Electrophysiological Indicators of Selective Attention to Affect

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Summary

For several decades, the interplay between attention and emotion has attracted significant interest in the fields of neuroscience and psychology. While much is known about the ability of emotional content to involuntarily capture human attention, less research has focused on the voluntarily directed attention to (the valence of) specific emotional stimuli. In order to better understand the underlying neural mechanisms of this highly dynamic process, researchers frequently rely upon event-related potentials (ERPs), which allow the separation of distinct temporal processing stages. The few studies on this specific topic have demonstrated that emotional stimuli benefit from selective attention to valence primarily during late, controlled processing. However, recent work has suggested that selective attention may also modulate emotional processing during early, perceptual stages. The present dissertation therefore aimed to clarify the nature of this previously observed effect and to generalize the observations to other types of emotional stimuli.

To this end, a series of four ERP studies was conducted using an experimental task in which attention was selectively directed toward one particular valence (e.g., positive). In *Study I*, the influence of lexical word properties on the early processing of selectively attended emotional words was investigated. In *Study II*, the neural processing of emotional words whose valence had *not* been selectively attended was explored in greater detail and integrated into theories on affective information processing. In *Study III*, emotional faces were used as stimuli in order to examine potential differences in neural processing during the selective attention to affect compared to words and pictures. In *Study IV*, the influence of participant gender and face gender on the processing of emotional faces whose expression was selectively attended was explored.

The combined findings demonstrate that selective attention to affect partially elicits analogous neural processing for emotional words and faces, while also revealing notable differences between the two stimulus categories. Most importantly, it was confirmed that the perceptual processing of emotional stimuli at very early stages can be modulated by selective attention. While this effect appeared to be more pervasive for words, a particularly interesting pattern was also identified for faces under specific conditions. On the other hand, subsequent holistic visual stimulus processing was characterized

by attention-independent processing of the emotional content. At mid-latency ERPs, there was moderate evidence for an attention-sensitive enhancement of emotional face processing, presumably indicative of the special role of emotional faces in human social life. Finally, the largest effects of task-related attention as well as a sustained attentional bias toward unattended negative stimuli manifested during late processing stages. As a whole, this work extends previous research and provides valuable insights into the electrophysiological signatures of top-down selective attention to affect and its interaction with the bottom-up processing of emotional stimuli.

Zusammenfassung

Das Zusammenspiel von Aufmerksamkeit und Emotion ist seit mehreren Jahrzehnten ein zentrales Forschungsfeld der Neurowissenschaften und der Psychologie. Während bereits umfangreiche Erkenntnisse über die Fähigkeit emotionaler Inhalte, die menschliche Aufmerksamkeit unwillentlich auf sich zu ziehen, vorliegen, wurde die willentliche Steuerung der Aufmerksamkeit auf bestimmte emotionale Stimuli (und deren Valenz) vergleichsweise spärlich erforscht. Um die neuronalen Mechanismen dieses hochdynamischen Prozesses besser zu verstehen, stützt sich die Forschung dabei häufig auf ereigniskorrelierte Potenziale (ERPs). Diese ermöglichen eine Differenzierung zwischen verschiedenen zeitlichen Verarbeitungsphasen. Die wenigen Studien zu diesem spezifischen Thema haben gezeigt, dass emotionale Reize von der selektiven Aufmerksamkeit auf ihre Valenz vor allem während der späten, kontrollierten Verarbeitungsphasen profitieren. Neuere Forschung legt jedoch nahe, dass selektive Aufmerksamkeit auch die emotionale Verarbeitung während der frühen, perzeptuellen Phasen modulieren kann. Die vorliegende Dissertation hatte daher zum Ziel, die Wirkungsmechanismen dieses zuvor beschriebenen Effekts zu beleuchten und die Beobachtungen auf andere Formen emotionaler Reize zu verallgemeinern.

Zu diesem Zweck wurden vier ERP-Studien mit einer experimentellen Aufgabe durchgeführt, bei der die Aufmerksamkeit selektiv auf eine bestimmte Valenz (z. B., positiv) gerichtet wurde. In *Studie I* wurde der Einfluss lexikalischer Worteigenschaften auf die frühe Verarbeitung von selektiv beachteten emotionalen Wörtern erforscht. In *Studie II* wurde die neuronale Verarbeitung von emotionalen Wörtern, deren Valenz nicht selektiv beachtet wurde, genauer untersucht und im Rahmen von Theorien zur affektiven Informationsverarbeitung betrachtet. In *Studie III* wurden emotionale Gesichter als Reize verwendet, um mögliche Unterschiede in der neuronalen Verarbeitung während der selektiven Aufmerksamkeit auf Affekt im Vergleich zu Wörtern und Bildern zu untersuchen. In *Studie IV* wurde getestet, welchen Einfluss das Geschlecht der Versuchspersonen und des präsentierten Gesichts auf die Verarbeitung von emotionalen Gesichtern, deren Ausdruck selektiv beachtet wurde, hat.

Die zusammengefassten Ergebnisse legen nahe, dass selektive Aufmerksamkeit auf den Affekt eine zumindest in Teilen ähnliche neuronale Verarbeitung für emotionale

Wörter und Gesichter auslöst, wobei aber auch deutliche Unterschiede zwischen den beiden Stimuluskategorien zu erkennen sind. Insbesondere wurde dabei bestätigt, dass die perzeptuelle Verarbeitung emotionaler Reize in sehr frühen Stadien durch selektive Aufmerksamkeit moduliert werden kann. Hier zeigte sich, dass dieser Effekt bei Wörtern ausgeprägter zu sein scheint, auch wenn bei Gesichtern unter bestimmten Bedingungen ebenfalls ein besonders interessantes Muster beobachtet werden konnte. Im Gegensatz dazu war die anschließende holistische visuelle Stimulusverarbeitung durch eine aufmerksamkeitsunabhängige Verarbeitung des emotionalen Inhalts gekennzeichnet. Hinsichtlich der ERPs mit mittlerer Latenz fanden sich moderate Hinweise auf eine aufmerksamkeitsabhängige Verstärkung der Verarbeitung emotionaler Gesichter, was die besondere Relevanz emotionaler Gesichter im menschlichen Sozialleben betont. In den späten Verarbeitungsphasen zeigten sich schließlich die größten Effekte der aufgabenbezogenen Aufmerksamkeit sowie eine anhaltende Verschiebung der Aufmerksamkeit in Richtung unbeachteter negativer Reize. Zusammenfassend erweitert diese Dissertation frühere Forschungsarbeiten und liefert wertvolle Einblicke in die elektrophysiologischen Signaturen, die die selektive Top-down-Aufmerksamkeit für Affekt und ihre Interaktion mit der Bottom-up-Verarbeitung emotionaler Stimuli abbilden.

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1. Introduction

Imagine you are traveling alone in a foreign city and you want to socialize in the evening. Thus, you decide to visit a bar hoping to meet like-minded individuals there. What features would you look for in the people when entering the bar? Among other characteristics, you would probably specifically search for happy, smiling faces rather than grim or gloomy ones. In other words, you would be selectively attending to faces whose expressions convey positive valence. Now consider a second scenario. After you have recently started a new job, your boss unexpectedly calls you into the office. Although you feel you have performed well in your first week, you have heard that your boss is very demanding and highly critical of even the smallest details. What features would you look for when entering the office? Presumably, you would search for signs of anger on your boss's face and listen for irritation in the voice when greeting you. More generally, you would be selectively attending to negative valence to quickly determine whether you need to recall recent events and prepare an apology or defense if necessary.

When you are asked how you performed these seemingly mundane acts of selectively attending to a particular valence, you might intuitively say that you searched for a smiling, U-shaped mouth as a sign of happiness in the first scenario and furrowed eyebrows in the second scenario. However, introspection alone is hardly sufficient to capture the underlying neurophysiological processes that take place in a fraction of a second (e.g., the decision whether a face is happy or not). Hence, for a deeper understanding of how we process affective stimuli of a certain valence to which we currently attend, the application of neurophysiological techniques is essential. In particular, the excellent temporal resolution of event-related brain potentials (ERPs) derived from the electroencephalogram (EEG) makes them ideal for capturing the cognitive and underlying neural processes involved in such a fundamental element of human behavior. Over the past four years, I have applied this technique to investigate extensively the electrophysiological correlates of selective attention to affective stimuli. This resulted in four journal articles that constitute the core of the present thesis. However, before presenting the novel contributions from our work and integrating them into the existing scientific literature in the present synopsis, it is imperative to create a common understanding of

the psychological and methodological concepts on which this doctoral thesis is based. Therefore, I will start by introducing the concept of emotion and briefly present two major emotion theories in the following section. Building on these fundamental concepts, in the second section I will present the two principal ways in which attention and emotion interact, before turning to the main topic of the current dissertation.

1.1. Emotion

Emotions are a ubiquitous topic in psychology and play a fundamental role in our everyday lives where they serve a variety of purposes. From a classical perspective, these include increasing the probability of survival and/or the reproductive success of an individual, but emotions are also relevant to social well-being as they have both an affiliation and distancing function (Fischer & Manstead, 2016; Tooby & Cosmides, 2008). Fear of enemies, for example, is adaptive in that individuals who can feel this fear tend to be more vigilant and evasive, thus avoiding the danger altogether or alternatively attack the enemy (Tooby & Cosmides, 2008). Even though all of us probably intuitively know what an emotion is, there is no universally accepted definition of emotion in any of the scientific disciplines that investigate this phenomenon (Mulligan & Scherer, 2012; Ortony, 2022). Nevertheless, common components of what constitutes an emotion can be identified across all major emotion theories. It is assumed that emotions comprise
1) an episodic process in response to a perceived object or situation of great significance,
2) that is characterized by recursive causal effects between multiple components, which include the evaluation of the situation regarding its significance to one's values and goals,
3) evoking physiological reactions, motor expressions, and action tendencies, and
4) that this process is to some extent accessible to consciousness and results in feelings
5) which can be categorized and subsequently named by the individual in terms of its subjective conceptual structure (Scherer, 2022).

These or at least similar aspects are also at the core of two of the arguably most widely discussed types of psychological theories of emotion: *basic/discrete emotion theories* and *constructionist/dimensional theories* (a third type of theories, *appraisal theories*, are not discussed within this thesis; for an overview, see Moors et al., 2013).

1.1.1. Basic/Discrete Emotion Theories

The theories of basic/discrete emotions have their scientific roots in Charles Darwin's (1872/ 1965) book *The Expression of the Emotions in Man and Animals.* In his seminal

work he introduced the idea that emotional expressions were evolved and, at least at some time in the past, adaptive (Hess & Thibault, 2009). While discussing a variety of emotional expressions, he did not yet refer to any particular emotion as basic. This was first done by the psychologists Sylvan Tomkins (1962) and Robert Plutchik (1962) who each suggested that a small number of discrete emotions evolved in reaction to specific adaptive problems (Shiota, 2024). These ideas inspired decades of empirical research by emotion theorists, psychologists and neuroscientists (e.g., Ekman, 1992; Fehr & Russell, 1984; Frijda, 1986; Izard, 2007; Oatley & Johnson-Laird, 1987; Panksepp & Watt, 2011; Shaver et al., 1987) who each proposed a different set of basic emotions. Across all approaches, three distinct conceptions can be identified as to what *basic* actually means (Ortony, 2022; Ortony & Turner, 1990). The *conceptual basic* view refers to the basic level of an emotion category in a conceptual taxonomy while the *elemental basic* view considers an emotion to be basic if it has no other emotions as components. The third view, *biological basic*, takes the idea that basic emotions have an evolutionary origin and distinctive biological markers (Ortony, 2022). This notion is the most common conception of basic emotions and is reflected in numerous theories (see Tracy & Randles, 2011), with Ekman's (1992; Ekman & Cordaro, 2011) being arguably the most influential.

According to Ekman (1992; 2011) the term *basic* embodies (1) that there are discrete emotions which fundamentally differ from one another and (2) that emotions have evolved for their adaptive value in dealing with our surroundings. He originally presented nine criteria for what characterizes a basic emotion (Ekman, 1992) and later expanded this list to 13 criteria (Ekman & Cordaro, 2011). These can be summarized in the three categories of *distinctness* (e.g., in signal, physiology, antecedent events), *continuity* (e.g., presence in other primate species, same signals in all cultures) and *structure/function* (e.g., quick onset, brief, unbidden, automatic appraisal) which also inspired the criteria of other emotion theorists (see Levenson, 2011). Similar to his criteria, the exact number of basic emotions has changed over time. More recently, Ekman and Cordaro (2011) listed seven basic emotions for which evidence of universality was found: anger, contempt, disgust, fear, happiness, sadness and surprise. Comparing this list with the basic emotions proposed by other emotion researchers reveals that one positive emotion (e.g., labeled happiness or enjoyment) and the three negative emotions anger, fear, and sadness consistently emerge (Tracy & Randles, 2011; for an overview, see Ortony, 2022). The distinct physiological, behavioral, expressive and experiential responses of basic emotions are thought to be automatically elicited and directed by an affect program which can be partly influenced by social learning and individual experiences (Ekman & Cordaro, 2011). Central to the concept of basic emotions are facial (and other, such as vocal; see Tomkins, 1962) expressions because they "are vestiges of

once 'serviceable habits' for dealing with the vicissitudes of daily life" (Ortony, 2022, p. 43).

Concluding on the theories of basic emotions, it should be emphasized that some of the central ideas such as the universality of basic emotions across cultures and distinct patterns of physiological and brain activity have received support from various behavioral and neuroimaging studies (see Celeghin et al., 2017; Kragel & LaBar, 2016; Shiota, 2024). Nevertheless, there are a wide number of critics of the biological basic concept who reject the notion of basic emotions altogether and subscribe to constructionist/dimensional theories (see Barrett & Russell, 2015; Fernández-Dols & Russell, 2017; Ortony, 2022).

1.1.2. Constructionist/Dimensional Theories

Opposing the notion that emotions are biological categories imposed by evolution, constructionist/dimensional theories assume that emotions are psychologically constructed on each occasion to suit the specific circumstances, without any overall pattern being fixed in advance (e.g., Barrett, 2006a, 2006b; Russell, 2003). In one of the most influential models, Russell (2003) proposed that changes in the so-called *core affect* which are produced by the perceived *affective quality* of an external stimulus are attributed to the stimulus. This attributed affect initiates instrumental action toward the object, with both affect and action contributing to physiological and expressive changes. Russell's model assumes that expression and behavior associated with the core affect are categorized as an emotion when they take the form of a prototypical emotion pattern. This was further extended by Barrett (2006b) who suggested that feeling an emotion also relied on culturally shaped conceptual knowledge and language. At the heart of these approaches lies the *core affect* as "a neurophysiological state that is consciously accessible as a simple feeling" (Russell, 2003, p. 147). The subjective experience is a single blend along the two dimensions of pleasure–displeasure (*valence*) and activation–deactivation (*arousal*) which is shown in Figure 1.1.

Conceptualizing a feeling state (i.e., affect) on several dimensions is as old as experimental psychology itself and was first suggested by Wilhelm Wundt (1896) who proposed three independent dimensions of what would now be called valence, arousal and intensity (see Barrett & Bliss-Moreau, 2009). Since then, current affect has been structured along various dimensions, including *tense* and *energetic activation* (Thayer, 1986) but also unipolar continua of *positive* and *negative activation* (e.g., Tellegen et al., 1999; Watson & Tellegen, 1985) or *positivity* and *negativity* (Cacioppo et al., 1999; Cacioppo & Berntson, 1994). Importantly, most of these conceptualizations can be integrated

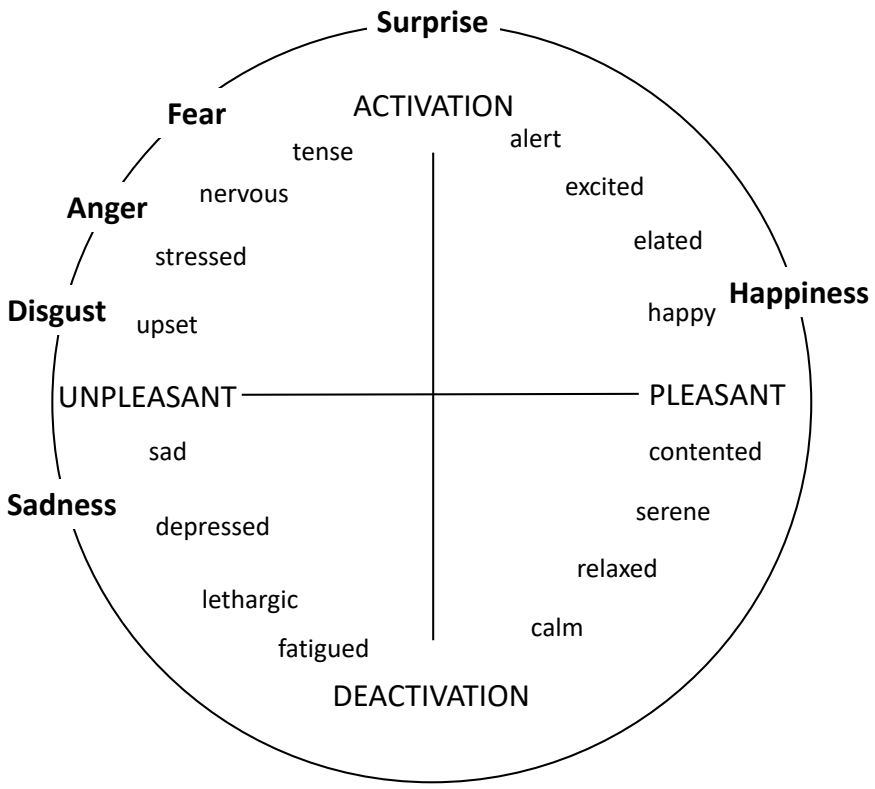

Figure 1.1.: The inner circle represents the structure of core affect. The location of prototypical emotional episodes is depicted in the outer circle. From Russell & Barrett (1999), p. 808. Copyright 1999 by the American Psychological Association. Reprinted with permission.

into a common space of affect defined by the two bipolar dimensions of valence and arousal (Yik et al., 1999, 2011).

Apart from differences in the conceptualization of the underlying dimensions of affect, another fundamental issue concerns the relationship between valence and arousal. A thorough understanding of their exact relationship has direct implications for the interpretation of psychological experiments that investigate effects of affective stimuli (Kuppens et al., 2013). The authors outlined several different possibilities, three of which will be presented in the following. First, in a number of models (e.g., Barrett & Bliss-Moreau, 2009; Yik et al., 1999), it is proposed that valence and arousal are orthogonal dimensions and thus independent of each other (see Figure 1.2, panel A). Arousal reflects not simply the intensity of pleasure or displeasure but, for example, also a state of extreme activation which is neutral on valence is conceivable. Evidence comes from near-zero correlations between both dimensions as well as good fits of orthogonal factor models to multiple data sets involving different stimulus materials (see Kuppens et al., 2013).

A second perspective suggests that valence and arousal have a V-shaped (or U-shaped)

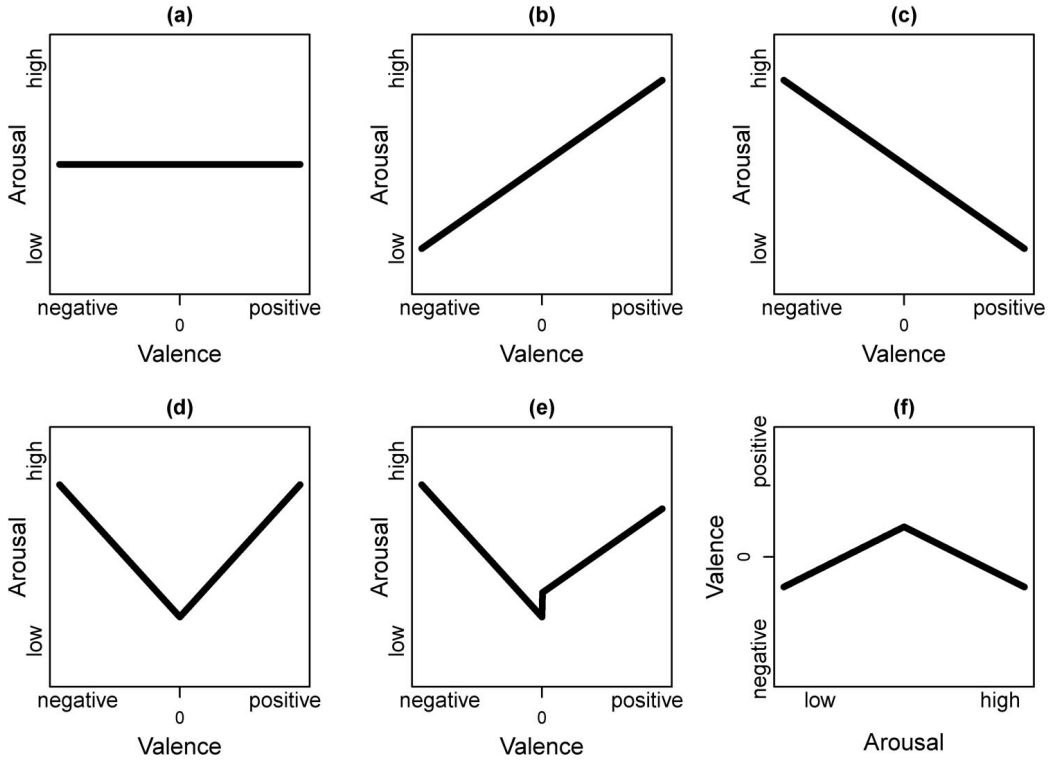

Figure 1.2.: Overview of possible relations between valence and arousal: (a) independence, (b) positive linear relation, (c) negative linear relation, (d) symmetric V-shaped relation, (e) asymmetric V-shaped relation including both positivity offset and negativity bias, and (f) an inverted V-shaped relation when valence is a function of arousal. From Kuppens et al. (2013), p. 919. In the public domain.

relation (see Figure 1.2, panel D). This idea can be inferred from theories which propose that arousal actually reflects the activity of two independent subsystems, such as positive and negative activation (e.g., Watson et al., 1999). In this sense, arousal is little more than the extremity of positive and negative valence (see Kuppens et al., 2013). Most of the support is provided by the observation of a V-shaped pattern in the data on arousal and valence ratings of people's responses to affective stimuli such as pictures (e.g., Bradley & Lang, 2007) or words (Kanske & Kotz, 2010; Monnier & Syssau, 2014; Võ et al., 2009; Warriner et al., 2013). However, it was argued that this relation is best interpreted in a weakly probabilistic rather than deterministic manner which still allows for all combinations of valence and arousal (Kuppens et al., 2013).

The third approach is related to the *evaluative space model* (ESM) in which functionally separable and partially independent dimensions of positivity and negativity are proposed as the underlying dimensions of the affect system (Cacioppo et al., 1997; Cacioppo & Berntson, 1994; Norris et al., 2010). Even though the relation between valence and arousal is not explicitly discussed, one possibility can be derived from this model (Kuppens et al., 2013). In the ESM, distinctive and asymmetric activation functions

(i.e., the relationship between system input and output) are postulated for positivity and negativity on the basis of evolutionary considerations. At low levels of emotional input (low activation), positivity outweighs negativity to promote the exploration of novel stimuli and the environment, which is called *positivity offset*. In contrast, for high levels of emotional input (high activation), there is a stronger response to negative stimuli due to their stronger implications for survival, known as *negativity bias* (Norris et al., 2010).

When arousal is used as a proxy for activation in each system (e.g., T. Ito & Cacioppo, 2005), the resulting relation between valence and arousal can be best described by an asymmetrical V-shape (see Figure 1.2, panel E). This figure shows the positivity offset as the discontinuous shift at zero valence, and the negativity bias is emphasized by the steeper slope for negative than for positive valence. Investigating self-reported affect across a variety of stimuli including affective pictures, Kuppens et al. (2013) found evidence for this asymmetrical V-shaped relation in the majority of their studies (for further evidence on positivity offset and negativity bias, see T. Ito & Cacioppo, 2005; Norris et al., 2010). The idea of a positive offset and negativity bias is also reflected in the *valence-arousal conflict theory* (Robinson et al., 2004). Underlying this theory is the notion that positive valence and low arousal are associated with approach tendencies in general, whereas negative valence and high arousal lead to withdrawal (Robinson, 1998). These tendencies are initiated independently at preattentive initial stages of emotional processing and result in a more efficient processing for congruent (positive/low arousing; negative/high arousing) compared to incongruent (positive/high arousing; negative/low arousing) stimuli which has been shown in both explicit and implicit affective tasks (e.g., Citron et al., 2014; Eder & Rothermund, 2010).

1.1.3. Conceptualization of Emotional Stimuli

The emotion theories presented above focus primarily on the elicitation of emotional responses and whether emotions are a result of evolutionary structures or psychological constructs. Less attention is devoted to the definition of the term *emotional stimulus* or the processes that play a role in the perception of such stimuli (Brosch et al., 2010). Nevertheless, some considerations on emotional stimuli are essential at this point because these are used in the current thesis (and frequently in psychological research) to study how humans process emotional information. One important question regards the definition of an emotional stimulus. Most theories of emotion acknowledge that emotional stimuli are a special type of stimulus in that they are highly relevant to the individual's survival and well-being. Whereas some stimuli indicate opportunities for growth, such as prospective mates or food resources, others may signal threats, such

as predators or enemies (Brosch et al., 2010). In the current thesis, I will consider an emotional stimulus as "any event capable of triggering emotional reactions, at any level (physiological, subjective, and/or behavioral) and to any extent, in the receiver" (Carretié, 2014, p. 1231). The terms "emotional stimulus" and "affective stimulus" will be used synonymously. A common categorization of the various emotional stimuli in the visual domain that people encounter in their daily lives is into symbolic (e.g., written emotional words) and non-symbolic material (e.g., emotional scenes, facial expressions).

In addition to this definition, more specific conceptualizations can be derived from the distinct theoretical approaches (Brosch et al., 2010). According to the basic emotion theories, emotional stimuli are assumed to be organized in a categorical manner. Of these, the most prominent examples are facial expressions which show evolved emotion categories such as anger or happiness that are universally found in humans. It is therefore not surprising that when facial expressions are used in psychological research, they are usually categorized into different basic emotions. However, extending the categorical structure to other stimuli, researchers have developed categorical norms for emotional images (Mikels et al., 2005) and databases of emotional words (Hinojosa et al., 2023; Stevenson et al., 2007; Syssau et al., 2021) for further studying the concept of discrete emotions. By contrast, constructionist/dimensional theories sort emotional stimuli along the two-dimensional space of valence and arousal which has become a fundamental approach to describe the emotional connotations of affective pictures (e.g., Bradley & Lang, 2007; Olofsson et al., 2008) and affective words (e.g., Citron, 2012). Even though it is less common, facial expressions have also been structured along the dimensions of valence and arousal (Russell, 1997). To summarize, in particular the two theories of basic emotions and dimensional affect form the basis for the classification of affective stimuli in psychological research and in the current thesis (a more detailed discussion of the different conceptualizations can be found in Brosch et al., 2010).

1.2. Attention and Emotion

As it was outlined above, emotional stimuli constitute a special type of stimuli that play a significant role in our daily lives. They (or more precisely, their perception as emotional) can elicit full-blown emotional responses including physiological and behavioral responses as well as a shift in subjective feelings[1] and they often require rapid responses

[1]Importantly, while an emotional stimulus in our environment (e.g., a spider) might indeed elicit a genuine emotional response including changes in behavior, physiology and subjective feelings, the corresponding types of emotional stimuli which are frequently used in psychological research (e.g., a picture of a spider, the word "spider") very rarely elicit the same full-blown emotional reactions.

like withdrawing from danger or approaching new opportunities. However, considering the vast amount of information in our environment, it cannot be guaranteed that all relevant stimuli are actually perceived and therefore responded to quickly. Due to limited processing resources, only a small fraction of the overwhelming flow of information that enters the human visual system will eventually be encoded and remembered (Driver, 2001). But how does the brain then detect the vital visual information and ensure that no key information is lost? This involves the guidance of sensory processing in such a way that the most relevant stimuli are rapidly selected while distracting ones are ignored (Vuilleumier, 2005), in other words, *attentional selection*.

Attention is a faculty of both humans and many animal species (Taylor & Fragopanagos, 2005) and can be considered as the cognitive processes that rapidly and efficiently allocate neural processing resources to stimuli (Schindler & Bublatzky, 2020). Two key characteristics of these processes are the limited capacity for processing information (i.e., competition) and the ability to filter out irrelevant information (i.e., selectivity) (see Desimone & Duncan, 1995; Posner, 1980). This notion is reflected in several influential models of selective attention which assume that objects in the visual field[2] compete for the limited resources at different time points between input and response (for an overview, see Driver, 2001). These models commonly differentiate between two distinct phases of visual processing. The early visual stage, occasionally designated as preattentive, operates in parallel over the entire visual field whereas a subsequent stage, frequently termed attentive, can only process a limited number of objects simultaneously (Theeuwes, 2010). Which stimuli are processed more deeply and may eventually enter consciousness depends on both bottom-up (stimulus-driven, exogenous) and top-down (goal-driven, endogenous) mechanisms (Posner, 1980; Serences et al., 2005; Theeuwes, 1994; but see Awh et al., 2012).

Specifically, bottom-up attentional control is driven by factors that are external to the individual such as the physical salience of stimuli (e.g., a bright flash or a sudden movement), whereas top-down attentional control is driven by factors that are internal (e.g., the goal to find a specific face in a crowd; see Awh et al., 2012). These two distinct mechanisms of attentional control are closely associated with the amplification and prioritized processing of emotional stimuli (Schindler & Bublatzky, 2020) and have long inspired researchers to investigate the interplay of emotion and attention (e.g., De Houwer & Hermans, 2010; Pessoa, 2008; Pourtois et al., 2013; Taylor & Fragopanagos, 2005; Vuilleumier, 2005). Most of the research relies on behavioral studies as well as

Nevertheless, there is ample evidence that the processing of emotional stimuli differs from that of emotionally neutral stimuli, some of which is presented in this thesis.

[2]Please note that attentional processes are not limited to the visual field. There is also a great deal of research on auditory attention, which however will not be discussed further in this thesis. For a good overview, please refer to Fritz et al. (2007) or Shinn-Cunningham et al. (2015).

neuroimaging and neurophysiological methods such as functional magnetic resonance imaging (fMRI) and EEG. During fMRI, hemodynamic changes are measured in the brain which evolve after enhanced neural activity. It is therefore limited in its temporal resolution by the slow nature of blood flow changes (Logothetis, 2008). However, with its very high spatial resolution, it allows the precise localization of the brain structures and circuits which are involved in the attentional selection of emotional stimuli. The principal investigation method in this thesis, the EEG, measures electrical activity originating from cortical neurons and is ideally suited to capture the rapid allocation of attention to emotional stimuli due to its excellent temporal resolution (a detailed overview is given in Chapter 2.1). The following sections will provide an overview of the basic neuroanatomical and temporal aspects of bottom-up processing of emotional stimuli before focusing on the attentional selection of emotional stimuli in a top-down fashion.

1.2.1. Bottom-up Attention to Emotional Stimuli

Bottom-up attentional selection is determined by feature properties of stimuli in the environment and occurs in an automatic fashion (Theeuwes, 2010). An important role in the initial selection plays the salience of a stimulus, which describes its quality to stand out from surrounding stimuli in some dimension such as color, shape, or size (see Awh et al., 2012; Theeuwes, 2010). The automatic shift of attention to the most salient stimulus is referred to as attentional capture (Theeuwes, 2010). Although it might not be described in terms of low-level perceptual features per se, emotional stimuli seem to capture attention in a bottom-up fashion similar to salient stimuli (Awh et al., 2012; Theeuwes, 2010; Weinberg et al., 2013). It has been proposed that, irrespective of the individual's current goals and intentions, this prioritized processing of emotional stimuli stems from their intrinsic motivational significance (Lang et al., 1997; LeDoux, 1996; Vuilleumier, 2005). In other words, the selective responding to specific stimuli is dictated by motivational states such as sexual needs or threats of harm (*motivated attention*; see Lang et al., 1997). In line with this perspective, an abundance of empirical evidence indicates that emotional stimuli indeed receive prioritized and enhanced processing compared to neutral stimuli. They are detected faster (see Brosch et al., 2010), capture and sustain attention more effectively (see Carretié, 2014; Lang et al., 1997; Vuilleumier, 2005) and elicit stronger neural responses in several brain areas (Pourtois et al., 2013). It has been proposed by some accounts that the processing of at least some emotional stimuli (e.g., fearful faces) is largely automatic and can take place not only independent of attention but also without reaching conscious awareness (for reviews, see Pessoa, 2005; Vuilleumier & Huang, 2009). However, other research has

suggested that even though the processing of emotional stimuli is prioritized, the notion of complete automaticity and independence from attention is not appropriate. Rather, emotional processing may critically depend on the available attentional resources (see Pessoa et al., 2013).

Dedicated neural circuits are thought to be involved in this form of (bottom-up like) attention to emotional stimuli (Vuilleumier, 2005; Vuilleumier & Huang, 2009). A crucial role plays the amygdala, a limbic region that is strongly involved in emotional processing (LeDoux, 2000; Vuilleumier & Huang, 2009). Dual-pathway models have been proposed to explain the rapid modulation of attention by emotional stimuli (LeDoux, 1996; Vuilleumier, 2005). In addition to longer pathways along the visual stream and cortical areas, sensory input is supposed to reach the amygdala through subcortical pathways. This "quick and dirty" route bypasses the cortex and runs via the superior colliculus and pulvinar (see Tamietto & De Gelder, 2010). The amygdala further exerts modulatory influences through direct feedback projections on the sensory and visual cortex (Vuilleumier & Huang, 2009). Regarding the temporal characteristics, exogenous attention to emotional stimuli elicits rapid neural responses, usually within the first 200 ms from stimulus onset (Carretié, 2014). In particular, ERP components at around this time range (the anterior P2 and the N2 family) are those that are most sensitive to attentional capture by emotional distractors (Carretié, 2014). Other paradigms investigating bottom-up processing of word and facial stimuli revealed differences between emotional and neutral stimuli after just 100 ms, although these are less reliable (see Kissler et al., 2006; Schindler & Bublatzky, 2020). Some of the observed ERP variations might be attributed to the specific type of emotional stimulus. On the one hand, emotional facial stimuli and emotional scenes seem to capture attention to a similar degree, although qualitative differences in the respective neural responses to these emotional distractors have to be acknowledged (Carretié, 2014). On the other hand, emotional words are able to capture attention in a bottom-up fashion (Kissler et al., 2009) but these effects are relatively weak compared to non-symbolic stimuli. This is explained by their less arousing nature and the notion that words, unlike, for example, faces, are not evolutionary prepared stimuli (Carretié, 2014; Rellecke et al., 2011).

Because investigations into the attentional capture of emotional stimuli in a bottom-up fashion rely on various experimental paradigms (e.g., Carretié, 2014; Schindler & Bublatzky, 2020), it is essential to define what is included in the concept of "bottom-up" in the current thesis. The reference to attentional selection of emotional stimuli in a bottom-up fashion includes all experimental designs in which the emotional content of the stimuli is irrelevant to the task (i.e., not a target) [3]. The most common among these

[3]Please note that different inclusion criteria have been used by other researchers to investigate the bottom-up or exogenous attention to emotional stimuli (Carretié, 2014).

designs that will be briefly presented in the main synopsis are (1) the use of emotional stimuli as distractors, (2) passive viewing of emotional stimuli and (3) attention to non-emotional features of stimuli. Similarly, the description of bottom-up effects of emotional stimuli emphasizes the independence of these effects from current goals and task relevance. Regarding the latter, it is obvious that attentional selection is not always driven in a bottom–up way. After all, we are capable of voluntarily attending to those stimuli that we deem relevant to our behavior.

1.2.2. Top-down Attention to Emotional Stimuli

Before turning to the top-down processing of emotional stimuli, some background has to be provided first. *Top-down* attentional selection is driven by higher-order goals, intentions, and expectations of the observer. It is an active volitional process, unlike bottom-up selection (Theeuwes, 2010), and it can be based on three different kinds of information (*spatial*, *feature-based*, and *object-based* attention) in the visual domain (Chapman & Störmer, 2024). As the present dissertation is specifically concerned with the (top-down) selective attention to the affect of emotional stimuli (such as emotional expressions that are characterized by specific facial components and lower-level visual features), the subsequent section will focus on (non-spatial) feature-based attention. This concept refers to the mechanism by which attention is directed to particular feature properties (e.g., color or shape) across the entire visual field that are most relevant for a current task (for similarities and differences with the two other modes of attention, see Cavanagh et al., 2023; Chapman & Störmer, 2024). In order to guide the attentional focus toward a visual target with specific features that match our search goal and to control competitive bias in our environment during this visual search, the concept of *attentional templates* was proposed (Desimone & Duncan, 1995; Duncan & Humphreys, 1989). These templates are internal representations comprising visual features that distinguish targets (i.e., objects with attributes that match our goals) from nontargets (Duncan & Humphreys, 1989). They can specify any attribute of required input (e.g., color, shape, size) and bias attention to target features in the environment even before the presentation of a stimulus (Desimone & Duncan, 1995). Importantly, these target templates are even activated in a preparatory fashion during non-search tasks (e.g., Go/NoGo task) when there is no competition between targets and irrelevant distractors, unlike in the visual search paradigm (Dodwell et al., 2024). Such preparatory attention (or tuning) enhances the subsequent visual processing of stimuli sharing the attended attribute (Battistoni et al., 2017).

At the neural level, top-down selection of (non-spatial) features involves a higher-order frontoparietal network which is involved in domain-general attention control and modu-

lates activation in visual areas (for reviews, see Baluch & Itti, 2011; Boshra & Kastner, 2022; Corbetta & Shulman, 2002). Key control regions of feature-based attention include the ventrolateral prefrontal cortex, the frontal eye fields, and the intraparietal sulcus (for additional involved structures, see Boshra & Kastner, 2022). Top-down feedback signals from these higher-order areas propagate to the visual cortex where they selectively increase the response of neurons that preferentially respond to the task-relevant feature (Bichot et al., 2019; Boshra & Kastner, 2022). In the visual cortex, the effects of feature-based (e.g., color, orientation, shape) attentional modulation are most evident in extrastriate areas such as V4 and the inferotemporal cortex along the ventral visual pathway, although lower visual areas (e.g., V1) already show some feature sensitivity (Baluch & Itti, 2011). This biased neural activity in both the primary and high-level visual cortex is already present in preparation for detecting task-relevant stimuli (Battistoni et al., 2017) and has been suggested to represent the neural correlate of attentional templates (see Battistoni et al., 2017; Desimone & Duncan, 1995), which eventually improve perceptual discrimination and performance in various experimental tasks. In terms of time course, electrophysiological studies have shown that effects of feature-based attention typically appear around 200 ms after stimulus presentation (see Chapman & Störmer, 2024). However, a number of findings suggest that feature-based attention can, in principle, enhance early perceptual processing already after 100 ms (Moher et al., 2014; Zhang & Luck, 2009).

While research has long focused on the voluntary allocation of attention to simple features, investigations into the attention to real-world objects and high-level categories such as (emotional) faces or words are becoming increasingly relevant (see Peelen & Kastner, 2014). Here again, the search template is thought to comprise an internal representation of features that best distinguish the target from distractors. In contrast to simple stimuli, the template further has to generalize across slight variations in the current target (i.e., if a happy face is the real-world target, the template has to generalize across various happy facial expressions from different individuals) and even varying points of view. Thus, not only features of the current target influence the template but also previous knowledge and encounters with the target (see Peelen & Kastner, 2014). Taken together, the templates of real-world objects are represented by both lower-level visual features and by higher-level visual and semantic features which constrain the attentional selection (see Chapman & Störmer, 2024). Neuroimaging studies have shown that attention can indeed be directed to real-world objects, such as human faces, by revealing enhanced neural responses in category-selective areas of the visual cortex corresponding to the attended stimuli compared to unattended stimuli (e.g., the *fusiform face area* for faces; see Battistoni et al., 2017; Chapman & Störmer, 2024; Gratton et al., 2013). Interestingly, the attentional selection of such complex

objects has also been found to rely on pattern-specific information sent to the early visual areas (E. H. Cohen & Tong, 2015). In particular, feedback from object-specific areas that targets low-level features associated with the complex stimulus can bias neural activity patterns in areas V1-V4 in favor of the attended stimulus and thus ultimately improve visual discrimination of stimuli.

With a general understanding of the mechanisms of top-down attentional selection and emerging neural evidence for attentional templates of more complex (real-world) objects and their features, I will now focus primarily on the top-down processing of *emotional stimuli* for the remainder of this thesis. While the ability of emotional stimuli to automatically attract attention, independently of the current goals of the individual, is highly useful, particularly from an evolutionary perspective, the explicit attention to affect for rapid affective discrimination can prove useful as well. One benefit could be the increased likelihood of conscious awareness of affect, which is essential for effective emotion regulation (Gibbons, Kirsten, et al., 2022). Another advantage could be the enhanced recognition of (partly hidden) affective information, so that an appropriate behavioral response can be made more quickly. Various experimental paradigms have been used to investigate the top-down processing of emotional stimuli (for an overview, see Gibbons, Kirsten, et al., 2022; Schindler & Bublatzky, 2020). In all these studies, the emotional content is directly relevant to the task; that is, they are explicit emotion tasks. As such, the notion of top-down effects of emotional stimuli in the current thesis emphasizes that these effects are related to the task relevance of the emotion itself. These explicit emotion tasks most commonly involve general attention to affect, as is the case in emotion identification or emotional-neutral classification tasks (see Schindler & Bublatzky, 2020). They have been applied in EEG and fMRI studies, thus helping to disentangle the spatial and temporal effects of top-down emotional processing from emotional processing in a bottom-up manner. For example, neuroimaging studies revealed less amygdala activation during the explicit emotional processing (e.g., judging whether a facial expression is emotional or neutral) compared to implicit (bottom-up) processing of emotional faces (e.g., passive viewing of faces; gender-decision task). The top-down, explicit processing seems to evoke greater activity in visual cortical areas linked to facial representations and certain areas of the prefrontal cortex (Critchley et al., 2000; Hariri et al., 2000; Lange et al., 2003), suggesting a neuroanatomical and functional dissociation between conscious and unconscious emotion processing (see LeDoux, 1996).

Focusing on the temporal aspects of top-down attention, numerous EEG studies investigated the explicit affective processing of various emotional stimuli such as faces (e.g., Acunzo et al., 2019; Itier & Neath-Tavares, 2017; Kolassa & Miltner, 2006; Rellecke et al., 2012; Valdes-Conroy et al., 2014; Wronka & Walentowska, 2011), words (e.g., Fis-

chler & Bradley, 2006; Frühholz et al., 2011; Hinojosa et al., 2014) and scenes (Hajcak et al., 2006; T. A. Ito & Cacioppo, 2000). As noted earlier, this approach is particularly useful for improving our understanding of exactly how attention modulates the distinct stages of affective processing. Summarizing findings across various studies shows that emotional processing of stimuli can be enhanced by explicit (versus implicit) general attention to emotion as early as 170 ms after stimulus onset (*N170*; see Wronka & Walentowska, 2011) although most consistently an attentional amplification of emotion effects occurred at later controlled processing stages (Schindler et al., 2022; Schindler, Vormbrock, et al., 2023; Schindler & Bublatzky, 2020).

1.3. Open Questions and Goals of the Present Thesis

As outlined in the previous sections, emotional processing and attentional selection are often closely connected. On the one hand, emotional stimuli may demand attentional resources and prioritized processing due to their intrinsic stimulus significance (*motivated attention*; see Section 1.2.1). This is usually investigated in experimental tasks in which affect or emotion is not relevant for the task, such as passive viewing or the use of emotional stimuli as distractors. On the other hand, voluntary attention can actively be allocated to the affect of emotional stimuli in order to facilitate their efficient processing and rapid recognition (see Section 1.2.2). This is usually achieved by tasks that direct attention to the affective dimension compared to a nonaffective dimension (i.e., *general attention to affect*; Gibbons, Kirsten, et al., 2022). For example, these tasks require participants to categorize stimuli of varying valence (positive or negative words) or emotional expressions (angry or happy faces) as emotional and all neutral stimuli (neutral words or neutral faces, respectively) as neutral. Each of these processes has been associated with the involvement of specific neural circuits (e.g., Critchley et al., 2000) and has shown distinct temporal effects (e.g., Schindler & Bublatzky, 2020). The crucial question now is the following: *What happens when the two processes converge and stimuli of a specific level of valence or emotion become the focus of attention?*

To date this question has only been addressed in a handful of studies (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007; Weidner et al., 2022). This approach corresponds to testing the upper limit of top-down attention to affect by directing voluntary attention to only one predefined specific level of valence (e.g., positive; Gibbons, Kirsten, et al., 2022). In each of the above studies, the effects of selective attention to three different levels of valence were investigated, namely negative, neutral and positive valence. For example, participants have to selectively attend and react to the target level of positive valence while not

responding to neutral or negative stimuli, that is, nontarget stimuli (i.e., *valence detection*). The specific target level of valence varies between blocks over the course of the experiment. Whereas attention is divided between several levels of valence in categorization tasks involving general attention to affect, the former studies specifically induce selective attention to only one target valence at a time. This top-down focus on one specific target valence should bias neural activity in category-selective and visual areas in favor of the selectively attended category (by preactivation of corresponding neuronal representations, cf. *attentional templates*; see Section 1.2.2), thus presumably allowing for a more rapid and efficient discrimination of target stimuli (i.e., the selectively attended) compared to nontarget stimuli (i.e., the stimuli that not match the target category and are not selectively attended). This general idea of improved stimulus discrimination in such detection tasks and the differences to tasks involving general attention to affect will be elaborated in greater detail in the first part of the following synopsis.

In the second part of the synopsis, I will present ERP results from four different EEG studies using different types of emotional stimuli and slight adaptations of the experimental tasks. All studies aimed to explore the neural processes which are associated with the selective attention to one specific level of valence[4]. In *Publication I* (Schmuck et al., 2025) and *Publication II* (Gibbons, Schmuck, et al., 2022), I directly continued earlier investigation from our working group on selective attention to valent words (Gibbons, Kirsten, et al., 2022, 2023). The first study implemented specific purposeful adjustments to the original experimental task from Gibbons, Kirsten, et al. (2022) by removing neutral words and focusing on the discrimination of positive and negative words. In addition, the experimental design was expanded by two lexical variables, *word length* and *word frequency,* to test for specific theoretical considerations associated with the selective attention to affective words. In *Publication II,* we reanalyzed behavioral and ERP data from our earlier valence detection study (Gibbons, Kirsten, et al., 2022) to examine novel types of emotion-(selective) attention interactions. The particular focus was on the processing of nontarget words as a function of their own valence and the current target valence of the block. Various hypotheses were derived from specific theories on affective information processing, that is, ESM (Cacioppo & Berntson, 1994) and valence-arousal conflict theory (Robinson et al., 2004), and tested using several ERP components.

[4]Whereas the concept of valence applies particularly to affective words and pictures, which are typically categorized on a valence continuum, facial expressions show discrete emotions. Nevertheless, the different emotions can also be seen as corresponding to three valence levels (negative, neutral, and positive). Therefore, in order to ensure maximum comparability with previous studies, the term "selective attention to (one level of) *valence*" will be generally used in the following. However, wherever I am exclusively referring to emotional faces, the term "selective attention to *expression/emotion*" is used (see also Schmuck et al., 2023).

In *Publication III* (Schmuck et al., 2023) we investigated the influence of selective attention on the neural processing of emotional facial expressions since the previous studies of selective attention to valence primarily used affective pictures and words as stimuli (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007). Using Frequentist and Bayesian statistics, we explored whether the early perceptual and late controlled processing of emotional expressions as indexed by four distinct ERP components benefited from selective attention. In *Publication IV* (Schmuck et al., 2024) we substantially extended the sample size of our first study (Schmuck et al., 2023) to uncover potential effects of participant gender and gender of facial stimuli on selectively attended emotional faces in the current task. Therefore, two early as well as one late ERP component associated with emotional face processing were investigated using linear mixed-effects models (LMMs).

This series of four journal articles with novel ERP findings will be presented and discussed within the broader context of the existing literature. While the synopsis synthesizes the articles, it is not intended to substitute the comprehensive experimental details, statistical analyses, and critical evaluations contained in each. Instead, the objective of the synopsis and the following discussion is on highlighting the interrelations between the publications and their contributions to the broader literature. Although the synopsis provides sufficient context to understand the four studies underlying this thesis, interested readers seeking a deeper examination are encouraged to refer to the original publications (see Table 1.1). The detailed methodological specifics and complete statistical analyses are omitted here but are available in the publications.

Table 1.1.: Publications Included in the Present Thesis

Publication	**Full Reference**
I	Schmuck, J., Schnuerch, R., Voltz, E., Kirsten, H., & Gibbons, H. (2025). The influence of lexical word properties on selective attention to emotional words: Support for the attentional tuning of valent word forms. *Psychophysiology*, *62*(1), e14748. https://doi.org/10.1111/psyp.14748
II	Gibbons, H., Schmuck, J., & Kirsten, H. (2022). Interactions of ignored and attended valence in a valence-detection task with emotional words support the model of evaluative space: An ERP study. *Language, Cognition and Neuroscience*, *38*(10), 1430–1450. https://doi.org/10.1080/23273798.2022.2088817
III	Schmuck, J., Schnuerch, R., Kirsten, H., Shivani, V., & Gibbons, H. (2023). The influence of selective attention to specific emotions on the processing of faces as revealed by event-related brain potentials. *Psychophysiology*, *60*(10), e14325. https://doi.org/10.1111/psyp.14325
IV	Schmuck, J., Voltz, E., & Gibbons, H. (2024). You're beautiful when you smile: Event-related brain potential (ERP) evidence of early opposite-gender bias in happy faces. *Brain Sciences*, *14*(8), 739. https://doi.org/10.3390/brainsci14080739

Note. The publications are sorted according to their thematic focus (particularly with regard to the type of emotional stimuli used) and their order in the main text, rather than by date of publication.

2. Methods

Prior to focusing on the central topic of the synopsis, which addresses the electrophysiological correlates of selective attention to affect, it is essential to establish a robust methodological foundation for the forthcoming sections. As previously stated, all of my research presented in this thesis relies on the assessment and analysis of ERPs, a technique that has also been employed in several recent studies on selective attention to affect (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007). Accordingly, I will first provide a concise introduction to the neurophysiological principles and technique of EEG and ERPs and present a brief overview of the most relevant ERP components for the current thesis. In the second part, I will focus on the statistical analysis of the collected EEG data. In addition to traditional analysis methods, various alternative approaches have emerged in recent years (e.g., Keysers et al., 2020), which are also particularly useful for the analyses of EEG data (Frömer et al., 2018). In line with my personal goal of employing state-of-the-art statistical methods, I will provide a brief overview of two such statistical techniques.

2.1. Event-Related Potentials

The ERP technique offers a powerful method for studying the human mind and brain and is extensively employed in cognitive neuroscience (see Cacioppo et al., 2007; M. X. Cohen, 2014; Luck, 2014; Luck & Kappenman, 2013). Among its most notable advantages is the ability to directly measure neural activity, thereby allowing for the capture of cognitive dynamics within the time frame in which human cognition typically unfolds (M. X. Cohen, 2014). These cognitive, but also perceptual, linguistic, and emotional processes occur within tens to hundreds of milliseconds (M. X. Cohen, 2014) and have been functionally associated with a variety of ERP components distinct in polarity, timing and scalp distribution (e.g., Luck & Kappenman, 2013). The ERPs, which represent variations in brain activity related to specific events, are derived from the continuous EEG.

2.1.1. Neurophysiological Background of the EEG

The EEG is the continuous recording of electrical brain activity on the surface of the scalp. In almost all cases, it reflects electrical potential differences (i.e., changes in voltage) at the dendrites of the postsynaptic neurons, which arise during the transmission of electrical signals between two neurons (Luck, 2014). More specifically, these postsynaptic potentials are generated when neurotransmitters bind to a receptor on the postsynaptic cell membrane, causing ions to flow into and out of the neuron (M. X. Cohen, 2014). The resulting transient changes in the distribution of positively and negatively charged ions create a tiny dipole (Luck, 2014). However, while the electric field generated by a single dipole is too weak to be recorded from a scalp electrode, the individual dipoles of several synchronously activated neurons can summate and become powerful enough to be measured from outside the head (M. X. Cohen, 2014). The vector sum of many nearby dipoles is referred to as the equivalent current dipole (Luck, 2014). In addition to a sufficiently large number of simultaneously active neurons (around 10,000 to 50,000; Murakami & Okada, 2006), the neurons must receive the same kind of input (either excitatory or inhibitory) and have approximately the same orientation (perpendicular relative to the surface) to produce a measurable EEG signal on the scalp (Luck, 2014).

These features are mainly found in the cortical pyramidal cells, which are therefore seen as the best candidates for EEG generators (Nunez & Srinivasan, 2006). Thus, when enough synapses in these superficial cortical layers fire at the same time, the electrical potential can be measured at the scalp with almost no delay, given the nature of electrical activity and the brain tissue (Nunez & Srinivasan, 2006). This instantaneous conduction of voltage fluctuations gives rise to the most commonly cited characteristic of this technique: the excellent temporal resolution (Luck, 2014). The EEG provides the possibility to continuously measure cognitive or emotional processing with millisecond resolution. In comparison, the temporal resolution of neuroimaging techniques like fMRI, which do not directly measure neural events but rather hemodynamic activity, is in the range of seconds (Logothetis, 2008). However, unlike fMRI, the EEG has a relatively low spatial resolution. On the one hand, it can hardly measure electrical activity from sources deep in the brain (e.g., basal ganglia, hippocampus, thalamus) due to the weaker field strength on the scalp and the rather randomly arranged subcortical neuron populations (M. X. Cohen, 2014; Luck, 2014). On the other hand, as described above, only large populations of neurons generate a measurable signal, which therefore limits precise localization of the generator sites.

2.1.2. General Features of ERP Components

ERPs represent changes in voltage recorded at the scalp, which are related to a specific event (Luck, 2014). Following the preprocessing of raw EEG data (e.g., bad channel detection, filtering, re-referencing, ocular correction; see individual articles for more details) they are extracted from the continuous recording by averaging a large number of epochs which are time-locked to the event of interest. Typically, this is either the onset of a stimulus (*stimulus-locked*) or a response (*response-locked*) (Amodio et al., 2014). Averaging multiple epochs time-locked to repeated events from the same task condition attenuates random, unsystematic noise (e.g., activity unrelated to the specific event such as skin potentials or muscle artifacts), leaving the consistent event-related brain activity which is supposed to be somewhat similar on each trial (Luck, 2014). From this perspective, the addition of a constant evoked response to the independent ongoing EEG fluctuations can be seen as the neural foundation of the ERP. In contrast to the *additive* model, it has been proposed that phase resetting of ongoing EEG oscillations in response to an event may also represent the neurophysiological basis of (early) ERP generation (*phase reset* model; see M. X. Cohen, 2014; Sauseng et al., 2007).

ERPs are characterized by a sequential series of voltage deflections (ERP *components*) relative to the event onset, which differ in polarity (positive or negative). On a conceptual level, a single ERP component can be defined as a "scalp-recorded neural signal that is generated in a specific neuroanatomical module when a specific computational operation is performed" (Luck, 2014, p. 66). While this is particularly useful from a theoretical perspective, a more practical approach considers components as reliable and systematic voltage changes across conditions and individuals that originate from a single neural generator (Luck, 2014). However, this does not necessarily imply that the precise location of the neural generator of an ERP component is known. Indeed, the observed voltage distribution on the scalp can be explained by multiple different combinations of neural generator sites and thus cannot be identified with complete certainty (*inverse problem*; see Luck, 2014).

ERP components are usually described in terms of their amplitude (the magnitude of the neural activity), latency (the timing of the neural activity), and characteristic scalp distribution (Fabiani et al., 2007; Luck, 2014). Each of these three features needs to be considered in relative rather than absolute terms. First, the amplitude (i.e., the voltage) of the ERP component is usually measured in relation to a predefined baseline phase in which no event-related activity is assumed (e.g., 100 ms before stimulus onset) and has either a positive or negative polarity. It is relatively small (1–30 microvolts) compared to the continuous EEG (up to 100 microvolts) (Fabiani et al., 2007; Luck, 2014). However, neither the polarity nor the absolute amplitude of a particular compo-

nent alone is very informative about the underlying neural processes. On the one hand, polarity depends on a combination of factors, including the type of neurotransmitters (excitatory or inhibitory) and synapses involved, as well as the orientation of neurons in the cortex relative to the recording electrodes (Luck, 2014). On the other hand, the amplitude size can be influenced by the strength and synchronization of neural activity but is also highly dependent on individual participant characteristics, such as age, brain structure, or fatigue (Luck, 2014). Thus, although the absolute amplitude and polarity of the component itself cannot be used to draw clear conclusions, the comparison of ERP components between experimental conditions and participants has proven to be all the more useful for gaining insight into the neural and psychological processes taking place. Second, the latency of a specific component is measured relative to event onset (either a stimulus or a response) and is typically in the range of one second or less, even though some components can last several seconds (see Hajcak & Foti, 2020). Third, ERPs are measured as differences in the electric potential between two recording sites (the electrode of interest and a reference electrode). The reference sites should ideally capture *none* of the event-related voltage fluctuations but *all* of the noise- or artifact-related activity; typical references are the linked mastoid electrodes or the average reference (D. Yao et al., 2019). Thus, scalp topography may vary depending on the electrode site from which the ERP is recorded and the type of reference used (Fabiani et al., 2007). These three key characteristics are also reflected in the naming of the individual ERP components. As pointed out by Fabiani and colleagues (2007), components have been labeled according to their polarity and latency (e.g., N170 or P300), the ordinal position of a peak of a given polarity (e.g., P1 or N2) or the psychological conditions that elicit the component (e.g., mismatch negativity). Additionally, the topographical distribution on the scalp can be used to characterize the component more precisely (e.g., frontal N400).

From a psychological perspective, several types of ERP components can be distinguished: exogenous, endogenous and motor components (Fabiani et al., 2007; Luck, 2014). *Exogenous* (or *sensory*) ERP components arise very shortly after stimulus onset and are primarily driven by the physical features of the triggering external stimulus. *Endogenous* components which are related to cognitive and information processing occur later in time and depend on the interaction between individual and event. *Motor* components are associated with the execution or preparation of a motor response (see Fabiani et al., 2007; Luck, 2014). However, this distinction is largely theoretical in nature, as the boundaries between the different categories are often blurred, with some ERP components exhibiting characteristics associated with more than one type. For example, both the P1 and N1 components are influenced by the physical features of a stimulus (e.g., size or contrast) and by cognitive processes (e.g., attention) (see Fabiani

et al., 2007; Luck, 2014). Beyond the aforementioned broad categorizations, decades of electrophysiological research have yielded a substantial corpus of literature on specific ERP components that have been linked to more specific psychological processes. In line with the primary focus of this thesis, which is the electrophysiological correlates of attention to affect, Section 2.1.4 will provide a concise overview of the most frequently investigated ERP components within emotion-attention research.

2.1.3. Measurement of ERP Components

ERP components are typically measured by calculating the amplitude or latency of the averaged ERP waveform within a specific time window for each participant and experimental condition (Kappenman & Luck, 2016). There are two key aspects that warrant particular attention: the spatial and temporal localization of the component (Kappenman & Luck, 2016; Zhang & Kappenman, 2024). Regarding the spatial localization, one common approach is the measurement of an ERP component at a single electrode site, which is typically the site where the component is largest. Alternatively, the signal from two or more electrode sites within a region may be averaged in order to mitigate the impact of interindividual variations at a single electrode on the study results. Consequently, the ERP component is quantified using the resulting electrode cluster (Zhang & Kappenman, 2024).

Following the spatial localization, there are two common approaches to measure amplitudes and latencies of specific ERP components (Kappenman & Luck, 2016; Luck, 2014). On the one hand, peak-based methods measure the size or time of the maximum voltage in case of positive-going components or the minimum voltage in case of negative-going components, often within a pre-specified time window (Kappenman & Luck, 2016). For this purpose, an algorithm identifies the peak voltage of a specific component within a specific time window for each individual, particularly when there are significant interindividual differences in the timing of the component (Amodio et al., 2014). On the other hand, mean- or area-based measures quantify the aggregated size or time of the mean voltage across a given time interval (Kappenman & Luck, 2016). In contrast to peak amplitude measures, the mean amplitude is usually more reliable and unaffected by trial-to-trial latency variability (Luck, 2014). Typically, a narrow time window (e.g., 30 ms) is employed to capture early, transient ERP components (such as the P1) with steep amplitude changes, whereas later, more protracted, and broader components (such as the N400) are measured using wider windows (e.g., 200 ms). The selection of the appropriate time window can be based either on *a-priori* hypotheses derived from previous research or on the visual inspection of the observed data (see Luck, 2014). In particular, the *collapsed localizer* approach in which grand-grand averaged

ERP waveforms across individuals and conditions are used to determine both the time window and the electrode cluster for the analysis of a particular component has gained popularity in recent years since it reduces the likelihood of bogus ERP effects (Luck & Gaspelin, 2017). This approach often combines peak- and mean-based measures by first identifying the component's peak in the grand-grand average and then calculating the mean amplitude within a surrounding time window (e.g., 20 ms around the P1 peak).

2.1.4. Emotion-Related ERP Components

There are multiple ERP components that are sensitive to a wide range of emotional content. While the extent to which the ERPs reflect actual emotions induced by the emotional content or "cold" cognitive processes associated with the emotional stimuli remains unclear, the emotion effects observed at specific ERP components nevertheless offer valuable insights into the temporal processing of emotional stimuli (Luck, 2014). Among the most commonly investigated are the early visual components P1 and N170 as well as the *early posterior negativity* (EPN) and the *late positive potential* (LPP) (see Hajcak et al., 2012; Luck, 2014; Schindler & Bublatzky, 2020). In particular, the EPN and LPP have also been frequently used to explore the interplay between attentional processes and emotional material (Hajcak et al., 2012), even though this line of research has more recently been extended to the earlier visual components (e.g., Gibbons et al., 2023; Schindler & Straube, 2020) and will be continued in the current thesis. An overview of the ERP components (including the respective time windows and electrode sites) analyzed in the four individual studies as part of this dissertation can be found in Table 2.1.

The P1 is typically the first major component in the ERP following visual stimuli, arising between 60 to 90 ms and peaking between 100 and 130 ms after onset (Luck, 2014). It is largest at lateral (parieto-)occipital electrodes (Hajcak et al., 2012; Luck, 2014) being generated at a relatively late stage of the visual pathway (Luck & Kappenman, 2013). More specifically, early P1 components (~100 ms) correspond to neural activity in the dorsal extrastriate cortex of the occipital gyrus, while late P1 components (~140 ms) seem to be generated in the ventral extrastriate cortex of the fusiform gyrus (Di Russo et al., 2002). Regarding psychological processes, the P1 component can be reliably modulated by spatial attention but also by feature-based attention, at least under certain conditions (Luck & Kappenman, 2013). Furthermore, it typically reflects the processing of low-level visual features, both for facial (Rossion & Caharel, 2011; Schindler et al., 2021) and word stimuli (Dien, 2009). Interestingly, effects of emotional content on the P1 amplitude have also been frequently reported, although the observed effects are highly variable and not consistently present across studies (Hajcak

Table 2.1.: Analyzed ERP Components in the Four Studies

	Study I (Schmuck et al. 2025)	**Study II** (Gibbons et al., 2022)	**Study III** (Schmuck et al., 2023)	**Study IV** (Schmuck et al., 2024)
P1	100 – 118 ms (PO7, PO8, O1, O2)	90 – 110 ms (PO7, PO8)	100 – 130 ms (PO3, PO7, O1, PO4, PO8, O2)	105 – 135 ms (PO3, PO7, O1, PO4, PO8, O2)
N170	150 – 180 ms (P7, P8, PO7, PO8, O1, O2)	150 – 180 ms (PO7, PO8)	140 – 190 ms (P7, P8, PO7, PO8)	145 – 175 ms (P7, P8, PO7, PO8)
EPN	150 – 270 ms (P7, P8, PO7, PO8, O1, O2)	150 – 250 ms (PO3, PO7, O1, PO4, PO8, O2)	270 – 380 ms (TP7, TP8, P7, P8, PO7, PO8)	
LPP		550 – 800 ms (PO3, POz, PO4)	400 – 700 ms (CP1, CPz, CP2, P1, Pz, P2, POz)	300 – 600 ms (P3, P1, Pz, P2, P4, PO3, POz, PO4)

Notes. For each study, all analyzed components with the respective time window as well the electrode cluster (in parentheses) are shown. In *Study I* and *II*, only an EPN-like complex emerged which was labeled N170/EPN due to its early onset. In *Study II*, the following components were additionally analyzed: fronto-central P2, medial-parietal P300 and medial-central N400.

et al., 2012; Schindler & Bublatzky, 2020). At least to some extent, variations in the stimulus material and the tasks employed may account for some of the inconsistencies observed (see Hajcak et al., 2012; Schindler & Bublatzky, 2020).

The subsequent N170 is a negative-going component at bilateral occipitotemporal sites in average-referenced data occurring between 130 and 200 ms (Bentin et al., 1996; Hajcak et al., 2012; Rossion & Jacques, 2012). It constitutes a subcomponent of the visual N1 wave, which consistently exhibits a more negative amplitude in response to facial stimuli compared to objects at around 170 ms (Luck, 2014). These properties – sensitivity to faces as well as a peak latency and topography as previously described – are the defining characteristics of the face N170 component (Rossion & Jacques, 2012). It is typically more pronounced over the right hemisphere with three dominant neural sources originating in multiple regions of the occipitotemporal cortex. These are the *occipital face area* in the inferior occipital gyrus, the *fusiform face area* in the middle fusiform gyrus and the *posterior superior temporal sulcus* in the anterior fusiform gyrus (Rossion & Jacques, 2012). In addition to its sensitivity to facial stimuli in general, the N170 has revealed robust increases in amplitudes for emotional compared to neutral faces

(Hinojosa et al., 2015; Schindler & Bublatzky, 2020). Importantly, it is presumed to indicate genuine configural face processing (Bentin et al., 1996; Rossion & Jacques, 2012) as opposed to processing of low-level visual cues (Rossion & Caharel, 2011; Schindler et al., 2021). It has further been suggested that the N170 may more generally reflect the holistic processing of stimuli (e.g., faces, but also fingerprints or cars) in which an individual has expertise (e.g., Busey & Vanderkolk, 2005; Gauthier et al., 2003). Although the N170 is mostly investigated in relation to face perception, a negative-going component with similar latency and left-lateralized scalp topography has been observed in response to written words (Dien, 2009). The word N170 is thought to be generated in the *visual word form area* (see Dehaene & Cohen, 2011) in the left fusiform gyrus and likely reflects early structural word form analysis (Dien, 2009) as well as holistic word processing (Simon et al., 2007).

Following the early visual components, the two most prominent markers of emotional processing emerge: the EPN and the LPP. The EPN is a mid-latency component overlapping with other N2 components that is larger for emotional compared to neutral content (Schupp, Flaisch, et al., 2006). It appears as a relative negative voltage deflection for emotional stimuli over lateral temporo-occipital electrodes between 150 and 350 ms in average-referenced ERPs (Junghöfer et al., 2001; Olofsson et al., 2008; Schupp & Kirmse, 2021). The neural generator sites have been suggested to reside within the lateral occipital extrastriate cortex (Schupp, Stockburger, et al., 2006) while emotional EPN modulations are also correlated with modulations in the amygdala and anterior cingulate (Sabatinelli et al., 2013). This differential ERP activity which shares features with ERP markers of selective attention to specific stimulus features in general may reflect early *natural selective attention* to highly arousing stimuli (Schupp, Flaisch, et al., 2006). The process of attentional capture can occur automatically (Olofsson et al., 2008); however, other research suggests that modulations of attentional engagement can strongly influence the EPN emotional effect (Schindler et al., 2022; Wiens & Syrjänen, 2013). More recent research even challenges the notion that the EPN reflects attentional capture; rather, it is proposed that it represents downstream effects of attention including object identification (Hoffman et al., 2020).

The LPP is a protracted slow-wave positivity over centroparietal sites that becomes evident after 300 ms and is increased for emotional compared to neutral stimuli (Hajcak & Foti, 2020). It typically extends for several hundred milliseconds during which its topography progresses from a parietal distribution to a more centrally maximal distribution (Hajcak et al., 2012). In particular the early phase is similar to the well-known P300 component (Luck, 2014); however, the emotional modulation of the LPP is more sustained and often covers the full duration of stimulus presentation (Hajcak & Foti, 2020). In comparison to the earlier components, the LPP is thought to reflect more

flexible and elaborative processes (Hajcak et al., 2012). This involves primarily the controlled, but also automatic allocation of attention to motivationally significant stimuli which generally elicit a larger LPP (Hajcak & Foti, 2020). In this context, the significance (or importance) of a stimulus can be understood to encompass both affective (e.g., emotional versus neutral) and cognitive (e.g., task-related such as targets versus nontargets) aspects. With regard to the affective aspects, the LPP further seems to distinguish between more detailed image content (e.g., erotic versus exciting sport images) within the same affective category (Hajcak & Foti, 2020). This notion is consistent with findings that the LPP may represent neural activity in both cortical (e.g., extrastriate occipital, inferotemporal visual cortex) and subcortical (e.g., amygdala, ventral striatum) areas that are involved in emotional discrimination processes (Sabatinelli et al., 2013).

2.2. Statistical Analysis

In the following sections, I will give a brief overview of various statistical approaches that I have applied in several of my own studies. In line with my aim of using state-of-the-art statistical methods, I have focused on two approaches that have been employed more widely in recent decades, including in EEG analysis: the Bayesian framework and linear mixed-effect models (LMMs). While these approaches certainly offer advantages over traditional approaches, their increasing popularity is also due to a steady advance in computational resources allowing for more complex and intensive calculations. The two sections will only provide an introduction to the most relevant ideas and basic concepts of the respective methods; for a detailed introduction and deeper understanding, the reader is invited to refer to the relevant literature. Technical details as well as the precise details of the statistical implementation can be found in the original publications on which this thesis is based.

2.2.1. Bayesian Framework

The field of neuroscience is characterized by a steady advance of measurement techniques and the implementation of novel experimental paradigms. In contrast, the analysis of data in this domain has, since its inception, been predominantly conducted within the standard framework of frequentist statistics, which features the well-known p-value *null-hypothesis significance testing* (Keysers et al., 2020). This approach is appropriate for quantifying the evidence *against* the null hypothesis (H_0: there is no effect); that is, evidence that the true effect is different from zero (Muff et al., 2022).

However, difficulties arise when one attempts to quantify evidence *for* the null hypothesis as two fundamentally distinct causal explanations for non-significant p-values are conceivable (Keysers et al., 2020): in addition to sampling variation, the results can either support the null hypothesis (i.e., evidence for absence) or be inconclusive due to insufficient power (i.e., absence of evidence). This bias toward the emphasis of positive effects as well as the misuse of p-values have been shown to play a pivotal role in the reproducibility crisis in psychological research (Szucs & Ioannidis, 2017). One alternative statistical approach that may help to overcome these issues is *Bayesian inference.* The following part will provide a brief overview of the underlying theoretical framework (for detailed information, see Keysers et al., 2020; Kruschke, 2015; Van De Schoot et al., 2014; Wagenmakers et al., 2018).

While all common statistical tests such as a t-test or analysis of variance (ANOVA) can be computed in both the Bayesian and the frequentist framework, the fundamental difference between the two approaches regards the properties of the unknown parameters (Van De Schoot et al., 2014). Frequentist approaches assume that population parameters have only one fixed value (which is unknown) and that the data are random, whereas Bayesian approaches treat all unknown parameters as uncertain and describe each by a probability distribution (Van De Schoot et al., 2014). There are three main components that constitute the core of Bayesian statistics (Van De Schoot et al., 2014). The first element is the *prior distribution* which captures any background knowledge on the parameters before actually observing the data. In the absence of specific knowledge regarding the parameters, prior distributions may be uninformative (e.g., a uniform distribution). However, informative priors can incorporate some a priori information (e.g., from meta-analyses) about the population parameter (e.g., a narrow normal distribution with a specified mean). The second element is the information contained within the data, which is expressed by the likelihood function of the data given the parameters. Thirdly, based on the combination of prior distribution and the observed data (using Bayes' Theorem), the *posterior distribution* of the parameter is obtained from sampling algorithms such as Markov chain Monte Carlo (MCMC). The underlying idea of MCMC sampling is to approximate the posterior distribution through an iterative sampling process (see Kruschke, 2015). In order to characterize the statistical significance of effects, one simply describes the posterior distribution using centrality and dispersion measures. For instance, one could calculate the Bayesian *credible interval* which provides a range in which the effect falls with a specified probability in the population (Van De Schoot et al., 2014). Additionally, the Bayesian framework also allows to quantify the relative evidence of competing hypotheses H_0 and H_1 (i.e., there is an effect) as expressed by the *Bayes factor* (Keysers et al., 2020). It should be interpreted as a continuous measure of evidence, comprising three general qualitative categories: first, support for H_1;

second, support for H_0; and third, a Bayes factor close to one indicates that neither of the two hypotheses is preferred (Keysers et al., 2020). Whereas the Bayes factor reflects the relative plausibility of two competing models, the contribution of individual effects of interest in the models can be analyzed using the inclusion Bayes factor. It compares models that differ regarding the presence or absence of a particular effect (e.g., the interaction in a two-way ANOVA), thus allowing inferences about the relevance of each component (Keysers et al., 2020).

While frequentist and Bayesian estimation typically produce similar outcomes with large sample sizes and normally distributed parameters (Van De Schoot et al., 2014), a number of unique practical advantages of the Bayesian approach have been highlighted in the scientific literature (see Keysers et al., 2020; Kruschke, 2015; Van De Schoot et al., 2014). First, Bayesian hypothesis testing can help to differentiate between actual support for the null hypothesis (evidence of absence) or merely inconclusive results (absence of evidence; see Keysers et al., 2020). Second, Bayesian inference allows for the inclusion of background knowledge (via the prior distribution) in order to conduct a more diagnostic test (Keysers et al., 2020). The resulting findings can then be used to update one's own knowledge and can be incorporated into future analyses as new prior distributions (Van De Schoot et al., 2014). It is important to note that priors have the potential to significantly influence the posterior distribution (Van De Schoot et al., 2014). Thus, choosing reasonable prior distributions is essential for correct statistical inference (Wagenmakers et al., 2018). Third, Bayesian analysis enables researchers to continuously monitor the outcomes while the data are accumulating (Keysers et al., 2020). In light of these benefits, Keysers et al. (2020) recommended reporting Bayesian statistics alongside the classical frequentist statistics in neuroscience research to combine the best of both statistical approaches. This strategy was adopted in *Study III* (Schmuck et al., 2023) of the current thesis.

2.2.2. Linear Mixed-Effects Models

As it was outlined in Section 2.1.3, ERP components are most commonly quantified by their mean amplitude in a specified time window averaged within individuals and experimental conditions. These mean amplitude voltages are subsequently analyzed using traditional repeated measures ANOVAs (frequentist or Bayesian) in order to determine potential effects of the experimental manipulation on neural processing (Frömer et al., 2018). While the ANOVA method is an efficient, straightforward approach, particularly in the case of balanced data (i.e., equal number of observations for each participant and condition), it is nevertheless subject to certain limitations (Frömer et al., 2018). First, it is implicitly assumed that the number of observations is similar or identical in each

group and thus that each participant's average is weighted equally across all conditions. However, this assumption is typically violated in the case of unbalanced or even missing data. Second, random variance in effect sizes, which can be attributed to differences between individuals but also items, cannot be accounted for in the ANOVA method. Third, the approach requires categorical independent variables, thus resulting in the potential loss of information and statistical power due to the dichotomization of continuous variables (Frömer et al., 2018).

One alternative to averaging the ERP amplitudes within participants and conditions is the use of LMMs which can be performed on single trials. LMMs constitute a generalization of standard regression in which the dependency between data points is explicitly captured by random-effects parameters (Singmann & Kellen, 2019). They take all available data into account and can accommodate several limitations of the classical ANOVA approach, including unbalanced designs and the variability of effect sizes between participants and items (Frömer et al., 2018). In addition to the specification of the experimental main and interaction effects of primary interest – *fixed effects* – it is necessary in LMMs to explicitly define the structure of random effects present in the experimental design (Singmann & Kellen, 2019). Fixed effects represent the population-level average effect of a specific model term and are interpreted as in the standard ANOVA, whereas random effects represent the stochastic variability in the data attributable to distinct sources (usually individuals and items) and may be considered as nuisance variables (Singmann & Kellen, 2019). Essentially, LMMs can estimate the variance for the mean response of each random factor – that is, random intercepts – and for each within-individual and within-item main and interaction effect – that is, random slopes – and their associated correlation parameters (Matuschek et al., 2017). Importantly, the interpretation of the fixed effects remains unaffected by the random effects which only indicate whether there is variability in the fixed effect across the distinct levels of the random effect (Singmann & Kellen, 2019). An appropriate specification of the random-effects structure is crucial for maximizing statistical power and avoid Type I errors (Matuschek et al., 2017).

In contrast to alternative approaches such as a simple regression model that ignores all individual variability (i.e., *complete pooling*) or one individual regression and parameter set for each participant (i.e., *no pooling*), LMMs rely on a *partial pooling* approach in order to improve estimation on the individual level (see Singmann & Kellen, 2019). Similar to the no-pooling approach, the inclusion of random effects allows subjects to have individual parameter estimates which deviate from the population-level mean. Importantly, it is assumed that these individual estimates are random samples derived from one common, typically normal, distribution and thus share characteristics to a certain degree. Building on this assumption, the information from all subjects is used

to inform the estimates for individual subjects and specifically estimates for individuals with little data and large variability are adjusted toward the population mean, thus providing more accurate and generalizable estimates of the effects (Singmann & Kellen, 2019). Due to their inherent characteristics and their ability to overcome limitations of classical repeated measures ANOVAs, LMMs have been recommended as an alternative approach to ERP analysis (Frömer et al., 2018). Therefore, the data of *Study III* (Schmuck et al., 2023) and *IV* (Schmuck et al., 2024) of the current thesis were analyzed with LMMs. For a more detailed description of the actual implementation and software used, the reader may refer to the original publications as well as to other resources (Brauer & Curtin, 2018; Meteyard & Davies, 2020).

3. Synopsis

The dynamic interplay between attention and emotion has long attracted the interest of researchers, leading to a wealth of behavioral, electrophysiological and neuroanatomical findings (e.g., De Houwer & Hermans, 2010; Pessoa, 2008; Pourtois et al., 2013; Vuilleumier, 2005). These studies have frequently highlighted two lines of research: first, bottom-up attentional control driven by intrinsic stimulus significance (e.g., a fearful face) in tasks in which emotion is not relevant; and second, top-down attentional control driven by voluntary attention allocated to emotional stimuli in tasks that direct attention to an emotional dimension (see Section 1.2). Focusing on the temporal aspects, scholars in the field of ERPs have made significant progress over the past decades in unraveling the dynamics underlying these attentional selection mechanisms. Most of the findings were obtained from studies that applied experimental designs manipulating the extent to which attention is allocated to emotional stimuli. The most common tasks can be broadly categorized as those that involve (1) the use of emotional stimuli as distractors, (2) passive viewing of emotional stimuli, (3) attention to non-emotional features of stimuli (emphasizing implicit bottom-up processing of emotional stimuli) and (4) general attention to emotional features, thus focusing on explicit top-down emotional processing (for review, see Gibbons, Kirsten, et al., 2022; Schindler & Bublatzky, 2020). While the degree of attention paid to emotionally relevant features increases across the four categories, the upper limit of top-down attention to emotion has rarely been reached. This "maximal" top-down attention has so far been investigated in a limited number of studies (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007; Weidner et al., 2022) that focused on the effects of selective attention to one specific level of valence. Only these studies can help answer the question formulated in Section 1.3: *What happens when stimuli of a specific level of valence become the focus of attention?* Prior to presenting my own novel research, the objective of which is to corroborate existing findings as well as to extend our understanding of the temporal dynamics of selective attention to a particular valence, it is essential to establish a solid foundation of the current ERP literature on the interplay of attention and emotion.

3.1. Previous Findings

3.1.1. General Attention to Affect

Following the presentation of visual emotional stimuli, a number of different components emerge in the ERP, which reflect the temporal processing of this emotional information. The earliest prominent deflection is the occipital P1, which has yielded mixed findings regarding the early emotion effects across different emotional stimuli. Using words, researchers reported both increased (Keuper et al., 2014; Schindler et al., 2019; Schindler, Vormbrock, et al., 2023; D. Zhang et al., 2014) as well as decreased (e.g., Bayer et al., 2012b; Gibbons et al., 2023; Hofmann et al., 2009; Kuchinke et al., 2014; Rellecke et al., 2011; Scott et al., 2009) P1 amplitudes for negative compared to neutral or positive words. Some of these effects were restricted to only one hemisphere (Schindler, Vormbrock, et al., 2023; D. Zhang et al., 2014), a specific font type (Kuchinke et al., 2014) or high-arousal words (Hofmann et al., 2009; Scott et al., 2009). Nevertheless, a considerable number of studies failed to report any P1 emotional effects (Bayer et al., 2012a; Bayer & Schacht, 2014; Frühholz et al., 2011; Herbert et al., 2008; Kissler et al., 2007, 2009; Palazova et al., 2011; Schindler et al., 2018). Regarding emotional faces, several studies observed larger P1 amplitudes for fearful (Santos et al., 2008; Wieser et al., 2012; D. Zhang et al., 2013), angry (Blechert et al., 2012; Bublatzky et al., 2014; Rellecke et al., 2012) or happy faces (Rellecke et al., 2011; Rossignol et al., 2012; D. Zhang et al., 2013); but sometimes also smaller amplitudes for emotional compared to neutral faces (e.g., Valdes-Conroy et al., 2014). Again, many studies did not reveal any emotion modulations during the P1 time range (for review, see Schindler & Bublatzky, 2020). Finally, there is also evidence that negative pictures can elicit greater P1 amplitudes compared to positive or neutral pictures (Delplanque et al., 2004; Schindler et al., 2022; Schindler & Straube, 2020; Smith et al., 2003), although this pattern has not been observed in all studies (Bayer & Schacht, 2014; Bekhtereva & Müller, 2017; Schacht & Vrtička, 2018). These emotion effects are believed to be mainly driven by low-level visual cues for both words (Dien, 2009), faces (Rossion & Caharel, 2011; Schindler et al., 2021) and scenes (see De Cesarei et al., 2017). Focusing on the modulation of the reported P1 emotion effects by attentional conditions, a recent review on facial expressions concluded that these effects are more frequently observed during tasks involving implicit emotional processing and greater perceptual difficulty (Schindler & Bublatzky, 2020). Similarly, P1 emotion effects for words and scenes were typically observed during implicit emotional processing (e.g., passive viewing, lexical decision tasks, rapid serial visual presentation). Interestingly, for all three stimuli types, these effects neither seem to differ between varying degrees of bottom-up emotional processing (e.g., Bayer et al.,

2012b; Kissler et al., 2009) nor between perceptual discrimination, non-emotional (i.e., bottom-up) and emotional categorization (i.e., top-down emotional processing) of stimulus content (e.g., Schindler et al., 2020, 2022; Schindler, Vormbrock, et al., 2023).

The earliest consistent ERP modulations by emotion (especially those in facial stimuli) are typically observed at the N170. In a meta-analysis of 57 experiments, Hinojosa et al. (2015) reported significantly larger amplitudes for emotional compared to neutral faces, with the largest effect sizes for fearful, followed by angry and happy expressions. This finding is consistent with a more recent review that identified N170 emotion effects more frequently in threat-related compared to happy expressions (Schindler & Bublatzky, 2020). In a similar vein, evidence suggests that the N170 (sometimes termed N1, although observed at a similar latency) in response to words (Fraga et al., 2021; Gibbons et al., 2023; Kissler et al., 2009; Kissler & Herbert, 2013; Scott et al., 2009; Z. Yao et al., 2016; D. Zhang et al., 2014) and pictures (Carretié et al., 2003; Schindler et al., 2022; Schindler & Straube, 2020; Weinberg & Hajcak, 2010) might also be modulated by emotional content. Nonetheless, these findings are not as robust as the N170 modulations by facial expressions. On the one hand, findings for words tend to be less consistent with some studies indicating an absence of N170 emotion effects (Herbert et al., 2008; Palazova et al., 2011; Schindler et al., 2018; Schindler, Vormbrock, et al., 2023). On the other hand, emotional effects for pictures are likely to be at least in part modulated by low-level visual features (see Olofsson et al., 2008; Schettino et al., 2016). This is in contrast to the N170 expression effect which is assumed to be driven by configural face rather than low-level visual cue processing (Rossion & Caharel, 2011; Schindler et al., 2021). Both reviews (Hinojosa et al., 2015; Schindler & Bublatzky, 2020) also concur in their conclusion that N170 emotion effects (for faces) are more pronounced and prevalent in indirect tasks that do not direct explicit attention to emotional expressions (such as passive viewing designs). In line with this, studies that directly compared such indirect tasks to direct tasks often revealed no modulation by attentional conditions. For example, no differential N170 emotion effects for words were observed when participants had to make perceptual versus emotional judgments (Frühholz et al., 2011; González-Villar et al., 2014; Schindler, Vormbrock, et al., 2023) or when word reading was compared to lexical decisions (Bayer et al., 2012b; Kissler et al., 2009). The same pattern was also evident in some tasks involving faces that required either the discrimination of perceptual versus emotional features (Frühholz et al., 2011; Holmes et al., 2006) or the categorization of gender versus emotional expressions (Itier & Neath-Tavares, 2017; Rellecke et al., 2012; Schindler et al., 2020) and finally in tasks using emotional pictures (Schindler et al., 2022). However, there have also been studies reporting a greater increase for emotional compared to neutral faces when expressions were task-relevant (emotion categorization) rather than task-

irrelevant (gender categorization) suggesting that under specific conditions, the N170 can also be influenced by attention (Dou et al., 2021; Kolassa et al., 2007; Kolassa & Miltner, 2006; Valdes-Conroy et al., 2014; Wronka & Walentowska, 2011).

The attentional modulations of emotion effects become more prevalent in mid-latency and late components. The EPN, as a negative deflection in the ERP waveform, is typically larger for emotional compared to neutral faces (for review, see Schindler & Bublatzky, 2020), words (for review, see Citron, 2012) and pictures (for review, see Olofsson et al., 2008). These effects have been obtained for a variety of tasks and stimulus durations (Citron, 2012; Olofsson et al., 2008; Vormbrock et al., 2023). Regarding faces, threatening expressions (in particular angry, but also fearful) seem to elicit more reliable EPN modulations than happy expressions (Schindler & Bublatzky, 2020), while EPN emotion effects in words are commonly driven by similar increases for both positive and negative compared to neutral words (Gibbons, Kirsten, et al., 2022; Herbert et al., 2008; Kissler et al., 2007, 2009; Schacht & Sommer, 2009b; Scott et al., 2009; for review, see Citron, 2012). Regarding attentional modulation, EPN emotion effects for faces, pictures and words seem to require at least some post-perceptual elaboration. Merely perceptual decisions, such as identifying the orientation of superimposed bars or the stimulus color are insufficient to elicit emotion effects in words (e.g., Frühholz et al., 2011; González-Villar et al., 2014; Hinojosa et al., 2010; Schindler, Vormbrock, et al., 2023; but see Schacht & Sommer, 2009b), faces (e.g., Rellecke et al., 2012; Schindler et al., 2020; but see Frühholz et al., 2011) or scenes (Schindler et al., 2022). However, once stimuli undergo more than superficial processing, EPN effects were robust to various attentional modulations. Several studies observed no differential emotion effects between attending to the gender versus emotion of a face (Itier & Neath-Tavares, 2017; Rellecke et al., 2012; Schindler et al., 2020; Valdes-Conroy et al., 2014) or categorizing the type versus emotion of a word (Schindler, Vormbrock, et al., 2023). It is worthy of note that only in one study, the EPN emotion effect tended to be more pronounced during emotional than during gender categorization (Wronka & Walentowska, 2011).

Finally, the latter pattern of results—that is, increased emotion effects for affective compared to nonaffective processing—is most frequently observed in the LPP. In general, regardless of attentional conditions, the LPP has been found to be elevated for emotional compared to neutral stimuli across several stimulus categories (Citron, 2012; Olofsson et al., 2008; Schindler & Bublatzky, 2020; Schupp, Flaisch, et al., 2006). Despite mixed findings regarding the differences between positive and negative stimuli (e.g., Citron, 2012), recent reviews suggest that there is a negativity bias (i.e., larger amplitude for negative stimuli) for both facial (Schindler & Bublatzky, 2020) as well as scenic stimuli (Yuan et al., 2019) and a positivity bias (i.e., larger amplitude for positive stimuli) for verbal stimuli (Yuan et al., 2019) during late processing. Returning

to the attentional modulation of LPP emotion effects, these reviews and an overview by Gibbons, Kirsten, et al. (2022) indicate that emotion effects are consistently larger when explicit attention is directed to the emotional content, in contrast to implicit attention tasks. For faces, for example, this is evident in greater LPP emotion effects when participants are required to make judgments about the emotional expression compared to the face's gender (Rellecke et al., 2012; Schindler et al., 2020; Van Strien et al., 2010). Another study also observed more pronounced effects in an emotion versus color categorization task (Kolassa et al., 2007; but see Frühholz et al., 2011). In one study, no LPP emotion effects emerged across three tasks involving symbol, gender and expression discrimination (Valdes-Conroy et al., 2014). Regarding emotional pictures, affective evaluations again seem to increase emotion effects compared to perceptual or nonaffective tasks (e.g., Hajcak et al., 2006; Schindler et al., 2022; but see T. A. Ito & Cacioppo, 2000). Interestingly, emotion effects of words seem to benefit most from explicit attention to emotional content (see Gibbons, Kirsten, et al., 2022). Multiple studies reported greater LPP emotion effects during emotional categorization compared to perceptual (González-Villar et al., 2014; Schacht & Sommer, 2009b), lexical (Fischler & Bradley, 2006), grammatical (Schindler, Vormbrock, et al., 2023) or semantic decisions (Hinojosa et al., 2014; Naumann et al., 1997). It appears that decisions only pertaining to grammatical features are inadequate in evoking more pronounced emotional responses in comparison to those associated with perceptual attributes (Kissler et al., 2009; Schindler, Vormbrock, et al., 2023; but see Hinojosa et al., 2010). Nevertheless, there are some contradictory findings as LPP emotion effects did not always differ between emotion and color (Frühholz et al., 2011) or semantic judgments (Schacht & Sommer, 2009b).

3.1.2. Selective Attention to Affect

This concise overview of the differential ERP emotion effects across a range of tasks, from perceptual decisions to emotional categorization, suggests that the influence of attentional focus on early visual components in the aforementioned tasks is rather weak. Only at late components (LPP) do emotion effects seem to consistently benefit from increasing attention toward emotion-relevant features. The absence of earlier potentiation of emotion effects may be surprising (but see Wronka & Walentowska, 2011), given that one advantage of enhanced attention to emotion should be its faster and more efficient processing. However, until here, I have not presented any studies that investigated the effects of selective attention to *one* specific level of valence. The typical affective categorization tasks (e.g., Frühholz et al., 2011; Itier & Neath-Tavares, 2017; Rellecke et al., 2012; Schindler et al., 2020) require participants to decide whether a

presented stimulus is emotional or neutral, or to identify the specific emotion. In any case, attention must be directed toward multiple emotional categories, implying that the final evaluative decision may be delayed compared to a task that prioritizes a *single* emotional category. On the one hand, the first task requires increased resources since each stimulus has to be first identified in relation to the *several* categories, and is only assigned to one of these categories at a relatively late stage. On the other hand, the latter task (i.e., *valence detection*), may allow for a more efficient processing of stimuli associated exclusively with the selectively attended emotion, given that processing of all other stimuli can be very early terminated in the event of (visual) template mismatches.

Such a *valence detection task* induces selective attention to only one target level of valence (i.e., positive words or happy faces), while all other valence categories (i.e., neutral/negative words or angry/neutral faces) are regarded as task-irrelevant (see Gibbons, Kirsten, et al., 2022). The target level of valence is systematically varied across blocks, such that each stimulus is presented both as a *target* when matching the target valence of the block and as a *nontarget* when stimulus valence and target valence did not correspond (see Figure 3.1). Consequently, in the latter task, the bottom-up emotional significance of the stimulus coincides with the "maximal" top-down selective affective-attentional focus toward the very same stimulus, thus representing the upper limit of top-down attention to affect. This valence detection paradigm was first introduced by Schupp et al. (2007) who investigated the neurophysiological effects of selective attention to emotional pictures taken from the IAPS database. Since this seminal study, four more studies[1] either replicated the task using different IAPS pictures (Schindler & Straube, 2020) or transferred the paradigm to emotional words (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016) or faces (Weidner et al., 2022).

In all experiments, participants had to attend to only one specific level of affect per block; however, while two studies required participants to count the occurrences of stimuli from the target category (Schindler & Kissler, 2016; Schupp et al., 2007), participants had to press a button in reaction to target stimuli in the remaining three studies (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Straube, 2020; Weidner et al., 2022). All studies reported ERP effects for mid-latency (EPN; ranging from 180 to 380 ms) and late components (LPP; ranging from 400 to 1000 ms). During the EPN time window, all studies observed a main effect of emotion, either driven by arousal (emotion > neutral; see Gibbons, Kirsten, et al., 2022; Schindler & Kissler, 2016; Schindler & Straube, 2020) or one specific emotion (Schupp et al., 2007; Weidner et al., 2022). All

[1]Please note that Gibbons, Kirsten, et al. (2022) and Gibbons et al. (2023) focused on distinct processing stages within the same experiment.

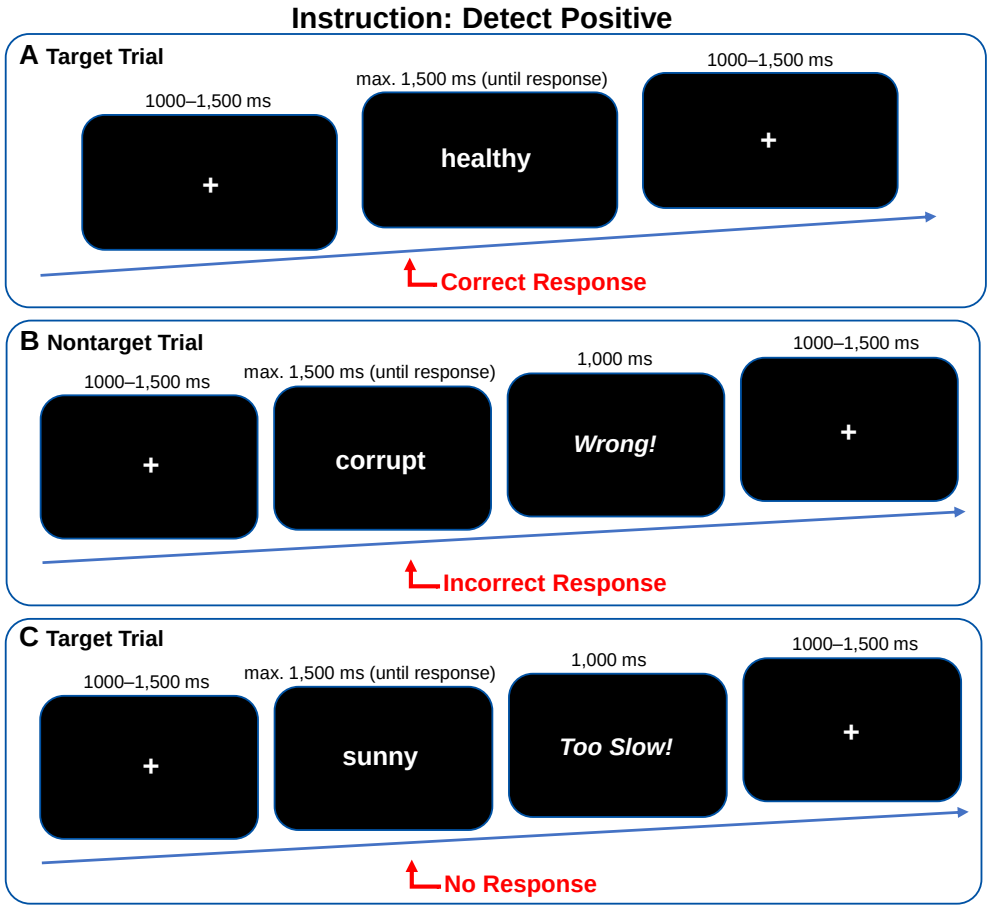

Figure 3.1.: Exemplary illustration of trial events from the valence detection task (*Study I*). For the expression detection task (*Study III*), emotional faces were used instead of words. (A) Participant responds correctly in a target trial. (B) Participant responds incorrectly in a nontarget trial and creates a false alarm. (C) Participant does not respond in a target trial and creates a miss.

but one (Weidner et al., 2022) revealed a main effect of status[2] (target > nontarget, but see Gibbons, Kirsten, et al., 2022). Concerning the LPP, main effects of status (target > nontarget) as well as emotion (emotional > neutral) were revealed across all studies, with the only exception being the study from Weidner et al. (2022). Finally, four studies also reported significantly greater LPP emotion effects in target compared to nontarget stimuli (Gibbons, Kirsten, et al., 2022; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007). These results suggest that it is only during late processing that additional processing enhancements arise from the synergy of attention (i.e., status) and emotion (see Schindler & Straube, 2020). However, and in line with previous considerations about faster and more efficient emotion processing during valence detection, Gibbons, Kirsten, et al. (2022) observed an attentional boost

[2]The experimental factor is labeled "status" rather than "attention", because in this type of detection task, stimuli that represent a nontarget are nonetheless subject to attention to affect. Accordingly, the term "target/nontarget stimuli" will be preferred over "attended/nonattended stimuli".

of emotional word processing already during the EPN starting at around 180 ms. Even more intriguing is the notion that selective attention to valence might already impact the discrimination of affective stimuli at still earlier visual stages.

In particular, Gibbons et al. (2023) proposed that the feature-based visual selective attention to one specific valence, induced by the valence detection task, should allow for the preactivation of neural representations of the respective valence. This preparatory neural activity toward properties of task-relevant stimuli before stimulus appearance is an important principle of (top-down) feature-based attention and has been observed for both simple and complex objects and their features (see Section 1.2.2). In the context of emotional words, the preparatory neural activation of valence-specific representations should also spread to neural representations of visual word forms that are associated with the particular valence. This line of reasoning has been referred to as the *hypothesis of valent word forms* (see Gibbons et al., 2023; first introduction of general concept by Kissler et al., 2006). It states that, following repeated encounters, the human brain links the mere visual word form with its affective connotation, in accordance with the principles of Hebbian learning. Consequently, upon presentation of the word form, corresponding neural representations of the associated valence are concurrently activated. Similar associative learning mechanisms have previously been used to explain early emotion ERP effects *prior* to semantic processing (see Fritsch & Kuchinke, 2013; Hinojosa et al., 2020; Kissler et al., 2006). Thus, when instructed to attend to a specific valence, neural activity within visual cortical areas is hypothesized to be biased for valence-congruent word forms (see Gibbons et al., 2023). Hence, only upon target (but not nontarget) appearance, the visual features would be rapidly integrated, thus facilitating early perceptual discrimination and processing of the target stimulus (see Noah et al., 2020). Supporting this idea, it was observed that top-down modulation of visual processing enables rapid processing of the stimulus category within the first 200 ms exclusively for targets (Kaiser et al., 2016) and that feature-based selective attention can, at least under specific conditions, already modulate the P1 component (Zhang & Luck, 2009).

Accordingly, Gibbons et al. (2023) revealed attention-modulated ERP effects of emotional words during the early perceptual and structural processing stages. These were characterized by a P1 effect of word valence (positive > neutral > negative) and an N170 effect of arousal (emotional > neutral) specific to target words, that is, the selectively attended stimuli. For nontargets, no such effects were observed for P1 while the pattern was reversed for the N170. This was interpreted as facilitation of task-relevant word processing and simultaneous inhibition of currently irrelevant words during selective attention to valence. This study was the first to demonstrate early interactions of attention and emotion in the valence detection paradigm. It is unknown whether these

early P1 and N170 effects were also observed in the other comparable studies since their research exclusively focused on mid-latency and late components (Schindler & Kissler, 2016; Schupp et al., 2007; Weidner et al., 2022). Only one valence detection study using emotional pictures (Schindler & Straube, 2020) investigated the modulation of emotion effects by attention across the entire processing sequence, but no attention-emotion interactions at P1 or N170 were identified. However, this absence of evidence might be related to the stimulus material. In contrast to words (and faces), pictures are complex visual stimuli devoid of clearly defined and spatially predictable visual features linked to a specific level of valence (Gibbons et al., 2023). Drawing upon the seminal observations of Gibbons et al. (2023) on attention-modulated emotion effects, the overarching aim of this thesis was to delve deeper into the idea of facilitated early emotional processing in selectively attended stimuli. Specifically, the objectives were twofold: first, to substantiate and expand the observed findings with emotional words, and second, to examine the early attention-emotion interactions in the context of emotional face processing.

3.2. Novel Contributions

The subsequent chapter will provide an overview of the studies contained within this thesis, including a concise summary of the corresponding experimental approach and the most significant results. Detailed information regarding the methodology and the comprehensive results, along with the relevant statistics, can be found in the four original articles.

3.2.1. Study I: Word Processing in a Two-Level Valence Detection Task

The attention-based modulation of early affective processing observed by Gibbons et al. (2023) is assumed to be contingent on associative learning, in which visual word forms have been consistently linked to their respective affect (Hinojosa et al., 2020). First, this raised the question of whether the early emotion effects at P1 and N170 become particularly evident in instances of particularly strong (word) form–affect associations. Therefore, the two lexical variables word frequency and word length, which have previously been found to influence early visual processing (e.g., Hauk et al., 2006), were added to the experimental design. In particular, both frequent word forms, due to their more prevalent occurrence (and thus neural activation), and short words, due to their less complex and easily distinguishable features, were regarded as having strong

form-affect associations. It was thus hypothesized that they would drive valence discrimination in target words, allowing for a rigorous test of the hypothesis of valent word forms. In other words, when participants selectively attended to one level of valence, it was assumed that preparatory neural activity should be biased toward both frequent and short valent words. Second, with the intent to further amplify effects of valence discrimination, the original design by Gibbons et al. (2023) was simplified to include only two levels of valence, positive and negative. By removing neutral words, the discrimination between positive and negative words should become less ambiguous due to their greater valence distance and thus facilitate top-down tuning processes and early perceptual integration. Third, the arousal of the words was included to investigate the interplay of valence and arousal that have been proposed in the valence-arousal conflict theory (Robinson et al., 2004; similar to the ideas postulated in the ESM, Cacioppo & Berntson, 1994). Given that previous ERP studies of implicit affective processing (e.g., Citron et al., 2013; Z. Yao et al., 2016) have observed differential effects for (ESM-)bias-congruent (positive low-arousal and negative high-arousal) and incongruent (negative low-arousal and positive high-arousal) words, the idea of facilitated processing for bias-congruent words was now tested during explicit affective processing.

In the EEG study, a two-level valence detection task was employed, including 72 positive and 72 negative words, which were additionally subdivided according to the experimental factors of arousal, word length and word frequency. The experiment comprised two blocks, within which the 144 words were presented in random order. In each block, a total of 58 participants responded as quickly as possible to words with a predefined target valence (either negative or positive), which was counterbalanced between the two blocks. A timely button response to all target words (valence of the word matched the target valence) was counted as a hit, whereas too slow responses to target words and responses to nontarget words were classified as misses and false alarms, respectively.

The visual P1 component revealed enhanced amplitudes for negative compared to positive target words, while this difference was not observed in nontarget words. Crucially, this interaction between valence and status was most pronounced for short rather than long and high-frequency rather than low-frequency words (see Figure 3.2). With regard to the N170, low-frequency words demonstrated increased amplitudes when they belonged to the bias-congruent compared to the bias-incongruent category, while there was no indication for any attention-modulated emotion effects. The greater amplitude for congruent compared to incongruent words was still evident at an N170/EPN complex, although it was mainly driven by high-arousal words. Finally, increased N170/EPN amplitudes were observed particularly for negative target words, which was further modulated by word length and frequency.

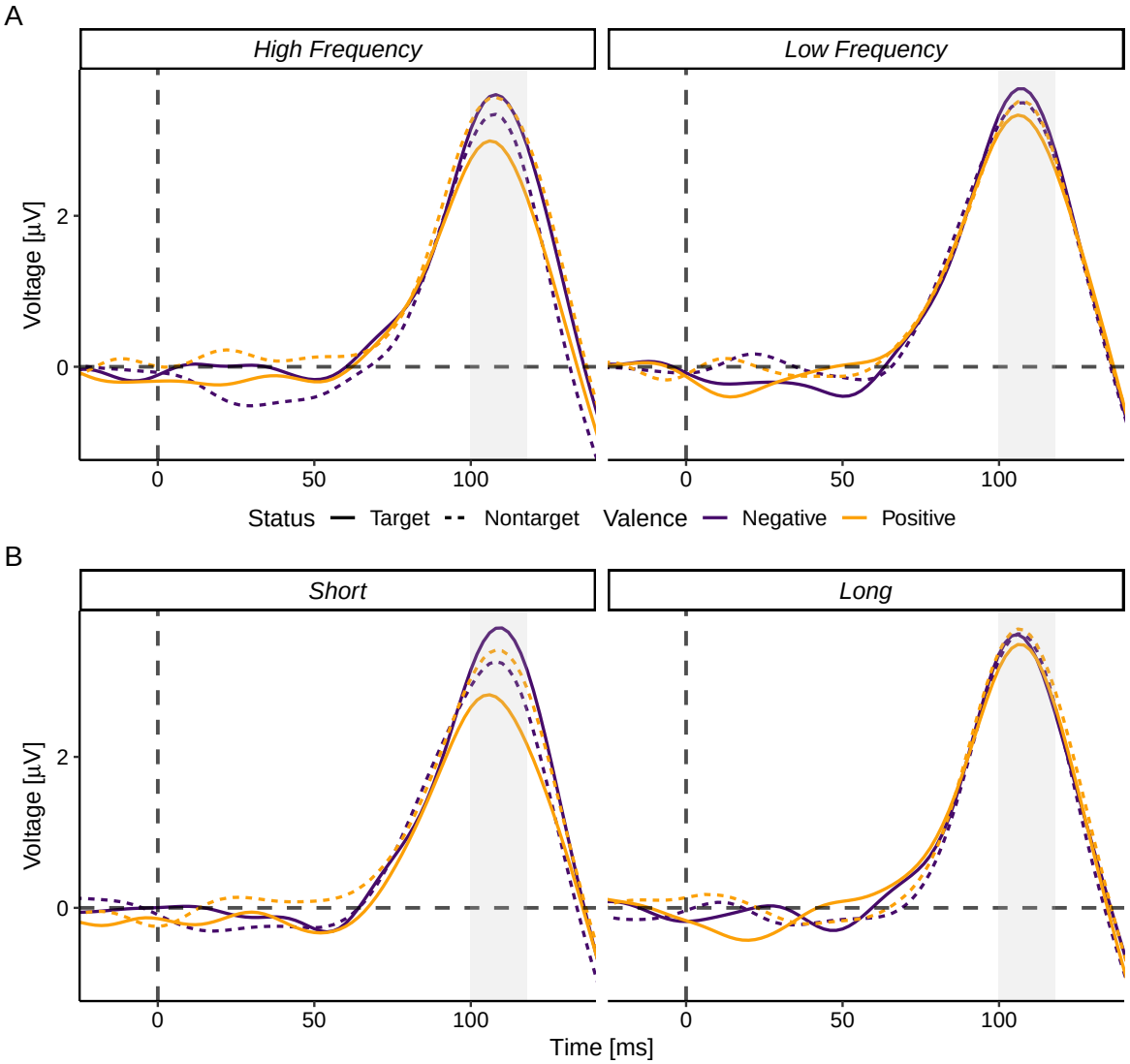

Figure 3.2.: Key Results of *Study I*. (A) Greater P1 valence discrimination for target but not nontarget words is restricted to *high-frequency* words. (B) Greater P1 valence discrimination for target but not nontarget words is restricted to *short* words. The time window for the analysis is highlighted in light gray. Adapted from Schmuck et al. (2025), p. 10. CC BY-NC 4.0.

In total, the study has provided new evidence that task-induced selective attention can facilitate valence discrimination at early perceptual stages. The restriction of these effects to frequent and short words supports the assumption that these early valence effects in words are based on associative learning (e.g., Gibbons et al., 2023; Hinojosa et al., 2020). Therefore, the P1 amplitude may—at least in part—be indicative of an initial match with the preactivated word forms by the task-induced attentional set. Interestingly, the direction of the P1 effect (negative > positive targets) was reversed compared to Gibbons et al. (2023), indicating a crucial role of the task-induced attentional set, which will also be explored in *Study II*. Independently of attention, the

N170 mainly reflected early automatic integration of valence and arousal in line with the valence-arousal conflict theory (Robinson et al., 2004). This corresponded nicely with the idea of N170 as a marker of automatic and holistic (word) processing (e.g., Simon et al., 2007). Subsequently, findings from the N170/EPN complex suggested that, independent of attention and thus bottom-up related processing, the discrimination of affective words benefited from the greater attention attraction by high-arousal words.

3.2.2. Study II: Nontarget Word Processing in a Valence Detection Task

Previous ERP studies employing a valence detection task have concentrated on differences in neural processing of emotional stimuli on the basis of whether they were targets or nontargets (e.g., Gibbons et al., 2023; Schindler & Kissler, 2016; Schupp et al., 2007). However, no analysis has hitherto been dedicated exclusively to the processing of *nontarget* words. With the objective to identify interactions between the actual word valence and the (divergent) valence of the current attentional set, ERP data from a previous study were reanalyzed (Gibbons, Kirsten, et al., 2022). This novel approach was expected to reveal ESM-conform modulations of ERP effects on the one hand and distractor-target distance effects in terms of valence on the other hand. The study focused on two well-studied components in the interplay of attention and emotion, EPN and LPP (Hajcak et al., 2012). First, it was hypothesized that the task-induced selective attention facilitates not only the processing of the respective valence but also of the congruent arousal (e.g., for the negative attentional set, this implies negative *and* high arousal) in accordance with ESM-related biases (Cacioppo & Berntson, 1994) and the related valence-arousal conflict theory (Robinson et al., 2004). This in turn should modulate the processing of nontarget words, which either fit or do not fit the attentional set in terms of arousal. The highly automatic ESM-related biases are primarily expected to emerge at the EPN which is a reliable marker for automatic attraction of attention. Second, the evaluation of distractor-target distance can either be comparably easy for nontarget valent words in opposite-to-ignored attentional sets (e.g., positive words during a negative attentional set) or more difficult during neutral attentional sets (e.g., positive words during a neutral attentional set). Due to its sensitivity to varying task demands (see Matsuda & Nittono, 2015), it was assumed that these effects would mainly emerge at the posterior LPP. While lower mental effort in the opposite-to-ignored attentional sets should generally lead to smaller LPP amplitudes compared to the neutral attentional sets, it was suggested that, in line with a persistent negativity bias (e.g., Norris, 2021), negative nontargets might mitigate the LPP-reducing distance effect.

The study sample comprised 57 participants who engaged in a three-level valence detection task. In each of the three blocks, 120 words – 40 from each valence level (positive, neutral, and negative) – were presented in random order. Each valence was once designated as target level and participants had to respond only to words matching the target valence. While the interactions between (target) status and valence have been presented elsewhere (Gibbons, Kirsten, et al., 2022, 2023), the current study focused exclusively on interactions between the attentional set and the valence of *nontarget* words.

Results revealed that the ERP effects were largely restricted to the affective, that is positive and negative, nontarget words and their interactions with the attentional set (neutral or opposite-to-ignored word valence). At lateral parietooccipital sites, an N170/EPN-like posterior negativity showed an interaction between ignored valence (of the words) and the attended valence. The complex was smaller for positive nontarget words in the neutral attentional set compared to both positive nontargets in the opposite-to-ignored set and, importantly, negative nontargets in the neutral attentional set. No such effects across both attentional sets were observed for negative words. The LPP revealed a reduction to nontargets in the opposite-to-ignored compared to the neutral attentional set, which was mainly driven by smaller amplitudes for positive compared to neutral nontargets in the negative set with no differences between negative and neutral nontargets in the positive set.

In sum, the findings emphasize the relevance of the attentional set and the emotional context it fosters in the processing of emotional words. Particularly, the idea of specific biases in emotional processing as proposed by the ESM (Cacioppo et al., 1997) was extended to valence-specific attentional sets additionally including aspects of arousal. The effects of these attentional sets became evident during early processing stages at which the integration of valence and arousal is assumed to occur (see Robinson et al., 2004). On the one hand, the arousal-sensitive N170/EPN was reduced for positive nontargets (which are mainly driven by the congruent *low-arousal* words at this early stage) compared to negative nontargets (which are mainly driven by the congruent *high-arousal* words at this early stage) when neutral words had to be selectively attended. On the other hand, the negative attentional set implying a sense of high arousal may have strongly facilitated processing of the (incongruent) high-arousal positive words, thereby preventing a reduction in N170/EPN amplitudes for this particular combination of stimulus and attentional set. The LPP in contrast reflected effects of task difficulty related to the distractor-target distance in terms of valence given that a larger distance (i.e., the easier task) between attentional set and word valence resulted in reduced amplitudes compared to smaller distances. Finally, this reduction did not occur for negative words in the positive attentional set suggesting that a negativity bias (see

Norris, 2021) at the level of late controlled processing, which frequently manifests itself in an increased LPP (e.g., see *Study III*), counteracted the previous task-related effect.

3.2.3. Study III: Face Processing in an Expression Detection Task

As previously mentioned, selective attention to valence can facilitate affective discrimination in target words and even inhibit processing of nontarget words (Gibbons et al., 2023). It was postulated that the former effect relied on the task-induced preactivation of neural representations of word forms (or more broadly, their perceptual features) which matched the selectively attended level of valence. Similar to word forms, the different emotional expressions of faces are characterized by specific perceptual features which are clearly defined and highly predictable regarding their exact location (see Gibbons et al., 2023). Therefore, selective attention to one particular emotional expression should preactivate neural networks coding for the expression and its associated first-order (i.e., lower-level) visual features. Indeed, such attentional tuning has been demonstrated for human faces being located in face-selective visual cortices such as the fusiform face area (see Chapman & Störmer, 2024; E. H. Cohen & Tong, 2015; Gratton et al., 2013; Störmer et al., 2019). Interestingly, feedback from these object-specific areas that targets lower-level features associated with the object biases neural activity already within the early visual cortices (V1-V4) in favor of the attended stimulus (E. H. Cohen & Tong, 2015). For example, selectively attending to emotional faces may bias activity in early visual cortices toward expression-defining first-order elements such as a U-shaped line for happy faces (i.e., smile) or a narrow horizontal line for angry faces (i.e., clenched mouth). Consequently, this preactivation facilitates the rapid integration and early perceptual discrimination upon target appearance which should be reflected in differential effects in the P1 component similar to the findings from Gibbons et al. (2023). Regarding later processing, previous studies with valence detection tasks (Gibbons, Kirsten, et al., 2022; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007) have revealed an attentional boost of emotional processing during the LPP time range. Thus, the second aim of the study was to replicate this boost in facial stimuli (but see Weidner et al., 2022) and investigate whether it might even occur earlier in these highly relevant social stimuli.

A total of 65 participants engaged in an expression detection task which involved 38 different facial identities each displaying a fearful, happy and neutral expression. Across three experimental blocks, all 114 faces were presented in random order and participants had to respond exclusively to those faces displaying the prespecified target level of expression. The order of the target levels (fearful, happy or neutral) was counterbalanced across the blocks.

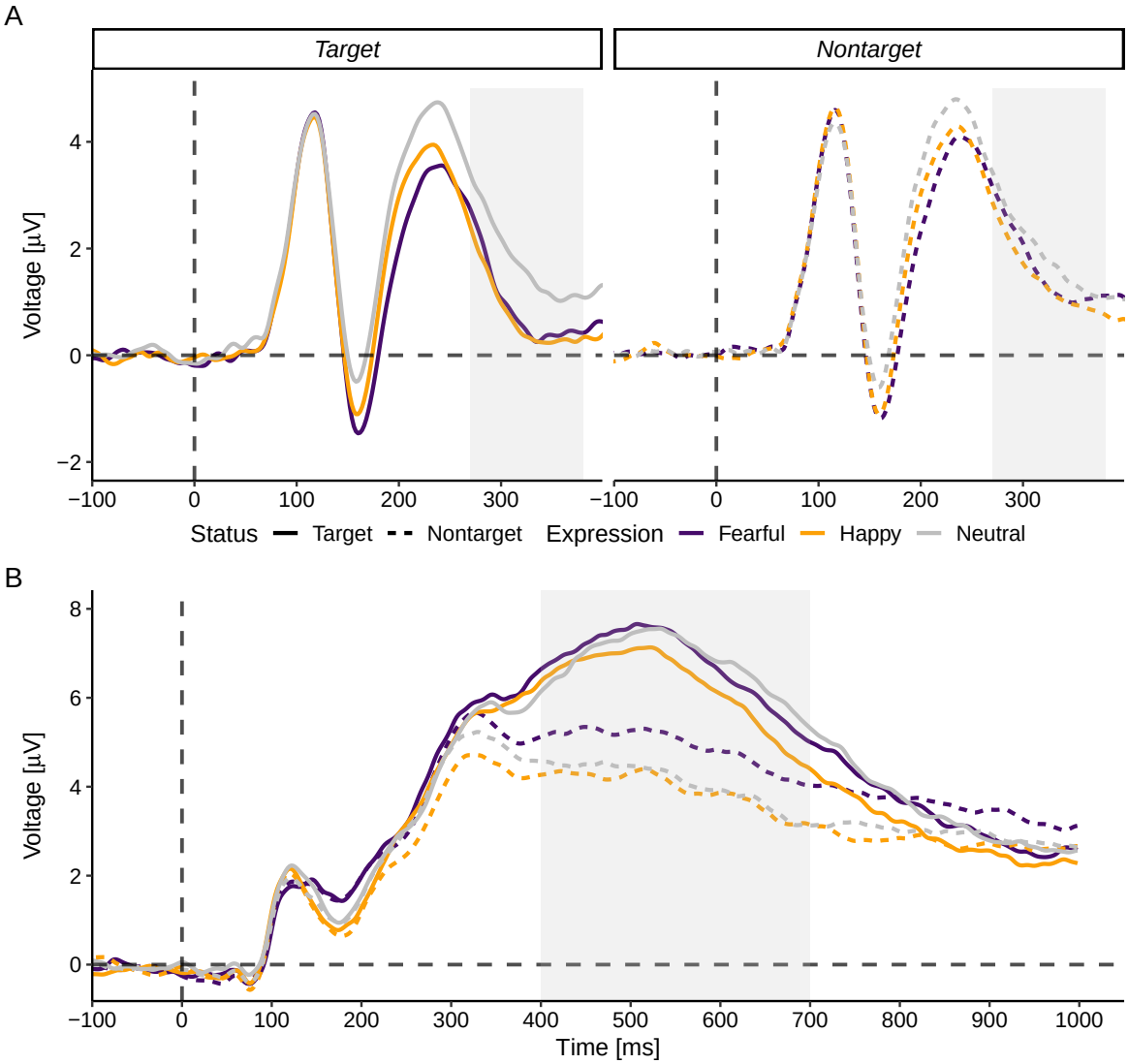

Figure 3.3.: Key Results of *Study III*. (A) Enhanced processing of emotional expressions in target compared to nontarget faces at the EPN. (B) Emotional expression and status interact during the LPP time window. For target faces, happy expressions have the smallest amplitude. For nontarget faces, fearful faces elicit the largest amplitude. The analyzed time window is highlighted in light gray. Adapted from Schmuck et al. (2023), p. 14-15. CC BY-NC 4.0.

Bayesian analyses were conducted to explore the relative evidence of both null and alternative hypotheses. Regarding the early visual components, they provided evidence for a main effect of expression at P1 (happy > fearful) and N170 (fearful > happy > neutral). Focusing on the interaction between expression and status, Bayes factors suggested moderate evidence against the inclusion of this effect. Following the early perceptual stimulus processing, the two later emotion-related components—EPN and LPP—emerged (see Figure 3.3). First, for the EPN, no clear best model could be identified. The data were marginally more likely under the model including main effects

of expression (fearful and happy > neutral) and status (target > nontarget). However, when fearful and happy were combined to emotional expressions, there was moderate support for the inclusion of the expression × status interaction, characterized by a greater emotion effect for target than nontarget faces. Second, for the LPP, the model including the interaction was the most probable. Interestingly, it was driven by a reduced LPP for happy compared to fearful (and anecdotally to neutral) target faces, whereas only fearful faces elicited higher amplitudes in the nontarget condition.

In total, the absence of a P1 interaction effect was in contrast with previous findings from a study using affective words (Gibbons et al., 2023) and our own considerations. Even though faces arguably have more predictable features at certain positions than complex images, these elements may have nevertheless varied (too) greatly between the depicted individuals (see Section 4.1.1). The only observed P1 effect, increased amplitudes for happy compared to fearful faces, can be interpreted in terms of a positivity offset (Cacioppo & Berntson, 1994), even though low-level image differences cannot be completely ruled out (Schindler et al., 2021). Similarly, no attention-expression interaction effect was identified for N170. Thus, its role as an indicator of emotional face processing, which is resistant to various attentional manipulations (Hinojosa et al., 2015; Schindler & Bublatzky, 2020), was further confirmed. In contrast, there was moderate evidence for a greater expression effect in target than in nontarget faces during the EPN time range. These findings tentatively indicate that selective attention to facial expression may enhance emotional processing at earlier stages than previously observed in valence detection tasks (e.g., Schindler & Kissler, 2016; Schupp et al., 2007; but see Gibbons, Kirsten, et al., 2022). Unexpectedly, we did not observe an attentional boost of emotional processing during the LPP (see Weidner et al., 2022), which was mainly characterized by a strongly increased amplitude for target compared to nontarget faces. Within the nontarget faces, the larger LPP for fearful than happy or neutral faces seems to reflect the sustained involuntary (i.e., bottom-up) capture of attentional resources in terms of a negativity bias.

3.2.4. Study IV: Effects of Participant and Face Gender on Face Processing

Studies of social cognition have observed several differences in facial processing between women and men (Proverbio, 2023), with women performing better at recognizing human faces (Herlitz & Lovén, 2013) and identifying facial expressions (Kret & de Gelder, 2012). In line with their better behavioral performance, women show greater ERP amplitudes in reaction to facial stimuli at face-sensitive components such as P1 (Dzhelyova et al., 2012), N170 (Nowparast Rostami et al., 2020) and LPP (Hahn et al., 2016).

While these findings stem from a variety of tasks (e.g., memory tasks) and often did not include emotional expressions, no gender differences have yet been explored in an expression detection task (i.e., in which affect is directly task-relevant). Therefore, the first aim was a detailed investigation of the differential ERP effects between men and women in the current task. However, not all faces may impact neural processing in an observer in the same manner (Kret & de Gelder, 2012). Interestingly and in line with an evolutionary mating account (Buss & Barnes, 1986), the face gender was found to interact with the observer gender, such that neural activation in reward-related brain areas was increased when opposite-gender faces, but not same-gender faces, were viewed (e.g., Spreckelmeyer et al., 2013). This opposite-gender bias was also observed in EEG studies, starting earlier than a same-gender bias which was only observed during late components (e.g., Proverbio et al., 2010). Crucially, from a mating perspective, the emotional expression as a critical cue during social interactions might further modulate such a bias. The preferential processing of opposite-gender faces might become particularly evident in happy, smiling expressions which have been associated with greater perceived trustworthiness and attractiveness (e.g., Lau, 1982; Oosterhof & Todorov, 2009), two important criteria in mate selection (e.g., Little et al., 2011). Consequently, in line with prior studies (e.g., Proverbio et al., 2010), it was hypothesized that larger amplitudes for opposite-gender compared to same-gender faces would manifest in face-sensitive components, particularly when the faces expressed happiness.

The study was built upon *Study III* (Schmuck et al., 2023) and substantially increased the sample size to 100 participants (50 women, 50 men). The experimental task and all stimuli were therefore identical to the former study. In addition to the original experimental factors *status* and *expression* from *Study III*, both the within-subject factor *face gender* (the 38 different face identities depicted 19 female and 19 male faces) and the between-subjects factor *participant gender* were included. In line with the research question, the focus was exclusively on main effects or interactions involving *face gender* and/or *participant gender*.

LMMs were computed for the three face-sensitive components P1, N170 and LPP to account for random effects of individual participants and stimuli. For the P1, the LMM revealed larger amplitudes for female compared to male participants. Notably, a four-way interaction involving all independent variables was observed, manifesting an opposite-gender bias specifically for happy target faces (see Figure 3.4). This bias was absent for the two other expressions and nontarget faces. The only reliable effect during the N170 time window was a main effect of emotion, characterized by larger amplitudes for both happy and fearful expressions compared to neutral ones. In contrast, main effects of participant gender and face gender emerged at the LPP, with larger amplitudes for both women and female faces. In addition, the difference between the LPP amplitude

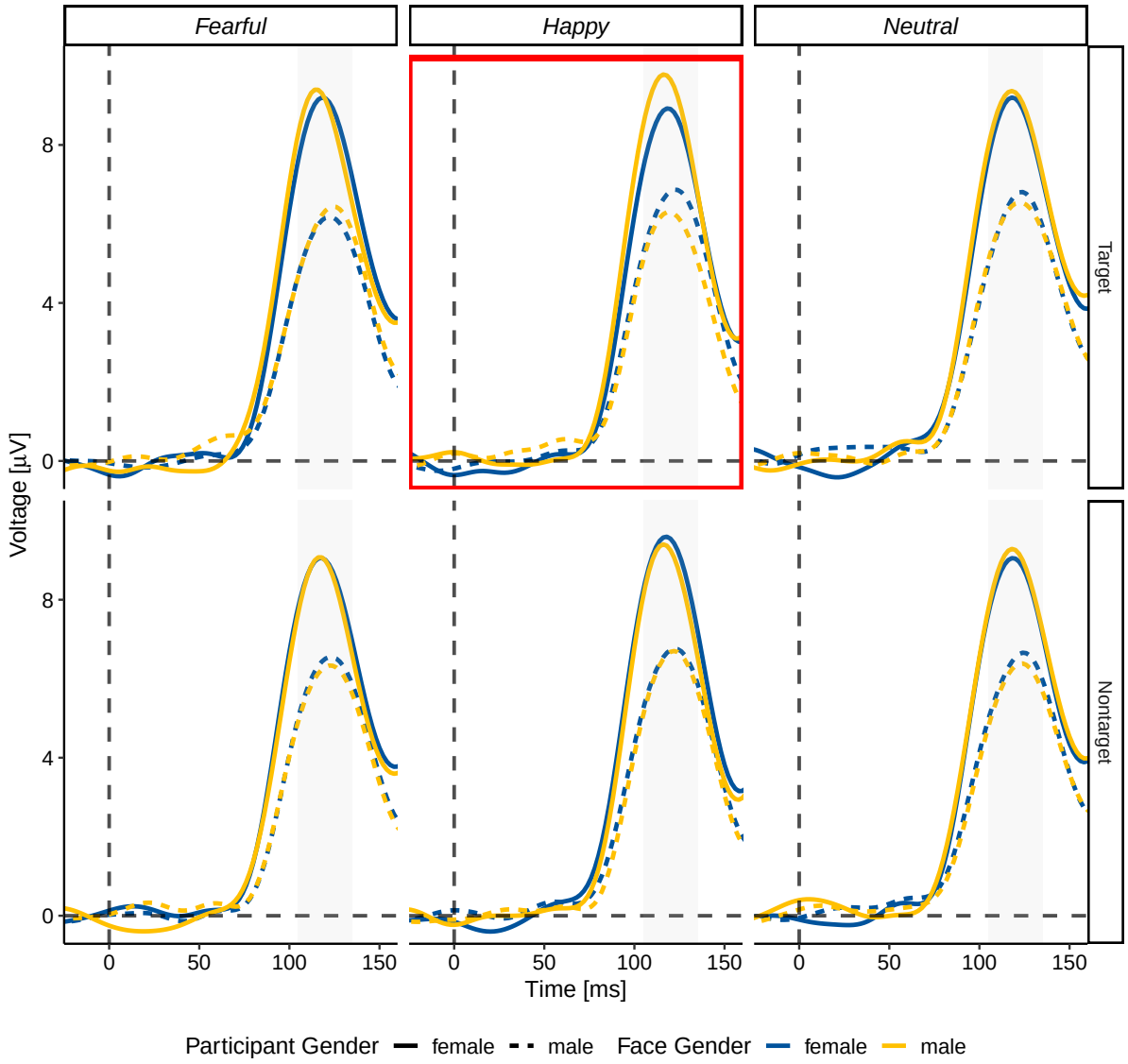

Figure 3.4.: Key Results of *Study IV*. Opposite-gender bias is exclusively observed in happy target faces as highlighted by the red rectangle. Adapted from Schmuck et al. (2024), p. 9. CC BY-NC 4.0.

for women compared to men was more pronounced in target than nontarget stimuli, giving rise to a significant interaction of participant gender and status. Finally, a three-way interaction again pointed to a special role of happy target faces, the only combination for which female versus male faces showed higher LPP amplitudes.

In conclusion, the current study has, for the first time, demonstrated gender differences and their interaction with facial features in an expression detection task. Consistent with previous research (e.g., Dzhelyova et al., 2012), female participants showed larger P1 and LPP amplitudes compared to males, suggesting an increase in both early perceptual and sustained processing due to the presumed greater significance of human faces for women. Importantly, this was not driven purely by bottom-up attentional

capture, but also by a greater voluntary allocation of attentional resources to facial stimuli and task engagement, as implied by the LPP interaction of gender with status. Crucially, an early opposite-gender bias was observed during visual processing at the P1, which was restricted to happy target faces but did not arise for neutral or fearful faces. Previous research explained these early attention-modulated emotion effects at P1 through the activation of target templates (Gibbons et al., 2023). Based on this idea and incorporating an evolutionary mating perspective, the P1 interaction might suggest that when selectively attending to happy faces, participants' attentional templates may emphasize more opposite-gender facial features. Fearful and neutral faces are unrelated to mating and may not have such strong associations with a particular face gender, explaining why target-sensitive opposite-gender effects did not occur in these stimuli. The subsequent N170 only showed larger amplitudes for emotional expressions relative to neutral expressions, thus confirming its reliable sensitivity to emotional expressions, independent of face gender (see T. A. Ito & Urland, 2003). During late processing as indexed by the LPP, female faces and in particular happy female target faces were found to attract the greatest attentional resources. The latter finding, in conjunction with the behavioral results, might be indicative of specific underlying gender-emotion stereotypes (see Adams et al., 2015) which increased the emotional salience of the face.

4. Discussion

The goal of this dissertation was to explore the modulation of emotional stimuli processing by top-down attentional selection. Specifically, four ERP studies were conducted to investigate the behavioral and, more importantly, neural processes that occur when the bottom-up attentional selection of an emotional stimulus due to its motivational significance and top-down attention toward the affect of the very same stimulus coincide in an experimental task. These processes can be studied particularly well using a valence detection paradigm, which has first been introduced by Schupp et al. (2007). Since this first publication, only a handful of studies have employed this task (Gibbons, Kirsten, et al., 2022, 2023; Schindler & Kissler, 2016; Schindler & Straube, 2020; Weidner et al., 2022), with a main focus on the mid-latency (EPN) and late neural processing (LPP) of various emotional stimuli. Gibbons et al. (2023) recently revealed attention-modulated emotion effects already during perceptual processing (P1, N170) which have been taken as further indication that early, presemantic emotion effects in words are related to associative learning mechanisms (see also Hinojosa et al., 2020; Kissler et al., 2006). This idea was pursued further in *Study I*, which employed a modified valence detection task including only positive and negative words. By adding the two lexical variables word length and frequency, the previously observed emotion-attention interactions and their presumed dependence on associative learning were examined in greater detail. Additionally, specific predictions derived from the ESM (Cacioppo & Berntson, 1994) about the interplay of the two main affect dimensions in words, valence and arousal, were tested. Similarly, these ESM-related associations between valence and arousal were further explored in *Study II* which for the first time focused on the processing of nonattended affective words in valence detection and the role of the attentional set. By contrast, *Study III* investigated the neural processing of emotional facial expressions during directed selective attention toward one particular expression. This allowed for a comparison with previous findings from valence detection tasks that have predominantly used affective words (e.g., Schindler & Kissler, 2016) and pictures (e.g., Schupp et al., 2007). Finally, the detailed investigation of the neural processing of faces during an expression detection task was continued in *Study IV*, which focused on the combined influences of face gender and participant gender.

4.1. Integration of Findings

Prior to summarizing the ERP findings as the key research objective of the current dissertation, the behavioral results will be discussed briefly. First of all, both the valence detection task in *Study I* and the expression detection task employed in *Study III* and *IV* were relatively straightforward tasks. This is indicated by the extremely low number of errors made by participants on average (around 2%). Only in *Study II* were the error rates slightly higher, probably due to the inclusion of neutral words. This presumably reflects the challenges in differentiating neutral words from emotional and, particularly, positive words (see Gibbons et al., 2023). Second, the investigation of reaction times revealed an advantage for positive stimuli across the various domains. It should be noted that these analyses were necessarily restricted to the target trials, since participants had to withhold their response in all nontarget trials. Consequently, no such analyses were reported in *Study II*, which focused exclusively on nontarget outcomes. For words, faster responses were observed for positive compared to negative words (*Study I*). Similarly, reactions to happy faces were faster than those to fearful faces, and both were faster than those to neutral faces (*Study III, IV*). This pattern is consistent with previous valence detection tasks using words (Gibbons et al., 2023) and faces (Weidner et al., 2022). Moreover, these findings align well with the broader literature that also points to a positivity advantage for word and face processing in similar tasks (for review, see Kauschke et al., 2019). In addition to a possible greater visual distinctness of happy compared to negative expressions (see Kauschke et al., 2019), one potential explanation may be related to earlier and more frequent encounters with positive stimuli throughout one's life (see Calvo et al., 2014; Kauschke et al., 2019). Subsequently, this may have contributed to their facilitated processing in the valence detection task. This is notable for the fact that, in contrast to categorization tasks, participants only need to attend to one valence level *at a time*, which could have resulted in smaller differences between the different emotional categories. Finally, further comparisons with emotional categorization tasks (e.g., Itier & Neath-Tavares, 2017; Rellecke et al., 2012; Schindler et al., 2020; Schindler, Vormbrock, et al., 2023) indicate that participants were in general both faster and committed fewer errors during the valence detection tasks, suggesting an overall facilitation of stimulus processing. Consequently, this observation supports the notion that the current task may be particularly well suited to investigate the *rapid* processing of emotional stimuli. However, given that these results are constrained to the target—that is, selectively attended—stimuli, the behavioral findings alone cannot inform us about processing differences to nontarget stimuli, nor about the distinct stages of neural processing. Comparing the neural processing of the same (emotional) stimulus once when its valence is selectively attended and once when not can only be done by employing the ERP methodology.

4.1.1. Early Perceptual Processing of Selectively Attended Stimuli

The first examination of the differential processing of emotional stimuli typically commences with the P1 component (e.g., Kissler et al., 2006; Olofsson et al., 2008; Schindler & Bublatzky, 2020). Recently, Gibbons et al. (2023) revealed that selective attention induced by the valence detection task can already facilitate the early perceptual processing of emotional stimuli as indicated by the P1. Exclusively for the target—that is, selectively attended—stimuli, greater valence discrimination was observed, as indicated by larger P1 amplitudes for positive compared to negative words. This was not the case for the exact same words when their valence did not match the target valence, that is, in cases where the words were not selectively attended. The finding supported the authors' hypothesis stating that the task-induced selective attention to *one* level of valence preactivates neural representations of the specific valence and associated word forms. This attentional tuning, restricted to the target words, should facilitate their *visual* integration (see Noah et al., 2020) and increase their signal-to-noise ratio, thus modulating the *visual* P1 component for target words. As part of this dissertation, the nature of this novel attention-emotion interaction was to be explored in more detail and in the context of further stimulus material.

First, using positive and negative words in a basic valence detection task, the overall pattern of greater P1 valence discrimination in target compared to nontarget words was replicated (*Study I*). While it was assumed that this valence discrimination as well as P1 effects of emotional words (e.g., Hinojosa et al., 2020; Kissler et al., 2006) are based on associative learning between the visual word form and its valence, this hypothesis was not directly tested in the original study by Gibbons et al. (2023). Thus, words were now grouped according to their frequency and length which should have a direct influence on the association strength. On the one hand, high-frequency words are read more often, implying that representations of word form and valence are more frequently coactivated and thus strongly associated. On the other hand, short word forms possess reduced visual complexity which in turn should create less ambiguous and stronger associations with valence. The results of *Study I* demonstrate that P1 attention-dependent valence discrimination can be observed exclusively for short (versus long) and frequent (versus rare) words. The observation that the P1 emotion effects were most pronounced when word forms and their valence were presumably strongly associated corroborates the involvement of associative learning mechanisms in early emotion effects during word processing.

It is noteworthy that P1 amplitudes were largest for negative target and smallest for positive target words, which is the opposite of the pattern observed by Gibbons et al. (2023). Considering the generally mixed P1 patterns across tasks (e.g., Bayer et al.,

2012b; Hofmann et al., 2009; Kuchinke et al., 2014) which lack a consistent interpretation, a tentative explanation for the observed pattern was provided. Here (in the valence detection task), the P1 component might reflect the degree to which a word fits the preactivated target template induced by the task. In the previous study (Gibbons et al., 2023), this template might have been biased toward positive valence as participants might have focused on detecting positive valence in words in order to successfully distinguish them from neutral words. Importantly, such a (positively biased) template may also have been used in the attend-to-negative block (in particular when participants started with the attend-to-positive block). Here, given the same perceptual decision situation, participants may simply have re-mapped the task-related decision for reasons of parsimony. In other words, the decision for a (negative) target was made if it only *minimally* matched the (positively biased) template. By contrast, the valence detection task in *Study I* included only positive and negative words, which could have led to an increased focus on negative valence in terms of a negativity bias (D. Zhang et al., 2014; for review, see Norris, 2021) by removing the difficult distinction between neutral and positive words. Thus, negative target words matched the (negatively biased) template best, while selectively attending to positive words (at least in part) might have involved detecting the absence of negative affect. It is important to note that this is an initial, tentative explanation for the reversal of the valence effect, and further research is required to substantiate it. Taken together, these findings suggest that both task-induced as well as implicit attentional sets may influence early word processing (further investigated in *Study II*) and contribute (at least partially) to the mixed P1 emotion effects across tasks.

Second, the aim of *Study III* was the investigation of early attention-emotion interactions during visual face processing. It was suggested that the specific features inherent to certain facial expressions at predictable locations allow for attentional tuning toward the respective expression (for similarities with words, see Gibbons et al., 2023). In the current expression detection task, this should facilitate the rapid perceptual discrimination of target expressions after appearance (see Noah et al., 2020). However, there was no evidence of greater emotional expression effects in target faces as compared to non-target faces during the P1 time window which is in contrast to the results from *Study I* and Gibbons et al. (2023). A comparison with the only other expression detection study (Weidner et al., 2022) is not informative because it focused exclusively on later processing and had a small sample size that probably did not have sufficient power for detecting interaction effects. While the broader literature indicates little impact of attention on emotional face processing in emotion categorization tasks (Schindler & Bublatzky, 2020), a different explanation might apply in the context of the expression detection task.

The absence of attention-modulated emotion effects at P1 as indicated by Bayesian analysis might be attributable to excessive interstimulus variability in the emotional expression features of the naturalistic faces. The variability of each individual face, manifesting for example as variations in the exact size and location of the mouth (i.e., the smile), impedes the formation of an accurate attentional template and consequently hinders the efficient integration of target stimuli (for discussion on template specificity, see Geng & Witkowski, 2019). By contrast, words usually possess a specific shape to which individuals have been exposed on countless occasions throughout their lives and thus allow for more accurate neural representations. The discrepancies between the attentional templates of words and faces should be further elucidated in future studies. For example, it could be tested whether the font type in which the words are presented modulates the attention-dependent valence effects. It has previously been found that P1 emotion effects were restricted to a familiar font, as opposed to an unfamiliar one (Kuchinke et al., 2014). Consistent with this study and previous considerations, it can be assumed that the enhanced valence discrimination in target words, which presumably relies on associative learning, may only be evident in words of a familiar but not an unfamiliar font. Regarding faces, the notion that a more precise attentional template should improve target-match decisions (see Geng & Witkowski, 2019) and facilitate rapid target discrimination could be tested with computer-generated faces systematically varying in their emotional face features. Indeed, we recently collected EEG data ($N = 80$) from an expression detection task with similar and dissimilar artificial faces (Schmuck et al., in preparation). Even though the similarity manipulation within the artificial faces did not influence P1 amplitude, we observed an overall greater expression discrimination for target compared to nontarget faces. Given that the artificial faces in themselves are already highly similar (compared to the naturalistic faces), the results tentatively suggest that the P1 in response to specific faces may also be sensitive to attentional modulations of emotional processing.

Finally, further indication that emotional face processing at the P1 can be influenced by specific facial features and additional participants' characteristics comes from *Study IV*. Here, enhanced processing of opposite-gender faces was restricted to happy target faces. More specifically, only when selective attention was directed toward happy faces and a happy face appeared, the P1 amplitude of men was larger for female (versus male) happy faces while male (versus female) happy faces elicited a larger P1 amplitude in women. Consistent with the idea that early P1 effects might, at least in part, be driven by facilitated rapid integration of target faces following attentional tuning (see Gibbons et al., 2023), this finding suggests that the preactivated attentional templates of happy (but not neutral or fearful) faces might additionally include facial features related to the opposite sex. Thus, the more precise and detailed template during the attend-to-happy

block better matches the presented face resulting in an increased P1 amplitude (for P1 target effects, see previous section and Klimesch, 2011). The specificity could be explained from an evolutionary standpoint in which the search for happy faces, which are perceived as more trustworthy (Oosterhof & Todorov, 2009) and attractive (Lau, 1982) compared to other expressions, implies an aspect of mate selection. Therefore, happy faces might be more strongly associated with the opposite gender across participants, which is not the case for neutral and fearful expressions. It is important to note that lower-level visual features differed slightly between male and female faces, but not between the three facial expressions. In general, P1 effects of (emotional) faces were found to be associated with the processing of low-level visual cues (Rossion & Caharel, 2011; Schindler et al., 2021). However, the present finding, an increase in P1 amplitude for *opposite-gender* faces, cannot be driven by perceptual features alone. Combined with the results of *Study I,* this leads to the conclusion that selective attention to emotional features (or the *attentional set*) can—under certain circumstances—influence the early perceptual stimuli processing as indicated by the P1.

Subsequent to the P1, the lateral occipitotemporal N170 emerges as a prominent marker of emotional processing. The modulation of emotion effects by selective attention was investigated in three studies using the valence detection task. The only exception was *Study II* which focused exclusively on the processing of nontarget words. To date, almost all earlier valence detection studies did either not explore the N170 component (Schindler & Kissler, 2016; Schupp et al., 2007; Weidner et al., 2022) or reported a main emotion effect using pictures (Schindler & Straube, 2020). Only Gibbons et al. (2023) observed attention-dependent emotion effects which were characterized by larger N170 amplitudes for emotional compared to neutral words when selectively attended, whereas this pattern was reversed for the not selectively attended words. Interestingly, there was no evidence of an interaction between emotional content and selective attention across the present studies. Using only negative and positive words in the two-level valence detection task, neither a main effect of emotion nor an interaction between emotion and attention was revealed (*Study I*). In the context of an expression detection task that included happy, fearful, and neutral faces, only a main effect of emotion was observed, but no interactions with selective attention (*Study III*), face gender, or participant gender (*Study IV*).

Beyond the specifics of the valence detection paradigm, the broader literature on affective processing highlights the general N170 sensitivity to emotional content. While the N170 is reliably increased for emotional compared to neutral facial expressions across attentional conditions (e.g., Hinojosa et al., 2015; Schindler & Bublatzky, 2020), larger N170 amplitudes have also been frequently reported for emotional (positive and/or negative) versus neutral words (e.g., Kissler & Herbert, 2013; D. Zhang et al., 2014).

Consistent with the literature, the word N170 results of *Study I* therefore do not necessarily contradict the findings from the three-level valence detection task (Gibbons et al., 2023). Rather, the restriction to positive and negative words in the two-level valence detection task provides a plausible explanation why neither facilitation of affective target words nor inhibition of affective nontarget words was observed. Here, more research is needed to elucidate the factors under which task-irrelevant affect in words is inhibited. Similarly, the attention-independent N170 increase for emotional compared to neutral facial expressions in *Study III* and *IV* is well in line with the previous meta-analyses (e.g., Schindler et al., 2020). In contrast to the P1, the three studies therefore suggest that emotional face processing during the N170 time range was not further facilitated when task-induced top-down attention and motivational significance converged in the same face stimulus. This has recently been corroborated by the observation of a sole main effect of emotional expression (but no emotion-attention interaction) in our follow-up study which employed an expression detection task with computer-generated faces (Schmuck et al., in preparation).

In summary, the N170 component has manifested itself as a marker of initial configural face processing (e.g., Schindler et al., 2021) which is furthermore sensitive to the affective expression of the face. Given the evolutionary significance of emotional faces, it seems reasonable that they can automatically capture our attention and are similarly processed across various tasks (see Carretié, 2014; Schindler & Bublatzky, 2020). This might also explain why emotional face processing did not additionally benefit from selective attention to expression.

4.1.2. Mid-Latency and Late Processing of Selectively Attended Stimuli

All four studies of this dissertation showed that mid-latency (EPN) and late processing (LPP) of emotional stimuli can be modulated by selective attention to valence. While the results regarding nontargets from *Study II* will be addressed later (see Section 4.1.3), the present focus will be on differential affective processing between target and nontarget stimuli. The EPN reflects a mid-latency ERP marker which is related to early attentional selection processes based on the task relevance or emotional significance of the stimulus (e.g., Schindler & Kissler, 2016; Schupp, Flaisch, et al., 2006; Schupp et al., 2007). Consistently, increased EPN amplitudes were observed for both emotional (happy and fearful) compared to neutral faces and for target compared to nontarget faces in *Study III*. This replicates the findings obtained in comparable valence detection tasks using non-face stimuli (Gibbons, Kirsten, et al., 2022; Schindler & Kissler, 2016;

Schindler & Straube, 2020; Schupp et al., 2007). The only other study employing valence detection with facial expressions revealed a larger EPN amplitude exclusively to happy faces, but no effect of selective attention (Weidner et al., 2022). However, this might be related to differences in stimulus presentation duration (see Vormbrock et al., 2023) or to the unusually small sample size.

Highly intriguing and going beyond previous findings, the Bayesian analysis provided moderate evidence for an interaction between emotional expressions and selective attention. During the EPN time range, the difference between combined emotional and neutral expressions was greater for the target than for the nontarget condition. Consistently, an attention-sensitive EPN emotion effect was previously reported in Gibbons, Kirsten, et al. (2022) who employed the identical task with affective words. In general, EPN emotion effects seem to increase with attention toward more emotionally relevant features while they disappear during perceptual tasks directing attention away from emotional features (e.g., Rellecke et al., 2012; Schindler et al., 2020). Thus, it was proposed that the EPN reflects a "bottleneck" during which emotional discrimination competes with top-down attention processes (Schindler et al., 2020), compatible with the idea that emotional processing may depend on available attentional resources (see Pessoa et al., 2013). The present task required that both targets and nontarget faces had to be processed regarding their emotional expression, while no other attentional task competed for resources. This explains why the EPN emotion effect was observed even for nontargets, as they were still the subject of attention to emotion. Crucially, the attention-sensitive emotional boost for target faces can only be attributed to attentional tuning processes which serve as the distinguishing factor between target and nontarget faces. Therefore, we proposed that the attentional tuning to a specific emotional expression and the associated neural preparatory activity specifically potentiates the emotional tagging and facilitates the perceptual encoding occurring within the EPN time window (Olofsson et al., 2008). These findings are supported by the observation of an even stronger attention-sensitive emotional boost in our recent study employing an expression detection task with happy, neutral and angry artificial faces (Schmuck et al., in preparation). Finally, several explanations emerge as to why this interaction effect has not been observed in previous valence detection tasks (Schindler et al., 2020; e.g., Schindler & Kissler, 2016). On the one hand, reaction times from the expression detection task in *Study III* indicate that processing of emotional faces is faster compared to emotional words (see Gibbons et al., 2023) or pictures (Schindler & Straube, 2020). While most of the studies with non-face stimuli observed interactive effects during late processing, such an attention-modulated enhancement might start earlier for the rapidly processed and evolutionary relevant facial stimuli. On the other hand, differences in the duration of stimulus presentation could contribute to the discrepan-

cies. Interactions between attention and emotion were found in the two studies with longer presentation duration (up to 1500 ms; see Gibbons et al., 2023; Schmuck et al., 2023), but not in those studies in which emotional stimuli were presented for no longer than 350 ms (Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007; Weidner et al., 2022).

While the previous findings support an attention-sensitive EPN enhancement for emotional—positive and negative—compared to neutral stimuli in a three-level valence detection task, *Study I* investigated the EPN exclusively in response to positive and negative words in a two-level valence detection task. It is noteworthy that the only EPN-like deflection started unusually early within the typical N170 window and lasted about 100 ms. Therefore, the component was assessed as an N170/EPN complex which resembled the word-related EPN from a previous valence detection task (see Gibbons et al., 2023). In line with the latter study, the complex was most pronounced over the left hemisphere (see also Schindler & Kissler, 2016), likely reflecting the involvement of language-related regions. Additionally, a main effect of word valence was observed which was driven by larger amplitudes for negative versus positive words. This goes beyond the typical EPN pattern characterized by similar increases for positive and negative compared to neutral words (e.g., Citron, 2012; Herbert et al., 2008; Kissler et al., 2007).

Crucially, with respect to the main research goal of this dissertation, the observation of valence effects was restricted to words whose valence was selectively attended. This interaction was further modulated by the lexical factors word frequency and word length, emphasizing the importance for investigating lexical factors during emotional word processing (see Section 4.1.1). In particular, the valence discrimination (negative > positive), which was present in target but not in nontarget words, was exclusively observed for low-frequency and rare words. First, these findings suggest that emotional, that is positive and negative, words appear to be processed similarly within the EPN time range when participants do not selectively attend to their valence (as noted, they are still processed for their *emotion*). This is in line with both valence detection tasks using emotional words (Gibbons, Kirsten, et al., 2022) or emotional faces (see *Study III*) as well as other experimental tasks (e.g., Kissler & Herbert, 2013; Scott et al., 2009). Second, when the valence of the word is selectively attended, a fine-grained discrimination between negative and positive words can be observed for specific word categories during the EPN time range. In accordance with the assumed focus on negative affect (see Section 4.1.1), amplitudes were generally larger for the negative targets (for a discussion on the influence of lexical features, see Schmuck et al., 2025). Interestingly, a similar overall pattern could be observed in Gibbons et al. (2023) where negative words tended to elicit a larger EPN amplitude in comparison to positive words, again only

in the target condition. Additionally, this target-selective emotion discrimination also emerged in our recent expression detection study, where EPN amplitudes were larger for angry than happy target faces with no difference in nontarget faces (Schmuck et al., in preparation; but see *Study III*).

Combining the results of *Study I* and *III*, the EPN appears to reflect the earliest processing stage at which attentional processes can promote the processing of emotional versus neutral stimuli. While nontarget stimuli showed the typical arousal-related EPN effect observed in a variety of tasks, emotional stimuli (and neutral stimuli in *Study III*) were discriminated even better in the target condition. These findings go beyond previously obtained results from tasks involving general attention to affect and are driven by processes directly related to the selective attention to *one* level of valence. *Study III* (and results from Schmuck et al., in preparation) revealed that when top-down selective attention induced by the task and bottom-up attentional selection by emotional significance converged on the same face, specifically *emotional* facial expressions gained an additional processing boost. In *Study I*, which used emotional words in a two-level valence detection task, selective attention to valence improved the discrimination between emotional target words for specific word categories.

Finally, attention-modulated emotion effects during late, sustained stimulus processing as indicated by the LPP were investigated in *Study III* and *IV*. Previous studies employing valence detection tasks with words and pictures have indicated that an attention-selective emotion effect is most reliably found during this time window (Gibbons, Kirsten, et al., 2022; Schindler & Kissler, 2016; Schindler & Straube, 2020; Schupp et al., 2007). It was proposed that the greater differences between emotional and neutral stimuli for target compared to nontarget stimuli arise from the interaction of emotional signals from the amygdala and top-down signals from frontoparietal attention networks (Schindler & Straube, 2020). Interestingly, such a multiplicative pattern did not emerge when facial expressions were used as stimuli in the expression detection task (*Study III*). This observation is consistent with the only other expression detection task with emotional faces (Weidner et al., 2022), pointing to a special status of emotional expressions in the current task.

Rather, *Study III* revealed a large LPP effect of attention, which has been reliably observed across all stimuli used in the valence detection task (e.g., Gibbons, Kirsten, et al., 2022; Schindler & Straube, 2020; Weidner et al., 2022). The greater LPP amplitude to target faces was suggested to reflect the increased attentional and cognitive effort to ascertain a *match* between the presented face and the current target expression, in comparison to identifying a *mismatch* (for a detailed explanation, see *Study III*). To some extent, response-related processes might also contribute to the overall larger target

amplitudes; however, it is difficult to assess their exact influence due to the inherent confound with target trials. Happy target faces elicited a particularly small amplitude, presumably attributed to their greater visual distinctiveness which facilitates the discrimination from other facial expressions and thus the match decision. Thus, less attentional resources need to be allocated to happy compared to both fearful and neutral target faces, leading to a smaller LPP (see also Calvo & Beltrán, 2013). For nontarget faces, the LPP amplitude was significantly increased for fearful faces. That is, when the presented faces were no longer relevant for the task, the LPP increase reflected the automatically captured and sustained attentional engagement with fearful expressions (see Hajcak & Foti, 2020). This distinctive processing of fearful expressions, which is frequently observed during the LPP (Schindler & Bublatzky, 2020), is likely associated with their evolutionarily significant role as indicators of potential danger (Vuilleumier, 2005). Highly similar results were recently observed in an identical expression detection task with angry, happy and neutral computer-generated faces (Schmuck et al., in preparation). First, the LPP was significantly larger for all target faces, with happy target faces showing the smallest amplitude. Second, among nontarget faces, angry faces elicited the largest LPP. Focusing on the general nature of the former effects, *Study IV* revealed that the overall pattern of LPP results did not depend on the gender of participants or faces.

Overall, the late processing of emotional faces in the expression detection task is markedly different from that of emotional words or pictures which can be explained by two key factors. First, the three categories differ with respect to the stage at which emotional and neutral stimuli can be distinguished. While the affect of pictures and words can be differentiated in terms of their *emotional meaning*, the differentiation of emotional expressions is directly determined by their *physical properties* (Bayer & Schacht, 2014; Rellecke et al., 2011). Thus, in valence detection studies using pictures and words, the late assessment of the emotional meaning, which presumably happens in the LPP time range (Hajcak & Foti, 2020), might benefit from additional attentional resources allocated to the task-relevant stimuli. By contrast, the emotional content of faces is processed earlier than that of words (e.g., Schacht & Sommer, 2009a) which also becomes evident in faster overall reaction times for faces compared to pictures and words in valence detection tasks (see Section 4.1). Consequently, top-down attention induced by the task may boost the processing of emotional faces, which is strongly guided by their perceptual features, already during the EPN (for relation between EPN and perceptual features, see Olofsson et al., 2008; Schupp, Flaisch, et al., 2006). Second, emotional faces are among the most important visual stimuli for human social life. Unlike words, they are assumed to represent evolutionary prepared stimuli (Rellecke et al., 2011) whose adequate processing is highly adaptive. This is particularly true for

negative and, more specifically, threat-related expressions, which signal imminent danger and are primarily relevant for survival (see Ekman, 1992). Therefore, threat-related expressions, in contrast to negative words, but also negative scenes, may undergo sustained monitoring for the duration of their presentation, as indicated by the increased LPP amplitude for fearful nontarget faces in *Study III* (and angry nontarget faces in Schmuck et al., in preparation).

4.1.3. Modulations of Emotional Word Processing Related to the Evaluative Space Model

The primary objective of the present dissertation was the examination of ERP markers that are indicative of emotional stimuli processing during selective attention to one level of valence. However, the unique characteristics of the valence detection task made it possible to test specific predictions which were derived from a prominent theory on affective information processing, the ESM (Cacioppo & Berntson, 1994). Here, the reactions to emotional stimuli are characterized by the concepts of *positivity offset* and *negativity bias* (see Section 1.1.2). These two ideas are also reflected in the *valence arousal conflict theory* in which positive valence is associated with low arousal, and negative valence with high arousal (Robinson et al., 2004). Stimuli that possess congruent characteristics in this respect (positive/low arousing; negative/high arousing) are assumed to be processed more efficiently.

First, *Study II* investigated whether the assumed interdependence between valence and arousal influenced the processing of *nontarget* words in the valence detection task. One key finding was a smaller N170/EPN complex for positive words compared to both negative words during selective attention to neutral words and compared to positive words during attention to negative words. This pattern can be explained by ESM-related influences on the target template induced by the current task instructions. The integrated affect of (incongruent) high-arousal positive words was not yet available during the particularly arousal-sensitive EPN in the neutral attentional set, therefore the affect of (congruent) high-arousal negative words strongly contributed to their increased amplitude. However, the negative attentional set, which also implied an aspect of high arousal, accelerated the processing of high-arousal positive words whose integrated affect was thereby earlier available. It is important to note that the arousal of the valent words was not directly assessed in this study. Rather, the findings show that the ESM-related constraints on valence and arousal can be extended beyond the actual stimulus to the valence-specific attentional sets. In other words, the identical stimulus can be processed differently already at early stages depending on the valence- (and thus also arousal-) specific context. Consistent with this idea, a reanalysis of *Study III* showed

that the N170 amplitude tended to be smaller for happy faces during attention to neutral faces compared to both fearful faces in the same attentional condition and happy faces during attention to fearful faces. This again emphasizes the influence of the emotional context induced by attentional conditions on early affective processing (for review regarding faces, see Schindler, Bruchmann, et al., 2023).

Second, the combined influences of arousal and valence on emotional word processing were investigated in *Study I.* The main finding was an interactive effect of arousal and valence on low-frequency word processing during the N170 time window which was characterized by a higher N170 amplitude for congruent compared to incongruent words, as defined by the valence arousal conflict theory (Robinson et al., 2004). The general pattern is similar to observations from abstract emotional word processing during a lexical decision task (Z. Yao et al., 2016), and in line with the broader ERP literature which revealed differential early emotion processing between congruent and incongruent words (Citron et al., 2013). While the independence of attentional status emphasized the presumed preattentive, and therefore bottom-up, nature of arousal and valence integration (Robinson et al., 2004), the integration of the two affect dimensions might depend on specific word-related factors (such as word concreteness, see Z. Yao et al., 2016). In our study, no valence-arousal interaction was observed in high-frequency words. Due to their frequent occurrence, the integration of any incongruent valence-arousal combinations might be strongly overlearned, resulting in processing that is similar to that of congruent combinations of affect. However, this may not be the case for low-frequency words in which integration of arousal and valence may be required before further semantic processing. The more difficult integration for words with incongruent affective features can thus explain the observed N170 differences to congruent words.

In summary, these findings reveal that interdependencies between valence and arousal can influence early word processing during the valence detection task. The integration of the two dimensions of affect was previously hypothesized to be performed at a preattentive level, preceding any conscious evaluation (Robinson et al., 2004). This fits well with the observation of effects at the N170 component and during an N170/EPN complex which reflect early visual word processing (N170; Dien, 2009) and early automatic attention processes (EPN) that occur prior to more conscious stimulus evaluation. Finally, these effects were evident even when participants selectively attended to valence, thus further supporting the rather automatic nature of affect integration independent from top-down influences (see Robinson et al., 2004).

4.2. Limitations

As with nearly all research work, the four studies in the present dissertation are not without limitations. These shortcomings will be addressed in greater detail below, in order to facilitate true scientific progress and improve future research (see Ioannidis, 2007). First, with regard to the generalizability of the observed results, a thorough inspection of both the sample characteristics and the stimuli used in the studies is imperative. In all four studies, participants came from a Western, educated, industrialized, rich and democratic (*WEIRD*; Henrich et al., 2010) society, with the overwhelming majority being young female students. Thus, while the findings may best be interpreted within very similar experimental contexts, any large-scale generalization should be approached with caution. For example, both the age and gender of participants have been found to influence the amplitude of several ERP components (e.g., Fernandes et al., 2023; Schmuck et al., 2024; Van Dinteren et al., 2014) as well as the neural processing of emotional content (e.g., Pollock et al., 2012; Wieser et al., 2006) or language-related material (e.g., Ramos-Loyo et al., 2022). Although *Study IV* suggests that at least the emotion effects in the expression detection task do not differ between men and women (except for the opposite-gender bias involving face gender), it is particularly important to see whether the observed ERP effects can be generalized to other populations.

Similarly, the generalizability of the results is restricted by the particular stimulus selection. In *Study I* and *II*, emotional and neutral adjectives were presented during the valence detection task. While comparable findings regarding early P1 valence discrimination were previously obtained when a different set of adjectives was used (Gibbons et al., 2023), nouns or verbs might be differently processed in the current task. Indeed, it was found that effects of emotion depend on the word class which might be explained by their respective relationship with emotions (see Palazova et al., 2011). In particular, adjectives appear to have the most direct association with emotions compared to nouns or verbs, since they are generally used to describe qualities or states. This could, at least in part, account for the observed discrepancy between the results with adjectives (*Study I*) and those of a valence detection task with emotional nouns (Schindler & Kissler, 2016). Furthermore, several high-arousal negative words but also low-arousal positive adjectives had to be removed during stimulus selection in *Study I*. Since the relationship between the two affective dimensions is typically asymmetric in written words (high negative words are typically rated as more arousing than high positive words; see Võ et al., 2009), this selection is necessary to match the valent words according to their arousal (and additional nonaffective word parameters). While the matching process ensures that the actual emotion effects are not driven by potential confounds, it may create rather "artificial" stimulus sets that may no longer contain the

most prototypical valent words. In *Study III* and *IV,* emotional faces were investigated in the expression detection task. Whereas happiness as the only clearly positive emotional expression represented the positive valence dimension, the negative dimension was limited to fearful expressions. Consequently, it remains uncertain whether similar results would be obtained with other negative expressions such as anger. Although the results cannot be generalized with regard to the different facial emotions, *Study IV* nevertheless allows for a careful generalization beyond the specific set of facial identities, by modeling the facial stimuli as random effects in the LMMs and accounting for the stimulus-level variability. Finally, complex visual stimuli such as emotional faces (and pictures) vary regarding their low-level image features (such as brightness or local spatial frequencies). Although the emotional expressions did not differ across several parameters in the current studies, the influence of any uncaptured differences especially on (main) effects of expression during early visual processing at the P1 cannot be ruled out (see Schindler et al., 2021).

Second, the characteristics of the valence detection task did not allow for a comprehensive investigation of the relationship between the observed neural signals and the actual behavioral responses. While the neural signal is measured for both target and nontarget stimuli processing, the overt reaction—the button press—is exclusively assessed in response to target stimuli. Importantly, only this specific setup with a single pre-defined target level of valence creates the link to the literature on *selective* attention in the valence domain and therefore to attentional templates (e.g., Gibbons et al., 2023; Schindler & Straube, 2020; Schupp et al., 2007). Nevertheless, it suffers from the disadvantage that it remains unknown whether, for example, the early valence discrimination for target words at P1 in *Study I* or the enhanced processing of emotional target (versus nontarget) faces during the EPN in *Study III* is actually related to behavioral performance with respect to the target versus nontarget stimuli detection. By contrast, other common experimental tasks such as valence *categorization* which might seem highly similar would allow a complete assessment of reaction times to *all* stimuli. However, categorization requires the simultaneous monitoring of more than one level of valence and subsequently the selection of one from at least two motor responses, making its cognitive architecture more complex. Future research may develop modifications of the valence detection task that could help to examine the link between the mere electrophysiological markers and behavioral responses utilizing various approaches (see Bridwell et al., 2018).

Another limitation that merits mentioning is related to a technical aspect of EEG recording. While the assessment of the P1, N170, and LPP corresponded very closely to previous valence detection tasks and the broader ERP literature, the scoring of the EPN was not optimal. This component is hypothesized to be generated within the

lateral occipital extrastriate cortex and is typically measured over occipitotemporal sites in average-referenced data (Schupp, Flaisch, et al., 2006). Therefore, in addition to the measured electrodes (see Table 2.1), it would be beneficial to sample the extreme lateral posterior electrodes, such as P9 and P10, which are commonly used in ERP studies of emotional processing (see Bayer et al., 2012b; Palazova et al., 2011; Schindler & Straube, 2020). Unfortunately, these were not included in the current EEG configuration.

Finally, it is important to consider a few remaining limitations. Not all studies were preregistered, and even if they were, the detailed power analysis and sample size calculation could not always be based on the effect sizes of relevant previous studies. This is related to the novelty of early attention-emotion interaction effects, the limited number of studies using valence detection tasks, as well as the complexity of the designs. The first two aspects also made it difficult to derive both the electrodes and the time windows required for the ERP analysis from the literature which was therefore mostly done following the collapsed localizer approach (Luck & Gaspelin, 2017). The latter aspect—the design complexity—led to a relatively large proportion of exploratory results in addition to the predicted central findings of each study. In *Study I*, the high complexity also resulted in a limited number of trials for each specific condition (e.g., positive, high-arousal, short, high-frequency words). And, although each word was assigned to one specific condition in the design based on validated word norms (e.g., Võ et al., 2009), not all participants may feel exactly the same way. Ultimately, all four studies investigated the neurophysiological correlates of selective attention to affect in a highly controlled environment in our EEG laboratory. It should be noted that encounters with emotional stimuli in daily life are much more complex and further influenced by various factors, such as current mood or motivation.

4.3. Future Avenues

The four studies in this dissertation have provided fascinating insights into the temporal dynamics of the processing of selectively attended emotional stimuli. In addition to the specific limitations of each study, which have already highlighted certain task modifications, the present findings call for further investigations into the robustness of the observed patterns and open new avenues for future research.

To begin, this thesis examined the nature of previously observed attention-emotion interactions during early perceptual processing at P1 (Gibbons et al., 2023) in greater detail. While a similar pattern of emotional word processing was found exclusively for certain word categories (*Study I*), no early attention-modulated effects were revealed for emotional faces (*Study III*). To better understand the mechanisms behind these

effects, future studies should focus strongly on the factors that influence the perceptual processing of stimuli immediately after onset. As we have previously speculated (see Section 4.1.1), the degree of similarity across different face identities might represent such a factor, which is supported by our preliminary results (Schmuck et al., in preparation). Furthermore, consistent with the observation of greater valence discrimination in *high-frequency* target words, P1 effects in the expression detection task might be stronger for *familiar* (versus unfamiliar) faces. Indeed, effects of face similarity in a face categorization task were previously reported for this early perceptual component (Huang et al., 2017). Thus, it could be hypothesized that attentional tuning might work particularly well for familiar faces since they have been encountered more frequently over one's lifetime (similar to frequent words; see *Study I*).

In light of the idea that the P1 in the valence detection task may, at least in part, reflect an early perceptual match between the stimulus and the preactivated attentional template, it would also be highly interesting to explore the role of initial gaze fixation location (see Itier & Durston, 2023). In general, any template representation is biased toward features that best differentiate target from distractor stimuli (Geng & Witkowski, 2019). In the context of emotional faces, this would refer to the visual characteristic which are most diagnostic for each expression. For instance, the mouth (i.e., the smile) is the most distinct feature of happy faces, while fearful faces are best distinguished by their eyes (e.g., Calvo & Beltrán, 2013; Schyns et al., 2007). These features should be most emphasized in the attentional templates for the respective target expression (by biasing neural activity in early visual areas toward first-order features such as a U-shaped line for the smile or circles for the wide-open eyes; see *Study III*). Consequently, the observation of stronger P1 attention-emotion interaction effects when the initial gaze fixation is placed on the most diagnostic facial features for each target expression (e.g., initial fixation on the mouth when happy faces are task-relevant) would further support the functional role of P1 described above. Finally, different emotional expressions could be tested in the expression detection task. This would not only increase the generalizability of the results (see Section 4.2), but it would also allow for a more fine-grained differentiation of attentional tuning processes toward negative emotional expressions (e.g., fear, anger, disgust). It is, for example, conceivable that angry expressions might affect processing of opposite- and same-gender faces differently compared to fearful expressions (see Kret & de Gelder, 2012; Schmuck et al., 2025).

Furthermore, future research may apply different analyzing approaches. A particularly interesting method that could further enhance our comprehension of the attentional mechanisms involved in processing emotional stimuli is the time-frequency analysis of EEG data. On the one hand, this method allows the retrieval of additional information and task-relevant dynamics (including non-phase-locked) which cannot be identi-

fied using ERPs (M. X. Cohen, 2014). On the other hand, cortical oscillations are a fundamental property and mechanism of the brain and can reveal direct information about the neurophysiological mechanisms underlying the cognitive processes (Buzsáki & Draguhn, 2004). Therefore, time-frequency analyses would provide a more comprehensive perspective on the knowledge acquired from this dissertation about the processing of emotional target stimuli after their presentation. However, even more intriguing would be the investigation of neural oscillations occurring *before* stimulus onset in the valence detection task. One promising approach involves prestimulus alpha oscillations between 8 and 12 Hz which may serve as a general mechanism for feature-based selective attention (see Battistoni et al., 2017; Noah et al., 2020). This alpha-band activity and its topography was shown to vary with the particular category of attended high-level objects, including human faces (Noah et al., 2020). In the present context, future studies could investigate whether prestimulus alpha-band activity in the valence detection task is also modulated by selective attention to emotional expressions, thus providing one potential neural mechanism for the top-down selective attention to emotional features. More broadly speaking, the observation of differential prestimulus alpha-band activity for several emotional expressions could represent a neurophysiological correlate of attentional templates for emotional faces.

Finally, future studies may investigate the influence of specific participants' characteristics on the early and mid-latency attention-modulated emotional effects (see *Study I* and *III*) as well as on the positivity offset and negativity bias observed in emotional words and faces (see *Study II* and *III*). In the context of emotional stimuli, a focus on social anxiety and depression scores would be particularly intriguing. For example, social anxiety has been associated with an early attentional bias toward threatening faces (e.g., Günther et al., 2021), whereas the attention of depressed individuals is often broadly biased toward negative information (e.g., Peckham et al., 2010). These findings are substantiated by ERP studies that found differential emotional stimulus processing for participants with major depressive disorder (e.g., Foti et al., 2010) and social anxiety disorder (e.g., Pei et al., 2023). Therefore, it might be highly interesting to examine whether the present results regarding the neural processing of negative stimuli (e.g., the assumed stronger focus to negative affect in *Study I* or the late negativity bias in *Study III*) would be even stronger in certain population samples. Lastly, it is also imperative to consider the potential benefits of using the valence detection task in individuals diagnosed with depression or social anxiety disorder. This approach could contribute to a more sophisticated understanding of the preparatory and early neural mechanisms that underlie the disorder-specific processing of emotional stimuli.

4.4. Concluding Remarks

The present dissertation sought to investigate the electrophysiological signature of selectively attended emotional stimuli. To this end, an experimental task was employed in which the top-down attentional selection directed by the task instructions and the bottom-up attentional selection due to motivational significance converged on the same stimulus. Using ERPs, all four studies provided intriguing insights into the temporal processing of such stimuli. While replicating some central findings from previous research, they also made several highly novel contributions to the study of attention-emotion interactions. In particular, it was found that selective attention to affect can modulate the perceptual processing of emotional stimuli as early as 100 ms after stimulus onset. For words, this became apparent as greater valence discrimination in certain target stimuli in *Study I*, whereas for faces, it manifested as an opposite-gender bias in happy target faces in *Study IV*. These P1 effects pointed to the importance of attentional templates in the facilitation of early target stimuli processing. The role of the attentional set was further elucidated in nontarget words in *Study II*. Here, the identical words were processed differently depending on the specific valence context, suggesting that implicit associations between arousal and valence conjointly influenced the attentional template. In *Study III*, the task that had mostly been conducted with words and pictures was transferred to emotional faces. There was moderate evidence for an attention-sensitive enhancement of emotional face processing during the EPN, which occurred earlier than previously observed for emotional pictures and words. In conclusion, the present findings indicate that selective attention to a particular valence or emotional expression can modulate the neural processing of stimuli that match this affect from very early, perceptual stages until late, controlled stages. As this dissertation has undoubtedly expanded our knowledge about the neural mechanisms that underlie the selective attention to the affect of emotional stimuli, future research striving for a more comprehensive understanding of this topic can build upon this work.

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A. Publication List

This thesis is based on four original publications (see Table 1.1). To avoid potential copyright infringement, this thesis does not include the full texts of these articles. They are available online from their respective publishers.

Article I: Schmuck, J., Schnuerch, R., Voltz, E., Kirsten, H., & Gibbons, H. (2025). The influence of lexical word properties on selective attention to emotional words: Support for the attentional tuning of valent word forms. *Psychophysiology*, *62*(1), e14748. https://doi.org/10.1111/psyp.14748

Article II: Gibbons, H., Schmuck, J., & Kirsten, H. (2022). Interactions of ignored and attended valence in a valence-detection task with emotional words support the model of evaluative space: An ERP study. *Language, Cognition and Neuroscience*, *38*(10), 1430–1450. https://doi.org/10.1080/23273798.2022.2088817

Article III: Schmuck, J., Schnuerch, R., Kirsten, H., Shivani, V., & Gibbons, H. (2023). The influence of selective attention to specific emotions on the processing of faces as revealed by event-related brain potentials. *Psychophysiology*, *60*(10), e14325. https://doi.org/10.1111/psyp.14325

Article IV: Schmuck, J., Voltz, E., & Gibbons, H. (2024). You're beautiful when you smile: Event-related brain potential (ERP) evidence of early opposite-gender bias in happy faces. *Brain Sciences*, *14*(8), 739. https://doi.org/10.3390/brainsci14080739