemed the most appropriate procedure for our purposes.

A second point concerns potential influences of experienced mood during task performance. While participants’ levels of positive and negative affect (PANAS; Gaudreau et al., 2006) were measured at the beginning of the experiment, the cycling and the relaxation session were only followed by a single question assessing participants’ current mood (i.e., pleasantness of session on 10-point Likert scale). These data alone do not allow to rule out with absolute certainty that task performances were (partly) influenced by mood states. Findings indeed showed that consumers make arousal-congruent choices, but only if they are in a positive mood-state. Conversely, experienced arousal during negative mood led to arousal-incongruent choices (Di Muro & Murray, 2010). Further studies should thus consider administering a short, but more detailed, mood questionnaire (e.g., the PANAS) after the arousal manipulations.

Finally, the quality of our studies could have further improved through the addition of a baseline control condition. While we examined CRT performances at baseline heart rate in our pre-test, our AB and familiarity studies are lacking such a control condition. That is, participants only realized the AB/provided familiarity rating while experiencing higher and lower HR compared to baseline. Although the comparison of increased and decreased bodily arousal seemed sufficient for our research purposes, a supplementary condition would have provided further, potentially interesting, comparative data.

Conclusion

Since time immemorial, the relationship between bodily reactions, affect, and cognition has been the source of enduring fascination to philosophers, scientists, and laymen. In the domain of neurosciences and psychology, numerous studies have examined the influence of facial and motor expressions on emotional experience and cognitive processing. Surprisingly, however, there has been only little research on the role of physiological arousal in this respect. In the present dissertation, we attempted to fil this gap in literature by examining whether changes in bodily arousal influence the processing of emotional information. In 3 experiments we investigated the effects of high and low bodily arousal on the detection accuracy (Study 1: attentional blink paradigm), categorization time (Study 2b: constructive recognition task), and perceived familiarity (Study 3) for high and low arousal emotional stimuli. Findings revealed overall better performances for highly arousing words (Study 1, 2a, and 2b) as well as partial processing advantages for stimuli matching participants' current arousal state. Together, those results provide first evidence for the occurrence of "arousal-congruency" effects in cognitive word processing and subjective familiarity of novel pictures. Moreover, the present dissertation encourages future research to investigate the underlying mechanisms accounting for arousal-congruency, while focusing on embodied modal-priming theories. Besides, follow-up studies should address the question of potential interindividual and contextual moderating variables, to provide a more complete picture of arousal-congruent processing advantages.

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Appendix 1

Study 1 (Kever, Grynberg, et al., 2015): List of T1-T2 pairs used in the AB paradigm

Neutral	*Neutral*	*English translation*[1]	
sel	vis	salt	screw
sac	sol	bag	floor
toit	écho	roof	echo
verre	stylo	glass	pen
appel	soupe	call	soup
vitre	évier	window	sink
lettre	cheveu	letter	hair
agrafe	visage	staple	face
montre	anneau	watch	ring
pinceau	journal	brush	newspaper
message	chapeau	message	hat
omelette	comptoir	omelet	counter
thé	son	the	sound
drap	gant	sheet	glove
sens	rail	sense	rail
sable	avion	sand	plane
lacet	carte	lace	card
salle	métro	room	subway
phrase	marché	sentence	market
carton	moment	cardboard	moment
ticket	brique	ticket	brick
plumier	branche	pen-case	branch
tirette	panneau	zipper	panel
bâtiment	lunettes	building	glasses
vue	bus	view	bus
pied	tour	foot	round
radio	tissu	radio	fabric
crème	siège	cream	seat
point	arbre	point	tree
craie	train	chalk	train
salade	dessin	salad	drawing
affiche	bonnet	poster	cap
carotte	tableau	carrot	painting
parking	feuille	parking	sheet
assiette	pantalon	plate	pant
ordinateur	coquillage	computer	shell

[1] Because of language differences, English translations do not always perfectly overlap in meaning with the original French material we used.

Neutral	*High arousal (HA)*	*English Translation*	
clou	viol	nail	rape
trace	crise	track	crisis
liste	orgie	list	orgy
camion	effroi	truck	horror
nombre	salope	number	slut/bitch
couloir	inceste	corridor	incest
drapeau	rancune	flag	grudge
pupitre	couille	desk	« balls/nuts »
triangle	aguicheur	triangle	flirty
fil	pet	wire	fart
banc	sexy	bench	sexy
gomme	désir	eraser	desire
compas	baiser	compass	fuck
pierre	succès	stone	success
crayon	joyeux	pencil	joyful
voiture	gagnant	car	winner
article	sourire	article	smile
ponceuse	champion	sander	champion
bouteille	amusement	bottle	fun
four	vomit	oven	vomit
rang	bite	rank	dick
carré	merde	square	shit
glaçon	stress	ice cube	stress
avocat	menace	lawyer	threat
marteau	douleur	hammer	pain
clôture	meurtre	close	murder
janvier	biroute	January	dick
buisson	terreur	bush	terror
bar	con	bar	schmuck
conjugaison	culpabilité	conjugation	guilt
echo	sein	echo	breast
tasse	génie	cup	genius
puzzle	amitié	puzzle	friendship
poivre	trésor	pepper	treasure
colonne	séduire	column	seduce
poignée	fortune	handle	fortune
envoyer	plaisir	send	pleasure
longueur	richesse	length	wealth
instruction	intelligent	instruction	intelligent
électronique	félicitation	electronic	congratulations
scie	choc	saw	shock
onde	anus	wave	anus
bureau	herpès	office	herpes
goblet	phobie	goblet	phobia
bouchon	panique	plug	panic
cabinet	connard	office	asshole
tablier	putasse	apron	hooker

classeur	incendie	binder	fire
téléphone	hurlement	phone	howl
propriétaire	condamnation	owner	conviction
tapis	jouir	carpet	enjoy
aigle	amour	eagle	love
toupie	cadeau	top	present
armoire	sensuel	cupboard	sensual
étagère	bonheur	shelf	happiness
collier	orgasme	necklace	orgasm
document	médaille	document	medal
buisson	énergie	bush	energy

Neutral	*Low arousal (LA)*	*English Translation*	
fourchette	souffrance	fork	suffering
calculatrice	anniversaire	calculator	birthday
mètre	enfer	meter	hell
cadre	larme	frame	tear
ciseau	colère	scissors	anger
surface	chômage	surface	unemployment
planche	malheur	board	misfortune
marqueur	blessure	marker	injury
serviette	détresse	towel	distress
cd	or	cd	gold
drap	joli	sheet	pretty
pull	voix	sweater	voice
veste	dîner	jacket	dinner
étang	fleur	pond	flower
savon	livre	soap	book
levier	loisir	lever	leisure
papier	parole	paper	word
liquide	cuisine	liquid	kitchen
tabouret	vacances	stool	holiday
cartouche	accident	cartridge	accident
boule	ennui	ball	boredom
barbe	deuil	beard	mourning
ville	perte	city	loss
énoncé	misère	wordings	misery
chariot	chagrin	trolley	grief
horloge	maladie	clock	illness
brouette	gonzesse	wheelbarrow	broad
chaussure	impudique	shoe	indecent
propos	bâtard	words	bastard
nez	âme	nose	soul
clef	ciel	key	heaven
porte	congé	door	leave
titre	bonté	title	kindness
lampe	image	lamp	picture
lavabo	amical	washbasin	friendly

poivre	maison	pepper	house
dicton	bougie	saying	candle
théorie	bouquet	theory	bouquet
courgette	printemps	zucchini	spring
farde	honte	folder	shame
note	peur	note	fear
poste	échec	post	failure
règle	garce	rule	slag
niveau	défaut	level	default
beurre	fatigue	butter	fatigue
plafond	crainte	ceiling	fear
clavier	attaque	keyboard	attack
cuillère	solitude	spoon	solitude
profondeur	dépression	depth	depression
lait	doux	milk	soft
boîte	chaud	box	warmth
champ	sucré	field	sweet
salon	photo	lounge	photo
feutre	soleil	felt	sun
panier	tendre	basket	tender
ballon	beauté	ball	beauty
boisson	caresse	drink	caress
électricité	boulangerie	electronic	bakery
brosse	équipe	brush	team

Study 2a (Kever et al., 2019): List of words used in the constructive semantic categorization and the constructive lexical decision task .

Constructive semantic categorization[2]

Positive High Arousal	*Negative High Arousal*
Aventure	Terroriste
Surprise	Peur
Amour	Haine
Passion	Colère
Erotisme	Détresse
Succès	Phobie
Orgasme	Meurtre
Orgie	Trahison
Energie	Rage
Séduction	Panique
Désir	Inceste
Plaisir	Stress
Diplôme	Terreur
Bonheur	Deuil
Baiser	Viol
Sexy	Accident

Positive Low Arousal	*Negative Low Arousal*
Douceur	Larme
Sagesse	Ennui
Loisir	Effroi
Champion	Divorce
Comédie	Souci
Génie	Fatigue
Bouquet	Crainte
Vacances	Malheur
Tendresse	Défaut
Cadeau	Crainte
Bonté	Solitude
Soleil	Nostalgie
Paix	Chômage

[2] The same set of words has been used in Study 2b (Kever, Grynberg, & Vermeulen, 2017).

Ami	Erreur
Détente	Perte
Congé	Dépit

Neutral	
Onde	Bureau
Compas	Echo
Trace	Poste
Levier	Fer
Couloir	Nez
Lavabo	Toupie
Ciseau	Marteau
Four	Ville
Nombre	Cadre
Plat	Liste
Carré	Camion
Brosse	Classeur
Plafond	Carré
Banc	Feutre
Gobelet	Table
Tente	Tapis

Constructive lexical decision

Positive High Arousal	*Negative High Arousal*
Aventure	Terroriste
Amour	Peur
Passion	Haine
Erotisme	Détresse
Succès	Phobie
Orgasme	Meurtre
Energie	Rage
Séduction	Panique
Désir	Inceste
Plaisir	Stress
Bonheur	Terreur

Positive Low Arousal	*Negative Low Arousal*

Douceur	Larme
Sagesse	Effroi
Champion	Divorce
Comédie	Souci
Génie	Fatigue
Bouquet	Crainte
Tendresse	Larme
Bonté	Défaut
Soleil	Ennui
Paix	Solitude
Détente	Nostalgie
Congé	Erreur
Neutral	
Levier	Bureau
Couloir	Echo
Lavabo	Poste
Four	Fer
Nombre	Toupie
Brosse	Marteau
Plafond	Ville
Banc	Classeur
Gobelet	Carré
Tente	Feutre
Pseudowords	
Vory	Noll
Lube	Holu
Goas	Enol
Eruti	Fahma
Kaydi	Zomot
Bipoc	Tunnu
Vunat	Optau
Omusau	Plieba
Wanuto	Feicca
Virras	Toruru
Ercour	Crahro

Busonnd	Poeardi
Cysopen	Ethatro
Selsbif	Rurecto
Eritaci	Vorulps
Ceveoxol	Exaluces
Luctceum	Veuivell
Dovallos	Bosbiiso

Study 1: Supplementary results

T1 (emotional) and T2 (neutral) reports

With regard to the reports of neutral, high arousal and low arousal T1 (with neutral T2), statistical analyses reveal a main effect of T1 arousal value, F (2, 71) = 10.30, $p < .001$, $\eta^2 = .23$, with high arousal T1 reported more accurately (M = .91 ; SE = .01) than low arousal (M = .86 ; SE = .01), t(72) = 4.04, $p < .001$, and neutral T1 reported more accurately (M = .90 ; SE = .01), than low arousal T1, t(72) = 4.17, $p < .001$. There was no main effect of participants' level of physiological arousal (cycling vs relaxation) and no significant interaction between the physiological arousal conditions and the type of T1 reported.

As for neutral T2 reports (with emotional T1), results show a main effect of T1 arousal value on the report of neutral T2, F (2, 71) = 10.02, $p < .001$, $\eta^2 = .23$, with neutral T2 better reported following high arousal T1 (M = .66; SE = .03) than following low arousal T1 (M = .58; SE = .03), t(72) = 4.39, $p < .001$, and neutral T1 (M = .60 ; SE = .03), t(72) = 3.25, $p <$ .001. Participants' level of physiological arousal (cycling vs relaxation) did not influence T2 reports.

Appendix 2

Positive Affect Negative Affect Scale (PANAS), version française (Gaudreau et al., 2006)

Lisez chaque mot et mettez une croix dans la case qui correspond le mieux à l'intensité de ce que vous ressentez **maintenant**.
"**En ce moment**, je me sens …" (veuillez mettre une seule croix par ligne; s'il vous plaît)

*1= **pas du tout*** *2= **un peu**.* *3= **moyennement**.* *4= **beaucoup*** *5= **extrêmement***

		1	2	3	4	5
1	intéressé(e)…	☐	☐	☐	☐	☐
2	en détresse, bouleversé(e)…	☐	☐	☐	☐	☐
3	gai(e), amusé(e), exalté(e)…	☐	☐	☐	☐	☐
4	agacé(e), énervé(e), perturbé(e)…	☐	☐	☐	☐	☐
5	fort(e), d'attaque…	☐	☐	☐	☐	☐
6	coupable…	☐	☐	☐	☐	☐
7	effrayé(e)…	☐	☐	☐	☐	☐
8	hostile, agressif(ve)…	☐	☐	☐	☐	☐
9	enthousiaste…	☐	☐	☐	☐	☐
10	fier(e)…	☐	☐	☐	☐	☐
11	irritable, irascible…	☐	☐	☐	☐	☐
12	alerte, vif(ve)…	☐	☐	☐	☐	☐
13	honteux(se)…	☐	☐	☐	☐	☐
14	inspiré(e), plein(e) d'inspiration…	☐	☐	☐	☐	☐
15	nerveux(se)…	☐	☐	☐	☐	☐
16	décidé(e), déterminé(e)…	☐	☐	☐	☐	☐
17	attentif(ve), prévenant(e)…	☐	☐	☐	☐	☐
18	agité(e)…	☐	☐	☐	☐	☐
19	actif(ve)…	☐	☐	☐	☐	☐
20	apeuré(e)…	☐	☐	☐	☐	☐

State Trait Anxiety Inventory (STAI), version française (Bruchon-Schweitzer & Paulhan, 1993)

19	Je me sens solide, posé(e), pondéré(e), réfléchi(e)	χ	χ	χ	χ
20	Je me sens de bonne humeur, aimable	χ	χ	χ	χ

Cotation :

Le score anxiété-état varie entre 20 à 80

— Très élevé : > à 65

— Elevé : de 56 à 65

— Moyen : de 46 à 55

— Faible : de 36 à 45

— Très faible :< ou =35

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2	Je me sens en sécurité, sans inquiétude, en sûreté	χ	χ	χ	χ
3	Je suis tendu(e), crispé(e)	χ	χ	χ	χ
4	Je me sens surmené(e)	χ	χ	χ	χ
5	Je me sens tranquille, bien dans ma peau	χ	χ	χ	χ
6	Je me sens ému(e), bouleversé(e), contrarié(e)	χ	χ	χ	χ
7	L'idée de malheurs éventuels me tracasse en ce moment	χ	χ	χ	χ
8	Je me sens content(e)	χ	χ	χ	χ
9	Je me sens effrayé(e)	χ	χ	χ	χ
10	Je me sens à mon aise (je me sens bien)	χ	χ	χ	χ
11	Je sens que j'ai confiance en moi	χ	χ	χ	χ
12	Je me sens nerveux (nerveuse), irritable	χ	χ	χ	χ
13	J'ai la frousse, la trouille (j'ai peur)	χ	χ	χ	χ
14	Je me sens indécis(e)	χ	χ	χ	χ
15	Je suis décontracté(e), détendu(e)	χ	χ	χ	χ
16	Je suis satisfait(e)	χ	χ	χ	χ
17	Je suis inquiet, soucieux (inquiète, soucieuse)	χ	χ	χ	χ
18	Je ne sais plus où j'en suis, je me sens déconcerté(e), dérouté(e)	χ	χ	χ	χ

Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012)

Scoring Instructions

Take the average of the items on each scale.
Note: Reverse-score items 5, 6, and 7 on Distracting, and items 8 and 9 on Worrying.

1. **Noticing:** Awareness of uncomfortable, comfortable, and neutral body sensations
   Q1______ + Q2______ + Q3______ + Q4______ / 4 = ___________

2. **Not Distracting:** Tendency not to ignore or distract oneself from sensations of pain or discomfort
   Q5(**reverse**)______ + Q6(**reverse**)______ + Q7(**reverse**)______ / 3 = ___________

3. **Not Worrying:** Tendency not to worry or experience emotional distress with sensations of pain or discomfort
   Q8(**reverse**)______ + Q9(**reverse**)______ + Q10______ / 3 = ___________

4. **Attention regulation:** Ability to sustain and control attention to body sensations
   Q11_____ + Q12_____ + Q13_____ + Q14_____ + Q15_____ + Q16_____ + Q17_____ / 7 = ________

5. **Emotional Awareness:** Awareness of the connection between body sensations and emotional states
   Q18_____ + Q19_____ + Q20_____ + Q21_____ + Q22_____ / 5 = ___________

6. **Self-Regulation:** Ability to regulate distress by attention to body sensations
   Q23_____ + Q24_____ + Q25_____ + Q26_____ / 4= ___________

7. **Body Listening:** Active listening to the body for insight
   Q27_____ + Q28_____ + Q29_____ / 3= ___________

8. **Trusting:** Experience of one's body as safe and trustworthy
   Q30_____ + Q31_____ + Q32_____ / 3= ___________

Please indicate how often each statement applies to you generally in daily life.

	Circle one number on each line					
	Never					Always
17. I am able to consciously focus on my body as a whole.	0	1	2	3	4	5
18. I notice how my body changes when I am angry.	0	1	2	3	4	5
19. When something is wrong in my life I can feel it in my body.	0	1	2	3	4	5
20. I notice that my body feels different after a peaceful experience.	0	1	2	3	4	5
21. I notice that my breathing becomes free and easy when I feel comfortable.	0	1	2	3	4	5
22. I notice how my body changes when I feel happy / joyful.	0	1	2	3	4	5
23. When I feel overwhelmed I can find a calm place inside.	0	1	2	3	4	5
24. When I bring awareness to my body I feel a sense of calm.	0	1	2	3	4	5
25. I can use my breath to reduce tension.	0	1	2	3	4	5
26. When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing.	0	1	2	3	4	5
27. I listen for information from my body about my emotional state.	0	1	2	3	4	5
28. When I am upset, I take time to explore how my body feels.	0	1	2	3	4	5
29. I listen to my body to inform me about what to do.	0	1	2	3	4	5
30. I am at home in my body.	0	1	2	3	4	5
31. I feel my body is a safe place.	0	1	2	3	4	5
32. I trust my body sensations.	0	1	2	3	4	5

Affect intensity measure (AIM), French version (Mathieu et al., 2014)

Instructions : Les questions suivantes portent sur les réactions émotionnelles aux événements de vie habituels. Merci d'indiquer comment **vous** réagissez à ces événements en inscrivant un nombre entre 1 et 6 (échelle ci-dessous) dans l'espace vide précédant chaque item. Merci de baser votre réponse sur la manière dont vous réagissez et **non pas** sur la manière dont les autres réagissent ou sur comment vous pensez qu'une personne devrait réagir.

Jamais	Presque jamais	Occasionnellement	Habituellement	Presque toujours	Toujours
1	**2**	**3**	**4**	**5**	**6**

1. Quand j'accomplis quelque chose de difficile, je suis ravi(e) ou exalté(e).
2. Quand je suis heureux(se), c'est avec une forte exubérance.
3. J'aime énormément être avec les autres.
4. Je me sens très mal quand je fais un mensonge.
5. Quand je résous un petit problème personnel, je me sens euphorique.
6. Mes émotions ont tendance à être plus intenses que celles de la plupart des autres personnes.
7. Mes périodes d'humeur joyeuse sont si fortes que j'ai l'impression d'être au paradis.
8. Je deviens exagérément enthousiaste.
9. Si je termine une tâche que je jugeais impossible à faire, je me sens en extase.
10. Mon cœur bat vite en attendant un événement excitant.
11. Les films tristes me touchent profondément.
12. Quand je suis heureux(se), c'est un sentiment d'être sans inquiétude et content(e) plutôt qu'excité et plein d'enthousiasme.
13. Quand je parle devant un groupe pour la première fois, ma voix devient tremblante et mon cœur bat vite.
14. Quand quelque chose de bien m'arrive, je jubile habituellement plus que les autres.
15. Mes amis peuvent dire que je suis émotif(ve).
16. Les souvenirs que je préfère sont ceux de périodes où je me sentais content(e) et en paix plutôt que plein d'enthousiasme.
17. La vue de quelqu'un qui est blessé gravement m'affecte profondément.
18. Quand je me sens bien, c'est facile pour moi d'osciller entre des périodes de bonne humeur et des moments où je suis très joyeux(se).

19. « Calme et imperturbable » pourraient facilement me décrire.
20. Quand je suis heureux(se), je me sens comme si j'éclatais de joie.
21. Regarder les images d'un accident de voiture violent dans un journal me donne la nausée.
22. Quand je suis heureux(se), je me sens plein d'énergie.
23. Quand je reçois une récompense, je me sens rempli(e) de joie.
24. Quand je réussis quelque chose, ma réaction est une satisfaction calme.
25. Quand je fais quelque chose de mal, j'ai un sentiment très fort de culpabilité et de honte.
26. Je peux rester calme, même les jours les plus pénibles.
27. Quand les choses vont bien, je me sens comme si j'étais « au sommet du monde ».
28. Quand je suis en colère, c'est facile pour moi de rester rationnel et de ne pas réagir trop fort.
29. Quand je sais que j'ai fait quelque chose très bien, je me sens détendu(e) et content(e) plutôt qu'excité(e) et exalté(e).
30. Quand je suis anxieux(se), c'est habituellement très fort.
31. Mes humeurs négatives sont habituellement d'intensité légère.
32. Quand je suis excité(e) à cause de quelque chose, je veux partager mes sentiments avec tout le monde.
33. Quand je me sens heureux(se), c'est un sentiment de bonheur calme.
34. Mes amis diraient probablement que je suis quelqu'un de tendu ou très énervé.
35. Quand je suis heureux(se), je déborde d'énergie.
36. Quand je me sens coupable, cette émotion est forte.
37. Je décrirai mes émotions heureuses comme étant plus proches de la satisfaction que de la joie.
38. Quand quelqu'un me fait des compliments, je suis si heureux(se) que je pourrais « exploser ».
39. Quand je suis heureux(se), je tremble.
40. Quand je suis heureux(se), mes sentiments sont plus proches de la satisfaction et du calme interne que de l'excitation et de la joie de vivre.

Body Consciousness Questionnaire (BCQ), (Miller et al., 1981)

Answer the following questions about yourself by circling the number that indicates how characteristic each statement is of you, using the following scale.
(0) extremely uncharacteristic
(1) uncharacteristic
(2) neutral
(3) characteristic
(4) extremely characteristic

1. When with others, I want my hands to be clean and look nice.
0 1 2 3 4
2. For my size, I'm pretty strong.
0 1 2 3 4
3. I am sensitive to internal bodily tensions.
0 1 2 3 4
4. I know immediately when my mouth or throat gets dry.
0 1 2 3 4
5. I can often feel my heart beating.
0 1 2 3 4
6. I'm light on my feet compared to most people.
0 1 2 3 4
7. It's important for me that my skin looks nice…for example, has no blemishes.
0 1 2 3 4
8. I am quick to sense the hunger contractions of my stomach.
0 1 2 3 4
9. I'm capable of moving quickly.
0 1 2 3 4
10. I am very aware of my best and worst facial features.
0 1 2 3 4
11. I like to make sure that my hair looks right.
0 1 2 3 4
12. I'm very aware of changes in my body temperature.
0 1 2 3 4
13. I think a lot about my body build.
0 1 2 3 4
14. I'm better coordinated than most people.
0 1 2 3 4
15. I'm concerned about my posture.
0 1 2 3 4