Valence as an Affective Semantic Feature

Children Process it just like Small Adults

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Abstract

Panksepp (1998) was the first researcher to propose a theory on the evolutionary development of emotions that accounted for the role of language. In his theory, Panksepp assumed that emotions arise in subcortical areas of the brain, are linked to learning experiences in the limbic system, and interact with higher cognitive functions including language, in the cortical areas. Thus, these three levels should play a role when looking at the affective component of words here called affective semantics. The representation of affective semantics can be examined by testing explicit valence decisions, that is, whether a word is evaluated as positive or negative. Furthermore, the relationship of language and emotions can also implicitly be tested, for example, when participants make lexical decisions on stimuli that are systematically manipulated valence. Recently, the explicit and implicit modes of valence processing have been extensively examined in adults. Consequently, the corresponding behavioral and neuronal correlates of valence are already well-established. However, it remains unclear how these explicit and implicit influences develop during childhood on both a behavioral and neural level. This dissertation seeks to address this open issue and attempts to provide answers regarding how children compared to adults process the valence of words. Three empirical studies were conducted to approach the central question of whether children between the ages of six and twelve show the same behavioral phenomena and neuronal correlates of valence processing as adults.

As a basis for the studies, a word database was designed to specifically target the vocabulary of children called the Berlin Affective Word List for Children. The words were selected based on the Berlin Affective Word List, which is a German word database for adults. The adult version of the affective word list was used as a template in order to ensure comparability between child and adult ratings. Study I (Sylvester et al., 2016) examines the question of whether children between the ages of six and twelve evaluate words in the same way as adults

when they rate words in terms of their valence, arousal, and imageability. The results point to similar affective semantic representations in children and adults, including a U-shaped function relating valence and arousal ratings and an inverse U-shaped function relating valence and reaction times encompassing the positivity superiority effect (Lüdtke & Jacobs, 2015), indicating that positive words lead to shortest reaction times.

Subsequently, the neuronal correlates of explicit valence processing were examined in Study II (Sylvester et al., 2021a). According to the framework of Panksepp (1998; 2005a; 2005b), neural activation was expected in the affective semantic network which includes the amygdala, striatum, thalamus, insula, orbitofrontal, supplementary and cingulate cortex, inferior and middle frontal, superior and middle temporal gyrus. In order to test the affective semantic network, children between the ages of six and nine and adults between ages 19 and 30 performed a valence decision task. Based on the behavioral results of Study I, similar rating behavior was observed in children and adults. Furthermore, similar neural activation patterns were expected across age groups.

The neural response patterns of the children and adults of Study II are very similar to the results previously reported in adults. Specifically, we observed extensive activation within the presumed affective semantic neural network over all three valence categories (positive, negative, and neutral). However, there were differences regarding the regions predominantly recruited for valence decisions, for example there was an increased activation in amygdala in children. Moreover, activation beyond the assumed affective semantic network was observed, for example, in occipito-parietal regions, especially among adults. The different results between children and adults suggest that differences in the size of the mental lexicon between children and adults and/or the experiences from which affective semantics are derived may lead to different neural activation. It is suggested that children primarily recruit information from regions primarily associated with affective processing, whereas adults recruit regions devoted to the integration of information from various resources related to affective semantics, which includes regions in the supplementary motor cortex, middle temporal and precentral gyrus. Thus, adults seem to rely their valence decisions more strongly on multimodal affective semantic hubs since they already have integrated affective semantic information, whereas children tend to recruit valence-related information directly from the 'source'.

In Study III (Sylvester et al., 2021b), the implicit influences of valence were assessed by using lexical decisions. The question arose as to whether the similarities found for the explicit valence decisions in Study II could also be found for implicit ones. Consequently, a similar neural pattern with activations in the large-scale affective semantic network was assumed. Similar to the results in Study II, both age cohorts showed greatly overlapping activation for processing (positive, negative and neutral) words. However, when looking more precisely at differences between the valence categories, children and adults show different processing streams. Although the adults showed similar neuronal activation as adults in previous studies, i.e., activation in orbitofrontal and anterior cingulate cortex activation (e.g., Kuchinke et al., 2005), a different picture emerged in children. The children mainly showed activation in regions associated with lexico-semantic processing, i.e., supramarginal and superior parietal gyrus activation (e.g., Price, 2012). In contrast, we observed less activation in regions directly linked to valence processing. However, positive words compare more favorably between children and adults, possibly due to that positive words are learned earlier in life (Ponari et al., 2018). These results are consistent with the interpretation of Study II in that children primarily display task-specific activation, meaning the recruitment of primarily valence-specific region during explicit valence decisions occurs whereas valence plays a subordinate role during lexical decisions. These results indicate that less connected affective semantic information is processed in children than in adults. In contrast, the adults demonstrated greater activation of valence-related areas, suggesting that valence is an important implicit source of information in lexical decisions, facilitating the decision process.

In summary, the three empirical studies of the current work are among the first to show that children and adults have similar affective semantic representations. It is, however, noteworthy that some aspects of affective semantic processing are still not adult-like in children up to the age of twelve, specifically they show more task-specific activation. Furthermore, the differences in neural activation in the affective semantic network, especially the IFG (Hofmann & Jacobs, 2014) indicate deviations between the mental lexica in children and adults. As such, the neural results in the present dissertation are interpreted in the light of differences between the children's and adults' mental lexicons, resulting from children's limited experience with experiential and distributional data and/or their smaller vocabulary.

Based on the central results of this dissertation, a developmental hypothesis for affective semantics is proposed. The developmental hypothesis assumes that the amount of the apperceptive mass (Kintsch, 1980), as defined here as the size of the vocabulary and the amount of available experienced and distributed data, moderates the neural processing of affective semantics. The results could contribute to the developmental computational and cognitive models to model the influence of vocabulary on and for learning affective semantics.

Glossary

General remark. Left-hemispheric brain regions are described unless expressly stated (right, bilateral).

ACC	Anterior Cingulate Cortex
AG	Angular Gyrus
AM	Apperceptive Mass
ANEW	Affective Norms for English Words
ANOVA	Analysis of Variance
AROM	Associative Read-Out Model
BAWL	Berlin Affective Word List
fMRI	Functional Magnet Resonance Imaging
IAM	Interactive Activation Model
IFG	Inferior Frontal Gyrus
ITG	Inferior Temporal Gyrus
kidBAWL	Berlin Affective Word List for Children
LDT	Lexical Decision Task
MFG	Middle Frontal Gyrus
MRI	Magnet Resonance Imaging
MTG	Middle Temporal Gyrus
OFC	Orbitofrontal Gyrus
PAG	Periaqueductal Grey
PCC	Posterior Cingulate Cortex
PFC	Prefrontal Cortex
SFG	Superior Frontal Gyrus
SMA	Supplementary Motor Area
SMG	Supramarginal Gyrus
SPG	Superior Parietal Gyrus
STG	Superior Temporal Gyrus
VDT	Valence Decision Task

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I

THEORETICAL PART

1 Introduction to Affective Semantics in Children

Language is inevitably and tightly intertwined with our affective system (e.g., Binder et al., 2016; Bühler, 1934; Freud, 1891; Jacobs et al., 2016; Meteyard et al., 2012). The interplay of language and affect becomes evident when looking at the affective information of a word, which will be defined as affective semantics throughout this dissertational work. One feature of affective semantics is valence. For example, Jacobs et al. (2015) describe valence as an affective semantic super-feature that carries affective semantic information about positive to negative dimensions. In other words, the valence of a word allows us to decide within a glance whether we like or dislike a word (e.g., Jacobs et al., 2016). While the behavioral phenomena and neural underpinnings that characterize the interplay between language and affective semantics, in particular valence, are well described in adults (see Jacobs et al., 2015 for an overview), however, there is a lack of research examining its developmental trajectory. Thus, the main purpose of the present dissertation was to elucidate the relationship between language and affect in children. More specifically, the overall research question of the present thesis seeks to discover whether children in the age of six- to twelve-year-old children have already developed 'adult-like' behavioral and neural signatures when processing the affective semantic information of a word (e.g., Jacobs et al., 2015; Kauschke et al., 2019). The results of my empirical work will thus provide insights into the development of the language and its interaction with affect. Through this research, ground work is laid for gaining a deeper understanding of how these fundamental social and cognitive abilities that shape and influence our daily lives develop and change.

1.1 The Relation of Language and Emotional Development

The description of the relation between language and emotion development is challenged by the so-called language-emotion gap (Conrad, 2015; Jacobs et al., 2015; Koelsch et al., 2015). In other words, theories of language often neglect a possible integral part of emotions and vice versa. Furthermore, defining a precise model of how emotions develop from childhood into adulthood is difficult due to the complex interconnection with social, physiological, and cognitive domains, and (of greatest relevance for this dissertation) language (Saarni, 1999; Zeman et al., 2007). Jean Piaget, famous for his cognitive model of children's development, stated at one of his lectures at the Sorbonne (1953 – 1954) that “affectivity is like gasoline and cognition the motor. Structures like the motor are not modified [by affect] but fueled” (cf. Emde, 1982). According to Piaget, children go through one significant stage of emotional development before language acquisition starts and then a second stage when they have acquired substantial linguistic knowledge (Piaget, 1981). The first developmental period includes the development of fundamental sensorimotor skills in the first year of life. During this phase, the child expresses emotions through non-verbal actions and sounds. Furthermore, it is assumed that emotional expressions are related to basic emotion categories (Izard & Abe, 2004) and are directly related to a particular social situation (Carroll & Stewart, 1984; see Bretherton et al., 1986, for the importance of facial expressions). Moreover, parental language guidance plays a crucial role in helping children acquire emotional concepts in the first year of life, as parents comment on their children's behavior and thus demonstrate different linguistic and emotional concepts (Shablack et al., 2020). Despite the crucial role of verbal information from parents, facial expressions are the primary affective information source before language acquisition. Once children have obtained the most important linguistic structures approximately around an age of three years the focus quickly shifts to language (Balconi & Carrera, 2007; Widen et al., 2015; Widen & Russell, 2010a). This shift occurs because facial expressions are less differentiated, and information regarding the cause of the emotion is missing (Bamberg, 1997a; b; Russell & Widen, 2002; Widen & Russell, 2008, 2010a; b). In contrast, when an emotion is expressed linguistically, the child may receive additional information about the emotions' causes and consequences. With this additional information, emotions can be differentiated into more finely grained emotional categories beginning at around two years of age (Bazhydai et al., 2019; Russell & Bullock, 1986, Widen & Russell, 2016). As a child's semantic knowledge develops, it can then express its own internal state, the emotional state of others (Bretherton & Beeghly, 1982), and evaluate the emotional connotations of spoken language (Ribody et al., 1988). Additionally, three-year-old children can relate current emotional information to past events, e.g., 'my sister is angry because I've broken her toy yesterday' (Lagattuta & Wellman, 2001; Lagattuta et al., 1997), which makes it possible to ask children for their affective semantic evaluation without examining their present emotions. To summarize, the developmental shift from primary motor sensory related evaluation of emotions based on facial expressions to language-based evaluation allows children to improve and refine their emotional categories. In addition, the process of language acquisition is heavily influenced by social interaction, such as the language guidance of the caregivers, which influences both language understanding and production and, ultimately, the ability to express emotional states. As a result, one of the most important aspects driving emotional development could be vocabulary growth. Conversely, understanding and expressing one's emotions might be a driving factor for vocabulary growth, highlighting the mutual influence of language and emotional development.

Vocabulary Growth

In general, vocabulary growth means that new semantic categories are learned, and broader categories are divided into more fine-grained categories (Abend et al., 2017; Saxe et al., 2019). During this period of development, nouns are learned earlier than verbs (Bergelson & Swingley, 2012; Nomikou et al., 2017), and polysemous words are learned more easily than words with only one related meaning (Floyd & Goldberg, 2021).

Previous research shows that children gradually learn category boundaries based on language use and their experiences in the world (Bowerman, 1980). Thereby children rely heavily on their available social information sources to infer a speaker's intentions (Bohn et al., 2021). To improve children's understanding of language, caregivers modulate their child-directed speech according to their child's vocabulary, providing a balance between already known and new words as a way to foster the growth of the child's mental lexicon (Vigliocco et al., 2020). As a result, caregivers actively encourage the development of children's vocabulary. Additionally, results from computational models based on child-directed speech corpora show that children are confronted with a highly structured input so that children can learn semantics without strong presumptions regarding the organizational structure of semantics (Huebner & Willits, 2018). In the same vein, Fourtassi et al. (2019) found that semantic learning trajectories appear to be very robust irrespective of interindividual differences between the linguistic input. Therefore, despite differences in social context-dependent input across children, the development of semantic concepts and learning trajectories should be relatively stable.

Regarding the influence of the social environment on vocabulary growth, Hills et al. (2009) found that toddlers depend on information regarding the connectedness of the new word to words in the social learning environment, word frequency, and the number of phonological neighbors. Thus, toddlers learn new words and connections best based on their pre-defined semantic structure resulting from their social learning environment (e.g., Bergelson & Aslin, 2017). Specifically, toddlers prefer to learn new words used in their social environment (preferential acquisition) than words closely connected to already known words (e.g., Borovsky et al., 2016; Sizemore et al., 2018; Stella et al., 2018). However, Sizemore et al. (2018) summarized that preferential acquisition alone is not sufficient to explain semantic network growth. There are other variables which almost certainly play a role, including parental interaction, small-worldness of co-occurring networks, co-occurrences with associates, repetition, phonological patterns, and communication quality. In addition to finding similar results, Stella et al. (2018) also noted a word explosion around the age of seven, after which word acquisition becomes more automatic, and word meaning is accessed instantly. However, whether the mental lexica of children and adults are similarly structured is still unclear. To explore the semantic structure using a cue-target word-pair task, Unger et al. (2020) compared children and adults regarding taxonomic and associative (co-occurrences) relations. They found that both children (mean age 4.5 years) and adults (mean age 20.1 years), organized semantic relations within different experimental paradigms easily using co-occurrence links. However, the degree of semantic organization based on taxonomic relations was higher among adults, supporting previous findings (see Mirman et al., 2017, for an overview).

Together, language and emotion development are highly influenced by social context and are mutually interdependent. In particular, the caregiver's influence on this interplay is remarkable since children learn words primarily from their social environment. Despite individual semantic inputs lead to differences in the size and composition of vocabulary across individuals, semantic learning trajectories to acquire and structure newly learned words are very robust and stable across children. Also, by the age of six, children already use language as the primary source of emotional information and are able to report them (e.g., Balconi & Carrera, 2007; Lagattuta & Wellman, 2001; Lagattuta et al., 1997; Ribody et al., 1988; Widen et al., 2015; Widen & Russell, 2010a). The ability to report affective information from their mental lexicon makes it possible to directly compare children's and adults' affective semantic processing, which is investigated by three studies in this dissertation.

2 How Emotional are Words for Children? The kidBAWL

The first study focuses on the question of how children evaluate the perceived emotional content of a word. Are the behavioral patterns of affective semantic evaluations similar to the results previously reported in adults (e.g., Jacobs et al., 2015)? A vast body of literature has shown that adults can decide in milliseconds whether a presented word is positive or negative in terms of valence (e.g., Jacobs et al., 2016), high or low activating in terms of arousal, and easier or more difficult to imagine in terms of imageability (e.g., Harp et al., 2021; Kuperman et al., 2014). There has been no research on how children evaluate the affective semantic information of language. Similarly, there is only preliminary knowledge about these evaluations in non-linguistic domains, emphasizing the feasibility of testing affective semantic decisions in children. Specifically, children as young as three show a valence rating pattern of facial expressions that is highly comparable to the observed behavior in adults. In contrast, children show more variance in arousal ratings (Widen & Russell, 2016). Furthermore, by the age of four, children and adults use similar taxonomies of valence (Wintre & Vallance, 1994), meaning that affective semantic ratings should be comparable between children and adults. Children's abilities to make affective semantic ratings serve as another argument that it is (A) possible to examine affective semantics in children, and (B) that adult and child affective semantic evaluations can be compared. However, as already pointed out, it has not yet been examined how children evaluate language-based affective semantic information. A possible caveat might be that testing affective semantic phenomena requires highly controlled stimulus material. The use of such stimulus material provides the basis to examine the behavioral and neural effects of affective semantic decisions.

Thus, in order to achieve the central aim of the present dissertation, which is to examine the developmental trajectory of affective semantics in children and compare it with that of adults, the first step is to develop appropriate stimulus materials for children. For adults, several word databases provide highly controlled word stimulus material (e.g., ANEW; Bradley & Lang, 1999, its translations in other languages, e.g., Redondo et al., 2007; Montefinese et al., 2014, and derivations, e.g., Schmidtke et al., 2014) facilitating the research of different aspects of affective semantics. A prominent German word database is the BAWL (Võ et al., 2006; 2008; 2009). The BAWL (Võ et al., 2006; 2009) was the first German-language database to include participants' valence, arousal, and imageability ratings for approximately 3000 words. The database made it possible to investigate language-based behavioral and neurocognitive phenomena using systematically controlled stimulus material, not only for lexical properties (e.g., word frequency, neighborhood measures), but also for affective semantic features.

To overcome the dearth of controlled semantic stimulus material for children, I devised a word database as a part of my dissertation. The children's word database (kidBAWL) was compiled by choosing words from children's school lexica that is taught starting in the first grade to ensure the children's familiarity with these words. Furthermore, the words were extracted according to their appearance in the BAWL (Võ et al., 2009) to ensure overlapping words in both databases for comparative studies between children and adults. The kidBAWL makes it possible to conduct research on affective semantics in children and also allows for the comparison with older age cohorts (see Sylvester et al., 2016, for further details).

In summary, the kidBAWL provides the methodological framework to approach the major goal of this dissertational project, namely how emotional words are evaluated and processed by children. Specifically, this dissertation is focused on a particular aspect of affective semantics, that is, valence effects in language processing. In the next section, how valence is conceptualized and operationalized in the present work will be discussed.

2.1 Valence – an Affective Semantic Super-Feature

As Osgood et al. described, valence, arousal, and potency are the dimensions that are affective in nature as well as the primary dimensions of the meaning of words (Osgood et al., 1957; Snider & Osgood, 1969). The dimensions valence (synonymous to the range between pleasure and displeasure) and arousal (synonymous to activity) are commonly used in psychological research (see Russell, 1978, for an overview).

The most known and applied valence model goes back to Wundt's work (1874), where affect was defined as a bipolar construct containing a single dimension between the extreme poles, positive and negative. Building on the bipolar model perspective, Russell (2017) distinguished different core affects, referring to neurophysiological states. He assumed that only one state at a time is possible, and thus, valence is bipolarly modeled.

On the behavioral level, this valence model would predict increasing or decreasing reaction times ranging between positive and negative words, for example, positive words should lead to faster reaction times than negative words. Due to inconsistent findings (see Kauschke et al., 2019, for review), meaning that reaction times are sometimes shorter for negative and sometimes shorter for positive words, this model could not be conclusively supported or rejected until today. However, the majority of research reports shorter reaction times for positive words. This finding is supported by computational models such as the AROM, which relate the advantage of positive words to their increased association clusters (Alves et al., 2017; Hofmann & Jacobs, 2014). As such, this means that positive words have more associated words than negative ones. However, inconsistent behavioral findings do not necessarily mean that the model makes wrong assumptions. The conflicting results could also be due to further moderator variables not accounted for in the previous studies (e.g., word features like word length, frequency, and familiarity). Also, arousal can play a key role as investigated within the framework of an interactive point of view on valence as proposed by

Jacobs et al. (2015). Furthermore, whether words are either positive or negative is debatable (Cacioppo & Berntson, 1994; Norris et al., 2010; Vaccaro et al., 2020; Watson & Tellegen, 1985).

In summary, the valence of a word can be investigated by asking participants for their affective evaluations ranging between positive and negative, leading to particular reaction times, which provide valuable information regarding affective semantics. During this decision process, two ubiquitous behavioral phenomena were repeatedly found.

2.2 Two Ubiquitous Behavioral Phenomena

The pioneering work by Osgood (1969) and Russell (1978) led to the common task of directly asking participants whether they think a particular word is positive or negative. The task, called VDT varies regarding the options of answers between a forced-choice paradigm with only positive and negative answers or an additional neutral response option. Rating scales are a second method for studying explicit affective decisions, in which participants are asked to rate the degree of valence on a scale ranging from four to seven points. These are also widely used for investigating other affective semantic features such as arousal or imageability.

Independently of explicitly or implicitly measuring valence effects, some classical behavioral patterns were repeatedly reported (see Jacobs et al., 2015, Kauschke et al., 2019, for an overview). The following phenomena are typical findings in those paradigms.

The Relation of Valence and Arousal

A common finding is an asymmetric U-shaped function relating valence to arousal ratings (e.g., Jacobs et al., 2015; Kauschke et al., 2019; Schmidtke et al., 2014, Võ et al., 2009). Here, the valence extremes of positive and negative are rated as more arousing than neutral, whereby negative words are associated with higher arousal than positive words. These effects can be explained by phylogenetic and ontogenetic circumstances. First, according to the model of motivated attention and affective states (Lang et al., 1990), valenced stimuli capture more attention than neutral stimuli due to their increased survival value. Second, since negative stimuli have a greater impact on survival than positive and neutral stimuli, the affect system may have developed more strong responses to negative stimuli (Norris et al., 2010; Taylor, 1991) associated with higher arousal.

The Relation of Valence and Reaction Times

The second typical finding is an inversely asymmetric U-shaped function between reaction times and valence (e.g., Jacobs et al., 2015; Kauschke et al., 2019; Võ et al., 2006). Here, positive words are often associated with shortest reaction times, followed by negative words and longest reaction times for neutral words. This processing advantage of positive words is called the 'positivity superiority effect' (Lüdtke & Jacobs, 2015) and was formerly interpreted in terms of the associative cohesiveness hypothesis (Phelps and LaBar, 1997). It contains the idea that positive words have more semantic associations and are thus more densely interconnected. This is in line with the informational density hypothesis (Hofmann & Jacobs, 2014; Unkelbach et al., 2008), which states that a higher interconnectivity of positive words leads to a speed advantage. As such, this processing advantage could be shown within affective semantic decision tasks and cognitive tasks regarding attention and memory effects (e.g., Kazanas & Altarriba, 2016; Kissler et al., 2009).

To test if these behavioral phenomena can also be found in six- to twelve-year-old children is the aim of Study I of the present dissertation. The fundamental foundation to approach this open question, is provided by previous research in adults (e.g., Jacobs et al. 2015; Kauschke et al., 2019). An age comparison of the children and adults based on adults' previous findings seems to be a sufficient approach since, no research on this topic has been done so far in children. Secondly, children from the age of six to twelve have already largely accomplished their language development (Enge et al., 2021). Thirdly, it has reliably been shown that children at that age use an adult-like valence taxonomy (Wintre & Vallance, 1994) and are able to report their evaluations (e.g., Lagattuta & Wellman, 2001; Lagattuta et al., 1997; Ribody et al., 1988). Finally, the kidBAWL provides an appropriate tool to examine the behavioral phenomena in children but also to compare the patterns of children and adults.

3 Neural Underpinnings of Valence Decisions in Adults and Children

Following the examination of the behavioral correlates of affective semantics in children in Study I, I moved further to shed light on the neural underpinnings of valence. Thus, the second focus of the present dissertation is to better understand the neural underpinnings of explicit valence decisions in children and adults. The question is, how children at the ages of six to nine process the affective meaning of a word and if this processing is similar to the neural signature found in adults. The results of Study II could serve as a milestone in the investigation of the neural basis of affective semantics in children. More specifically, the results could provide the first evidence for developmental neurocognitive approaches of affective semantics (Jacobs et al., 2015). However, investigating the neural link between affective processing and language is especially challenging since language is one of the most recent achievements in human evolution.

To investigate the neural link between affective and language processing, the neural underpinnings of language are paired with neural networks devoted to affective-cognitive processes, which have evolved long before (Koelsch et al., 2015; Panksepp, 1998). Thus, the underlying neural networks cannot be clearly separated. This interrelation is best described by the Panksepp-Jakobsen hypothesis (Jacobs & Schrott, 2011; Jacobs, 2015; Jacobs et al.

2015). The hypothesis is that aesthetic processing, in other words, enjoying words, involves ancient affective brain systems since evolution had no time for developing separate processing systems. Furthermore, since aesthetic processing is linked to affective experience, this hypothesis is a first step to bridging the language–emotion gap on the neural level. With his theory of emotions, Panksepp (1998, 2005a; 2005b; Panksepp & Watt, 2011) provides an empirical foundation for how emotions and language are intertwined, and thus how affect influences language processing (e.g., Cromwell & Panksepp, 2011).

3.1 Panksepp's Theory of Emotions

According to Panksepp (1998; Panksepp & Watt, 2011), emotions are an affective 'power' arising from subcortical systems, where emotions are created. Subsequently, by directing them to the cortex via the limbic system, these emotions are organized and conceptualized, allowing us to think and speak about them (Panksepp, 1998). In general, no emotion exists without a consequence on the behavioral or physiological level. Panksepp's theory (1998) is thus in line with theories assuming a functional view of emotions. That is, emotions are the result of an innate signaling system that includes a specific set of emotional concepts related to universal emotional guided reactions (e.g., Darwin, 1872; LeDoux, 2012; Izard, 1971; 1994).

As a part of his theory, Panksepp (1998; 2005a; b) assumes seven basic emotional circuits, which can be further differentiated depending on the level of processing. Three levels of processing are considered, arranged hierarchically and acting interactively, on which the emotional circuits act. Each level is associated with a different brain layer (see Figure 1A). The three levels are close to MacLean's 'Triune Brain' (1949). MacLean roughly broke down the mammalian brain into three layers related to evolution to provide a phylogenetic concept for brain evolution close to Papez (1937) and thus a theoretical basis for how emotion might have evolved. The lowest layer is associated with the midbrain up to the cortex (ventral tegmental area to hypothalamus), comprising the basal ganglia (caudate, putamen, pallidum), PAG, stria terminalis, and (hypo) thalamus at the subcortical level (see Figure 1C). Based on findings in animal studies, Panksepp (1998) assumed the origin of the seven (truly) basic emotional (motivational) circuits (i.e., seeking or rage) in these subcortical regions. Circuits labeled as truly emotional mean that these emotions are fundamental motivational sources leading to and guiding behavior. These are processed unconditionally on the primary level. The secondary level comprises of the limbic system (cingulate, hippocampus, and amygdala) defined close to the Papez Circuit (1937; Figure 1B; see Nieuwenhuys, 2008; Rolls, 2015, for the discussion regarding the definition of the limbic system). Moreover, the secondary level is associated with affective (conditioning, operant) learning and appraisal, i.e., punishment vs. reward. Additionally, unconditioned affective responses can become conditioned through environmental stimuli at the secondary level. However, it is still debatable whether emotions can at all be generated on the second level without first-level input (Panksepp, 1998; Watt & Pincus, 2004). The tertiary level comprises the neocortex associated with declarative (emotional) knowledge, decision making, language, executive control, and consciousness. This highest level is fed by information from the primary and secondary levels.

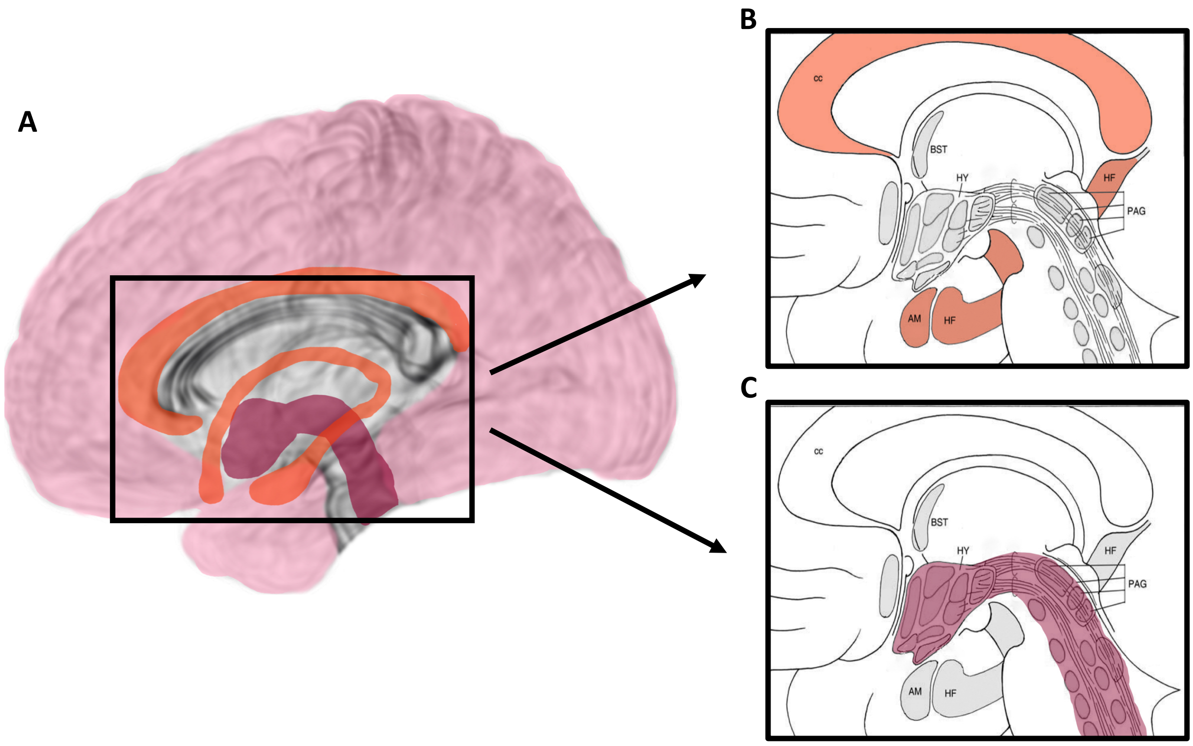

Figure 1. Schematic Illustration of the Process Levels of Panksepp's Theory of Emotion. (A) Schematic overview of the three process levels. Dark red: Primary-process level. Orange: Secondary-process level. Pink: Tertiary-process level comprising neocortex. **(B)** Sagittal view of secondary-process level comprising the limbic system including the cingulate cortex (CC), hippocampal formatio (HF), and amygdala (AM) according to Papez (1937). **(C)** Sagittal view of primary-process level comprising periaqueductal grey (PAG), hypothalamus (HY), and tria terminalis (BST).

All three process levels are connected via ascending and descending routes (Nieuwenhuys, 2008). The primary level acts like the command level, coordinating activities between all three process levels interactively (Watt & Pincus, 2004). As an example of the interconnectivity, the caudate and thalamus are part of a 'major subcortical-cortical connectivity system' (Pessoa, 2018). It transmits signals between the midbrain and forebrain and provides routes to the cortex (Vandekerckhove & Panksepp, 2011). Furthermore, Nieuwenhuys et al. (2008) named the thalamus as 'gateway to cortex', i.e., a relay station for subcortical information from the striatum via the thalamus to the cortex (motor, premotor cortex, and PFC). Ventral to the thalamus, the hypothalamus projects between the PAG and medial OFC (Nieuwenhuys et al., 2008).

To summarize, functional and structural connectivity patterns support the assumption of a highly interactive system of emotion processing between subcortical and cortical structures (see also Pessoa, 2017). Thus, derived from Panksepp's theory of emotion (1998; 2005a; 2005b), one would assume that all three levels of processing should be involved in affective semantic processing. The primary process level coordinates between all three process levels and provides information regarding a basic (unconditioned) emotional tendency. The secondary process level provides information regarding conditioned emotional experiences related to certain stimuli. Finally, the tertiary process level provides additional information, such as semantic properties to process affective semantics. The following section explains how affective semantics are represented in the brain.

3.2 Affective Semantic Representations

Derived from the model of the acquisition of semantic representations proposed by Andrews et al. (2009; 2014; Vigliocco et al., 2009), affective features of a word should be acquired by a joint function of experiential and distributional data, from which the affective meaning of a word is extracted. While experiential data (see Box 1 for more details) is gained non-linguistically through perceiving the physical world, distributional data (see Box 2 for more details) originates linguistically using statistical characteristics from language (Andrews et al., 2009). Both sources of information are entangled inseparably and jointly used for the acquisition of semantic representations (e.g., Andrews et al., 2009; Borghi et al., 2017; Davis & Yee, 2021).

Borghi et al. (2017) and Kousta et al. (2009) proposed investigating the mode of acquisition to shed further light on the question of whether the semantic nets in children and adults are similarly structured. Evidence in children shows that experiential information seems to have high importance for word acquisition (Peters & Borovsky, 2019). For example, it was found that concrete words, which are more strongly associated with experiential than distributional data, are learned earlier than abstract words, which are more closely related to distributional data (e.g., Declercq et al., 2019; Hadley et al., 2016; 2019; Kousta et al., 2011; Ponari et al., 2018; Schwanenflugel, 1991).

BOX 3| Experiential Data

The experiential data perspective goes back to Locke's (1689/1975) seminal work concerning human understanding. From his view, human knowledge is based on sensory information derived through all sensory modalities. Regarding semantics, the meaning of a word is the mental representation of the object it refers to comprising all perceived sensory information organized in a particular pattern. Thus, experiential information is related to the physical attributes and features of the words' referent, which are directly perceived by sense receptors. Furthermore, it is related to sensory-motor features experienced in our daily interaction with the world. Collins & Loftus (1975) found influences of the distance of entities measured by reaction times: the more distance between two entities, the longer the reaction times for jumping from one to the other. For example, the concept 'bird' is closer to concept 'animal' than the concept 'kitchen' (e.g., McClelland & Rogers, 2003; McClelland & Rumelhart, 1981).

The information source of experiential data also forms the basis for the embodiment approach, which assumes that word processing is associated with those neural regions, which represent their referent (Barsalou, 1999, 2008; Henningsen-Schomers & Pulvermüller, 2021; Meteyard et al., 2012; Pulvermüller & Fadiga, 2010; Vigliocco et al., 2013). Thus, within the experiential point of view, features of a word gain their meaning by perceptual information, whereby the distance between words results in the closeness of these features of the two words.

From a neural perspective, studies in adults have shown a particular neural pattern related to (affective) semantic representations. For example, Fernandino et al. (2021) found a processing advantage for experiential information compared to distributional information in participants' familiarity ratings of nouns. The associated widespread neural network encompasses regions normally associated to lexico-semantic processing (e.g., AG, SMG, STG, MTG, ITG, fusiform gyrus; e.g., Price, 2012) but also with valence processing (e.g., IFG, MFG, SFG, PCC, ACC; e.g., Citron, 2012; Lindquist et al., 2016; Man et al., 2017; Rolls, 2019). Furthermore, Binder et al. (2016) provided a framework for how different domains of semantics, such as sensory, social, cognitive, and emotional information, are represented in words. They reported neural activation associated with affective semantic features in OFC, dorsomedial PFC (parts of MFG, precentral, and SFG; Huth et al., 2016), SMA, ACC, PCC, IFG, anterior temporal lobe, amygdala, and anterior insula (Binder & Desai, 2011; Binder et al., 2016). These regions are broadly associated with language comprehension (IFG, MTG, SFG; Binder et al., 2009; Della Rosa et al., 2018; Price, 2012; Rodd et al., 2015; Walenski et al., 2019), semantic retrieval (AG; Binder et al., 2009; Kaiser et al., 2021; Price, 2012), task-specific visual or auditory stimuli processing (STG, fusiform gyrus; Binder et al., 2009; Price, 2012) and valence processing (OFC, ACC, PCC, amygdala, anterior insula; Citron, 2012, Lindquist et al., 2016; Man et al., 2017; Rolls, 2019). However, the classification of lexico-semantic and subordinate processes and valence processing greatly simplifies the fact that many of these regions were found for both processing streams due to the close functional connectivity (e.g., Du et al., 2020) supporting the view, that semantics and affect are inseparately intertwined.

BOX 4| Distributional Data

The distributional data perspective goes back to the work of Wittgenstein (1953/1997). He proposed that word meaning is defined by its use and its lexical environment. Based on this assumption, Harris (1954) proposed the distributional hypothesis, where the meaning of a word is derived by the context it occurs. Firth (1957) summarized this idea by the statement 'you shall know a word by the company it keeps'. Thus, if two words, A and B, share most of their language environments, i.e., the context they be used, they are synonyms. The more differences in A's and B's language environment, the more different their meaning. Computational models following this tradition such as the Hyperspace Analog of Language (e.g., Burgess & Lund, 1997) or the Latent Semantic Analysis (Deerwester et al., 1990; Landauer & Dumais, 1997), are based on co-occurrences of inter-word similarities in large text corpora.
In children, the acquisition of distributional data is well investigated. According to Wojcik's review (2018; Culbertson & Schuler, 2019), meaning in 1.5 - to two-year-old children is acquired by distributional cues, i.e., statistical learning. For example, Lany and Saffran (2010) presented strong evidence for statistical learning (associative learning) by training 21-22-month-old children in an artificial language, where the experimental group learned word -pictures pairs by statistical cues. In this experimental group, new category members were also more easily and faster added compared to a control group trained without distributional cues. Unger et al. (2020) could confirm this idea of statistical learning for four to five-year-olds. However, associative and taxonomic trajectories are largely not independent (Mirman et al., 2017). Both rely on word associations, by which already six-year-old children easily arrange semantic relations (e.g., Sloutsky & Deng, 2019).

To summarize, experiential and distributional information contribute to affective semantics, leading to a widespread neural network comprising regions associated with affective and semantic processing. The focus of the present dissertation is on one aspect of affective semantics, namely valence. In the following section, previous findings on the neural underpinnings of valence processing in adults are briefly described.

Neural Network of Valence Effects

In a meta-analysis, Lindquist et al. (2016) summarized valence-associated activation and found a widespread network. Their work encompasses cortical activation of the SFG, MFG, SMA, IFG, anterior insula, OFC, inferior occipital gyrus, MTG, and STG. Furthermore, subcortical activations were found in the ACC, amygdala, thalamus, midbrain, and nucleus accumbens (see also Man et al., 2017, for review). However, since this meta-analysis is comprised of studies using all kinds of stimuli, task-related co-activations are possible. For example, the reported occipital activation could be due to visual input processing (e.g., Kaiser et al., 2019). Citron (2012), on the other hand, specifically reviewed written word emotion processing and reported activation in the neocortex comprising of the medial PFC (IFG, MFG) and insula, and subcortical ACC, PCC and amygdala. These results showed a great overlap with the results of Lindquist et al. (2016; Man et al., 2017) and are strikingly in line with Panksepp's theory of emotion (1998; 2005a; 2005b), providing evidence for the involvement of all three process levels in processing valence.

In summary, research specifically focusing on valence processing provides striking evidence for Panksepp's theory of emotions. Therefore, the theory provides a basic framework to investigate affective semantic processing, or how affective features like the valence being an integral part of semantic representations at the neural level. However, it is largely unknown if this network is also applicable to children. Differences in the neural signature could be expected, especially due to the ongoing growth of the mental lexicon. However, in order to compare affective semantic processing in children, their brain maturation needs to be sufficiently aligned to the adult's neural network.

(Affective) Semantic Processing in the Maturing Brain

When examining the neural underpinnings of semantic processing in children at the age of three, there is already a remarkable overlap with the neural patterns of adults (Enge et al., 2021), although their syntactic abilities are not fully developed (Skeide, 2014; Wang et al., 2020). The semantic network encompasses the perisylvian language network, which is associated with lexical processing and activations sensitive to semantic processing in MTG, STG, IFG, SMA, and right insula. Here, the IFG, MTG, and SFG are associated with (affective) language comprehension (for similarities in adults see Binder et al., 2009; Della Rosa et al., 2018; Huth et al., 2016; Price, 2012; Rodd et al., 2015; Walenski et al., 2019). Results regarding semantic knowledge show a high consistency regarding activation in the insula and MFG and semantic relatedness in IFG and MFG in children (Enge et al., 2021).

A conjunction analysis between children and adults showed considerable overlap in the IFG, SMA, right insula, MTG, and STG (Enge et al., 2021). These results support previous findings by Croft et al. (2014), who reported activation in the temporal lobe related to semantic associations, AG in association with lexical access (see for adults, e.g., Kaiser et al., 2021), and IFG activation related to semantic decisions in four-to twelve-year-old children. Furthermore, Croft et al. (2014) reported OFC activation associated with semantic selection and retrieval. In their meta-analysis, Weiss-Croft & Baldeweg (2015) summarized that activation related to semantic and phonological processing in the SMA to SFG, precentral, IFG, OFC, STG, and MTG, which is in line with adults' activation for these processes (e.g., Price, 2012). Likewise, Weiss et al. (2018) found bilateral STG, MTG, and IFG activation in five to six-year-old children when performing a spoken meaning judgment task.

Despite the substantial overlap of the semantic networks of children and adults, Enge et al. (2021) found slight age-related differences of children between four and 15 years (median group split by ten years). While younger children (four to ten years old) showed larger effect sizes in MTG and STG, effect sizes in IFG increased with age. These results suggest that at around the age of six, neural underpinnings of the (affective) semantic language network seem to be tightly synchronized with the adults' (affective) semantic network with only slight changes in the IFG after (Weiss-Croft & Baldeweg, 2015).

In conclusion, the neural pattern of the semantic network is already mostly synchronized by the age of six, allowing comparisons between children aged six and older and adults. Interestingly, the semantic network in children, which is interpreted as valence-related in adults' research, becomes obvious when looking at the data (e.g., IFG, OFC, insula; Lindquist et al. 2016).

Bringing together Panksepp's theory of emotion (1998; 2005a; 2005b), the findings for valence and affective semantic representation it becomes evident that an orchestra of subcortical and cortical regions is recruited (see Figure 2). These subcortical and cortical regions are associated not only with affective or semantic processing but also with affective semantic processing. The neural underpinnings of these affective semantic representations have been widely examined in adults. However, it has not been explicitly examined in children yet. The neural alignment of the semantic network in children and adults indicates that the findings for valence related activations reported above could also hold for children. However, because children have smaller mental lexicons than adults and possess less experienced and distributional data, the results comparing the neural underpinnings of valence processing in children and adults may also show differences.

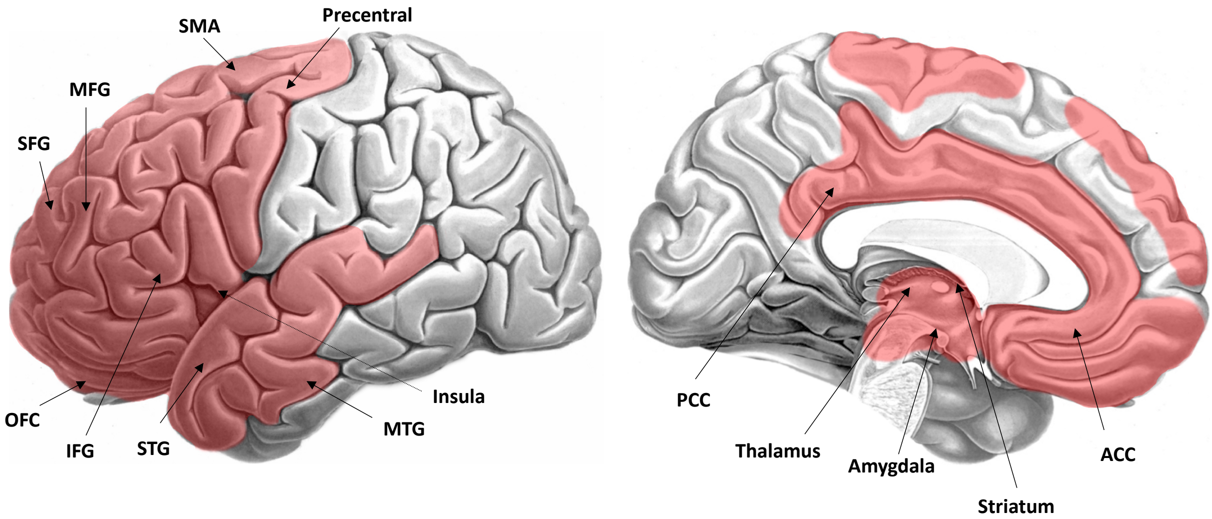

Figure 2. Overview of the Assumed Affective Semantic Network. Condensed activation in adults associated with affective semantic processing resulting from the evidence of Citron (2012), Lindquist et al. (2016), Man et al. (2017), and Panksepp (1998). **Left:** neocortex left hemisphere rendering. SMA: Supplementary Motor Area, MFG: Middle Frontal Gyrus, SFG: Superior Frontal Gyrus, OFC: Orbito Frontal Cortex, IFG: Inferior Frontal Gyrus, STG: Superior Temporal Gyrus, MTG: Middle Temporal Gyrus. Dotted arrow indicates insula location beneath surface. **Right:** Sagittal view of subcortical structures. PCC: Posterior Cingulate Cortex, ACC: Anterior Cingulate Cortex.

4 Neural Underpinnings of Valence Contributions to Auditory Word Recognition

The third study of this thesis sheds light on implicit processing of valence. The impact of valence is commonly investigated directly (e.g., Adelman & Estes, 2013), that is, by asking participants for their valence evaluation. However, previous research (e.g., Briesemeister et al., 2015; Jacobs et al., 2015; Kauschke et al., 2019; Kuchinke et al., 2005) has found evidence that valence plays an implicit role in cognitive processing, as early priming studies have shown (e.g., Murphy & Zajonc, 1993). These findings can be seen in the light of the affective primacy hypothesis (Zajonc, 1980; 2000), where it is assumed that affective reactions due to a broad stimulus evaluation in terms of good and bad can be elicited by minimal (affective) stimulus input. Murphy and Zajonc (1993) argue that this is due to the less voluntary control of affective reactions and that the affective input may be outside of conscious awareness. Furthermore, the authors assume that affect-laden stimuli can be processed more readily than neutral ones, meaning that affect captures attention without conscious awareness. The primacy hypothesis was challenged by the cognitive primacy hypothesis (Lazarus, 1984; see for discussion Lai et al., 2012), which states that cognitive processes predominate affective processing. Independently of this discussion, research regarding the impact of valence on lexical decisions could support the view that affective information plays a crucial role at early stages of processing. More specifically, it could be shown that affective information facilitates the decision process in LDT (e.g., Briesemeister et al., 2015; Citron, 2012; Kuchinke et al., 2005; 2007; Schlochtermeier et al., 2013). Thus, this task was used in Study III of this dissertation to investigate the neural underpinnings of the implicit contributions of valence to word recognition, with a focus on the development of this contribution.

The LDT is a common task to investigate lexical processing variables. Participants are asked whether a presented letter string was a word or a pseudoword, or sometimes even a non-word. A pseudoword is a word that follows the phonotactic rules without meaning; for example, 'stute'. This pseudoword could be an English word, but has no meaning. Unlike a pseudoword, non-words are letter strings that do not follow the phonotactic rules of a given language; for example, 'haxs'. In general, participants can thus make their decision based on the mere lexical status of the presented stimulus. This kind of decision can thus be based on shallow orthographic processing (e.g., Grainger & Jacobs, 1996; Jacobs et al., 2015; Jacobs et al., 1998; Treiman & Cassar, 1997; Ziegler & Ferrand, 1998). However, while classical speech processing models (e.g., Hickok & Poeppel, 2004) are silent regarding affective semantic processing, only the AROM (Hofmann et al., 2011; Hofmann & Jacobs, 2014) or the eMROM (Kuchinke, 2007) provide a computational framework for affective contributions to word recognition. It is based on former models of visual word recognition like IAMs (McClelland & Rumelhart, 1981; 1985; Rumelhart & McClelland, 1982) and their extensions (Grainger & Jacobs, 1996; Jacobs & Grainger, 1994), which consist of three layers. On the first layer, simple (visual) features are processed and handed over to the second layer for letter processing. The information is passed to the third layer for whole-word recognition based on the orthographic lexicon. The fourth semantic layer simulates semantic network activation. Each layer is computationally based on sentence co-occurrences and thus simulates associative-based spreading activation between semantic word units. It is hypothesized that the semantic layer elicits a recollection-like activation pattern (Hofmann, 2011). All four layers are interactively connected via exhibitory and inhibitory feed-forward and feed-backward loops. The model predicts that the more associated items are around a semantic word unit, the stronger the activation of the semantic word unit. Moreover, the AROM accounts for the affective component of semantics by calculating relations between valence and semantic associates. Although the present study employed an auditory LDT, orthographic processing still plays a role, since orthographical and phonological processing interact as soon as children learn to read (e.g., Ziegler & Ferrand, 1998).

The LDT is probably the most commonly employed task to study implicit emotion processing during word recognition in adults (Citron et al., 2014b). Windmann et al. (2002) were among the first to investigate the emotional ‘connotation’ of words within an LDT. A common finding at the behavioral level is that presented words elicit faster reaction times than pseudo- or non-words (e.g., Ziegler & Perry, 1998). When analyzing the underlying word valence, the positivity superiority effect reliably found in VDTs was also found for lexical decisions in children and adults which supports findings by the AROM (e.g., Kuchinke et al., 2005; Madan et al., 2017; Ponari et al., 2018; Scott et al., 2014; Yao et al., 2016). Furthermore, both children and adults process words with positive or negative valence faster than neutral words (e.g., Jacobs et al., 2015; Ponari et al., 2015; Vinson et al., 2014). It is noteworthy that other variables such as word frequency, semantic richness, or concreteness (e.g., Goh et al., 2016; Hofmann & Jacobs, 2014; Jacobs et al. 1998; Kanske & Kotz, 2007; Ziegler et al., 2003), to name a few, also influence the decision process. However, these are not within the scope of the present work.

From the neural perspective, an almost identical neural network was reported for implicit valence processing during LDTs as was found for explicit valence processing in, e.g., VDTs. For example, using the LDT, Briesemeister et al. (2015) reported activation for positive words compared to neutral words in the bilateral IFG and medial PFC. In addition to activation in bilateral IFG for emotional words, Kuchinke et al. (2005) discovered activation in the OFC, bilateral MTG, and right STG and SFG for positive words. Furthermore, the authors tested positive versus negative words and found PCC, bilateral ACC, and right hippocampus activation. In a similar line, Nakic et al. (2006) found that negative words are associated with activation in the bilateral amygdala, MTG, ACC, and PCC. Explicitly, Wong et al. (2020) observed in their connectivity analysis activation in PCC, AG, MTG, SFG, MFG, STG, postcentral, precentral, IFG, insula, thalamus, SMG, OFC, quite in line with the reported widespread network for explicit valence processing (cf. Figure 2).

Overall, the LDT provides the chance to test implicit valence contributions to lexical decisions associated with a particular behavioral pattern, that is, valenced words are processed faster than neutral words. Moreover, evidence suggests a similar underlying neural pattern as reported for explicit valence decisions comprising regions associated with valence processing in respect to Panksepp's theory of emotion (cf. Panksepp's Theory of Emotion) and findings regarding the neural underpinnings of affective semantic representations (cf. Affective Semantic Representations). The central hypothesis of Study III is that similar valence contributions should be found in children and adults because the neural network of semantic processing in children at the age of six is already largely aligned to the pattern of activation consistently found in adults (e.g., Enge et al., 2021; Weiss-Croft & Baldeweg, 2015). Furthermore, the loci of these similarities are assumed to be similar to the assumed neural pattern for explicit valence processing. Thus, if valence contributes similarly in children and adults to lexical decisions, activation should be found in the OFC, IFG, SFG, MFG, precentral, SMA, MTG, STG, insula, ACC, PCC, amygdala, and striatum (cf. Figure 2).

Altogether, the present dissertation sheds light on the behavioral and neural underpinnings of valence processing in children compared to adults. The research idea is based on Panksepp's (1998; 2005a; 2005b) emotion theory, which assumes that specific neural circuits process valence as an affective semantic feature. Since this feature was not investigated in children before, the hypotheses about the behavioral and neural effects are derived from previous findings in adults. The main difference between children and adults seems to be the smaller and still growing mental lexicon of children, who have less experience with experiential and distributed information of semantic representations.

To conduct the three studies of the present dissertation, specific stimulus material for children was compiled. In Study I, a word database was built to meet the vocabulary scope of children. This database was then used to collect behavioral ratings of the dimensions of valence, arousal, and imageability to test for similar behavioral phenomena as consistently reported in adults. For Study II, stimulus material of the newly established database kidBAWL was again used to examine the neural underpinnings of these valence decisions in children, to the best of my knowledge, for the first time. Lastly, pseudowords were added to the stimulus material to investigate the neural underpinnings of implicit contributions of valence to auditory word recognition. The three studies shed light on valence processing in children from different points of view, resulting in a comprehensive picture of affective semantics in children. In an additional step, a task comparison was calculated within the dissertation to finalize the picture regarding differences and commonalities in explicit and implicit valence processing in children and adults.

5 Research Questions and Hypotheses

The general aim of this dissertation is to investigate how six to twelve-year-old children process valence compared to adults. Thus, with my dissertational work, I aim to give (A) a comprehensive picture of valence processing in children compared to adults and (B) evolve a develop-mental perspective of valence processing through three studies.

For Study I, the following question was addressed:

1) Are the behavioral affective semantic response patterns similar in children and adults?

Since there has been no research in children regarding affective semantic decisions, the study was explorative in nature. We expected differences and similarities between the children's and adults' ratings. Differences were expected based on the smaller mental lexicon in children. Conversely, if the evolutionary assumptions regarding how affect shapes our behavior are correct, then the same behavioral tendency previously discovered in adults should be found. Thus, the following hypotheses were tested:

If both age cohorts have a similar behavioral pattern regarding valence decisions:

(1a) The U-shaped function relating valence and arousal ratings should be discovered

(1b) The inverse U-shaped function relating valence ratings and reaction times should be found

(1c) Similar valence ratings should be observable

Study II addressed the following question:

2) Do children and adults have similar brain responses when explicitly processing valence?

Similarly, the neural underpinnings of processing affective semantics are still unclear. Although children's affective semantic knowledge is based on a smaller but still growing mental lexicon, the neural pattern of the semantic network is already mostly synchronized at the age of six (e.g., Enge et al. 2021; Weiss-Croft & Baldeweg, 2015). Thus, the central hypothesis of Study II is that children between the ages of six- and nine-years recruit similar neural regions to adults when making affective semantics decisions. The recruited regions comprise of those associated with Panksepp's theory of emotion (Panksepp, 1998; 2005a; 2005b) and are in line with previous findings in adults that focused on the underpinnings of affective semantic representations (e.g., Citron, 2012; Lindquist et al., 2016). Thus, the research question was investigated by testing the following hypothesis:

(2a) If children process the valence of a word similarly to adults, the same neural pattern should be found in both age cohorts. These encompass activation in the OFC, IFG, SFG, MFG, precentral, SMA, MTG, STG, insula, ACC, PCC, amygdala, and striatum.

Concerning Study III, the following question was addressed:

3) Do children and adults show similar brain activation for implicit contributions of valence to lexical decisions?

Several studies found incidental effects of emotional valence on lexical decisions in adults, pointing to valence as an essential information source for lexical decisions (e.g., Jacobs et al., 2015; Kauschke et al., 2019). Moreover, evidence suggests a similar underlying neural pattern as reported for explicit valence decisions (e.g., Kuchinke et al., 2005). Since the neural network of semantic processing in children from the age of six is already aligned to that of adults, the central hypothesis of the present study is that similar valence contributions should be found in children and adults. Furthermore, the loci of these similarities are assumed to be similar to the assumed neural pattern for explicit valence processing. Thus, the following hypothesis was tested:

(3a) If children implicitly process implicitly valence similar to adults, the same neural pattern

should be found in both age cohorts encompassing activation in the OFC, IFG, SFG, MFG, precentral, SMA, MTG, STG, insula, ACC, PCC, amygdala, and striatum.

To reconcile the results of my dissertation's findings regarding the neural underpinnings of explicit and implicit valence processing, I included a section about the differences and commonalities between both processing streams. It is suggested by previous findings that similar neural networks exist for both processing streams in adults. However, it is noteworthy that only a direct task comparison that is tested in the same experimental setting and cohort of participants can shed light on this assumption. This section provides the final answer to the question of similar processing streams in both age cohorts. Hence, the data from Study II and Study III was used to directly compare the neural underpinnings of explicit and implicit valence processing in children and adults. The following question was addressed:

4) Is valence explicitly and implicitly processed in a similar manner?

To answer the above question, the following hypotheses were tested:

(4a) If valence processing is similar for both explicit and implicit processing, then no activation differences should be found between the VDT and LDT in children.

(4b) If valence processing is similar for explicit and implicit processing, then no activation differences should be found between the VDT and LDT in adults.

II

EMPIRICAL PART

6 General Methodology

This chapter provides a general methodological overview of how affective semantic processing in children and adults was approached. Several decision tasks were applied in the three studies of the present dissertation to examine behavioral and neural correlations of explicit and implicit affective semantic contributions. Study I (Sylvester et al., 2016) comprises three different experiments (Experiments A-C), including different VDTs. Study II (Sylvester, Liebig & Jacobs, 2021a) reports the results of a VDT and Study III (Sylvester et al., 2021b) comprises an LDT. The present chapter provides a brief overview of the participant samples, experimental paradigms, and data analyses. A more detailed description can be found in the original publications.

6.1 Participants

Study I: kidBAWL

Experiment A comprises 20 children (ten females) between seven and twelve years old (*M* = 9.2; *SD* = 1.4). The experiment was conducted at a primary school in Berlin. Experiment B comprises 47 children (17 females) between nine and twelve years of age (*M* = 10.3; *SD* = 1.18) conducted in Salzburg. Experiment C comprises of 32 children (13 female) between six and nine years old (*M* = 7.77; *SD* = 0.91). The experiment was conducted at a primary school in Berlin. The children of all three experiments were native German speakers.

Study II & Study III: Neural correlates of valence and lexical decisions

After accounting for participants who had to be excluded, 17 children (seven females) between six and nine years of age (*M* = 7.65; *SD* = 0.86) and 17 adults (ten females) between 19 and 30 years old (*M* = 24.0; *SD* = 3.97) entered the analyses. All participants were native German speakers and had no history of neurological diseases.

6.2 Stimuli

Words

For the experiments subsumed in Study I, 90 words were chosen from the kidBAWL (30 positive, negative, and neutral words each). The words were categorized into these valence categories according to adults' ratings of the BAWL since no values for the children were provided yet. For the experiments of Study II and Study III, 20 words were selected for each valence category according to the ratings children gave in the course of Study I. These were parametrically z-transformed, ranging from -2.5 to 2.5.

In Study II and III, valence category borders were set from -2.5 to -0.5 for negative words, between -0.5 and 0.5 for neutral words, and from 0.5 to 2.5 for positive words. Similarly, arousal ratings were taken from Study I and matched across valence categories to control for confounding effects (*M* = 0.16). Additionally, it was controlled for the following lexical variables: numbers of letters (*M* = 6.0 letters), syllables (*M* = 1.9 syllables), and word frequency (*M* = 70.63 words per million). Word frequency values were taken from the Childlex database (Schroeder et al., 2015). Even though no statistically significant frequency effect emerged between valence categories, it is essential to note that the positive valence category shows a nonsignificant higher word frequency.

Pseudowords

Pseudowords were created matching each of the chosen 60 words of Study II following the phonological rules of German: (1) only the first syllables were changed; (2) consonants were linearly exchanged by either articulation location or voicing, provided this results in no violation of any phonological rule of the German phonological system (Milberg et al., 1988); and (3) vowels were altered by changing roundness (e.g., [e] to [o:]).

6.3 Experimental Paradigms

VDT

In Experiments A, B of Study I, the children were asked to rate 90 words (30 positive, 30 negative, and 30 neutral) presented visually (see Figure 3A). In Experiment C, they rated 105 words (35 words per valence category) presented auditorily. In Experiments A and C, the participants responded on a five-point scale, whereas in Experiment B, a three-point scale was used, both visualized by smileys. Apart from valence ratings, children performed additional arousal ratings (in Experiments A, C) and imageability ratings (3-point scale) in Experiment A (see for an overview of the experiments Table 1).

TABLE 1. Overview of the three experimental VDT paradigms used in Study I and Study II.

Study	Presentation modality	Ratings	Response scale	Reaction times
Study IA	visual	Valence, Arousal Imageability	5-point 3-point	no
Study IB	visual	Valence	3-point	yes
Study IC	auditory	Valence & Arousal	5-point	yes
Study II	auditory	Valence	2-point	yes

For Study II, a forced-choice valence decision paradigm was used. Here 20 positive, 20 negative, and 20 neutral words were presented, but participants were forced to decide between positive and negative (see Table 1). As the children were not proficient readers, the words were presented auditorily. The fMRI task consisted of two runs. In each run, 30 words were presented. After the auditory presentation, the participants had two seconds for their response, during which a sad and a happy smiley were displayed as response options (see Figure 3B).

LDT

The participants had to decide whether a letter string is a word or pseudoword. Besides testing the access to the lexicon and retrieval process, it is also possible to examine whether affective information influences lexical processing. For this LDT, the words of the VDT (Study II) and 60 matching pseudowords were used. To facilitate the understanding of the task for the children, the pseudowords were called 'magic words'. To illustrate the choices, participants saw a pile of books for the answer 'word' and a magic wand for the response' magic word' (see Figure 3C). In parallel to the VDT of Study II, participants had two seconds to respond via a response button in each hand. The words and pseudowords were presented auditorily in the MRI scanner similarly to Study II (see Figure 3C).

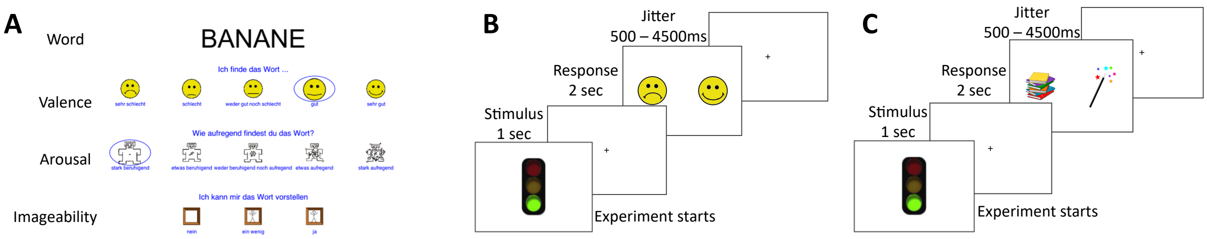

Figure 3. Applied Paradigms of Study I-III. (A) Exemplary overview of stimulus presentation of Study I (experiment A). Upper row word presentation, middle upper row valence dimension, middle bottom row arousal dimension, bottom row imageability dimension. **(B)** FMRI paradigm of Study II. **(C)** FMRI paradigm of Study III.

6.4 Data Analyses

Behavioral Data

In Study I, valence ratings of Experiment A were analyzed using a linear mixed model with six fixed effects (valence, arousal, imageability, syllables, frequency, and the number of orthographic neighbors) and two random effects (participants and words). Furthermore, age, gender, and grade effects were calculated. Finally, data were formally tested for asymmetry in all three experiments by a three-free parameter equation $y = A + B*(x - C)^2$ model. Moreover, in Experiment B, C correlations and ANOVAs were calculated to investigate mean differences of ratings and reaction times between valence categories.

In Study II and Study III, the reaction time data were analyzed with an ANOVA over all three valence categories and single t-tests between valence categories for the two age cohorts, children and adults.

Neural data

For Study II and Study III, the children were familiarized with the scanning procedure in the mock-scanner of the Max Planck Institute for Human Development Berlin. After, the fMRI data was acquired at the Center of Cognitive Neuroscience Berlin of the Freie Universität Berlin. The fMRI data were analyzed using the SPM12 software package (Ashburner et al., 2014) in Matlab (2012). On the first level, the data were modeled using a standard general linear model approach with the three valence categories as regressors. Baseline contrasts for positive, negative, and neutral words were computed on the second level, and differential contrasts for positive and negative valence were compared to neutral words. Additionally, conjunction analyses were performed to analyze overlapping activation over all three valence categories and overlapping activation of positive and negative valence in contrast to activation for neutral words.

7 Summary of Studies

7.1 Study I: Behavioral Correlates of Children's Affective Semantic Decisions

Sylvester, T., Braun, M., Schmidtke, D., & Jacobs, A. M. (2016). The Berlin affective word list for children (kidBAWL): exploring processing of affective lexical semantics in the visual and auditory modalities. *Frontiers in Psychology*, 7, 969.

Aims

Affective semantic ratings and decisions are widely studied in adults (e.g., Hofmann et al., 2018; Jacobs et al., 2015; Westbury et al., 2016), leading to specific behavioral patterns, which can be already computational predicted without participants' ratings (e.g., Jacobs et al., 2016; Westbury et al., 2015). However, the lack of research regarding affective semantics in children lead to Study I, which focuses on explicit affective semantic decisions and ratings of pupils between six and twelve years. Therefore, in a first step, the BAWL (Võ et al., 2009) developed for adults was adapted for children in that age group to establish the kidBAWL. In a first experiment, we investigated how six to twelve years old children rate chosen word stimuli regarding their valence, arousal, and imageability (Experiment A). In two further experiments, words within affective semantic decision tasks were presented in visual (Experiment B) and auditory (Experiment C) modality for testing modality-specific differences in decision behavior. These experiments aimed to examine whether in children similar behavioral patterns are observable previously found in adults.

Hypotheses

The hypotheses were derived from the adults' behavioral patterns. Thus, the null hypothesis of Experiments A, C was that children's valence ratings follow a similar distribution to adults' ratings regarding valence and arousal dimensions. This contains a negativity bias, meaning that the more negative a word is, the higher is its arousal value. Therefore, this hypothesis is similar for both modalities. Furthermore, two ubiquitous phenomena have been discovered concerning valence and arousal dimensions in adults. An asymmetric U-shaped function relates valence to arousal ratings (1), and an inverse U-shaped function relates reaction times to valence ratings (2). Therefore, the null hypothesis for Experiments A, C was that these ratings show a similar asymmetric U-shaped function relating valence ratings to arousal ratings (1). Regarding phenomenon (2), the inversely U-shaped function relating valence ratings to reaction times should be found in Experiments B, C.

Methods

Experiment A was a rating task in which the children rated the presented words regarding their valence and arousal on a 5-point scale and imageability on a 3-point scale. Experiment B comprised a VDT in which the children had to decide as quickly and accurately as possible whether the presented word was either positive, negative, or neutral. Finally, Experiment C was derived from Experiment A with the difference that words were presented auditorily, and only valence and arousal ratings were collected.

Results

The valence and arousal ratings collected in Experiment A showed an asymmetric U-shaped function relating valence to arousal ratings similarly to findings in adults, including the negativity bias (see Figure 4 A, B). Additionally, the adults' rating data taken from the BAWL (Võ et al., 2009) predicted the children's valence and arousal ratings (t(valence) = 15.37, p < 0.0001; t(arousal 7.36, p < 0.0001). Thus, the data of Experiment A points to a similar valence and arousal rating behavior in adults and children.

In Experiment B, the expected inversely U-shaped function was found in the reaction time pattern of valence decisions (see Figure 4 D, E). Words with higher valence values led to shorter reaction times than neutral words. More precisely, the children showed significantly shorter reaction times for positive words than negative and neutral words and significantly shorter reaction times for negative compared to neutral words. This effect, also called the positivity superiority effect (Lüdtke & Jacobs, 2015), was formerly found in adults. Although the children's reaction time pattern was comparable to patterns previously found in adults, the children's reactions were overall slower (see scaling y-axis).

The results of Experiment C showed an asymmetric U-shaped function of valence and arousal ratings, similarly to Experiment A (see Figure 4 C). Furthermore, the reaction times in Experiment C also showed an inversely U-shaped function. Thus, findings from the visual modality (Experiment A) were replicated for the auditory modality (Experiment C; see comparison Figure 4 A, C).

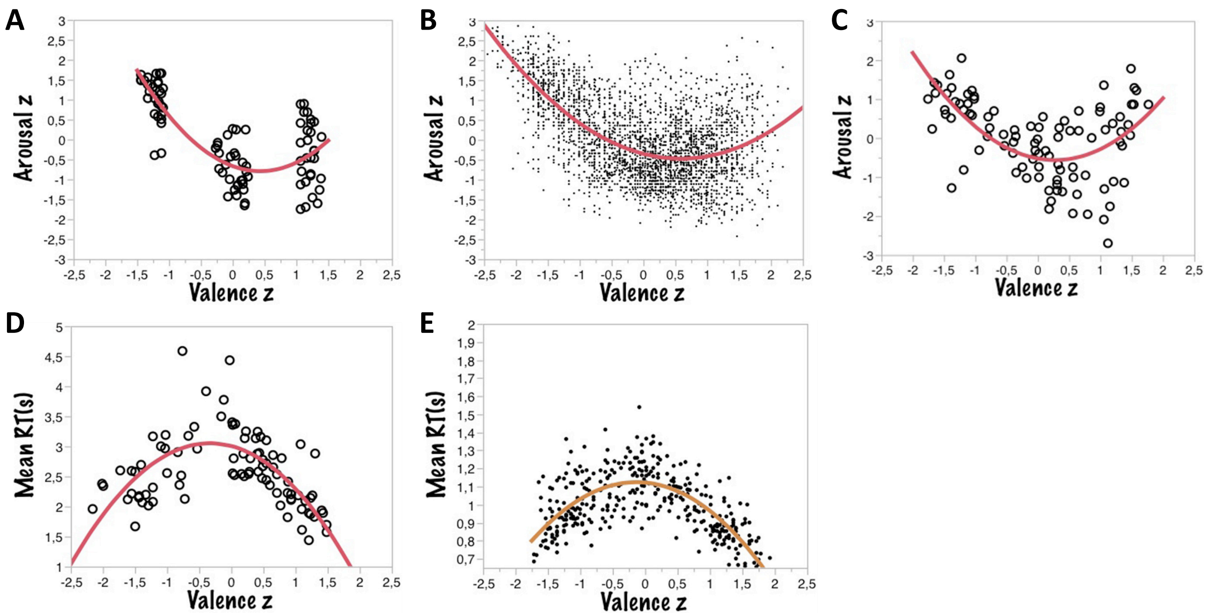

Figure 4. The U-shaped and inversely U-shaped functions in Children and Adults. (A) Correlations of z-transformed valence and arousal values for children's word ratings of Experiment A for the kidBAWL. (**B**) Correlations of z-transformed valence and arousal values for adults' word ratings taken from the BAWL (Võ et al., 2009). (**C**) Correlations of the z-transformed valence and arousal values for the auditory kidBAWL of Experiment C. (**D**) Mean response times (RT) in seconds (s) as a function of mean valence ratings (z-values) for the Experiment B of the kidBAWL. (**E**) Mean response times (RT) in seconds (s) as a function of mean valence ratings (z-values) taken from the BAWL (Võ et al., 2006).

Conclusions

The results of the three experiments of Study I indicate similar rating behavior of children and adults regarding the valence and arousal dimensions of words in both the visual and auditory modality. Positive words were rated fastest, followed by negative and longest reaction times to neutral words. Furthermore, the ratings of the arousal dimension of negative words tend to increase stronger with an increase of the valence value compared to the increase of the arousal value while increasing valence values of positive words. Besides, children had longer reaction times for neutral words, although a neutral response option was available.

7.2 Study II: Neural Correlates of Explicit Valence Processing

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021a). Neuroimaging of valence decisions in children and adults. *Developmental Cognitive Neuroscience*, 48, 100925.

Aims

Study II was directly built upon Study I since affective semantic processing in children was not yet investigated on behavioral and neural levels. Since Study I had shown a similar rating and decision behavior of six to twelve years old children and adults behaviorally, Study II aims to investigate whether the neural correlates of those decisions are similar as well. Additionally, a younger children's cohort was tested to shed light on possible processing differences in younger children's age. Thus, Study II focused on explicit affective word processing in children of six- to nine-year-olds. When comparing affective semantic processing in children and adults, neural similarities and differences have to be concerned. Commonalities in children and adults' affective semantic processing are reported regarding semantic processing, where at the age of six, children's processing streams are already widely aligned to the adults' semantic network (Enge et al., 2021; Weiss-Croft & Baldeweg, 2015) as described in the section regarding semantics in the maturing brain. This provides a basis for the affective semantic comparison since findings by Vigliocco et al. (2013) have suggested that affective components of words are tightly intertwined with lexical semantics. Whether the finding of the similar lexical-semantic network can be extended to affective semantic processing is thus the aim of Study II.

Hypotheses

As the neural foundation of affective semantic processing is well reported for adults (c.f. Neural Network of Valence Effects), the hypothesis was derived from findings in adults' studies (e.g., Citron, 2012). The hypothesis is that similar to the behavioral findings in Study I, a similar neural pattern should be found in children and adults. Thus, neural activations in the children's and adults' cohorts in ACC, amygdala, IFG, insula, MFG, MTG, OFC, PCC, precentral, SFG, SMA, striatum, STG, and thalamus were expected. However, since adults' results also have shown different activations for positive, negative, and neutral words (e.g., Maddock et al., 2003; Lewis et al., 2007), without a replicable pattern, commonalities and differences between these valence categories are expected.

Methods

For each age cohort, the expected neural activation pattern was examined separately. In addition, for testing pattern similarities of valence processing, i.e., a similar pattern for all three valence categories, a conjunction analysis against the conjunction null hypothesis (Friston et al., 2005) was calculated, showing the neural activation for positive ∩ negative ∩ neutral words.

Valence-specific effects were analyzed by the differential contrasts "positive > neutral" and "negative > neutral" words. A further conjunction analysis of the contrasts "positive > neutral" ∩ "negative > neutral" words were calculated to test for activation commonalities of positive and negative words compared to neutral words. Furthermore, baseline contrasts for the valence conditions are reported for a general overview. In the last step, a cohort comparison was calculated. Therefore, the differential contrasts of "positive > neutral" words were calculated for "children > adults" and vice versa "adults > children". Similarly for the other valence dimension "negative > neutral" words, the contrasts "children > adults" and "adults > children" were calculated.

Results

The conjunction analysis over all three valence categories shows activations in bilateral STG, bilateral thalamus, and bilateral calcarine sulcus, MTG, and right MFG. Children showed same brain responses and additional activation in the bilateral insula, right precentral gyrus, right middle cingulate cortex, and right putamen.

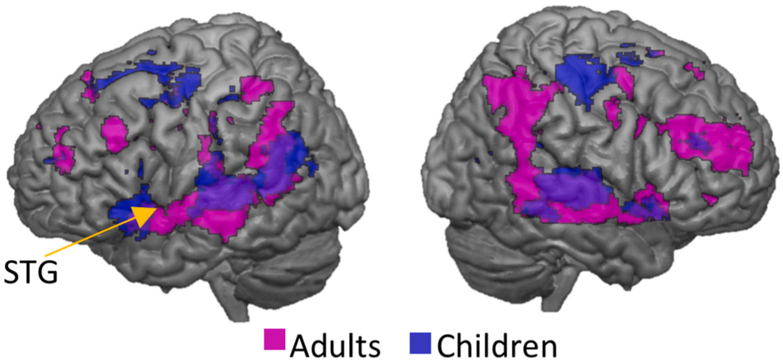

Figure 5. Affective Semantic Activations in Adults and Children. Conjunction analysis of activations associated with positive, negative and neutral words (adults in pink, children in blue) on a rendered brain surface. Overlapping activation of children and adults (purple) in the bilateral superior temporal gyrus (STG), middle temporal gyrus, and middle frontal gyrus.

Regarding the valence-specific effects, the adults show for the contrast "positive > neutral" words activation in the bilateral striatum, right ACC, bilateral precentral, right postcentral, bilateral SMA, insula, middle cingulate cortex, SFG, MTG, middle occipital gyrus, inferior occipital gyrus, lingual gyrus, right calcarine, superior occipital and fusiform gyrus. For the contrast "negative > neutral" words, activation was found in the bilateral SMA, right precentral gyrus, IFG, right AG, and PCC. However, the conjunction analysis for both valence categories ("positive > neutral" ∩ "negative > neutral" words) revealed no significant overlapping regions over both valence categories in adults. In children, activations for the contrast "positive > neutral" words were found in the bilateral IFG, bilateral precentral, SFG, thalamus, insula, hippocampus, right striatum, and right PCC. However, activation for the contrast "negative >

neutral" words was found in middle OFC, IFG, ACC, striatum, lingual gyrus, calcarine, middle occipital gyrus, right striatum, amygdala, right middle occipital gyrus, and AG. The children's conjunction analysis comprising "positive > neutral" ∩ "negative > neutral" words revealed similar activations in the ACC, striatum and IFG extending to the middle OFC.

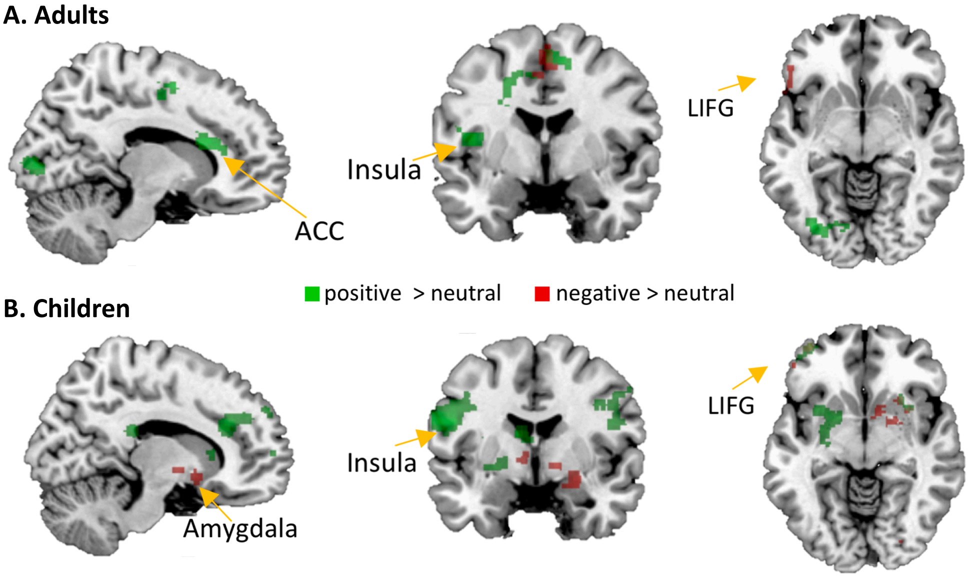

Figure 6. Differential Activations for Positive and Negative Words during Explicit Valence Decisions in Adults and Children. (A) Valence activation in adults for positive compared to neutral words (green) and negative compared to neutral words (red). **(B)** Valence activation in children for positive compared to neutral words (green) and negative compared to neutral words (red). Anterior Cingulate Cortex: ACC, Left Inferior Frontal Gyrus (LIFG).

The results of the cohort comparisons revealed the following: adults showed stronger activations than children for positive words in right STG, right SPG, MTG, lingual gyrus, fusiform gyrus, postcentral, middle occipital, and right occipital pole. For negative words, adults showed greater activation than children in bilateral MTG, right MFG, right precuneus, right postcentral, SMG, and SMA. However, the reverse conjunction analyses revealed a different pattern. Greater activation in children compared to adults for positive words was found in the right SPG extending to AG, right middle cingulate cortex, ACC, bilateral precentral, IFG, right thalamus, and pallidum. For negative words, activation in the insula extending to the amygdala, right SPG extending to AG, and right middle occipital gyrus showed greater activation in children than adults.

Conclusions

The conjunction analyses over all three valence categories revealed in both age cohorts a neural pattern in line with the expected affective semantic signature, which is already surprising since neutral words were included in the analyses. When activations due to neutral words were subtracted, the activations of positive and negative words have shown no further overlapping activation, suggesting different neural processing of positive and negative words beside commonalities over all three valence categories. These activations were formerly mainly associated with semantic processing. The children, however, have shown a common activation pattern for positive and negative words in regions previously associated with affective processing. Additionally, the activation patterns for positive and negative words differ as found in adults, but children's differences are mainly due to activations in regions formerly associated with affective processing. At first glance, the picture emerged that adults rely more on previously described lexical semantic networks than children, who rely more on regions associated with affective processing. This picture is supported by the direct comparison of both cohorts regarding positive words, but less concerning negative words.

7.3 Study III: Neural Correlates of Implicit Valence Processing

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021b). Neural correlates of affective contributions to lexical decisions in children and adults. *Scientific Reports*, 11(1), 1-11.

Aims

In Study III, a further aspect of valence processing was examined. While lexico-semantic processing is widely investigated in children and adults, the contributions of affective semantic information to lexical decisions were only subject of investigations in adults. Primarily orthographic-phonological processing on the cortical level was extensively examined in children (e.g., Enge et al., 2021; Weiss-Croft & Baldeweg, 2015). In adults, Briesemeister et al. (2015) and Kuchinke et al. (2005), among others, found incidental effects of valence within LDTs for positive and negative words, which were accompanied by activations in areas usually associated with affective processing. These findings are surprising since LDTs do not ask for valence judgments. In children, however, studies focusing on lexico-semantic processing report areas also associated with affective semantic processing, such as the insula, ACC, IFG, and parts of the basal ganglia (e.g., Liebig et al., 2017). Nonetheless, on the behavioral level, influences of valence on the performance in LDTs have already been comprehensively reported in children (e.g., Ponari et al., 2018; Lund et al., 2019). Study III aimed to investigate how these effects, e.g., a facilitation of positive and negative words processing compared to neutral words, are represented neurally.

Hypotheses

Study III deals with the question of whether children also activate regions associated with affective processing like the IFG, OFC, ACC, PCC, and amygdala when performing lexical decisions as previously described in adults. The following hypotheses were tested: Since lexico-semantic processing is already almost matured by the age of six, children might show neural activations associated with affective semantic processing when performing lexical decisions similarly to adults. Regarding lexico-semantic processing similarities in children and adults, neural activations were expected in the MFG regarding semantic retrieval and STG for auditory processing (Price 2012; Weiss-Croft & Baldeweg, 2015). Furthermore, similar reaction time patterns are expected such that both adults and children show the shortest reaction times for positive words, followed by negative and then neutral words. The longest reaction times are expected for pseudowords. Furthermore, as reported in Study I and Study II, reaction times should be longer in children than in adults.

Methods

Both age cohorts performed the same LDT with positive, negative, and neutral words and pseudowords in the MRI scanner. Participants were asked to decide as quickly and accurately as possible whether the auditorily presented word is a 'real' word (visually indicated by a pile of books) or a pseudoword (visually indicated by a magic wand).

To examine the neural correlates of implicit contributions of valence to lexical processing, contrast and conjunction analyses were calculated for the valence categories. Additionally, the contrast "words > pseudowords" was computed for children and adults, respectively.

Results

First, the differential contrasts of words (positive, negative, neutral) compared to pseudowords were calculated separately for children and adults. Children showed significant left-hemispheric activation in MFG, extending to IFG and dorsal cingulate extending to right SMA, as well as planum temporale extending to STG previously associated in explicit affective semantic processing (Sylvester et al., 2021a). In addition, right hemispheric activation in STG, superior temporal pole and bilateral anterior insula extending to right medial OFC and calcarine, became visible, which was reported concerning (auditory) affective semantic processing. In adults, neural activation appeared to be very similar to the children's pattern. Left hemispheric activation was found in adults in MFG extending to SFG, SMA, and right dorsal cingulate. In the right hemisphere, activation was shown in the STG extending to the temporal pole and the bilateral anterior insula extending to IFG. Since the results for both age cohorts appear similar, a conjunction analysis was calculated for children ∩ adults. Here, only the anterior insula extending to the IFG reached significance in line with the affective semantic hypothesis.

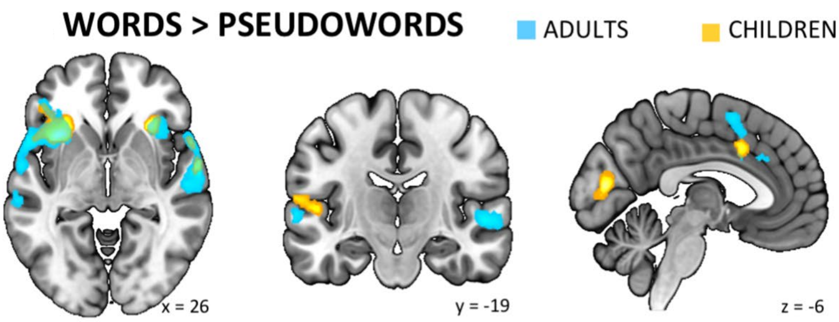

Figure 7. Neural Response Associated with Auditory Word Processing. Activation for words compared to pseudowords in adults (blue), children (yellow), and their overlap (green).

In the next step, valence-specific effects were analyzed. In line with previous findings in adults and thus in line with the hypotheses, adults' activations were significant in response to positive compared to neutral words in the left hemisphere in the precentral gyrus extending to the PCC and the ACC extending to the right SFG as hypothetically expected. Further activations were found in AG extending to the middle occipital gyrus, precuneus, and bilateral ventral diencephalon. Also, in line with the hypotheses, adults showed more robust activation in the medial OFC extending to the caudate and putamen and right ACC extending to the SFG in response to negative compared to neutral words. Additional activation was found in the hippocampus extending to the fusiform gyrus. A conjunction analysis of "positive > neutral" ∩ "negative > neutral" words showed expected activation in the ACC extending to the right SFG and medial frontal gyrus. Differential contrasts of both valence categories led to a non-expected difference in the contrast "positive > negative" words in the AG extending to the SPG only.

In children, activation differences supporting the hypotheses were found in the contrast "positive > neutral" words. Here, children showed more robust activation in the bilateral IFG, right anterior insula and MFG extending to the right ACC. Additional activation was found in the right planum temporale and lingual gyrus, precuneus, bilateral SGG, AG, SMG, postcentral gyrus, and precentral gyrus, which are associated with (auditory lexico-) semantic processing. For the contrast "negative > neutral" words, activation in line with the expectations was shown in the hemisphere in MFG and MTG, extending to ITG and middle occipital areas. Further activations were found bilaterally in the SPG, precuneus, SMG, postcentral, lingual gyrus, and cuneus, which are often associated with (auditory lexico-) semantic processing (e.g., Binder et al., 2009; Price, 2012). The conjunction analysis for "positive > neutral" words ∩ "negative > neutral" words showed bilateral activations in the SPG, precuneus, the SMG and MTG, and the right postcentral extending to the precentral gyrus as well as the lingual extending to calcarine gyrus. The further calculated differential contrasts led to no significant difference. The results suggest that performing the LDT elicited predominantly neural activation associated with auditory lexico-semantic processing.

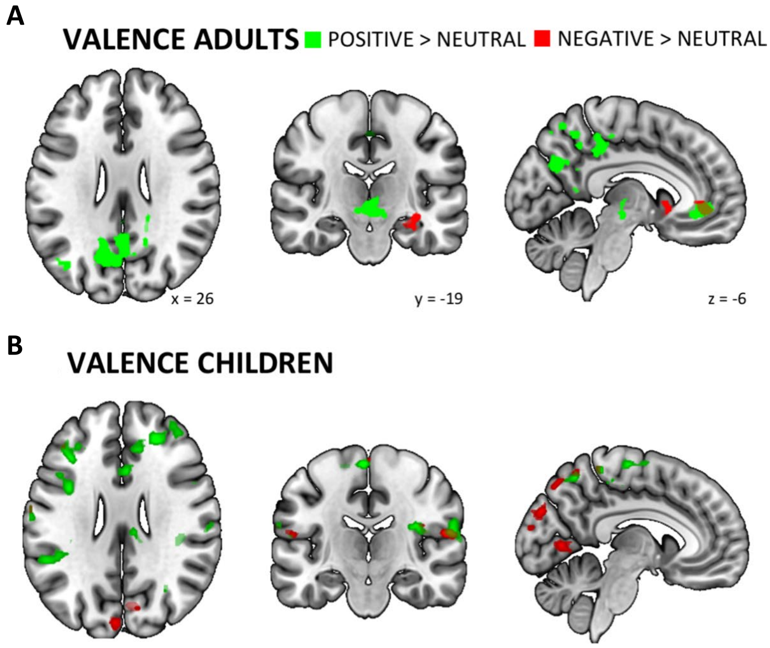

Figure 8. Differential Activations for Positive and Negative Words during Lexical Decisions in Adults and Children. (A) Valence activation in adults for positive compared to neutral words (green) and negative compared to neutral words (red). **(B)** Valence activation in children for positive compared to neutral words (green) and negative compared to neutral words (red).

When directly comparing children and adults, both age cohorts showed similar activations in the conjunction analysis over all three valence categories "positive ∩ negative ∩ neutral" words. Expected activations were found mainly in the left hemispheric MFG extending to SFG and STG extending to Heschl's gyrus, bilateral insula, and SMA extending to the right ACC. Non-expected activation was found in the bilateral calcarine gyrus. Within the differential contrasts, both age cohorts showed similar activations for the contrast "positive > neutral" words in the precuneus. For the contrast "negative > neutral" words, no overlapping activation was found.

Results of the Follow-Up Analysis

For the present dissertation, I ran additional analyses to complement the picture of affective semantic processing in children and adults regarding explicit and implicit processing streams. To do so, I made a direct task comparison to answer the research question regarding processing differences and commonalities between children and adults. Therefore, I calculated for each valence category the conjunction analyses for both tasks of both age cohorts. And finally, I calculated a conjunction analysis of all three valence categories of both tasks and ages.

The comparison of children and adults' activations for both tasks (VDT, LDT) showed for positive words similar activation in anterior insula extending to frontal operculum, SMA and bilateral middle cingulate. For negative words, activation only in the anterior insula, extending to the frontal operculum, became visible. Neutral words are associated with three clusters: anterior insula extending to the frontal operculum, right STG, and right middle cingulate extending to right SMA. Finally, the summarizing contrast over all three valence categories for both tasks and age cohorts revealed a significant cluster in the anterior insula, extending to the frontal operculum (see Supplementary Material).

III
DISCUSSION

8 Discussion of the Research Questions

1) Are the behavioral affective semantic response patterns similar in children and adults?

There is a vast body of research focused on valence as part of affective semantic representations in adults (see Jacobs et al., 2015; Kauschke et al., 2019, for a review). Several reliable findings have been reported, including higher a U-shaped function relating valence and arousal ratings and an inverse U-shaped function relating valence ratings and reaction times. These patterns encompass shorter reaction times for valenced words than neutral words and a processing advantage for positive words, leading to shorter reaction times than negative or neutral words. Two arguments can be used to explain these valence effects. Firstly, the increased significance of valenced words (Zeelenberg et al., 2006) might lead to early bottom-up affective evaluation (Kuchinke, 2007), and secondly, a higher semantic cohesion of valenced words, especially of positive words, may lead to shorter reaction times (Alves et al., 2017; Hofmann et al., 2011; Hofmann & Jacobs, 2014). However, it is unclear whether these effects evolve over the life span or can already be found in children. The increased significance of valenced stimuli in terms of relevance for human behavior (Panksepp, 1998) lends support to the hypothesis of a processing advantage in children. In contrast, their smaller, still growing mental lexicon with fewer semantic associations could account for processing differences during development. The results of Study I were used to approach the open questions regarding the similarities and differences between the behavioral phenomena in children and adults. To conduct the experiment, the word database kidBAWL was developed. The results showed similar ratings of the behavior of children and adults. These results are discussed in more detail below.

1a) The U-shaped function relating valence and arousal ratings

The first phenomenon regards the valence and arousal relationship: In children, an asymmetric U-shaped function was assumed, relating valence and arousal. Children's ratings reflect this function, in that higher arousal values are correlated with higher valence values. Additionally, the negativity bias became apparent, meaning the more negative a word, the higher the arousal value. These results illustrate that children tend to rate the extremes of negative words higher in arousal than positive words. Such a finding is consistent with an interactive perspective on valence (Jacobs et al., 2015): This model assumes that negative stimuli are congruent with high arousal, whereas positive stimuli are congruent with low arousal (Aryani & Jacobs, 2018; Citron et al., 2016; Lüdtke & Jacobs, 2015; Wang et al., 2018). The perception of congruency makes stimulus processing easier than conflicting (incongruent) information. Thus, the ratings could reflect that children and adults tend to rate congruently. With the results of the present dissertation, the interactive valence model also holds for children.

1b) The inverse U-shaped function relating valence ratings and reaction times

The second phenomenon concerns valence values and their corresponding reaction times. It was hypothesized that children should exhibit an inverse U-shaped relation between reaction times and valence ratings, meaning that they perform similarly to adults in VDTs. According to our results, positive words were rated the fastest, followed by negative words and then neutral words, which were rated the slowest in line with the findings regarding the positivity superiority effect (Lüdtke & Jacobs, 2015). In an attempt to explain the development of a processing advantage for positive words, Ponari et al. (2020) found that children learn positive words before words of any other valence category. Ponari et al. (2018) further assumed that this is the result of the higher frequency of positive words used when talking to children, and thus these words are learned earlier. Additionally, they provided data that in children's expressive language, more positive than negative words are used (Ponari et al., 2018). Interestingly, Kauschke et al. (2019) found the positivity superiority effect for words and faces. Thus, it seems that this effect may be multimodal, perhaps due to children's earlier and more frequent contact with positive words and faces. These findings reinforce Boucher and Osgood's (1969) 'Pollyanna hypothesis', which has been recently confirmed by text corpora analyses (Jacobs et al., 2020). It is possible that this positivity bias leads to earlier automation during decision tasks, such as skipping processing steps, resulting in the positivity superiority effect (Lüdtke & Jacobs, 2015). The earlier automation is consistent with previous results in children and adults (Kauschke et al., 2019; Vesker et al., 2020).

In sum, six-year-old children have already collected the affective semantic information from their social context and therefore have evaluated the presented words as adultlike. Furthermore, the results strikingly show that children older than six years show the same decision-making behavior as adults.

However, raw reaction times are longer in children than in adults, which aligns with previous findings (e.g., Bahn et al., 2017). It may be a result of slower action planning, motor response, slower accessing, or different steps of the complex processing pipeline of affective semantic representations, or a combination of these factors. One approach to investigating the influence of these different cognitive processes would be hierarchical diffusion drift models to examine the impact of the different components of decision behavior (e.g., Vandekerckhove et al., 2011). However, more data points are needed to apply a hierarchical diffusion drift model to obtain reliable results than have been gathered in Study I. Nevertheless, the emergence of similar reaction time patterns in children and adults suggests that children already use affective information as a component of semantic representation, which facilitates processing of valenced words compared to neutral words (e.g., Jacobs et al., 2015; Kauschke et al., 2019). Furthermore, this finding supports phylogenetic approaches by showing that valence in children already leads to specific (faster) reactions.

1c) Similar valence ratings of children and adults

Differences between the children's and adults' rating behaviors become visible when looking separately at each valence category. Their ratings reveal that children tend to make more extreme ratings of negative words than adults. On the other hand, they tend to rate positive words less positively than adults. Nonetheless, everything but the ratings for positive words were significantly correlated between both age cohorts. These slight differences in rating behavior between children and adults could be due to less experience in children with these words in general. Furthermore, children may be exposed more often to positive words (e.g., Ponari et al., 2018; Ponari et al., 2020) and thus perceive them as 'ordinary'. Contrary to this, negative words are less prevalent in their social environment, so children, respond more sensitively to them, rating negative words as more extreme than adults. However, since this is only a hypothetical interpretation, future research should investigate this behavior in younger children and evaluate its developmental effects. Together, the children and adults, despite the differences in rating behavior, both rated words according to their valence in the same direction. Thus, this indicates that children already possess the essential semantic knowledge about the valence of these words.

In summary, the kidBAWL, constructed specifically for this dissertation since no other word database existed for children, proved to be a suitable tool to investigate the children’s behavior regarding affective semantic processing and to compare their processing to adults. The results indicate that children from six to twelve years of age show similar behavioral phenomena to those consistently reported in adults (e.g., Jacobs et al., 2015; Kauschke et al., 2019). More specifically, both age cohorts show the U-shaped function relating valence and arousal ratings of words and the inverse U-shaped function relating valence and reaction times. Furthermore, the valence and arousal ratings show similar directions, although children tend to rate valence as more extreme for negative words and less positive for positive words. These findings indicate that six-year-old children already have similar representations of affective semantics as adults. Thus, affective semantic representations were gained in the years before. The results show the tremendous impact of social learning and the fact that word learning is also influenced by the social environment, which affects the affective semantics of words. However, more research is needed, for example, on how these findings develop earlier in life. Understanding the developmental trajectory would also allow us to track how and when affective semantics are learned, for example, its influence before children speak their own first words.

2) Do children and adults have similar brain responses when explicitly processing valence?

For specifying the neural network associated with affective semantic processing in children, the hypothesized neural network was derived from previous findings in adults (e.g., Binder et al., 2016; Citron, 2012; Lindquist et al., 2016; Man et al., 2017). This approach seemed sufficient since the behavioral results of Study I suggest similar processing already in six-year-old children. Therefore, it was hypothesized that if children process the valence of a word similar to adults, the same neural pattern should be found in both age cohorts, encompassing activation in the OFC, IFG, ACC, PCC, anterior insula, amygdala, and striatum linked to valence processing. Furthermore, activation in the SFG, MFG, precentral, SMA, MTG, and STG predominantly associated with lexico-semantic processing was also assumed. However, as mentioned in the introduction, the differentiation between lexico-semantic and valence processing is only made to mark the most prominent response pattern of those regions within the affective semantic system rather than an exclusive functioning.

Therefore, the hypothesis was tested in three different analyses. Firstly, the activation commonalities of all three valence categories were tested for each age cohort separately to get an overview of valence processing similarities within each age cohort. Secondly, valence effects for positive and negative words were examined within each age cohort to define the neural networks for each valence extreme. For that, valenced words were contrasted against neutral words. These two analyses allowed a characterization of the general activation pattern for valence processing for each age cohort. In the third and final step, the activation patterns of children and adults for positive and negative words were directly compared to reveal the developmental effects of valence processing.

Analyses of similar activation for positive, negative, and neutral words

Both age cohorts showed a similar pattern of similar activation for positive, negative, and neutral words. This neural network encompasses activation in line with the hypothesized affective semantic network in the right MFG, bilateral STG, SMA, MTG, and bilateral thalamus (e.g., Binder et al., 2016; Fernandino et al., 2021; Panksepp, 1998). Beyond the hypothesized semantic network, both cohorts showed activation in the bilateral calcarine, right lingual, and right middle cingulate gyrus. Furthermore, children showed further activation in line with the hypothesized neural network in bilateral anterior insula, IFG, ACC, and right striatum. Thus, it is suggested that children have more widespread activation within the hypothesized network than adults. These results are in line with Johnson's (2001; 2011) assumptions, who reported more widespread and less specific responses in children. Furthermore, the results are in line with a bunch of previous developmental studies showing similar behavioral outcome between different ages (e.g., children and adolescents) while the underlying neural pattern shows differences (see Johnson et al., 2002 for an overview).

Therefore, explicit valence processing regarding all three valence categories seems to be similar in children and adults, although children show more widespread activation in valence related regions than adults within the hypothesized neural network. The results provide concrete evidence that (A) the children’s affective semantic network comprises the same brain regions as the adults’ and (B) not only the lexico-semantic network is already largely aligned by the age of six years (e.g., Weiss-Croft & Baldeweg, 2015), but also the affective semantic network.

The children's activation pattern for explicit valence processing

Children show activation in diverse subcortical areas when looking at the differential contrast of "positive > neutral" words. More specifically, enhanced activation found in the thalamus, anterior insula, hippocampus, right putamen, ACC, and right PCC, was linked to positive words. Only activation in the SFG, precentral, and right IFG was found at the cortical level. All of these cortical and subcortical regions are part of the affective semantic network, except for the hippocampal region. Braun et al. (2019) assume that the hippocampus (and putamen) act as fundamental hubs for choosing the correct semantic candidate. Taken together with the results of the present study for affective semantic contributions of the hippocampus in children, future research needs to clarify whether the hippocampus acts as an integral part of the affective semantic network or not.

Similar to positive word processing, the differential contrast for "negative > neutral" words mainly revealed activation in subcortical regions comprising of the ACC, extending to the caudate and right putamen, and the amygdala. This supports the classical finding of amygdala activation associated with negative affective processing (Vytal & Hamann, 2010; Inman et al., 2020). Furthermore, cortical activation was found in the OFC, IFG, lingual gyrus, bilateral middle occipital gyrus, as well as the calcarine and right AG as part of the parietal cortex. While the OFC and IFG are part of the affective semantic network, the parietal and occipital activation point to enhanced phonological demands (Price, 2012). Altogether, the children's results indicate that the processing of positive words seems to be more aligned with adults' affective semantic network than for negative words. A possible explanation for this pattern is that the mental lexicon for positive words grows faster and/or earlier than for negative words (Ponari et al., 2018; Ponari et al., 2020). As a result, the mental lexicon for positive words is already more similar to an adult's mental lexicon than for negative words. Furthermore, the data is in line with Panksepp's theory of emotion, where all three process levels are involved in processing affective semantics.

The adults' activation pattern for explicit valence processing

A widespread activation pattern emerges when looking at the adults' results. More precisely, the contrast "positive > neutral" words revealed activation associated with the affective semantic network in the anterior insula, ACC, SMA, MTG, precentral, and striatum. Thus, similar to the children's results for positive words, all three process levels, according to Panksepp (1998), are represented. Furthermore, occipital activation (inferior occipital gyrus, lingual gyrus, right calcarine, superior occipital and fusiform gyrus) was found.

In contrast "negative > neutral" words activation in the affective semantic network was discovered in the bilateral SMA, IFG, right precentral, and right AG, extending to PCC. Thus, adults show widespread cortical activation comprising areas usually associated with auditory, lexico-semantic, and decision processes (e.g., Price, 2012). Compared to the positive words, less affective-related regions, according to Panksepp (1998), became visible for negative words. In general, the adults' activation was more widespread for positive than negative words. This could be due to deeper affective processing connected to complex lexico-semantic processing, as Hofmann and Jacobs (2014) have already argued. Their computational analysis showed more associations with positive words than negative ones, leading to different activation patterns for positive and negative words. Thus, activation beyond the affective semantic network could be due to the density differences of associated words that differ between valence categories. However, there is a dearth of comparable data since previous studies examining the neural correlates of affective semantics primarily used ROI analyses focusing on affective-related areas, despite the use of linguistic stimuli in the paradigm (e.g., Lewis et al., 2007). Consequently, there is a possibility that further activation in lexico-semantic regions might have simply been overlooked. Evidence that supports our results comes from studies reporting whole-brain results, which also report areas associated with the affective semantic network and beyond (e.g., Maddock et al., 2003; Demirakca et al., 2009). However, those studies reporting whole-brain results for affective semantic word material reveal a lack of interpretation of language-related results. As such, these results tend to favor the interpretation of distinct lexico-semantic and affective processing. However, the findings of the present study and similar studies such as by Maddock et al. (2003) are in line with previous results for affective semantic representation (e.g., Binder et al., 2016; Binder & Desai, 2011; Fernandino et al., 2021), showing a widespread network comprising valence and lexico-semantic related activation.

Furthermore, when looking at the proportions of semantic network activation and valence-related areas in previous studies, it becomes evident that adults seem to rely mostly on regions that are typically associated with lexico-semantics, with minor contributions from areas classically associated with affect (e.g., Maddock et al., 2003). The latter are located in the three process levels, according to Panksepp (1998). However, the dichotomization of semantics and affect might primarily emerge due to the chosen experimental designs or a biased interpretation of the results. Instead, when comparing present results with the results of previous studies without a linguistic or emotional bias, a different picture of a highly intertwined affective semantic system emerges. This pattern is also visible in the data from Study II. Specifically, the results suggest that affective semantic information is represented as highly integrated in a multimodal and distributional fashion (e.g., Kiefer & Pulvermüller, 2012). This is more evident with positive than negative words, which might be due to an increased number of semantic associates (Alves et al., 2017; Hofmann & Jacobs, 2014).

Altogether, the adults' results are also in line with Panksepp's theory of emotion (1998; 2005a; 2005b), where all three process levels are involved in affective semantic processing, at least for positive words. Adults, on the other hand, show broader activation on the tertiary level, in contrast to children, who show more pronounced activation on the primary process level, especially for negative words. Despite these results, this comparison is merely descriptive in nature since the two cohorts are not directly compared in one single model. A comparison between children and adults was done in the last step of the analysis.

Direct age comparison for positive and negative words

The direct age comparison supports the findings above. Adults recruit more cortical resources, going beyond the hypothesized affective semantic network, whereas children recruit more subcortical structures directly related to valence processing. Additionally, and similarly to the pattern found in adults, both valence categories show different neural responses regarding lexico-semantic processing.

More precisely, adults show increased activation for positive words than children in parts of the hypothesized affective semantic network, namely in the right STG and MTG. Additionally, adults show stronger cortical activation beyond the affective semantic network in the right SPG, lingual, fusiform, middle occipital, postcentral gyrus, and right occipital pole than children. This activation was not expected, since much activation is in neural regions beyond the assumed affective semantic network. When looking at functional imaging studies, occipitotemporal activation has been mainly associated with visual input processing or mental imagery (Kosslyn et al., 2001; Price, 2012). However, a growing body of literature points to the involvement of occipital regions in emotion processing, such as, interoception (Adolfi et al., 2017; Lindquist et al., 2016). Moreover, Camacho, et al. (2019) found in their classification analysis that occipital regions are reliable predictors of valence category (positive, negative, neutral) in both children and adults providing further support for multimodal valence processing.

A similar pattern emerges for negative words. As such, adults seem to rely more heavily on neural resources in the cortex located outside the assumed affective semantic network than children. In line with the affective semantic network, activation in the bilateral MTG, right MFG, and SMA was more profound in adults than in children. Furthermore, the precuneus, postcentral, and SMG were linked to negative valence in adults but not in children. When comparing the results of positive and negative words, more widespread activation was found for positive than negative words, which is in line with the predictions made by Hofmann and Jacobs (2014).

Comparing the results of adults and children, the present data indicates that adults rely more on multimodal information outside the hypothesized affective semantic network, or they require less directly valence-related information to make explicit valence decisions than children, especially for positive words. However, the findings point to more multimodal integration of affective semantic information in adults (Camacho et al., 2019) than in children. Whether this could be interpreted as an outcome of a broader mental lexicon and/or more available affective semantic information, for example, distributional and experiential data regarding these words, should be an object of future research. Furthermore, since this evidence is predominately visible for positive words, the neural correlates of semantic associations and their interrelation to valence processing should be further investigated. It should be investigated whether the widespread neural network beyond the affective semantic network is due to a demand for selecting the best candidate word or due to advanced information integration of experiential and distributional data.

However, the idea regarding more integrated (cortical) information in adults than children holds also, when testing for stronger activation in children compared to adults. For processing positive compared to neutral words, children recruit additional regions connecting different subcortical areas associated with valence processing, such as the pallidum (e.g., Lambert et al., 2012) and right thalamus which might be connecting different sources of affective

information. Furthermore, children tend to rely on the IFG, ACC, and bilateral precentral gyrus compared to adults, which are part of the affective semantic network. Additionally, there was activation found in the, right SPG, AG, and middle cingulate gyrus.
Similarly, when examining their responses to the contrast "negative > neutral" words, children show enhanced activation in the anterior insula and amygdala, compared to adults. These results are in line with the hypothesized affective semantic network and additional activation in the right SPG, AG and middle occipital gyrus.

The main difference between children and adults' results is that children mainly recruited regions in line with Panksepp's theory of emotion (1998; 2005a; 2005b) in the assumed affective semantic network. In contrast, adults recruited widespread additional cortical resources, possibly linked to multimodal semantic hubs integrating different aspects of semantic information (Camacho et al., 2019), or especially for positive words, may due to the increased number of semantic associates (Alves et al., 2017; Hofmann & Jacobs, 2014). This idea is supported by the conjunction analyses of positive and negative words compared to neutral words. In this analysis, adults showed no significant overlap of both valence categories, suggesting they use different processing strategies for the valence categories. In contrast, children showed considerable overlap in parts of the affective semantic network, namely in the ACC and IFG extending to OFC, which is directly associated with valence processing. This suggests that children process both valence categories more similarly than adults. The differences could point to different affective semantic feature distributions in the adults' mental lexicon, such as semantic associates, which differ between valence categories.

By comparing the results of the adults with those of the children, the data from this dissertation strongly suggests that there is a wide overlapping processing of affective semantics. The greatest overlap of both age cohorts was found for similar activation of positive, negative, and neutral words, where activation of both age cohorts matched in respect to activated regions. However, in a more detailed analysis, which was aimed at disentangling the two poles of valence from the differential contrasts by subtracting neutral words from positive and negative words, respectively, a slightly different picture emerged. The major difference here is that adults recruit predominately cortical regions, whereas children rely more on subcortical regions. The data suggests that adults might integrate more widespread (multimodal) cortical affective semantic information than children. In line with Panksepp (1998), children recruit more parts of the primary process level, indicating less integrated affective information into the language-related cortical multimodal hubs, despite the fact that emotion- and language-related areas are already strongly connected by the age of three to 54 months (Gabard-Durnam et al., 2018; Gilmore et al., 2012). This suggests that the neural connections for affective semantics need further input, such as experiential and distributional information, in order to connect affective semantic information hubs specifically. However, the present data points to extended valence processing in children, where children recruit a whole bunch of regions associated with valence processing compared to adults, which is in line with Johnson's developmental theory regarding more unspecific activation during development (Johnson 2001; 2011) while the behavior is similar (e.g., Johnson et al., 2002). Thus, children depend highly their affective decisions on a wide range of regions associated with valence processing. At the same time, in adults, functional specialization is more fine-tuned regarding valence processing, and thus, they recruit fewer areas directly associated with affective processing, at least according to Panksepp (1998). This could be due to increased integration of affective semantic information in adults due to more experience with available distributional and experiential data and/or a greater mental lexicon. If the observed neural activation represents enhanced processing demands, e.g., choosing the right candidate word or facilitation processes, e.g., cortical affective semantic information leads to less required valence, specific information should be examined in future research.

3) Do children and adults show similar brain activation for implicit contributions of valence to lexical decisions?

It was hypothesized that if children implicitly process valence similarly to adults, the same neural pattern should be found in both age cohorts encompassing activation in the OFC, IFG, SFG, MFG, precentral, SMA, MTG, STG, insula, ACC, PCC, amygdala, and striatum (e.g., Binder et al., 2009; Citron, 2012; Lindquist et al., 2016; Man et al., 2017; Rolls, 2019). This hypothesis was tested in two steps of analysis. The first step was to examine the general valence contributions to word recognition. Here, similar activation profiles for all three valence categories were analyzed by the contrast "words > pseudowords" to get a general overview of valence contributions to word recognition over all three valence categories. The second step focused on the activation of the contrasts of "positive > neutral" and "negative > neutral" words that were used to define the neural network specifically for both valence extremes.

Valence contributions to word recognition

Regarding the implicit valence processing during word recognition, both cohorts showed similar activation for the contrast "words (positive, negative, neutral) > pseudowords" in line with the hypothesized affective semantic neural network in the anterior insula, extending to the IFG. The analysis suggests that there are common valence contributions to word recognition in both age cohorts since the regions that have been previously reported as important for valence processing (Kuhlmann et al., 2016; Lindquist et al., 2016). Furthermore, both age cohorts show similar activations in MFG extending to SFG, bilateral STG, bilateral SMA extending to ACC, and bilateral calcarine. That means that children aged six years already implicitly recruit valence information in a similar manner to adults in order to perform lexical decisions. These results thereby provide evidence that affective semantics plays a role in facilitating lexical decisions at an early age, while the mental lexicon is still growing.

The conjunction analyses over all three valence categories for each age cohort revealed that children additionally recruit subcortically right thalamus extending to caudate and angular gyrus. Adults recruit additionally precentral and right STG. However, since these are only slight differences compared to the widely overlapping activation pattern, the results suggest that the processing streams in both age cohorts seem to function similarly. The additional activations suggest widespread recruitments of regions providing additional (affective) semantic information for the decision process. Besides the activation in the calcarine, which is associated with mental imagery and visual decoding (Lambert et al., 2002) are all found regions part of the assumed affective semantics neural network. This suggests that children and adults process valence during word recognition implicitly and appear to do so in a pretty similar way, although children recruit a few additional neural resources for performing the task. Thus, the results impressively show that word recognition seems to be aligned by the age of six and already involves implicit contributions of valence processing. Together with the results for explicit valence processing, the data point to similar processing trajectories of valence categories (positive, negative, and neutral) when explicitly and implicitly processed by six-year-old children and adults.

The children's differential activation pattern for implicit valence processing

In line with the assumed neural network of affective semantics processing, the children showed activation in the bilateral IFG, extending to the right anterior insula, and MFG, and right ACC for positive compared to neutral words. The activation pattern found in the bilateral IFG and ACC has remarkable overlap with previous findings for explicit valence processing of positive words. Additionally, children showed increased activation in the bilateral SPG, AG, right planum temporale, postcentral, SMG, and lingual gyrus. These regions are often associated with auditory lexico-semantic processing (e.g., Binder et al., 2009; Correira et al., 2014; Price, 2012) and collecting task-relevant semantic information while suppressing irrelevant information (e.g., parietal regions, Noonan et al., 2013). Thus, children seem to require an orchestra of neural regions to perform auditory lexical decisions for positive words associated with lexico-semantic processing while recruiting only a few regions associated directly with affective processing. These findings suggest that children respond particularly to the task demands accompanied by implicitly recruited affective information.

The neural pattern for processing negative words within lexical decisions deviates from the pattern found for positive words. First, no regions directly associated with valence processing were found. Second, only activation in the MFG and MTG were found for the hypothesized affective semantic network. Third, widespread activation of regions associated with lexico-semantic processing showed an enhanced response, located beyond the affective semantic network and mainly represented bilaterally. This activation encompasses the precuneus and bilateral SMG, SPG, postcentral, cuneus, and lingual gyrus (e.g., Enge et al., 2021; Kronbichler et al., 2004; Price, 2012; Weiss et al., 2018; Weiss-Croft & Baldeweg, 2015). Thus, activation for negative compared to neutral words is associated with a widespread lexico-semantic network, which is not left-lateralized and without directly recruiting regions associated with valence processing above processing neutral words.

Three interesting findings need to be highlighted when interpreting both valence contrasts. Firstly, both reported contrasts (for positive and negative words) show the activation for valenced words compared to neutral words. When comparing the results of the conjunction analyses and the differential contrasts, it becomes visible that affective information disappears, for example activation of the insula (Lindquist et al., 2016). Thus, neutral words seem to carry also affective semantic information, which is subtracted when looking at the differential contrasts. Secondly, if lexico-semantic processing would be similar independent of valence, no activation difference should occur. However, since both contrasts show enhanced activation compared to neutral words, the results strongly suggest differences in processing lexico-semantic information depending on a words valence. This result was already reported in previous studies without further interpretation (e.g., Demirakca et al., 2009; Gawda et al., 2017;

Kensinger & Schacter, 2006). The finding provides further support that affective and lexico-semantic information is highly intertwined. However, how lexico-semantic information processing is shaped by affective information needs further investigation. Thirdly, regions associated with positive words during valence processing were enhanced compared to neutral words, but not for negative words. These results suggest that there are different processing streams for the two valence categories, whereby the affective semantic information plays a more crucial role for processing positive words (Shevrin et al., 2012). One explanation could be that there is an increased number of semantic associations for positive words as compared to negative words, which has been previously reported for adults (Hofmann & Jacobs, 2014). This was also already assumed for the processing differences encountered to approach question 2 about explicit valence processing. Regarding negative words this would mean that processing the affective semantic information would increase the effort without offering an advantage for making lexical decisions (e.g., Woodburn et al., 2021). Since in both tasks, explicit and implicit, the activation of positive words is more aligned with the findings previously reported in adults than for negative words. This finding is in line with Ponari et al. (2018), who reported differences between positive and negative valenced word processing. They interpreted this finding as due to positive words being learned earlier and/or a larger vocabulary of positive words than negative words (Ponari et al., 2018; 2020). How both these factors influence affective semantic processing needs further examination since at least two possible explanations are provided: (A) an earlier learned word contains more experiential and distributional information than later learned words and/or (B) a larger lexicon for positive words lead to more affective semantic associates than negative words. However, these interpretations require further investigation, since the impact of, for example, the number of word associates or the size of available experiential and distributional data on decision processes in children have not yet been investigated.

The adults' activation pattern for implicit valence processing

Regarding the valence contributions to lexical decisions in adults, both differential contrasts of positive and negative words are associated with activation predominately within the affective semantic network, although in different parts. For positive words, activation was found in precentral areas, the PCC and ACC, and the right SFG. Additional activation was found in the AG, precuneus, and bilateral ventral diencephalon. The hypothesized activation was found in the medial OFC for negative words, the caudate and putamen, right ACC, and SFG. Additional activation was found in the hippocampus, and the fusiform gyrus. These results point to an enhanced contribution of valence processing in adults, which facilitates (auditory) word recognition, supporting previous findings (e.g., Kuchinke et al., 2005; Nakic et al., 2006). Furthermore, the findings are in line with Panksepp's hypothesis (1998) since all three process levels were found (e.g., striatum, ventral diencephalon, ACC, and OFC). However, the present data show fewer contributions of the regions associated with lexico-semantic processing than previous studies (e.g., Kuchinke et al., 2005). This could be due to differences in the stimuli between the current project and previous studies. For example, in their study, Kuchinke et al. (2005) chose the stimuli according to adults' word frequencies, whereas the present study did choose words according to children's word frequencies. Conversely, the adults' results are in line with previous findings of valence contributions to lexical decisions (e.g., Kuchinke et al., 2005; Nakic et al., 2006), thus presenting striking evidence showing that implicit valence processing appears to facilitate the decision process (e.g., Shevrin et al, 2012).

To summarize the results of Study III, both age cohorts show implicit valence contributions to word recognition providing evidence for the facilitating effect of valence during word recognition (e.g., Briesemeister et al., 2015; Citron, 2012; Kuchinke et al., 2005; 2007; Schlochtermeier et al., 2013; Shevrin et al., 2012) already in an age of six. However, when looking specifically at the valence categories separately and subtracting activation associated with neutral words, valence contributions to word recognition strongly differ between children and adults due to extended recruitment of regions associated with lexico-semantic processing in children and enhanced recruitment of areas related to affective (semantic) processing in adults. As a result, children rely on their lexical decisions primarily through lexico-semantic information, whereas adults recruit more affective information to solve the LDT regarding positive and negative compared to neutral words. The results suggest that affective information within the LDT increases its significance in parallel with a growing mental lexicon, in which the affective information may facilitate choosing the right candidate word. Conversely, for children aged six to nine who have a smaller mental lexicon, the affective information recruited for the negative and neutral valence categories is sufficient to solve the LDT. Altogether, the present research question that asks whether children recruit affective semantic information similarly to adults needs to be answered with a "Yes, but…" since the children's processing of positive words already tends to show similarities with the adults' data. Nevertheless, since the valence contrasts in both age cohorts, though stronger in children, illustrate differences in lexico-semantic processing between the valence categories, the role of affective information in regions predominantly associated with lexico-semantic processing should be further investigated.

4) Is valence explicitly and implicitly processed in a similar manner?

Previous research in adults examined explicit and implicit valence processing separately, thus, no direct comparison of both processing trajectories was possible before. In spite of this, the present data provide an opportunity to directly test whether both processing streams are similar since the data of Study II and Study III were collected using the same stimulus material and the same participants. To test whether valence is implicitly and explicitly similarly processed, it was hypothesized that no activation differences should be found between VDT and LDT. Furthermore, it was proposed that if affective semantic representations are similarly in children and adults, then no activation differences should be found between the age groups. The hypotheses were tested in two steps, the first comprised of an analysis of similar activation of both tasks. In the second step, the differences between both tasks were examined. Both analyses were calculated for both age cohorts together.

The most interesting finding is that both age cohorts showed overlapping activation in the anterior insula extending to the frontal operculum for both explicit and implicit valence processing over all valence categories. Thus, through these findings it is suggested that the anterior insula seems to be the central hub for valence processing in children and adults, irrespective of whether valence is processed explicitly or implicitly. This finding is in line with Lindquist et al. (2016), who found that the anterior insula has activation for overlapping valence category in their multilevel peak kernel density analysis (Wager et al., 2007). Moreover, activation in the anterior insula has been reported for the processing of emotional words, deep emotional processing, and as a hub for social understanding (Brooks et al., 2017; Smith et al., 2017). Structurally, the insula has bidirectional connections with the OFC, ACC, SMA, thalamus, and amygdala, which allows for connection of all three emotion processing levels as described by Panksepp (1998). Moreover, it has been shown that lesions found in the anterior insula are associated with impairments of both emotion and language processing (e.g., Gasquoine, 2014). Thus, the anterior insula can be viewed as a central hub for affective semantic processing. The preliminary results of my dissertation indicate that this is true for different processing streams (implicit, explicit) and different age cohorts.

Apart from the anterior insula activation for all valence categories for both age cohorts in both tasks, for positive words, overlapping activation in SMA and the bilateral middle cingulate is shown. For neutral words, activation in right the STG, and right middle cingulate extending to the right SMA were found. The middle cingulate activation is associated with integrating information coming from the ACC and PCC and projecting these to the SMA (Rolls & Wirth, 2018). Panksepp (1998) described the ACC and PCC as parts of the secondary process level associated with emotional learning. More precisely, the ACC sends detailed information regarding the goal-directed action (e.g., positive or negative evaluation of a word). Parallelly, the PCC sends spatial and action-related information to achieve a specific goal. The appearance of the middle cingulate activation for positive and neutral words could be due to the denser semantic networks of positive words and the (emotional) response conflict for neutral words. Both enhance processing demands, which leads to activation in the middle cingulate gyrus. Thus, both age cohorts have enhanced processing of positive and neutral words regarding explicit and implicit valence processing. For positive words, this can be interpreted with respect to the increased density of semantic associates (Hofmann & Jacobs, 2014). However, future research should directly focus on the processing of neutral words to better define and specify its processing. The task comparison and the analyses regarding explicit and implicit valence processing (activation commonalities over all three valence categories) provide strong evidence for valence processing for neutral words, which is in line with previous approaches (e.g., Lebrecht et al., 2012; Mattek et al., 2017).

The age-related task comparisons revealed no significant activation for the contrast "VDT > LDT" in adults. Conversely, activation for the contrast "LDT > VDT" in adults showed significant activity in the IFG, suggesting increased processing of semantic retrieval selection and integration of different affective semantic inputs (Kuhlmann, Hofmann, & Jacobs, 2017; Price, 2012). In children, a similar activation occurred. While for the contrast "VDT > LDT", no enhanced activation was found, the contrast "LDT > VDT" revealed bilateral precentral activation associated with lexico-semantic and phonological processing (Weiss-Croft & Baldeweg, 2015). Thus, the task comparison shows that for the affective component, over all three valence categories, adults tend to recruit additional affective semantic resources for implicit valence processing, while children are too preoccupied with solving the task. On the other hand, no further region is recruited during explicit processing which is similar in children and adults.

In sum, affective semantic features are similarly represented on the neural level in adults and children from the age of six. The associated region comprises of the anterior insula as a central hub for valence processing for both implicit and explicit processing streams. Adults show further activation in the IFG, suggesting they have enhanced implicit processing due to selecting the right candidate, whereas children show enhanced processing in precentral due to basic stimulus processing. This difference can be interpreted in the light of the smaller mental lexicon of the children and fewer experiences with experiential and distributional semantic information than adults. However, a different interpretation of these results would be that between-cohort differences exist simply due to less automated processes and less interconnected information in children, whereby they recruit more information from a 'source', meaning regions that are mainly related to a certain function.

9 Processing Affective Semantics: A Developmental Hypothesis

From the results of our studies, we were able to establish an idea of how affective semantic processing develops based on similarities and differences that exist between children and adults. The results show similar rating and decision behavior, pointing to comparable knowledge of the affective information of a word. In the light of the assumed neural network associated with affective semantic processing, both age cohorts show greatly overlapping activations regarding explicit and implicit processing over all three valence categories. Thus, the neural data suggest only small differences in affective semantic processing of children by the age of six and adults. These results highlight the interpretation of the behavioral results that both age cohorts have a similar understanding of affective semantics. The shared affective semantic understanding may be due to the strong impact of social interactions on word learning, where the affective semantic information is directly transferred from the adults to the children. However, the differential contrasts that show neural activation between positively and negatively valanced words (compared to neutral words) are different between children and adults and also differ between valence categories. Children rely processing explicit valence decisions predominately within the assumed neural network on regions associated previously with affective processing. The adults' valence decisions are more associated with a multimodal affective semantic network within and outside the assumed neural network, which indicates that adults have highly integrated affective semantic information processing. Despite processing differences between the age cohorts, the results reveal more widespread activations in both age cohorts for positive than negative words. These results are interpreted in the light of Hofmann and Jacobs (2014), who found that positive words have more semantic associates than negative words. However, the neural regions involved in the processing of positive and negative words differ between age groups, which point to age related differences. While the brain development of semantic processing is already nearly aligned to a mature adult brain (e.g., Enge et al., 2021; Wang et al., 2021; Weiss-Croft & Baldeweg, 2015), the found differences of processing positive and negative words might be due to differences in vocabulary size and/or fewer experiences with distributional and experiential data regarding these valence categories. In both the VDT and LDT for children, we found activation of IFG for all three valence categories, which was predicted by the AROM to be a consequence of weaker semantic associations (Hofmann & Jacobs, 2014). Here, this finding is interpreted as a result of the children's smaller mental lexicon.

Thus, the activation differences should not be due to maturation differences but rather to less integration of information due to differences in mental lexicons. The mental lexicons between age cohorts differ regarding (A) the vocabulary size and (B) the amount of available experiential and distributional information (see Ponari et al., 2018). The observed neural activations for positive word processing are more similar than for negative words in children and adults. This effect is supported in children by the observation that children learn positive words earlier and their lexicon is broader for positive than for words of other valence categories (Jacobs et al., 2020; Ponari et al., 2018). This points to earlier automatized 'adultlike' processing of positive words. Taken together, the results of the present dissertation led to a new hypothesis where we state that the amount of available experiential and distributional data and/or lexicon size shapes neural processing of affective semantics.

To explain the hypothesis, the term AM (Kintsch, 1980) is introduced. The term is used to illustrate the possible influence of vocabulary size and the available amount of experiential and distributional data for words of each valence category. For example, we assume that negative words contain less AM than positive words due to a lower vocabulary size and less associations of experiential and distributional data. These assumptions are made in respect to Ponari et al.'s (2018) assumption that negative words are learned later and are less present in the social interaction than positive words.

In the present data, the influence of AM differs between explicit and implicit valence processing. During explicit processing words of a low AM, here, negative words, valence information is directly recruited from all three processing levels (Panksepp, 1998). Therefore, processing words with less available information or interconnections means that the affective semantic information needs to be retrieved from the 'source', that is, valence-specific regions, especially at the primary and secondary process levels. However, positive words contain an increased AM since more experiential and distributional data is available. Here, information from the tertiary system seems to dominate affective semantic processing due to the already established integration of affective information in cortical multimodal affective semantic hubs, which has been well established for adults (e.g., Binder and Desai, 2011; Fernandino et al., 2016; 2021). These observations are in line with computational models showing more fuzzy emotional concepts with increasing vocabulary size (Jacobs & Kinder, 2022).

Regarding implicit processing of words containing low AM, the cortical task-specific information is sufficient without further information due to less available experiential and distributional information, similarly to explicit affective semantic processing. Nevertheless, additional valence information from all three processing levels seems to facilitate the decision-making process for words containing high AM. The three processing levels are therefore important for words containing high AM since they provide essential information for selecting the right (affective semantic) candidate.

Altogether, the proposed developmental hypothesis of affective semantics is built on the assumption that the AM, comprising vocabulary size and available experiential and distributional data, modulates affective semantic processing. The influence of experiential and distributional data and the vocabulary size (e.g., number of semantic associates) has previously been reported for adults (e.g., Fernandino et al., 2021; Hofmann & Jacobs, 2014). These findings are now supplemented by evidence from children, leading to the developmental hypothesis of affective semantics. However, further investigation is required to determine if differences in processing are due to less automated processes in children. The growth of the mental lexicon could be accompanied by repeated access and retrieval of concepts, leading to automatized processing. When the AM increases, the primary process level is less prominently activated, perhaps due to the increased automatized affective semantic processing facilitated by distributional and experiential information within the secondary and tertiary levels. However, whether an increase in experiential and distributional knowledge leads to automatic or general mechanisms (Hofmann et al., 2018) or a combination of both needs to be further investigated.

The results on the neural level call for replication due the lack of comparable studies. With regards to affect, different tasks should be examined. For example, priming, naming or similarity judgment tasks, could be used to investigate the robustness of the present results for explicit and implicit affective semantic processing (e.g., Agustí et al., 2017; Lüdtke & Jacobs, 2015; McNorgan et al., 2015; Rotaru et al., 2018). The main challenge for testing the developmental hypothesis is the definition of the AM, that is, to define which word features play a role in processing affective semantics (e.g., Barriga-Paulino et al., 2022; Hofmann et al., 2021; 2022). The proposed developmental hypothesis provides a basis for generating knowledge regarding the understanding of how valence is linguistically formed and the impact of valence as a semantic superfeature (Jacobs et al., 2016).

10 Limitations

I would like to start with methodological limitations that have not been solved but should be kept in mind when looking at fMRI results. There are several limitations regarding the spatial resolution of this neuroimaging method. During data collection, 3x3x3mm voxel-grids were predominately used, which disregards brain structural underpinnings. Thus, the separation of heterogeneous neural structures cannot be guaranteed. Furthermore, the method used for analysis was largely based on adults' data, that is, through mapping with the MNI space, which is suboptimal for children, especially young children. This is because the brain is stretched to MNI space, possibly leading to false-positive results.

From an experimental point of view, future studies should consider using a higher number of stimulus material (for an English version e.g., Tucker et al., 2019), especially with a focus on processing differences between valence categories. Additionally, future studies should resolve current issues regarding further word variables by either using a larger stimulus set while manipulating lexical and affective semantic variables, for example, word frequency, number of semantic associates, and arousal, or by finding a solution that ensures comparability between age cohorts. In general, finding appropriate stimulus material could be achieved in two ways: either through the use of different words in both age cohorts, which would then contain similar lexical and affective semantic values, or by using similar stimulus material, which could elicit different patterns, as demonstrated in Studies II and III where stimulus material was chosen to be suitable for children but not adults. There are arguments for both options, and further discussion and research should evaluate both.

Another limitation of Studies II and III is the use of neutral words as a baseline condition. This approach has been common in previous research (e.g., Maddock et al., 2003; Kuchinke et al., 2005), and for comparability of the results across tasks, this approach was used for Study II and Study III. However, the study results suggest instead to handle neutral words as valenced words until the question of how neutral words influence affective semantic processing trajectories is addressed (Kuhlmann et al., 2017). Until then, either a resting state or a control condition should be implemented in the experimental design. Moreover, different valence models should be subject to further testing before making any definitive conclusions, especially the interactive valence model, since interactions between valence and further affective semantic features are highly possible. Finally, since all of the findings were made through decision tasks, the findings need to be validated by different paradigms in order to check for neural activation in response to the decision-making process.

However, from a neuroscientific model perspective, the neurocognitive findings for affective semantics are still heterogeneous, mainly because of different task demands. For example, valence and naming decisions require distinct cognitive processes, due to for example, cognitive control, and thus, different aspects of affective semantics may be retrieved (Jackson, 2021; Jackson et al., 2016; 2021). Thus, future research will show whether the model of affective semantics is robust against task demands, generalizes over tasks, and can therefore predict the neural and behavioral outcome.

11 Conclusion and Future Directions

The overall question of the present thesis is how children between the ages of six and twelve process the valence of words compared to adults. The comparison between these two groups was deemed sufficient since the neural architecture of the lexico-semantic network is relatively stable starting at the age of six (Weiss-Croft & Baldeweg, 2015). From the age of six there are only small neural activation differences compared to adults, that is for example, a shift from the SMA and STG to IFG (Enge et al., 2021) which is possibly due to the growth of the mental lexicon. However, the current studies were not specifically designed to investigate the neural correlates of the mental lexicon nor the strength of word associates. As discussed, this research provides the hallmarks of affective semantic processing by showing that affect is a critical part of semantic processing in children.

In terms of behavior, children demonstrate the same positivity superiority effect as adults. This result point to three possibilities. The first is that either positive words have more semantic associates, as is found within the AROM simulations in adults (Hofmann & Jacobs, 2014). The second possibility is that positive words are processed more automatized because positive words are learned earlier (Jacobs et al., 2020; Ponari et al., 2018). Another explanation is that both possibilities are highly intertwined and mutually dependent. Independent of these possibilities, the facilitating effect of valence in performing affective semantic tasks is suggested to be established by the age of six.
Furthermore, a similar U-shaped function relating valence and arousal ratings and an inverse U-shaped function relating valence ratings and reaction times were found suggesting similar rating behavior in children and adults. Evidence regarding the relationship of valence and arousal suggests that faster response times occur for congruent pairs (e.g., Aryani & Jacobs, 2018; Citron et al.; 2014a; 2016; Larsen et al., 2008). If congruency drives children's and adults' rating behavior, then calculating congruency values could provide an interesting insight into affective semantic influences on whole sentence processing. The next step is to move beyond single word processing research to whole sentence or text-based research.

The most striking finding of the work is that children exhibit similar affective semantic processing to adults also on neural level. As such, similar neural activation patterns in children and adults indicate similar affective semantic processing when the (lexico) semantic network is already mostly built. In summary, the assumed affective semantic neural network, was supported not only for the adults' cohort but also for the children. Together, these findings provide substantial evidence for a) the suitability of computational approaches of semantic processing, such as the AROM, in children (Hofmann & Jacobs, 2014; Hofmann et al., 2011) and for b) the utility of a developmental perspective for behavioral and neural aspects of affective semantic word processing in children.

The data provides considerable evidence that the predictions of the AROM (Hofmann & Jacobs, 2014; Hofmann et al., 2011) also hold for children. Additionally, the AROM predicts IFG activation when there are weak association strengths between two words. These weak associations were also found in children. As such, children show activation within the VDT and LDT for all three valence categories in the IFG, which can be interpreted as a result of their smaller mental lexicon. With a smaller mental lexicon, there are potentially fewer competitors than found in the adults' mental lexicon who showed IFG activation only for negative words in the VDT (Hofmann & Jacobs, 2014). However, future research should test whether adult mental lexicons for positive words are still larger than for negative words, as previously assumed for children (Ponari et al., 2018).

The data also provides extensive evidence in order to propose a developmental hypothesis of affective semantics. The data shows that at a young age, affective semantic processing is more strongly focused on task-specific regions than it is in adults, who rely more strongly on integrating multimodal information from different sources. Based on the behavioral and neural findings of the studies in this dissertation, the basic assumption arises that development is probably related to the interconnectedness of words in the (individual) affective semantic network due to experiential and distributional data integration. Thus, future research should focus on the impact of the size of the mental lexicon and whether and how further affective (e.g., arousal, imageability, aesthetic potential, Jacobs, 2017; Jacobs & Kinder, 2020; abstractness, e.g., Meersmans et al., 2020) and lexical (e.g., word frequency, neighborhood frequency; Hofmann et al., 2007) features influence affective semantic processing and its underlying automated processing. In this context, the understanding of the neural correlates behind vocabulary growth and the increase of experiential and distributional data could provide useful insights into how specifically affective semantics develop over the life span.

A future body of research should continue to follow the presented research in relation to the developmental trajectory of affective semantic processing. Specifically, the proposed developmental hypothesis of affective semantics should be tested in children younger than six years. In future research, behavioral outcome could be predicted by machine learning tools (e.g., Hesp et al., 2021) to test the model assumptions. The individual corpus characteristics (Hofmann et al., 2020) should be considered as a basic stimulus set. There is potential for future language research to specify how different (lexical) affective semantic features influence the development of neural correlates of affective semantic processing. Additionally, the data can help shape our understanding of how individual word frequencies and semantic associates influence neural activations.

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Supplementary Material

Follow-Up Analysis: Task Comparison of Both Age Cohorts.

Table A. Conjunction analyses for children ∩ adults of VDT ∩ LDT (FWE corrected, $p < 0.05$, cluster level). Note. x, y, z = peak coordinates according to MNI stereotactic space, cluster size in voxels, t-values for peaks.

Anatomical location	**MNI**			**Size**	**Peak**
	x	**y**	**z**	**k**	**T**
Positive words					
L Anterior Insula	-36	16	2	225	5.27
L Frontal operculum	-50	16	-6		4.63
L SMA	2	18	40	416	5.01
L Middle cingulate	-10	14	32		4.18
R Middle cingulate	8	16	34		4.08
Negative words					
L Anterior insula	-34	16	2	354	5.71
L Frontal operculum	-48	18	-4		4.55
Neutral words					
L Anterior insula	-34	16	2	285	5.14
Frontal operculum	-50	16	-6		4.45
R STG	60	-16	-2	288	4.79
R Middle cingulate	2	22	36	175	4.16
R SMA	2	14	46		3.88
Positive, negative and neutral words					
L Anterior insula	-36	16	2	174	5.11
L Frontal operculum	-50	16	-6		4.32
LDT>VDT adults					
IFG	-56	18	2	169	5.52
LDT>VDT children					
L Precentral	-6	-26	56	241	4.69
R Precentral	6	-20	58		3.38

Appendix

I. Deutsche Zusammenfassung

Panksepp (1998; 2005a; 2005b) war der erste, der eine Theorie zur evolutionären Entwicklung von Emotionen vorschlug, die auch Sprache berücksichtigt. In seiner Theorie ging er davon aus, dass Emotionen im subkortikalen Bereich des Gehirns entstehen, im limbischen System mit Lernerfahrungen verknüpft und in den kortikalen Bereichen mit höheren kognitiven Funktionen, wie Sprache, interagieren. Daher sollten diese drei Ebenen auch eine Rolle spielen, wenn die affektive Komponente von Wörtern, hier affektive Semantik genannt, betrachtet wird. Die Repräsentation der affektiven Semantik lässt sich untersuchen, indem explizite Valenzentscheidungen getestet werden, also ob ein Wort als positiv oder negativ bewertet wird. Auch kann der Zusammenhang zwischen Sprache und Emotionen implizit getestet werden, zum Beispiel durch lexikalische Entscheidungen bei denen die Valenz systematisch manipuliert wird. Sowohl die explizite als auch die implizite Valenzverarbeitung wurden in den letzten Jahren ausführlich bei Erwachsenen untersucht. Folglich sind die entsprechenden Verhaltens- und neuronalen Korrelate expliziter und impliziter Valenzeinflüsse gut etabliert. Es bleibt jedoch unklar, wie sich diese expliziten und impliziten Einflüsse während der Kindheit sowohl auf Verhaltens- als auch auf neuronaler Ebene entwickeln. Im Rahmen der affektiven Semantik wird in der vorliegenden Dissertation dieses offene Problem behandelt indem Antworten auf die Frage gegeben werden, wie Kinder im Vergleich zu Erwachsenen Wortvalenzen verarbeiten. Drei empirische Studien wurden durchgeführt um sich der zentralen Frage zu nähern, ob Kindern im Alter zwischen sechs und zwölf Jahren die gleichen behavioralen Phänomene und neuronalen Korrelate bei der Valenzverarbeitung aufweisen wie Erwachsene.

Als Grundlage für diese Studien wurde eine Wortdatenbank namens Berlin Affective Word List für Kinder entwickelt. Die Wörter wurden auf Basis der Berlin Affective Word List, einer deutschen Wortdatenbank für Erwachsene, ausgewählt, um eine Vergleichbarkeit zwischen Kinder- und Erwachsenenbewertungen zu gewährleisten. Die Studie I (Sylvester et al., 2016) geht der Frage nach, ob Kinder zwischen sechs und zwölf Jahren Wörter genauso bewerten wie Erwachsene, wenn sie Wörter hinsichtlich ihrer Valenz, Erregung und Vorstellungskraft beurteilen. Die Ergebnisse deuten darauf hin, dass Kinder und Erwachsene die gleichen affektiven semantischen Repräsentationen aufweisen. Dies ist anhand einer gleichen U-förmigen Funktion die Valenz und Erregung verbindet zu sehen. Außerdem wurde eine umgekehrte U-förmige Funktion von Valenzbewertungen und Reaktionszeiten, die den ‚positivity superiority effect' beinhaltet, auch bei Kindern beobachtet. Dieser Effekt zeigt, dass positive Wörter zu den kürzesten Reaktionszeiten führen.

Anschließend wurden in Studie II (Sylvester et al., 2021a) die neuronalen Korrelate von Valenzentscheidungen untersucht. Im Rahmen der Arbeit von Panksepp (1998; 2005a; 2005b) wurde neuronale Aktivierung im sogenannten affektiven semantischen Netzwerk angenommen. Dieses beinhaltet die neuronalen Regionen Amygdala, Striatum, Thalamus, Insula, orbitofrontaler, supplementärer motor und cingulärer Kortex, inferiorer und mittlerer frontaler, superiorer und mittlerer temporaler Gyrus. Um dieses Netzwerk zu messen wurden Kinder zwischen sechs und neun Jahren und Erwachsene zwischen 19 und 30 Jahren eingeladen, Valenzentscheidungen zu treffen. Basierend auf den Ergebnissen der Studie I, die gleiches Bewertungsverhalten von Kindern und Erwachsenen zeigt, wurde entsprechend gleiche neuronale Aktivitätsmuster in beiden Altersgruppen erwartet.

Die Resultate der Kinder und Erwachsenen zeigen sehr ähnliche Ergebnisse wie frühere Studien mit Erwachsenen. Genauer gesagt, wurden umfangreiche Aktivierungen innerhalb des angenommenen neuronalen Netzwerks gefunden über alle drei Valenzkategorien hinweg (positiv, negativ und neutral). Allerdings gab es auch Unterschiede zwischen den neuronalen

Signaturen für die Valenzentscheidungen, zum Beispiel im Striatum, anterioren cingulären Kortex und Amygdala. Darüber hinaus wurden Aktivierungen über das Netzwerk hinausgehend gefunden, zum Beispiel in occipito-temporalen Regionen, insbesondere bei den Erwachsenen. Die unterschiedlichen Ergebnisse legen nahe, dass Unterschiede in der Größe des mentalen Lexikons zwischen Kindern und Erwachsenen und/oder die Erfahrungen, aus denen die Semantik abgeleitet wird, zu unterschiedlicher Aktivierung führen können. Dies führt dazu, dass Kinder hauptsächlich Informationen aus Regionen rekrutieren, die hauptsächlich mit Affektverarbeitung assoziiert sind, während Erwachsene Regionen rekrutieren, die der Integration von Informationen aus verschiedenen affektiv semantischen Ressourcen gewidmet sind, wie zum Beispiel der supplementäre motor Kortex, mittlerer temporaler und präzentraler Gyrus. Demnach scheinen die Erwachsenen für ihre Valenzentscheidungen stärker multimodale affektiv semantische Knotenpunkte zu rekrutieren, während Kinder eher valenzbezogene Informationen direkt von der ‚Quelle' verwenden.

In Studie III (Sylvester et al., 2021b) wurden die impliziten Einflüsse der Valenz anhand lexikalischer Entscheidungen untersucht. Es stellte sich die Frage, ob die für explizite Valenzentscheidungen in Studie II gefundenen Ähnlichkeiten auch für die implizite Valenzverarbeitung gefunden werden können. Dabei wurde das gleiche neurale Muster wie in Studie II angenommen. Wie die Ergebnisse der Studie II zeigten auch hier die Aktivierungen der Kinder und Erwachsenen große Überlappungen bei gemeinsamen Aktivierungen über Valenzkategorien hinweg (positiv, negativ und neutral). Aber auch hier zeigt der Blick auf unterschiedliche Aktivierungen zwischen den Valenzkategorien, dass Kinder und Erwachsene unterschiedliche Verarbeitungsrouten verwenden. Obwohl die Erwachsenen in früheren Studien eine ähnliche neuronale Aktivierung wie die Erwachsenen der vorliegenden Studie zeigten, wie zum Beispiel Aktivierung des orbitofrontalen und anterioren cingulären Kortex (Kuchinke et al., 2005), zeigt sich ein anderes Bild für die Kinder. Die Kinder zeigten hauptsächlich Aktivierung in Regionen, die mit lexiko-semantischer Verarbeitung assoziiert ist, zum Beispiel durch supramarginale und superiore parietale Gyrus Aktivierung. Im Gegensatz dazu wurde weniger Aktivierung in Assoziation mit Valenzverarbeitung gefunden. Die Verarbeitung positiver Wörter jedoch, erscheint bereits sehr ähnlich zwischen Kindern und Erwachsenen, eventuell aufgrund des früher einsetzenden Erlernen von positiven Wörtern (Ponari et al., 2018). Diese Ergebnisse stimmen mit der Interpretation von Studie II darin überein, dass Kinder hauptsächlich aufgabenspezifische Aktivierung zeigen, da vor allem valenz-spezifische Regionen während expliziter Valenzentscheidung rekrutiert werden, während Valenz eine eher untergeordnete Rolle während lexikalischer Entscheidungen spielt. Dies deutet auf weniger verbundene affektive semantische Informationen hin als bei Erwachsenen. Im Gegensatz dazu zeigten die Erwachsenen eine stärkere Aktivierung valenzbezogener Bereiche, was darauf hindeutet, dass Valenz eine wichtige implizite Informationsquelle bei lexikalischen Entscheidungen ist, die den Entscheidungsprozess erleichtert.

Zusammenfassend zählen die drei empirischen Studien der vorliegenden Arbeit zu den ersten die zeigen, dass Kinder und Erwachsene ähnliche affektive semantische Repräsentationen haben. Einige Aspekte der neuronalen affektiven semantischen Verarbeitung sind bei Kindern bis zum zwölften Lebensjahr jedoch noch nicht wie bei Erwachsenen, sondern bestehen eher aus aufgabenspezifischer Aktivierung. Darüber hinaus weisen die Unterschiede in den neuronalen Aktivierungen, insbesondere der Aktivierung des inferioren frontalen Gyrus (Hofmann & Jacobs, 2014), auf Unterschiede zwischen den mentalen Lexika zwischen Kindern und Erwachsenen hin. Die neuronalen Ergebnisse der vorliegenden Dissertation wurden auf Unterschiede zwischen den mentalen Lexika zwischen Kindern und Erwachsene zurückgeführt, die auf der geringeren Erfahrung mit erlebnisbezogene- und Sprachkontextdaten und/oder dem geringeren Wortschatz basieren.

Aufbauend auf den zentralen Ergebnissen dieser Dissertation wird eine entwicklungsbezogene Hypothese für affektive Semantik vorgeschlagen. Die entwicklungsbezogene Hypothese besagt, dass die apperzeptive Masse (Kintsch, 1980), bestehend aus der Größe des Vokabulars und der Menge an erfahrenen und verteilten Daten das Zusammenspiel der neuronalen Verarbeitung affektiver Semantik moderiert. Die vorliegenden Resultate haben das Potenzial, einen Beitrag zu entwicklungsbezogenen Computer- und kognitiven Modellen bezüglich des Einflusses von Vokabeln auf und zum Lernen affektiver Semantik zu leisten.

IV. Eidestattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Arbeit selbstständig und ohne unerlaubte Hilfe verfasst habe. Ich habe mich nicht bereits anderwärts um einen Doktorgrad beworben und besitze keinen Doktorgrad in dem Promotionsfach Psychologie. Die vorliegende Dissertation ist in keinem früheren Promotionsverfahren angenommen oder abgelehnt worden.

Berlin, den 2.5.2022

Teresa Sylvester

V. List of Publications

Peer-reviewed First Author Journal Articles - Published

Sylvester, T., Braun, M., Schmidtke, D., & Jacobs, A. M. (2016). The Berlin affective word list for children (kidBAWL): exploring processing of affective lexical semantics in the visual and auditory modalities. *Frontiers in Psychology*, *7*, 969.

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021). Neuroimaging of valence decisions in children and adults. *Developmental Cognitive Neuroscience*, *48*, 100925.

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021). Neural correlates of affective contributions to lexical decisions in children and adults. *Scientific Reports*, *11*(1), 1-11.

Further Peer-reviewed Published Articles

Xue, S., Lüdtke, J., Sylvester, T., & Jacobs, A. M. (2019). Reading shakespeare sonnets: combining quantitative narrative analysis and predictive modeling—an eye tracking study. *Journal of Eye Movement Research*, *12*(5).

Pulvirenti, G., Gambino, R., Sylvester, T., Jacobs, A. M., & Lüdtke, J. (2020). The foregrounding assessment matrix: an interface for qualitative-quantitative interdisciplinary research. *Enthymema*, (26), 261-284.

Liebig, J., Froehlich, E., Sylvester, T., Braun, M., Heekeren, H. R., Ziegler, J. C., & Jacobs, A. M. (2021). Neural processing of vision and language in kindergarten is associated with prereading skills and predicts future literacy. *Human Brain Mapping*, *42*(11), 3517-3533.

VI. Original Publications

Sylvester, T., Braun, M., Schmidtke, D., & Jacobs, A. M. (2016). The Berlin affective word list for children (kidBAWL): exploring processing of affective lexical semantics in the visual and auditory modalities. *Frontiers in Psychology*, *7*, 969. https://doi.org/10.3389/fpsyg.2016.00969

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021). Neuroimaging of valence decisions in children and adults. *Developmental Cognitive Neuroscience*, *48*, 100925. https://doi.org/10.1016/j.dcn.2021.100925

Sylvester, T., Liebig, J., & Jacobs, A. M. (2021). Neural correlates of affective contributions to lexical decisions in children and adults. *Scientific Reports*, *11*(1), 1-11. https://doi.org/10.1038/s41598-020-80359-1