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The Neural Correlates of Attention Networks in Normally Developing Preschool Children

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The Neural Correlates of Attention Networks in Normally Developing Preschool Children

Abstract

The healthy development of attention networks is essential for cognitive functioning and plays a crucial role in social interaction and academic success. Attention, a key neuropsychological function, is thought to be organized into three networks: alerting, orienting, and executive control, which gradually matures from infancy through adolescence. This study explores the development of these networks in children aged 5.5 to 6.5 years using a child-friendly version of the Attention Network Test for Interactions (ANTI) to determine whether they can already be distinguished at this age. A total of 20 healthy children (5.5 to 6.5 years) underwent a comprehensive assessment, which included clinical and behavioral measures. The mean age of the children was 5 years and 11 months and 33,3% were female. The child-friendly ANTI-Birds task was administered during functional magnetic resonance imaging (fMRI) using a 3T PRISMA scanner. Imaging data was processed using fMRIPrep with age-appropriate brain templates and analyzed using fixed-effects models in FitLins. Of the 20 children studied, data from two were excluded from the behavioral analysis, while three were excluded from the fMRI analysis. Thus, a total number of 15 children completed all study assessments. The results from 15 typically developing children indicate that the alerting network engages right frontal and parietal regions, while the orienting network involves the frontal eye fields, inferior parietal cortex, midbrain, and thalamus. The executive control network activates regions such as the anterior cingulate cortex, lateral prefrontal areas, and basal ganglia. These findings provide early insights into the organization of attention networks in preschool children.

Keywords: attention networks, attention, functional magnetic resonance imaging, preschool children, attention network test for interaction

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Theoretical Background[1]

Attention is a multifaceted construct that supports and influences us in various ways in our everyday lives and can also affect our personal perspectives. One of the founders of modern psychology, William James, wrote about attention: "My experience is what I agree to attend to" (James, 1890, p.402). This quote highlights the subjective aspects of attention and the active role of an individual in deciding to focus our attention on certain things in our lives, thus actively shaping our life and subjective perception. In addition to this active and conscious aspect of attention, unconscious processes of attention also play a role in human life (Sternberg & Sternberg, 2017). For example, emotion regulation and impulse control are aspects of attention that involve both conscious and unconscious components and begin to develop in preschool age (Carlson & Wang, 2007).

Attention allows us to flexibly adapt our thoughts to a constantly changing environment and is a significant predictor of social and academic success (Casagrande et al., 2022). According to a general agreement, executive functioning includes the three core components: working memory, cognitive flexibility, and inhibition (Schäfer et al., 2024). Working memory, as one of the core executive functions, is responsible for the mental representation of information and allows us to continue working with that information after its presentation (Diamond, 2013). In a school context, an efficient working memory is essential for organizing information, such as structuring to-do lists or transforming instructions into actionable plans (Diamond, 2013). The concept of inhibition, or inhibitory control, refers to the ability to consciously direct one's attention to a specific stimuli while filtering out surrounding distractors (Diamond, 2013; Hofmann et al., 2012). In addition, inhibitory control is an important factor in regard to social interaction, as it is related to the development of a theory of mind (Moriguchi, 2014). Cognitive flexibility or mental shifting refers to the ability to switch between thought processes or tasks, which is especially important when multiple tasks need to be managed simultaneously (Hofmann et al., 2012).

[1] During the creation of this thesis, ChatGPT was used. ChatGPT was used for translation and for linguistic correction of isolated phrases and sentences. After using the tools, the passages were thoroughly reviewed and edited by the author.

Although the most rapid development of executive functions takes place in preschool years, improvement continues until adulthood (Zelazo & Carlson, 2012).

However, as already mentioned, attention is not a single, consistent construct, it is a multidimensional concept that has evolved over time into many distinct theoretical concepts. The following paragraphs will introduce some of the most frequently used concepts of attention.

Selective Attention

Selective attention refers to the ability to choose only those pieces of incoming information that are relevant, while filtering out irrelevant stimuli (Sternberg & Sternberg, 2017). Therefore, selective attention allows for a focused and efficient response to environmental stimuli, free from distractions. The most striking example illustrating the functioning of selective attention is the cocktail party effect, which dates back to the cognitive scientist Colin Cherry (1953). The cocktail party effect specifically refers to the ability to focus on a conversation while other conversations are happening simultaneously in the environment, which are filtered out in order to better follow one's own conversation (Sternberg & Sternberg, 2017). To investigate and explain the underlying mechanisms of selective attention, various paradigms and theories have been developed, which are categorized under the group of so-called filter and bottleneck theories (Sternberg & Sternberg, 2017). A filter functions by preventing irrelevant incoming information from passing through, while a bottleneck slows down the flow of incoming information (Sternberg & Sternberg, 2017).

The filter theory of attention, proposed by psychologist Donald Broadbent (1958), suggests that incoming information first enters a sensory memory, where it remains until it is passed on to a filter, which decides which information will move to a higher level to be further processed (Broadbent, 1958 as cited in Müsseler & Rieger, 2017). Only information that has passed through the filter can reach the level of conscious perception (Sternberg & Sternberg, 2017). As it became clear over time that specific aspects of information processing were not compatible with Broadbent's filter theory, the theory was extended by psychologist Anne Treisman (Sternberg & Sternberg, 2017). Treisman (1964) developed the attenuation theory, which suggests that instead of a filter, a kind of attenuator is involved in information processing, by weakening the intensity of certain stimuli (Treisman, 1964 as cited in Sternberg & Sternberg, 2017). According to this theory, information, although presented in an attenuated form, is not completely blocked, but instead remains available for further processing in a weakened form (Sternberg & Sternberg, 2017).

Sustained Attention and Vigilance

Sustained attention refers to the ability to maintain attention over an extended period of time and remain focused on a goal-directed activity or stimulus (Slattery et al., 2022). This form of attention serves many important everyday functions, such as focused reading of texts, attentive and active listening, or active participation in traffic (Sternberg & Sternberg, 2017). Sustained attention is one of the fundamental cognitive functions that underlie important aspects of attention and cognition, such as learning and memory, as well as divided and selective attention (Slattery et al., 2022). A very defining characteristic of selective attention is that it requires active motivational and emotional processes to be maintained (Slattery et al., 2022). A specific aspect of sustained attention is called vigilance. Vigilance refers to the ability to remain alert and responsive to very specific target stimuli over an extended period of time (Sternberg & Sternberg, 2017). Vigilance requires high cognitive performance and plays a particularly important role in situations where an environment must be continuously monitored for specific target stimuli and responded to accordingly (Sternberg & Sternberg, 2017). This includes various military positions as well as the jobs of air traffic controllers and lifeguards.

Divided Attention

In contrast to the previously described forms of attention, the concept of divided attention refers to the ability to focus on multiple stimuli simultaneously and divide attention across several tasks, which requires parallel processing of more than one stimulus at a time (Mahone & Schneider, 2012). According to Kahneman (1973), the brain's ability to divide attention among various stimuli depends on the complexity of different tasks and how many resources they require. According to the resource model, simultaneously processing multiple tasks results in a division of cognitive resources, with each task consuming a portion of the available overall capacity. More demanding tasks that require intensive processing consume more cognitive resources compared to tasks that are more or less automated (Kahneman, 1973).

Divided attention is an essential skill in our everyday lives. Colloquially, we refer to divided attention as multitasking (Sternberg & Sternberg, 2017). Divided attention is a necessary skill, for example, when driving, cooking, or playing video games (Sternberg &

Sternberg, 2017). To manage our daily lives, we need the ability to allocate cognitive capacity to each task in a way that allows us to complete them as efficiently as possible (Sternberg & Sternberg, 2017).

The Attention Network Model

The concept of "Attention Networks," which divides human attention into three aspects, originates from Posner and Petersen (1990). It distinguishes three main components of attention: "Alerting," "Orienting," and "Executive Control" (Petersen & Posner, 2012). The alerting function induces a phasic change in vigilance and prepares the body for an incoming signal (Petersen & Posner, 2012). It is particularly associated with the right frontal and parietal lobes, which receive noradrenergic projections from the locus coeruleus (Petersen & Posner, 2012; Vázquez-Marrufo et al., 2014). It is assumed that alerting is integrated into a subsystem for attention that, among other functions, supports visual orienting (Posner & Petersen, 1990). Physiologically, it is based on norepinephrine pathways originating from the locus coeruleus and is more strongly lateralized in the right hemisphere (Posner & Petersen, 1990). Orienting allows an organism to direct its attention to a specific stimulus and to reallocate focus after being disengaged (Mezzacappa, 2004). Thus, this network plays an important role in distinguishing important from unimportant information. Orienting is associated with the posterior parietal cortex, the thalamic pulvinar nucleus, the superior colliculus, and the frontal eye fields and receive projections from the cholinergic modulatory system (Vázquez-Marrufo et al., 2014). The executive network is involved in executing goal-directed behavior, regulating impulses, and adapting or interrupting actions as needed (Kang et al., 2022; Mezzacappa, 2004) and is associated with the anterior cingulate cortex as well as the lateral prefrontal cortex (Vázquez-Marrufo et al., 2014). Since these regions have numerous dopamine receptors, it is assumed that the dopaminergic system plays a role in the executive network (Vázquez-Marrufo et al., 2014).

Development of Attention Networks

The development of attentional networks occurs throughout the lifespan, with sensitive periods for development varying depending on the network (Rueda & Posner, 2012). Alerting refers to the ability to maintain attention over a prolonged period and, on the other hand, the readiness to respond to incoming stimuli (Pozuelos et al., 2014). In a study by Wiegand et al., 2017 it was found that both children and adults showed reduced reaction times in the experiment when a target stimulus was preceded by a cue. However, it was observed that children, compared to adults, process warning cues in a less efficient manner

(Kraut, 1976 & Smothergill & Kraut, 1989, as cited in Pozuelos et al., 2014). The alerting network begins to develop in early infancy and is associated with the noradrenergic neurotransmitter system, with the locus coeruleus playing an important role (Rueda & Posner, 2012). This area in the brainstem is particularly activated by incoming warning signals and is generally involved in the regulation of vigilance, attention, as well as physiological stress regulation (Kandel, 2013). The experience of excessive stress in infancy due to traumatic events, such as abuse or prolonged separation from parents, can lead to an overactivation of the locus coeruleus, which may result in a lasting increase in the child's stress sensitivity (Gunnar & Quevedo, 2007).

Orienting refers to the conscious directing of attention to a specific stimulus for its preferred processing (Pozuelos et al., 2014). On the one hand, orienting includes overt orienting, which involves externally visible eye and head movements, on the other hand, it includes covert orienting, which refers solely to the orientation of attention on a mental level without any eye movements (De Haan et al., 2008). The early development of orienting is suggested by the fact that newborns do not only move their eyes and head toward new stimuli, but also show a preference for specific characteristics of the stimuli, particularly their resemblance to human faces (Portugal et al., 2022). This sensitivity to social cues continues in early infancy, as demonstrated by findings that 4-month-old infants process objects more effectively when guided by human head and gaze direction, highlighting the special role of faces in attention development (Wahl et al., 2013). During the first years of life, up to preschool age, the orienting network continues to develop toward a conscious regulation and control of attention, which is also facilitated by the ongoing maturation of executive functioning (Rothbart & Posner, 2001). It is also believed that the orienting network, due to its early development, fulfills regulatory functions that are later taken over by the executive network as development progresses (Rueda & Posner, 2012).

Executive attention plays an important role in the regulation of emotions and thoughts and is particularly significant in the development of impulse control (Rueda et al., 2012). The development of executive attention begins at the end of the first year of life and reaches its peak during the preschool years (Rueda & Posner, 2012). Compared to the other two networks, alerting and orienting, executive attention develops the most slowly and takes the longest to mature and the earliest evidence for this network seems to be at about 7 months (Rueda & Posner, 2012). It has been shown that the efficiency of executive attention improves significantly between children at the age of 7 years and adolescents and further into late adolescence (Pozuelos et al., 2014).

Attention Assessment in Preschool Children

In clinical psychology, and particularly in clinical psychological diagnostics, testing attention is a key part of a practicing psychologist's work. Attention tests are used, in part, in the clinical field to assess a suspected attention deficit hyperactivity disorder (ADHD) diagnosis, and in part with healthy children as a part of school readiness evaluations. Since there are various concepts of attention in psychology and different aspects of attention interact through networks rather than being clearly separable, certain methodological issues and limitations should be considered when administering such tests (Mahone & Schneider, 2012). Due to individual differences in the development of attention networks at the neural level in preschool-aged children, it can be difficult to distinguish whether inattentiveness is a symptom of a psychiatric disorder, such as ADHD, or simply a normal variation in the development of the child's attention networks (Mahone & Schneider, 2012).

Over the years, different tests have been developed for many specific constructs of attention. In general, attention testing is distinguished between speed-based and performance-based tests (Reynolds & Kamphaus, 2003). Speed-based tests are typically used to assess abilities in processing speed and reaction time, and are primarily designed to measure the speed of task performance (Kubinger, 2019). In contrast, performance-based tests focus more on accuracy and efficiency in task execution and are primarily used in the context of attention testing in preschool children to assess sustained attention, selective attention, controlled attention, and attention span (Mahone & Schneider, 2012).

For the assessment, computer-based testing or paper-pencil methods can be used, each having advantages and disadvantages regarding the administration and evaluation of the tests (Mahone & Schneider, 2012).

A famous paradigm for testing selective attention is the so-called Stroop test (Fig.1). In a typical Stroop test, participants are presented with words that represent color names, which are either displayed in matching or non-matching colors (Sternberg & Sternberg, 2017). The task of the participant is to name the color of the word while not reading or ignoring the word itself.

Figure 1:

Illustration of a classic Stroop test, in which participants are asked to name the color of the words displayed. When the words do not match the color, participants take longer to respond (Tam, 2013).

Another well-known paradigm for testing selective attention is the Flanker paradigm. In tests using the Flanker paradigm, a target stimulus is presented, surrounded by additional stimuli (Eriksen & Eriksen, 1974). The surrounding stimuli can either match the target stimulus (congruent stimuli) or differ from the target stimulus and look different (incongruent stimuli) (Casagrande et al., 2022). Due to the complexity involved in the Stroop and Flanker paradigms, modified versions of these paradigms are used in the assessment of selective attention in preschool children, which are easier for children to complete (Gerstadt et al., 1994). To measure selective attention in preschool-aged children, tests are used that include so-called perceptual matching tasks, central-incidental learning tasks, as well as visual search or cancellation tasks (Mahone & Schneider, 2012). In perceptual matching tasks, participants are asked to compare visual stimuli and then indicate whether the newly presented stimulus is the same or different (Mahone & Schneider, 2012). Central-incidental tasks examine how well participants are able to focus on important and central stimuli while ignoring less important stimuli, and visual search or cancellation tasks ultimately assess how well participants can identify a target image among many different images (Hagen & Hale, 1973; Mahone & Schneider, 2012).

Divided attention is typically tested in practice using tasks that follow the dual-task interference paradigm (Mahone & Schneider, 2012). These are tests in which participants are asked to first perform two tasks separately and then perform them simultaneously. The performance of both parts of the test is then compared to determine under which conditions the participants achieved better performance (Mahone & Schneider, 2012).

To measure sustained attention, tests are used in practice where participants are asked to identify changes in a stimulus over a prolonged period of time (Mahone & Schneider, 2012). Tests of this type are also called continuous performance tests and measure a person's ability to maintain attention over a prolonged period of time (Mahone & Schneider, 2012).

The Attention Network Test (ANT) was developed by Fan et al. (2002) and it combines the measurement of various aspects of attention in one test. The three main components of the test include alerting, orienting, and executive control, whose assessment also overlaps with the previously described traditional aspects of attention (Fan et al., 2002). The duration of the ANT requires participants to be able to maintain their attention over a prolonged period of time (Fan et al., 2002). The ANT could indirectly also contribute to the measurement of sustained and divided attention, by using a flanker paradigm, which requires participants to correctly identify a target stimulus despite the presentation of congruent and incongruent stimuli, and to differentiate between target and cue stimuli, aspects of both sustained and divided attention could also be measured (Fan et al., 2005).

Attention Deficits

Attention deficits refer to either permanent or temporary disturbances in concentration ability that can negatively affect our daily lives in various ways (Rösler et al., 2010). A characteristic common to most neurodevelopmental disorders is the difficulty in attentional or cognitive control (Casey & Riddle, 2012) Individuals with Tourette Syndrome, Obsessive-Compulsive Disorder (OCD), Schizophrenia, or Attention-Deficit/Hyperactivity Disorder (ADHD) experience limitations in attentional control for example (Casey & Riddle, 2012). Children with ADHD rate their quality of life less negatively than their parents do, and they do not consider themselves less capable compared to other children (Danckaerts et al., 2010). While in adulthood, affected individuals often experience limitations related to their work life (Stockreiter et al., 2024). The term attention refers, on the one hand, to the ability to maintain a certain state of activation in order to process important information, and on the other hand, to the ability to selectively filter relevant information for further meaningful processing (Gauggel, 2020). Since attention is a complex and multifaceted construct encompassing various aspects, a uniform disorder profile is not assumed for attention disorders, and the diagnostic process takes into account the examination of different aspects of attention (Gauggel, 2020). Depending on the underlying attention disorder, different aspects of attention can be impaired (Gauggel, 2020). In the diagnostic process, phasic attention, sustained attention, vigilance, selective attention, divided attention, and executive attention are differentiated (Gauggel, 2020).

Phasic attention refers to a person’s ability to spontaneously activate their level of arousal to the extent that they can quickly respond to an external stimulus (Jaeger et al., 2021). Phasic and tonic attention are included in the concept of alertness and are generally understood as basic state of awareness or responsiveness to stimuli in general (Schmidt-Atzert & Amelang, 2012). When there is a disturbance in phasic attention, individuals may have difficulty in making decisions in daily life and, as a result, show delayed motor responses (Jaeger et al., 2021). Both cortical and subcortical structures are involved in phasic attention (Posner & Petersen, 1990). The prefrontal cortex is responsible for the top-down regulation of attention and plays a role in decision-making in this context (Kandel, 2013). The temporoparietal cortex and the inferior frontal cortex show strong lateralization to the right hemisphere and play an important role in detecting relevant stimuli, especially those that are salient or unexpected (Corbetta & Shulman, 2002). Relevant subcortical areas include the ascending reticular activating system, which regulates arousal (Posner & Petersen, 1990), the thalamus, which is involved in modulating attention (Petersen & Posner, 2012), and the locus coeruleus, which, through its involvement in the noradrenergic neurotransmitter system, is particularly important for responsiveness to external signals (Aston-Jones & Cohen, 2005).

Sustained attention refers to a person's ability to control and maintain their attention effortfully over an extended period of time (Gauggel, 2020). A disturbance in sustained attention occurs when the affected person is unable to maintain attention for at least 30 seconds while performing highly monotonous tasks (Gauggel, 2020).

Involved brain areas in this include the prefrontal cortex (Miller & Cohen, 2001) and the parietal cortex (Corbetta & Shulman, 2002), as well as the thalamus (Sturm & Willmes, 2001), and the ascending reticular activating system (Posner & Petersen, 1990). Additionally, the anterior cingulate cortex (ACC), which is responsible for adjusting cognitive control to maintain attention over longer periods, the striatum and the basal ganglia, which control the shift between attention and motor response, and the insula, which helps regulate emotional arousal, are involved (Petersen & Posner, 2012).

In a disorder of selective attention, affected individuals find it difficult to direct their attention to a specific stimulus and thus focus their attention on one aspect (Gauggel, 2020). The stimuli arise from two different sources or stimulus classes that must be distinguished from each other (Schmidt-Atzert & Amelang, 2012). When the ability to manage multiple tasks simultaneously is impaired, it is referred to as a disorder of divided attention (Gauggel, 2020). According to Corbetta & Shulman (2002), a dorsal attention network, consisting of the intraparietal sulcus and the frontal eye fields, and a ventral attention network, consisting of the temporoparietal junction and the ventral frontal cortex, are involved in divided attention (Corbetta & Shulman, 2002).

Lastly, a disorder of executive attention refers to a limitation in the voluntary control of processes that affect information processing, such as the ability to filter out irrelevant stimuli (Gauggel, 2020). Affected brain regions include particularly prefrontal cortex areas and the anterior cingulate cortex (ACC) (Robbins, 2007).

Research Gap

The neural mechanisms of attention development have been a central research topic in cognitive neuroscience for many years. The model of attention networks is based on the work of Petersen and Posner (1990, 2012), upon which several studies have sought to make these proposed attentional networks visible with the help of imaging techniques. Various studies have already shown that the three attentional networks (Alerting, Orienting, and Executive Control) can be differentiated in adults (Fan et al., 2005; Saito et al., 2022) and in children from school age to late adolescence (Pozuelos et al., 2014; Rueda et al., 2004). Early findings based on the Behavioral Assessment of the three attentional networks suggest that these networks can already be differentiated at the age of four, with significant developmental strides in attention-related abilities occurring particularly between ages 3 and 4 (Casagrande et al., 2022). However, it remains unclear at what age the three attentional networks can be functionally differentiated. Since preschool children are in a critical phase of attention development, particularly regarding the further maturation of executive functions (Pozuelos et al., 2014), which are of significant importance for academic success (Mezzacappa, 2004), it is of particular interest to investigate the age group of children from 5.5 to 6.5 years.

This investigation is especially relevant in the context of early developmental risks, such as prematurity. Some studies have shown that preterm children are at an increased risk for attention deficits later in life, particularly during school age (Giordano et al., 2017; Van De Weijer-Bergsma et al., 2008). However, it is still insufficiently researched which specific changes in the underlying anatomical brain networks are associated with this and whether differences manifest in earlier stages of development.

Therefore, the present study investigates a healthy control group of preschool children within the study "Attention in Preterm Children" to examine whether the three attentional networks can already be functionally differentiated at this age. These data can serve as reference values for future investigations to better understand how the neural organization of attention in children at elevated risk, such as preterm children, differs from typical development.

Research Questions and Hypotheses

This study is based on the following primary research question: “Can the specific neuronal networks underlying each aspect of attention (alerting, orienting, executive control) be differentiated already in preschool age?”

Additionally, it will be investigated whether the results of the test performances in the ANTI correlate with those from the KABC-II and the subtests of the KiTAP.

This leads to a total of 3 hypotheses, which will be analyzed separately for the data of the functional imaging and behavioral data.

Functional Imaging:

Hypothesis 1: The specific networks of the three aspects of attention (alerting, orienting, executive control) can already be differentiated in preschool age. The results align with the proposed areas by Petersen and Posner (1990).

Behavioral Data:

Hypothesis 2: There is a correlation between the performance on the KiTAP and the attentional effects (alerting, orienting, executive control).

Hypothesis 3: There is a correlation between the performance on the KABC-II and the attentional effects (alerting, orienting, executive control).

Methods

Recruitment

In this study, a total of N = 20 typically developing preschool children aged 5.5 to 6.5 years were recruited. Data on the neurocognitive development of children was collected using the Kaufman Assessment Battery for Children 2nd Edition (KABC-II) (Kaufman & Kaufman, 2016), and data on attention was obtained using an adapted version of the Attention Network Test for Interaction (ANTI-Birds) for children (Fan et al., 2002), as well as through the Test Battery for Attention Assessment in Children (KiTAP) (Zimmermann et al., 2002). To examine the relationship between performance in the ANTI-Birds and the attention networks, each participating child undergoes an fMRI measurement, during which the ANTI-Birds is repeatedly presented.

The recruitment of study participants took place from June 2024 to January 2025 and was mainly carried out actively by personally approaching parents with children in the target age group, for example, in children's gymnastics groups, as well as through regular distribution of the study flyer with information about the study via social media channels, such as Facebook and Instagram. A great deal of support for recruitment was also provided by the "Kinderarztpraxis Schumanngasse" which offered to actively approach parents from our target group in their pediatric practice and additionally raise awareness of the study using the provided informational materials.

Procedure and Study Design

After an initial phone interview with the parents, appointments for subsequent testing sessions were scheduled. The study was conducted at the Department of Pediatrics and Adolescent Medicine at the Medical University of Vienna. In the first session, data on the children's neurocognitive development was collected using the Kaufman Assessment Battery for Children (KABC-II) (Kaufman & Kaufman, 2016), and data on attention was assessed using a child-adapted version of the Attention Network Test (ANTI-Birds) (Fan et al., 2002) as well as the Test Battery for Attention Assessment in Children (KiTAP) (Zimmermann et al., 2002). After the initial testing session, parents had the opportunity to visit the MRI with their child either immediately after the first session or during a separate second appointment. The process of an MRI scan was first introduced to the children in a playful way using LEGO® figures. Additionally, the booklet "Ich schaffe das MRT" helped reduce anxiety and increased the children's excitement for the upcoming scan. In the final session, the fMRI scan took place. During the scan, the children first watched a cartoon series for 10 minutes, followed by a resting state, where a black fixation cross on a white background was shown for another 6 minutes. Afterward, adjustment measurements were made, and the ANTI-Birds was administered. Upon completion of the ANTI-Birds, anatomical brain scans were conducted, followed by additional adjustment measurements.

Sample

In this study, 20 full-term born children were recruited. Two children were excluded from the data analysis due to an age of 3.5 years (1 child) and incomplete data acquisition (1 child). Thus, the study sample consisted of 18 typically developing full-term born children. Regarding the gender distribution, 66,7% ($n = 12$) of the children studied were male, and 33,3% ($n = 6$) were female. At the time of the first examination, the children had a mean age of 5 years and 11 months ($SD = .45$). Additionally, three children had to be excluded from fMRI data analysis due to excessive movement during the scan and sleeping during the examination. Thus, a total number of 15 typically developed children completed all study assessments.

Instruments

Kaufman Assessment Battery for Children-II (KABC-II)

The Kaufman Assessment Battery for Children was published in its second, revised edition in 2004 and was developed by psychologists Nadine and Alan Kaufman (Kaufman & Kaufman, 2016). It is a standardized procedure that measures the cognitive abilities of children and young adults aged 3 to 18 years (Kaufman & Kaufman, 2016). The KABC-II is based on a dual theoretical framework. It draws on both the Cattell-Horn-Carroll (CHC) model of cognitive abilities and Luria's neuropsychological model of cognitive processing (McGill, 2020). The KABC-II measures various cognitive abilities through different subtests, which are divided into five scales: Sequential Thinking (short-term memory), Simultaneous Thinking (visual-spatial organization), Learning (long-term storage & crystallized intelligence), Planning, and Knowledge (Kaufman & Kaufman, 2016). In clinical psychological diagnostics, the KABC-II is used for intelligence testing as well as for diagnosing learning and developmental disorders. In the context of this study, the KABC-II was employed to assess whether the children under investigation exhibited age-appropriate cognitive development.

Test of Attentional Performance for Children (KiTAP)

The KiTAP is a computer-based testing procedure used to assess attention performance in children aged 6:0 to 12:11 years (Zimmermann et al., 2002). The test procedure was developed based on the TAP (Test Battery for Attention Assessment), which is used to assess attention performance in adults, and has been adapted to suit the various developmental stages of children of different ages (Zimmermann et al., 2002). The KiTAP consists of various subtests that measure different aspects of attention. These include tests for selective attention, divided attention, sustained attention, alertness, flexibility, and visuospatial attention (Zimmermann et al., 2002).

The subtest "The House of Dragons" measures selective attention and cognitive flexibility. In this context, cognitive flexibility refers to the ability to shift attention from an ongoing focus and spontaneously direct it to new, relevant stimuli (Zimmermann et al., 2002). In the practical execution of the test, a green and a blue dragon appear simultaneously on the left and right of a gate on the screen. The children are required to alternate their responses to two different target stimuli: the blue and the green dragon. First, the child must press the button on the side where the green dragon is located. In the next round, they should press the button on the side where the blue dragon is located, so that the two colors, green and blue, are alternately selected. However, the position of the dragons can vary in each round. The child's task is to identify the correct side with the dragon of the appropriate color, while always keeping track of the alternating target criterion. The subtest ultimately measures how well the child can flexibly respond to changing demands while maintaining focus and concentration (Zimmermann et al., 2002).

The subtest "The Bat" measures both the ability to sustain attention and the ability to control impulses (Zimmermann et al., 2002). In this test, children are presented with two stimuli alternately: a cat and a bat. The children are instructed to respond only to the bat by pressing a button each time it appears on the screen. When the cat appears, no response should be made.

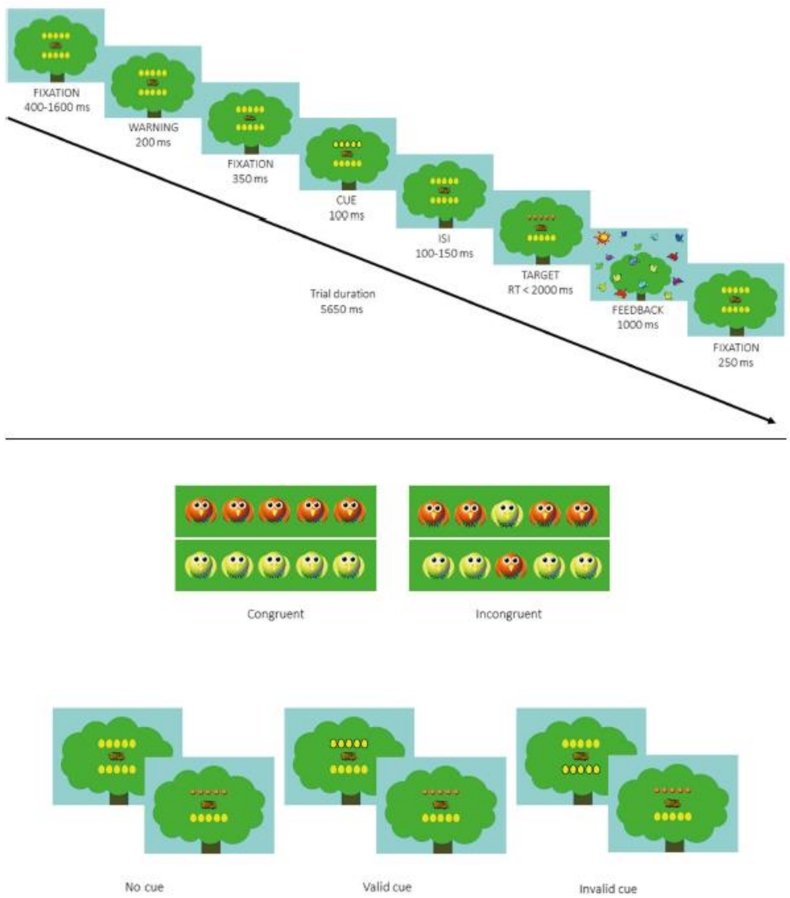
Attentional Network Test for Interaction – Birds (ANTI-Birds)

The ANTI-Birds (Casagrande et al., 2022) is a child-friendly version of the Attentional Network Test for Interaction, developed to measure the attentional networks according to Petersen & Posner (1990) in children aged 3 to 6 years. With the ANTI, it is possible to assess the three core aspects of attention: alerting, orienting, and executive control (Fan et al., 2002). At the beginning of each trial, the children are shown a nest as a fixation point on the screen. In the next step, a row of five yellow eggs appears above and below the fixation point, with the target stimulus later appearing in the center of the eggs. The target stimulus is a bird, which is either yellow or orange, and is flanked by four other birds, which may be either the same color or a different color (Fig. 2). The task of the child is to identify the color of the bird that appears in the center and then press the corresponding button. The right button is used to select yellow, and the left button is used to select the color orange.

The ANTI-Birds includes different conditions, which are based on a combination of a Flanker paradigm and a Cueing task (Casagrande et al., 2022). This combination of paradigms results in a total of 12 possible conditions: 2 alerting conditions (with or without a warning cue) × 3 cueing conditions (valid, invalid, or no cue) × 2 congruency conditions (flanking birds in the same or a different color as the target bird) (Casagrande et al., 2022; Weinmüller, 2022).

Figure 2:

Representation of the procedure and the different stimuli in the ANTI-Birds Casagrande et al., 2022)



After each response, the children receive feedback. Correct answers are rewarded with positive feedback, such as bird chirps, while errors are met with negative feedback in the form of a sad "No." The test measures reaction time and accuracy to assess the child's ability to respond to warning signals, focus attention appropriately, and resolve conflicts between conflicting information (Casagrande et al., 2022).

Handbook "Ich schaffe das MRT"

To prepare children for the MRI examination, the booklet *"Ich schaffe das MRT"* was used. This booklet was originally developed at the Department of Pediatrics and Adolescent Medicine at the Medical University of Vienna to familiarize children with the procedure of an MRI scan in a playful manner. In addition to the booklet, a LEGO® replica of an MRI setup was used to simulate the MRI examination situation with the children in a calm environment prior to the actual test appointment. This playful approach aimed at reducing anxiety and help the children feel more comfortable with the upcoming MRI procedure.

Analysis

Analysis of Behavioral Data

The data analysis was conducted using the statistical software IBM SPSS Statistics v. 29.0.2.0 for Windows (*IBM SPSS Statistics*, 2023). The significance level was set at $p \leq .05$. To examine linear correlations, a Spearman correlation was applied. Additionally, a one-sample Wilcoxon signed-rank test was conducted exploratively to check for significant differences between the medians for the attentional effects in this study and the study results of Casagrande et al. (2022). Due to the small sample size, non-parametric methods were used in this analysis.

For the analysis of the behavioral data, separate attentional effects were calculated: the alerting effect was derived from the subtraction of the mean values of all 'no tone' and 'tone' conditions (no tone - tone), the orienting effect was calculated from the subtraction of the mean values of all 'invalid' and 'valid' conditions (invalid – valid), and the executive control effect was computed by subtracting the mean values of the incongruent and congruent conditions (incongruent – congruent).The guidelines for these calculations were based on the work of Casagrande et al. (2022).

To correlate the test performance in the KiTAP with the test performance in the ANTI, the respective calculated values of attentional effects were compared with the reaction time values from the two subtests for focused attention, 'House of the Dragons' (Flexibility) and 'The Bat' (Go/No-Go) (Zimmermann et al., 2002).

To further correlate the test performance in the KABC-II with the test performance in the ANTI, the values of attentional effects were also compared with the corresponding values of the individual assessed dimensions, as well as the index for cognitive processing (Overall).

Analysis of fMRI Data

The fMRI scans were conducted using a 3 Tesla Siemens Vida scanner (Siemens Medical Solutions, Erlangen, Germany).

The preprocessing of the functional magnetic resonance imaging (fMRI) data was performed using fMRIprep (Esteban et al., 2019). fMRI, in contrast to the application of MRI in the clinical context, is used to visualize neural activity indirectly through a change in the concentration of oxygenated blood (Esteban et al., 2020). Through this BOLD (blood-oxygen-level-dependent) response, active regions can be inferred indirectly by the presence of oxygenated blood in areas with neural activity (Kandel, 2013). However, to make these active areas visible, several steps are required, such as preprocessing of the data and further statistical analyses. Data preprocessing involves several steps to prepare the data for the subsequent second-level analysis, the statistical evaluation.

In the first step of data preparation, motion artifacts are corrected. Since individuals move during the MRI scan, the position of the brain relative to the MRI space changes during the measurement. This leads to so-called "spin history effects," meaning voxel shifts between different layers, which can ultimately result in motion artifacts in the image, as a "halo effect" (Lemmin et al., 2010; Yancey et al., 2011). Motion correction then computationally adjusts the position of the head through an algorithm. The goal of the correction is to ensure that each voxel corresponds to a specific area of the brain and that the position has not been distorted by head movements (Muresan et al., 2005).

In addition to motion correction, a distortion correction is also performed, addressing geometric distortions caused by magnetic field inhomogeneities (B0-inhomogeneities) (Robinson et al., 2023). These B0-inhomogeneities can further lead to susceptibility artifacts, which can compress or stretch the image (Robinson et al., 2023). Using reference images applied to the raw data, corrections for these distortions can be made.

In the next step of preprocessing, the acquired functional images are aligned to anatomical reference images to assign active brain areas to corresponding anatomical structures (Ashburner & Friston, 1997). This process is called intermodal co-registration. After intermodal co-registration, spatial normalization is performed using a standardized anatomical template from the Montral Neurological Institute (MNI). In this step, the brain scans of the participants are transformed into a standardized space, making them comparable to the scans of other individuals (He & Razlighi, 2022).

The final step is called spatial smoothing. In this step, neighboring voxels in a scan are averaged to enhance the signal across adjacent brain regions and to reduce image noise (Mikl et al., 2008). Spatial smoothing leads to an overall increase in the signal-to-noise ratio, which results in less noise and thus better data quality for subsequent statistical analysis (Mikl et al., 2008).

For the statistical analysis of the fMRI data, a General Linear Model (GLM) was used, which was calculated using the FitLins software (v.0.11.0). A regression model was employed to model the relationship between the experimental conditions (alerting, orienting, executive functioning) and the measured fMRI signals.

The analysis was conducted as a whole-brain analysis, examining all voxels of the brain to identify activation patterns across regions. The focus was on comparing the activations of the three attentional networks with the resting state condition. For the statistical analysis, only clusters with a minimum size of 10 voxels were included to ensure that the results were robust and not driven by random fluctuations. The significance threshold was set to a two-tailed p-value of $p = .05$, which accounted for both positive activations and deactivations.

The results are presented in color-coded images (Fig. 3). Significant activations are visualized as colored regions, with the color scale reflecting the strength of activation (Fig. 3) Red represents lower activation (lower T-values), while yellow and other colors indicate higher activation (higher T-values). This scale is continuous, without fixed assignments of specific p-values to specific colors. Overall, the colored regions represent the significant neural activities detected at the defined cluster size and significance threshold.

The fMRI data was processed based on an age-appropriate, pediatric template (Fonov et al., 2011). Both the first and second levels of analysis were modeled using fixed-effect models to capture and analyze the effects of the experimental conditions on neural activity.

Results

fMRI

The fMRI analysis was conducted within the framework of the ANTI-Birds paradigm by Casagrande et al. (2022), with the aim of testing Hypothesis 1, which posited that the three attention networks (alerting, orienting, and executive control) can already be differentiated in preschool-aged children, in line with the proposed areas by Posner and Petersen (1990). In this experimental paradigm, the children were asked to focus their attention on relevant target stimuli and adjust their responses to changing demands. The activations in the three networks (Fig. 3) were triggered by the following experimental conditions:

1. Alerting Condition

This condition promotes the maintenance of a general arousal level and preparation for upcoming stimuli. Significant activations in the alerting network were observed under this condition. Activated regions included the right frontal and parietal areas, as well as temporal regions such as Brodmann areas 38 and 41. Activity in these areas is particularly observed in the right hemisphere, with significant activation in the right prefrontal cortex and the posterior parietal cortex (Fig. 3a).

2. Orienting Condition

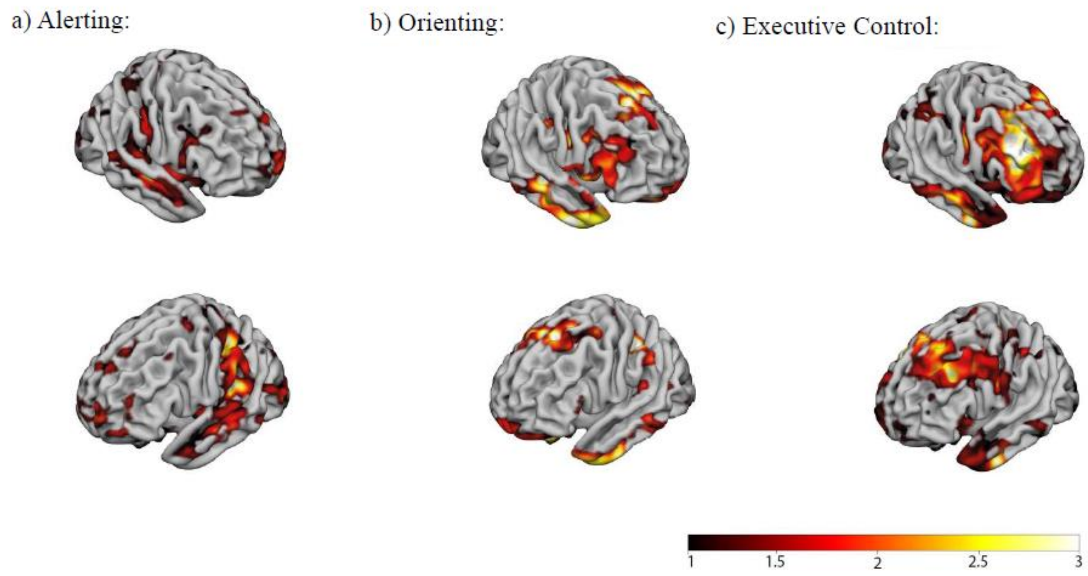
This condition requires the children to direct their attention to relevant stimuli while ignoring irrelevant ones (invalid cues). Activation of the orienting network was significant in the frontal eye fields, interior parietal lobe, as well as the thalamic regions and the midbrain (Fig. 3b).

3. Executive Control Condition

In this condition, the children were required to flexibly shift their attention between competing stimuli, especially when incongruent flankers interfered with the response to the target. Activation of the executive control network was observed significantly in the midline frontal regions, including the anterior cingulate cortex and basal ganglia (Fig. 3c).

Figure 3:

fMRI images of the three Attention Networks (a)Alerting, b) Orienting, and c) Executive Control) are shown, with a minimal cluster size of 10 voxels and a two-tailed probability threshold of p = .05. The brighter areas represent the regions with significant activation, as determined by the analysis. These activated areas reflect the underlying cognitive processes associated with each attention network, as they were engaged during the task. The color scale indicates the intensity of activation, with yellow and light yellow representing the highest T-values (strongest activation), and red and orange indicating progressively weaker, but still significant, activations (lower T-values).



These results align with the hypothesis that the three attention networks can already be differentiated in preschool-aged children, consistent with the proposed areas by Posner and Petersen (1990).

Behavioral Data

Attentional effects

In the first step, the alerting, orienting, and executive control effects were calculated from reaction times. Calculations were based on the method proposed by Casagrande et al. (2022). The alerting effect was calculated by subtracting the medians of the reaction times for the "No Tone" and "Tone" conditions (No Tone – Tone). The orienting effect was derived by subtracting the medians of the "Invalid" and "Valid" conditions (Invalid – Valid), while the executive control effect was calculated by subtracting the medians of the "Incongruent" and "Congruent" conditions. For better clarity, the results are presented in the following table (Tab. 1).

Table 1:

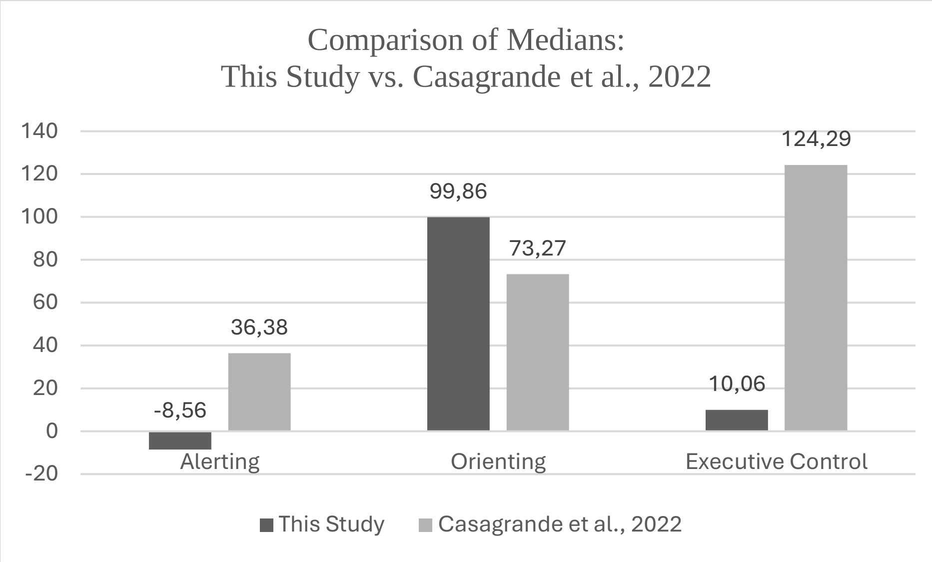
Medians and percentiles for the attentional effects

	Minimum	Q1	Median	Q3	Maximum
Alerting	-121,25	-26,125	-8,56	36,375	128,25
Orienting	-57,50	41,50	99,68	133,90	227,50
Executiv Control	-120,00	-20,43	10,06	55,46	107,50
Attentional Costs	-66,25	-19,59	29,37	61,62	123,62
Attentional Benefits	-35,25	12,35	69,00	104,03	173,125

To examine whether the results from this study align with or significantly deviate from those of Casagrande et al. (2022), a one-sample Wilcoxon signed rank test was conducted. For the alerting effect, a significant difference was found between the results of this study and those from the literature ($W = 31{,}000$, $p = .018$). No significant difference was observed for the orienting effect ($W = 109{,}000$, $p = .306$). However, a significant difference was found between the executive control effect calculated in this study and that from Casagrande et al. (2022) ($W = .000$, $p < .001$). The following diagram (Fig. 4) illustrates the results of the analysis graphically.

Figure 4:

Results of the one sample Wilcoxon signed-rank test



KABC-II

Overall the total score showed a median of *Mdn* = 120,00, with the 25th percentile at 108,00 and the 75th percentile at 134,00.

For the “Sequential” scale, the median score was *Mdn* = 114,00, with the 25th percentile at 105,25 and the 75th percentile at 125,75.

For the “Simultaneous” scale, the median score was *Mdn* = 118,00, with the 25th percentile at 106,50 and the 75th percentile at 126,50 and for the “Learning” scale, the median was *Mdn* = 110,00, with the 25th percentile at 100,00 and the 75th percentile at 125,00. For better clarity, the results are presented in the following table (Tab.2).

Table 2:

Results of the KABC-II

	Minimum	Q1	Median	Q3	Maximum
Overall	104,00	108,00	120,00	134,00	146,00
Sequential	97,00	105,25	114,00	125,75	146,00
Simultaneous	100,00	106,50	118,00	126,50	145,00
Learning	92,00	100,00	110,00	125,00	144,00

KiTAP

For the subtests “Flexibility” (House of the Dragons), the median score for the reaction time was *Mdn* = 1598,78. The 25th percentile was 1274,33, and the 75th percentile was 1955,87.

For “Go/No-Go” (The Bat), the median score for the reaction time was *Mdn* = 601,26, with the 25th percentile at 510,98 and the 75th percentile at 684,12.

The results are presented in the following table (Tab. 3)

Table 3:

Median values for the reaction time (RT) of the Subtests "House of the Dragons" (Flexibility) and "The Bat" (Go/No-Go) of the KiTAP

	Minimum	Q1	Median	Q3	Maximum
Flexibility	1042,58	1274,33	1598,78	1955,87	4571,84
Go/No-Go	419,27	510,98	601,26	684,12	845,95

Correlations between the Attentional Effects & KiTAP

To test Hypothesis 2, which posited that there is a correlation between the performance on the KiTAP and the attentional effects (alerting, orienting, executive control), a Spearman correlation was calculated. The results indicate that none of the correlations were statistically significant (Tab. 4).

1) Correlations between alerting and KiTAP Subtests

The correlation between alerting and Go/No-Go was moderately positive but not significant (*rho* = .420, *p* = .083). A weak positive but non-significant correlation was also observed between alerting and Flexibility (*rho* = 0.166, *p* = .510).

2) Correlations between orienting and KiTAP Subtests

A weak negative but non-significant correlation was found between orienting and the subtest Go/No-Go (*rho* = -.121, *p* = .633) The correlation between orienting and Flexibility was also negative and not significant (*rho* = -.350, *p* = .155).

3) Correlations between executive control and KiTAP Subtests

Between executive control and Go/No-Go, a correlation close to zero was observed, which was not significant (*rho* = -.042, *p* = .868). The correlation between executive control and Flexibility was weakly positive but not significant (*rho* = .176, *p* = .484).

4) Correlations among the KiTAP Subtests

A weak negative and also non-significant correlation was found between Go/No-Go and Flexibility (*rho* = -.137, *p* = .587).

Table 4:

Results of the Spearman Correlation between the attentional effects and the results of the KiTAP

Variable	1	2	3	4
1. Alerting				
2. Orienting	.003			
3. Executive Control	-.311	.226		
4. Go/NoGo	.420	-.121	-.042	
5. Flexibility	.166	-.350	.176	-.137

Overall, these results suggest that there was no significant relationship between performance on the KiTAP and the ANTI as measured by the three attentional effects.

Correlations between the Attentional Effects & KABC-II

To test Hypothesis 3, which posited that there is a correlation between the performance on the KABC-II and the attentional effects (alerting, orienting, executive control), a Spearman correlation was calculated. The results indicate that there are no significant correlations between the attentional effects and the different scales of the KABC-II (Tab. 5).

1) Correlations between alerting and KABC-II Scores

The correlation between alerting and orienting was close to zero (*rho*= .003) and not significant (*p* = .990). A moderate negative but non-significant correlation was found between alerting and executive control (*rho* = -.311, *p* = .210). The correlation between alerting and KABC-Overall was weakly positive and not significant (*rho* = .192, *p* = .461).

Similarly, the correlations between alerting and KABC-Sequential (*rho* = .179, *p* = .476), alerting and KABC-Simultaneous (*rho*= -.077, *p* = .762), and alerting and KABC-Learning (*rho* = .123, *p* = .628) were weak and not significant.

2) Correlations between orienting and KABC-II Scores

No significant correlations were found between orienting and KABC-Overall (*rho* = .022, *p* = .933), orienting and KABC-Sequential (*rho* = -.087, *p* = .731), orienting and KABC-Simultaneous (*rho* = -.147, *p* = .560), or orienting and KABC-Learning (*rho* = .153, *p* = .545).

3) Correlations between executive control and KABC-II Scores

Between executive control and KABC-Overall, a weak negative but non-significant correlation was observed (*rho* = -.138, *p* = .598). The correlation between executive control and KABC-Sequential was weakly positive but not significant (*rho* = .071, *p* = .781). Similarly, weak and non-significant correlations were found between executive control and KABC-Simultaneous (*rho* = -.241, *p* = .336) and executive control and KABC-Learning (*rho* = .089, *p* =.724).

4) Correlations among KABC-II Subscales

In contrast, significant positive correlations were found between KABC-Overall and KABC-Sequential (*rho* = .656, *p* = .004), KABC-Overall and KABC-Simultaneous (*rho* = .874, p < .001), and KABC-Overall and KABC-Learning (*rho* = .744, *p* < .001). Additionally, KABC-Sequential and KABC-Simultaneous were positively correlated (*rho* = .497, *p* = .036), and KABC-Simultaneous and KABC-Learning also showed a significant positive correlation (*rho* = .513, *p* = .030). The correlation between KABC-Sequential and KABC-Learning was moderately positive but not statistically significant (*rho* = .392, *p* = .108).

Overall, no significant correlations were found between alerting, orienting, or executive control and the KABC-Scores, while strong correlations were observed among the different KABC subscales.

Table 5:

Results of the Spearman Correlation between the attentional effects and the results of the KABC-II

Variable	1	2	3	4	5	6
1. Alerting						
2. Orienting	.003					
3. Executive Control	-.311	.226				
4. KABC overall	.192	.022	-.138			
5. KABC Sequential	.179	-.087	.071	**.656****		
6. KABC Simultaneous	-.077	-.147	-.241	**.874****	**.497***	
7. KABC Learning	.123	.153	.089	**.744****	.392	**.513***

Overall, these results suggest that there was no significant relationship between performance on the KABC-II and the ANTI as measured by the three attentional effects.

Discussion

The aim of this study was to investigate the three attention networks (alerting, orienting, and executive control) in preschool children and to demonstrate that they can already be differentiated in the age group of 5.5 to 6.5 years. The study aimed to examine whether the Attention Networks measured in this study correspond to the areas proposed by Posner and Petersen (1990) using fMRI measurement. Additionally, an exploratory analysis was conducted to determine whether the attentional effects calculated in this study align with those observed in the same-aged group from Casagrande et al. (2022). Furthermore, a correlation analysis was performed to examine whether the aspects of attention measured using KiTAP and ANTI, as well as the assessed general cognitive abilities measured by the KABC-II are interrelated.

Summary

The fMRI results revealed notable similarities with the networks described by Posner and Petersen (1990) across multiple brain regions. It was found that the alerting network was active in several cortical areas, including frontal, parietal, and temporal regions, including Brodmann Areas 38 and 41, particularly in the right hemisphere. This is consistent with the findings of Posner & Petersen (1990) as well as later studies by Petersen & Posner (2012), which described strong activation of the right hemisphere in tasks that examined alerting. One point I find worth discussing here is that, despite a negative alerting effect in the behavioral data, correlates of the alerting network were visible in the fMRI-scans. This finding may indicate that the neurobiological systems underlying attention control remain fundamentally active, even when the behavioral response does not exhibit the anticipated positive alerting effect. The work of Mullane et al. (2016), Rueda & Posner (2012), and Posner & Petersen (1990) suggests that the brain may be preparing for cue stimuli, even if the behavioral response is influenced by developmental factors or relevant contextual factors. The activation of Brodmann Areas 38 and 41 suggests that the auditory warning signal may have led to activation at the neural level. Regarding the orienting network, activations were also observed in this study, in line with the findings of Posner & Petersen (1990), in the frontal eye fields, the parietal lobes, and the thalamus. Regarding the executive control network, activations were seen in midline frontal regions, including the anterior cingulate cortex, and the basal ganglia, which also align with the areas proposed by Posner & Petersen (1990).

In the context of this study, the three attentional effects (alerting, orienting, and executive control effect) were initially calculated according to the specifications in the paper by Casagrande et al. (2022) and compared with the results of the 6-year-old children from the same study using a one-sample Wilcoxon signed-rank test. My analysis revealed significant differences between my results and those of Casagrande et al. (2022) for the alerting and executive control effects, but not for the orienting effect. A possible explanation for these differences lie in the development of the various attentional networks. Different studies on the development of attentional networks have shown that these networks develop in a differentiated manner, each with its own developmental trajectory (Mullane et al., 2016). It has been shown that children at the age of 5 exhibit smaller alerting effects compared to children at the age of 7 (Mezzacappa, 2004, as cited in Mullane et al., 2016), and that alerting steadily improves until after middle childhood (Mullane et al., 2016). Regarding the development of orienting, however, it seems that there are no significant changes after the age of 6 or 7 (Mullane et al., 2016). This is in line with the findings of Rueda & Posner (2012), who state that orienting reaches adult maturity in middle childhood. The executive network develops during childhood through an increasing improvement in cognitive control, particularly in the areas of conflict resolution, inhibition of irrelevant information, and cognitive flexibility, with a significant maturation occurring between the ages of 4 and 7 (Rueda et al., 2005) and undergoing the most significant maturation process during the preschool years (Rueda & Posner, 2012).

Another point worth discussing is the quality of the warning signal. In this study, following the setup of Casagrande et al. (2022), a cue tone with a frequency of 2000 Hz and a duration of 200ms was presented. This means that it was purely an auditory signal with no additional spatial or temporal information. It is therefore possible that the cue was perceived by children as non-informative and irrelevant. Given that the alerting effect in this study had a negative value of Mdn = -8.56, it can be assumed that the mean reaction times in the conditions without sound were faster compared to the conditions with sound. However, since an effect was found in the same age group in the study by Casagrande et al. (2022), the procedural aspects of this study should also be critically examined. Due to limited time resources for many parents, cognitive testing using the KABC-II and attention testing with the KiTAP were sometimes conducted in a single session before the testing with the ANTI-Birds. Despite breaks being taken, it is possible that fatigue effects occurred. Another factor to consider is the inhibition of return proposed by Posner et al. (1985), which suggests that our brain prevents us from directing our attention to a stimulus that has already been deemed non-informative (Posner et al., 1985). This would mean that once the presented auditory cue has been classified as non-informative, attention is less likely to be redirected to the same cue when a new stimulus is presented (Posner et al., 1985).

To examine whether the cognitive development of the children studied is age appropriate, the KABC-II was used for general cognitive abilities, and the two subtests (Flexibility and Go/No-Go) were used to test the two aspects of selective attention, inhibition and flexibility. In this study, no significant correlations were found between the three attentional effects and the test performances in the KABC-II or the corresponding subtests of the KiTAP. These results are consistent with the previously discussed developmental stage of the sample studied in relation to the alerting and executive functioning networks. It is quite possible that the executive functions, including the ability to inhibit and the flexibility, as well as alerting, are still in a developmental phase (Rueda & Posner, 2012).

Moreover, it should be considered whether the selected procedures might have captured different constructs of attention, which could explain the lack of correlation between them. While the KABC-II primarily assesses general cognitive abilities, the KiTAP subtests (Go/No-Go and Flexibility) are designed to measure more specific aspects of executive functioning, such as inhibition and cognitive flexibility. The lack of correlation between these measures might suggest that they capture distinct constructs of attention or executive control, which do not necessarily overlap. Differences in task demands, measurement methods, or underlying cognitive processes may have contributed to these findings, emphasizing the complexity of attention as a multifaceted construct.

Limitations and further research

The main limitations of this study stem from the small sample size and the challenges associated with the recruitment process. The sample size was very small, with 18 children completing the behavioral assessments and only 15 children participating in the fMRI scans due to dropouts. As a result, the study has low statistical power, and the generalizability of the findings should be interpreted with caution. Due to the three scheduled sessions, which took place at the Department of Pediatrics and Adolescent Medicine at the Medical University and each session took 1 to 2 hours, it was difficult to recruit suitable participants in this narrowly defined age group (children aged 5.5 to 6.5 years) within a short period of time. It is important to note that the parents who agreed to participate in the study had a strong interest in participating, often had an academic background, and viewed participation as an opportunity to contribute to current research. Due to the significant time commitment required from parents, those who either had a long commute or were employed were excluded from the study. Another limitation in the context of the study's execution was access to the test materials. Since the test materials from the follow-up clinic for premature infants were used for the study, they could only be borrowed in consultation with the psychologists working there. This situation further complicated the recruitment of suitable participants due to the difficult scheduling process.

For future research, several implications arise from this study. One of the major challenges of this study was related to the recruitment process and the resulting small sample size. In this study, the recruitment of suitable participants was severely limited, among other reasons, due to the high time demands placed on parents and the limited availability of appropriate rooms for testing. For future studies, more flexible recruitment strategies would be recommended to make participation more attractive for interested families. One possibility could be conducting testing at the participants' homes or establishing partnerships with various pediatric clinics in advance. A more flexible study design that offers participants more options and less time pressure could significantly ease the recruitment of suitable participants and improve the generalizability of the results.

In addition to these organizational aspects, it would certainly be valuable for future research to also investigate younger age groups in order to better determine when attention networks begin to differentiate at the neural level during development. A more precise investigation of the early developmental phases could allow for a better understanding of the temporal dynamics of neural changes in relation to different aspects of attention. Such findings could not only help in understanding the development of attention networks in more detail but also contribute to identifying early indicators of the later development of cognitive abilities.

Conclusion

Overall, this study demonstrated that the observed activations in the three attentional networks correspond to the areas proposed by Posner and Petersen (1990), supporting the idea that these networks can already be differentiated from one another in preschool-aged children. These activations were visible at the neural level, despite the low values observed for the alerting and executive control effects at the behavioral level. This discrepancy between neural and behavioral results highlights the complexity of attention control mechanisms and suggests that neural activity may be a more sensitive indicator of attentional processes in young children, even when behavioral effects are not yet fully developed or measurable.

References

Ashburner, J., & Friston, K. (1997). Multimodal Image Coregistration and Partitioning—A Unified Framework. *NeuroImage*, *6*(3), 209–217. https://doi.org/10.1006/nimg.1997.0290

Aston-Jones, G., & Cohen, J. D. (2005). AN INTEGRATIVE THEORY OF LOCUS COERULEUS-NOREPINEPHRINE FUNCTION: Adaptive Gain and Optimal Performance. *Annual Review of Neuroscience*, *28*(1), 403–450. https://doi.org/10.1146/annurev.neuro.28.061604.135709

Backes, V., Kellermann, T., Voss, B., Krämer, J., Depner, C., Schneider, F., & Habel, U. (2011). Neural correlates of the attention network test in schizophrenia. *European Archives of Psychiatry and Clinical Neuroscience*, *261*(S2), 155–160. https://doi.org/10.1007/s00406-011-0264-9

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, *22*(4), 489–510. https://doi.org/10.1016/j.cogdev.2007.08.002

Casagrande, M., Marotta, A., Martella, D., Volpari, E., Agostini, F., Favieri, F., Forte, G., Rea, M., Ferri, R., Giordano, V., Doricchi, F., & Giovannoli, J. (2022). Assessing the three attentional networks in children from three to six years: A child-friendly version of the Attentional Network Test for Interaction. *Behavior Research Methods*, *54*(3), 1403–1415. https://doi.org/10.3758/s13428-021-01668-5

Casey, B. J., & Riddle, M. (2012). Typical and atypical development of attention. In *Cognitive neuroscience of attention* (S. 345–356).

Cherry, E. C. (1953). Some Experiments on the Recognition of Speech, with One and with Two Ears. *The Journal of the Acoustical Society of America*, *25*(5), 975–979. https://doi.org/10.1121/1.1907229

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201–215. https://doi.org/10.1038/nrn755

Danckaerts, M., Sonuga-Barke, E. J. S., Banaschewski, T., Buitelaar, J., Döpfner, M., Hollis, C., Santosh, P., Rothenberger, A., Sergeant, J., Steinhausen, H.-C., Taylor, E., Zuddas, A., &

Coghill, D. (2010). The quality of life of children with attention deficit/hyperactivity disorder: A systematic review. *European Child & Adolescent Psychiatry*, *19*(2), 83–105. https://doi.org/10.1007/s00787-009-0046-3

De Haan, B., Morgan, P. S., & Rorden, C. (2008). Covert orienting of attention and overt eye movements activate identical brain regions. *Brain Research*, *1204*, 102–111. https://doi.org/10.1016/j.brainres.2008.01.105

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149. https://doi.org/10.3758/BF03203267

Esteban, O., Ciric, R., Finc, K., Blair, R. W., Markiewicz, C. J., Moodie, C. A., Kent, J. D., Goncalves, M., DuPre, E., Gomez, D. E. P., Ye, Z., Salo, T., Valabregue, R., Amlien, I. K., Liem, F., Jacoby, N., Stojić, H., Cieslak, M., Urchs, S., … Gorgolewski, K. J. (2020). Analysis of task-based functional MRI data preprocessed with fMRIPrep. *Nature Protocols*, *15*(7), 2186–2202. https://doi.org/10.1038/s41596-020-0327-3

Esteban, O., Markiewicz, C. J., Blair, R. W., Moodie, C. A., Isik, A. I., Erramuzpe, A., Kent, J. D., Goncalves, M., DuPre, E., Snyder, M., Oya, H., Ghosh, S. S., Wright, J., Durnez, J., Poldrack, R. A., & Gorgolewski, K. J. (2019). fMRIPrep: A robust preprocessing pipeline for functional MRI. *Nature Methods*, *16*(1), 111–116. https://doi.org/10.1038/s41592-018-0235-4

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the Efficiency and Independence of Attentional Networks. *Journal of Cognitive Neuroscience*, *14*(3), 340–347. https://doi.org/10.1162/089892902317361886

Fan, J., Mccandliss, B., Fossella, J., Flombaum, J., & Posner, M. (2005). The activation of attentional networks. *NeuroImage*, *26*(2), 471–479. https://doi.org/10.1016/j.neuroimage.2005.02.004

Fonov, V., Evans, A. C., Botteron, K., Almli, C. R., McKinstry, R. C., & Collins, D. L. (2011). Unbiased average age-appropriate atlases for pediatric studies. *NeuroImage*, *54*(1), 313–327. https://doi.org/10.1016/j.neuroimage.2010.07.033

Gauggel, S. (2020). Neuropsychologische Grundlagen. In *Klinische Psychologie & Psychotherapie* (3. Aufl., S. 285–316). Springer, Berlin, Heidelberg.

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 312–7 years old on a stroop- like day-night test. *Cognition*, *53*(2), 129–153. https://doi.org/10.1016/0010-0277(94)90068-X

Giordano, V., Fuiko, R., Leiss, U., Brandstetter, S., Hayde, M., Bartha-Doering, E., Klebermaß-Schrehof, K., & Weiler, L. (2017). Differences in attentional functioning between preterm and full-term children underline the importance of new neuropsychological detection techniques. *Acta Paediatrica*, *106*(4), 601–611. https://doi.org/10.1111/apa.13723

Gunnar, M., & Quevedo, K. (2007). The Neurobiology of Stress and Development. *Annual Review of Psychology*, *58*(1), 145–173. https://doi.org/10.1146/annurev.psych.58.110405.085605

Hagen, J. W., & Hale, G. A. (1973). THE DEVELOPMENT OF ATTENTION IN CHILDREN1. *ETS Research Bulletin Series*, *1973*(1). https://doi.org/10.1002/j.2333-8504.1973.tb00453.x

He, H., & Razlighi, Q. R. (2022). Landmark-guided region-based spatial normalization for functional magnetic resonance imaging. *Human Brain Mapping*, *43*(11), 3524–3544. https://doi.org/10.1002/hbm.25865

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16*(3), 174–180. https://doi.org/10.1016/j.tics.2012.01.006

IBM SPSS Statistics (Version 29.0.2.0). (2023). [Windows]. IBM Corp.

Jaeger, D. A., Gawehn, N., Schneider, D. T., & Suchan, B. (2021). Phasic and tonic alertness in preterm 5-year-old healthy children. *Child Neuropsychology*, *27*(8), 1073–1087. https://doi.org/10.1080/09297049.2021.1919297

James, W. (1890). *The Principles of Psychology: Vol. 1*.

Kahneman, D. (1973). *Attention and effort*. Prentice-Hall.

Kandel, E. R. (Hrsg.). (2013). *Principles of neural science* (5th ed). McGraw-Hill.

Kang, W., Hernández, S. P., Rahman, Md. S., Voigt, K., & Malvaso, A. (2022). Inhibitory Control Development: A Network Neuroscience Perspective. *Frontiers in Psychology*, *13*, 651547. https://doi.org/10.3389/fpsyg.2022.651547

Kaufman, A. S., & Kaufman, N. L. (2016). *Kaufman Assessment Battery for Children* [Dataset]. https://doi.org/10.1037/t27677-000

Kubinger, K. D. (2019). *Psychologische Diagnostik* (3. Aufl.). Hogrefe. https://doi.org/10.1026/02779-000

Lemmin, T., Ganesh, G., Gassert, R., Burdet, E., Kawato, M., & Haruno, M. (2010). Model-based attenuation of movement artifacts in fMRI. *Journal of Neuroscience Methods*, *192*(1), 58–69. https://doi.org/10.1016/j.jneumeth.2010.07.013

Mahone, E. M., & Schneider, H. E. (2012). Assessment of Attention in Preschoolers. *Neuropsychology Review*, *22*(4), 361–383. https://doi.org/10.1007/s11065-012-9217-y

McGill, R. J. (2020). An instrument in search of a theory: Structural validity of the Kaufman assessment battery for children-second edition normative update at school-age. *Psychology in the Schools*, *57*(2), 247–264. https://doi.org/10.1002/pits.22304

Mezzacappa, E. (2004). Alerting, Orienting, and Executive Attention: Developmental Properties and Sociodemographic Correlates in an Epidemiological Sample of Young, Urban Children. *Child Development*, *75*(5), 1373–1386. https://doi.org/10.1111/j.1467-8624.2004.00746.x

Mikl, M., Mareček, R., Hluštík, P., Pavlicová, M., Drastich, A., Chlebus, P., Brázdil, M., & Krupa, P. (2008). Effects of spatial smoothing on fMRI group inferences. *Magnetic Resonance Imaging*, *26*(4), 490–503. https://doi.org/10.1016/j.mri.2007.08.006

Miller, E. K., & Cohen, J. D. (2001). An Integrative Theory of Prefrontal Cortex Function. *Annual Review of Neuroscience*, *24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Moriguchi, Y. (2014). The early development of executive function and its relation to social interaction: A brief review. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00388

Mullane, J. C., Lawrence, M. A., Corkum, P. V., Klein, R. M., & McLaughlin, E. N. (2016). The development of and interaction among alerting, orienting, and executive attention in children. *Child Neuropsychology*, *22*(2), 155–176. https://doi.org/10.1080/09297049.2014.981252

Muresan, L., Renken, R., Roerdink, J. B. T. M., & Duifhuis, H. (2005). Automated Correction of Spin-History Related Motion Artefacts in fMRI: Simulated and Phantom Data. *IEEE Transactions on Biomedical Engineering*, *52*(8), 1450–1460. https://doi.org/10.1109/TBME.2005.851484

Müsseler, J., & Rieger, M. (Hrsg.). (2017). *Allgemeine Psychologie*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-53898-8

Petersen, S. E., & Posner, M. I. (2012). The Attention System of the Human Brain: 20 Years After. *Annual Review of Neuroscience*, *35*(1), 73–89. https://doi.org/10.1146/annurev-neuro-062111-150525

Portugal, A. M., Viktorsson, C., Taylor, M., Mason, L., Tammimies, K., Ronald, A., & Falck-Ytter, T. (2022). *Infants' looking preferences for social versus non-social objects reflect genetic variation*. https://doi.org/10.31219/osf.io/fn8y5

Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience*, *13*(1), 25–42. https://doi.org/10.1146/annurev.ne.13.030190.000325

Pozuelos, J. P., Paz-Alonso, P. M., Castillo, A., Fuentes, L. J., & Rueda, M. R. (2014). Development of attention networks and their interactions in childhood. *Developmental Psychology*, *50*(10), 2405–2415. https://doi.org/10.1037/a0037469

Reynolds, C. R., & Kamphaus, R. W. (Hrsg.). (2003). *Handbook of psychological and educational assessment of children: Intelligence, aptitude, and achievement* (2nd ed). Guilford Press.

Robbins, T. W. (2007). Shifting and stopping: Fronto-striatal substrates, neurochemical modulation and clinical implications. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1481), 917–932. https://doi.org/10.1098/rstb.2007.2097

Robinson, S. D., Bachrata, B., Eckstein, K., Bollmann, S., Bollmann, S., Dymerska, B., Hodono, S., Cloos, M., Tourell, M., Jin, J., O'Brien, K., Reutens, D. C., Trattnig, S., Enzinger, C., &

Barth, M. (2023). Improved dynamic distortion correction for FMRI using single-echo EPI and a readout-reversed first image (REFILL). *Human Brain Mapping*, *44*(15), 5095–5112. https://doi.org/10.1002/hbm.26440

Rösler, M., Casas, M., Konofal, E., & Buitelaar, J. (2010). Attention deficit hyperactivity disorder in adults. *The World Journal of Biological Psychiatry*, *11*(5), 684–698. https://doi.org/10.3109/15622975.2010.483249

Rothbart, M. K., & Posner, M. I. (2001). Mechanism and variation in the development of attentional networks. In *Handbook of developmental cognitive neuroscience* (S. 353–363).

Rueda, M. R., Checa, P., & Cómbita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience*, *2*, S192–S204. https://doi.org/10.1016/j.dcn.2011.09.004

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*(8), 1029–1040. https://doi.org/10.1016/j.neuropsychologia.2003.12.012

Rueda, M. R., & Posner, M. I. (2012). *Development of Attention Networks*.

Saito, D. N., Fujisawa, T. X., Yanaka, H. T., Fujii, T., Kochiyama, T., Makita, K., Tomoda, A., & Okazawa, H. (2022). Development of attentional networks during childhood and adolescence: A functional MRI study. *Neuropsychopharmacology Reports*, *42*(2), 191–198. https://doi.org/10.1002/npr2.12246

Schäfer, J., Reuter, T., Leuchter, M., & Karbach, J. (2024). Executive functions and problem-solving—The contribution of inhibition, working memory, and cognitive flexibility to science problem-solving performance in elementary school students. *Journal of Experimental Child Psychology*, *244*, 105962. https://doi.org/10.1016/j.jecp.2024.105962

Schmidt-Atzert, L., & Amelang, M. (2012). *Psychologische Diagnostik*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-17001-0

Slattery, E. J., O'Callaghan, E., Ryan, P., Fortune, D. G., & McAvinue, L. P. (2022). Popular interventions to enhance sustained attention in children and adolescents: A critical systematic review. *Neuroscience & Biobehavioral Reviews*, *137*, 104633. https://doi.org/10.1016/j.neubiorev.2022.104633

Sternberg, R. J., & Sternberg, K. (2017). *Cognitive psychology* (Seventh edition). Cengage Learning.

Stockreiter, D., Reuss, F., Holzgreve, F., Germann, U., Oremek, G., Ohlendorf, D., & Wanke, E. M. (2024). Die Aufmerksamkeitsdefizit-/Hyperaktivitätsstörung (ADHS) am Arbeitsplatz. *Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie*, *74*(5), 234–240. https://doi.org/10.1007/s40664-024-00534-3

Sturm, W., & Willmes, K. (2001). On the Functional Neuroanatomy of Intrinsic and Phasic Alertness. *NeuroImage*, *14*(1), S76–S84. https://doi.org/10.1006/nimg.2001.0839

Tam, N. D. (2013). Improvement of Processing Speed in Executive Function Immediately following an Increase in Cardiovascular Activity. *Cardiovascular Psychiatry and Neurology*, *2013*, 1–6. https://doi.org/10.1155/2013/212767

Van De Weijer-Bergsma, E., Wijnroks, L., & Jongmans, M. J. (2008). Attention development in infants and preschool children born preterm: A review. *Infant Behavior and Development*, *31*(3), 333–351. https://doi.org/10.1016/j.infbeh.2007.12.003

Vázquez-Marrufo, M., Galvao-Carmona, A., González-Rosa, J. J., Hidalgo-Muñoz, A. R., Borges, M., Ruiz-Peña, J. L., & Izquierdo, G. (2014). Neural Correlates of Alerting and Orienting Impairment in Multiple Sclerosis Patients. *PLoS ONE*, *9*(5), e97226. https://doi.org/10.1371/journal.pone.0097226

Wahl, S., Michel, C., Pauen, S., & Hoehl, S. (2013). Head and eye movements affect object processing in 4-month-old infants more than an artificial orientation cue. *British Journal of Developmental Psychology*, *31*(2), 212–230. https://doi.org/10.1111/bjdp.12001

Weinmüller, S. (2022). *Differences in attentional functioning between preterm and fullterm born children and how these differences are mapped in the brain*. https://doi.org/10.25365/THESIS.71871

Yancey, S. E., Rotenberg, D. J., Tam, F., Chiew, M., Ranieri, S., Biswas, L., Anderson, K. J. T., Nicole Baker, S., Wright, G. A., & Graham, S. J. (2011). Spin-history artifact during functional MRI: Potential for adaptive correction. *Medical Physics*, *38*(8), 4634–4646. https://doi.org/10.1118/1.3583814

Zelazo, P. D., & Carlson, S. M. (2012). Hot and Cool Executive Function in Childhood and Adolescence: Development and Plasticity. *Child Development Perspectives*, *6*(4), 354–360. https://doi.org/10.1111/j.1750-8606.2012.00246.x

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List of abbreviations

ACC	Anterior Cingulate Cortex
ADHD	Attention Deficit Hyperactivity Disorder
ANT	Attention Network Test
ANTI	Attention Network Test for Interaction
BOLD	Blood Oxygen Level Dependent.
fMRI	Functional Magnetic Resonance Imaging
Hz	Hertz
ms	Milliseconds
OCD	Obsessive-Compulsive Disorder

Appendix

Abstract

The healthy development of attention networks is essential for cognitive functioning and plays a crucial role in social interaction and academic success. Attention, a key neuropsychological function, is thought to be organized into three networks: alerting, orienting, and executive control, which gradually matures from infancy through adolescence. This study explores the development of these networks in children aged 5.5 to 6.5 years using the Attention Network Test for Interactions (ANTI) to determine whether they can be distinguished at this age and to what extent they align with the proposed networks by Petersen and Posner. A total of 18 healthy children (5 to 6 years) underwent a comprehensive assessment, which included behavioral measures and measures from the fMRI-Scans. The mean age of the children was 5 years and 11 months and 33,3% were female. The child-friendly ANTI-Birds task was administered during functional magnetic resonance imaging (fMRI) using a 3T PRISMA scanner. Imaging data were processed using fMRIPrep with age-appropriate brain templates and analyzed using fixed-effects models in FitLins. Of the 20 children studied, data from two were excluded from the behavioral analysis, while three were excluded from the fMRI analysis. Thus, a total number of 15 typically developed children completed all study assessments. The results from 15 typically developing children indicate that the alerting network engages right frontal and parietal regions, while the orienting network involves the frontal eye fields, inferior parietal cortex, midbrain, and thalamus. The executive control network activates regions such as the anterior cingulate cortex, lateral prefrontal areas, and basal ganglia. These findings provide early insights into the organization of attention networks in preschool children

Keywords: attention networks, attention, functional magnetic resonance imaging, preschool children, attention network test for interaction

Zusammenfassung

Die gesunde Entwicklung der Aufmerksamkeitsnetzwerke ist entscheidend für die kognitive Leistungsfähigkeit und spielt eine zentrale Rolle in sozialen Interaktionen sowie im späteren akademischen Erfolg. Aufmerksamkeit ist eine zentrale neuropsychologische Funktion, die sich in drei miteinander interagierende Netzwerke unterteilen lässt: Alerting, Orienting und Executive Control. Diese Netzwerke entwickeln sich weitgehend unabhängig voneinander und durchlaufen von der Kindheit bis in die Adoleszenz unterschiedliche Reifungsprozesse. Diese Studie untersucht den Entwicklungsstand dieser Netzwerke bei Kindern im Alter von 5,5 bis 6,5 Jahren mithilfe des Attention Network Test for Interactions (ANTI), um festzustellen, ob sie innerhalb dieser Altersgruppe bereits voneinander unterschieden werden können. Insgesamt nahmen 20 gesunde Kinder (im Alter von 5,5 bis 6,5 Jahren) an einer mehrstufigen Untersuchung teil, die die Erhebung von Verhaltensdaten und Daten der fMRI-Scans beinhaltete. Das durchschnittliche Alter der Kinder betrug zum Zeitpunkt der Untersuchung 5 Jahre und 11 Monate, und 33,3 % der Kinder waren weiblich. Eine für Kinder angepasste Version des ANTI-Birds wurde während der funktionellen Magnetresonanztomographie (fMRT) in einem 3T PRISMA-Scanner vorgegeben. Die Bildgebungsdaten wurden mit fMRIPrep unter Verwendung altersgerechter Templates ausgewertet und mit Fixed-Effects-Modellen mit Hilfe der Software FitLins analysiert. Von den 20 untersuchten Kindern, wurden die Daten von 2 Kindern aus der Analyse der Verhaltensdaten und die Daten 3 weiterer Kinder aus der fMRT-Analyse ausgeschlossen. Daher schlossen insgesamt 15 Kinder alle Untersuchungen ab. Die Ergebnisse von 15 gesund entwickelten Kindern zeigen, dass das Alerting-Netzwerk rechte frontale und parietale Regionen aktiviert, während das Orienting-Netzwerk die frontalen Augenfelder, den inferioren parietalen Kortex, das Mittelhirn und den Thalamus umfasst. Das Netzwerk der exekutiven Kontrolle aktiviert Regionen wie den anterioren cingulären Kortex, laterale präfrontale Areale und Basalganglien. Diese Ergebnisse geben erste Einblicke in die neuronalen Korrelate von Aufmerksamkeitsnetzwerken bei Vorschulkindern.

Stichwörter: Aufmerksamkeit, Aufmerksamkeitsnetzwerke, funktionelle Magnetresonanztomographie, Vorschulkinder

Handbook "Ich schaffe das MRT"

Ich schaffe das fMRT

Weiler-Wichtl, L.J., Fohn-Erhold, V., Leiss, U. & Schwarzinger, A.

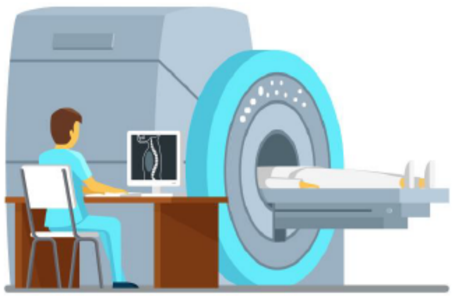
MEIN LOG BUCH

Infos zum funktionellen fMRT

Alles, was ich über das fMRT wissen muss!

Die Magnetresonanztomographie, kurz MRT, ist wie eine ganz große Kamera mit der man Bilder vom Körperinneren machen kann, um zu sehen, was in deinem Körper los ist.

Weißt du was man alles über das fMRT wissen muss?



Beim **fMRT**, das ist die Abkürzung für das komplizierte Wort **funktionelle Magnet-resonanztomographie**, wird geschaut, wie genau dein Körper arbeitet. Wie dieses Wort schon verrät, hat das etwas mit einem Magneten zu tun. Wie du wahrscheinlich schon weißt, ziehen Magnete metallische Dinge an. Der Magnet vom MRT befindet sich in einem großen Gehäuse in einem eigenen Raum. Manche nennen das fMRT auch **Röhre**, weil es irgendwie ja auch so aussieht.

Jetzt bekommst du ein paar ganz wichtige Informationen, wie die fMRT-Untersuchung abläuft.

MEIN LOG BUCH

Ich schaffe das MRT

Damit die Bilder von deinem Körper gemacht werden können, legst du dich auf die Liege des fMRT-Geräts.

Um gute Bilder zu bekommen, ist es besonders wichtig, ganz ruhig liegen zu bleiben. Zur Unterstützung gibt es daher oft sogenannte **Lagerungshilfen**, die sind so ähnlich wie große Polster.

Wer soll dich zur Untersuchung begleiten?

Werden Bilder von deinem Kopf gemacht, bekommst du so eine Art Spezialhelm (**Spule**) aufgesetzt. Über einen Spiegel kannst du einen Cartoon anschauen oder das Computerspiel durchführen.

Wenn die Bilder dann gemacht werden, macht der Magnet richtig laute **Klopfgeräusche**. Damit das aber nicht stört, bekommst du dicke Kopfhörer und/oder Ohrstöpsel. In die Hände bekommst du eine Joystick, mit dem du das Übungsspiel durchführen kannst.

Puuh, da muss man eine ganze Menge beachten.

Frag nach, wie die meisten Kinder das so machen – da gibt es bestimmt ein paar Tipps und Tricks!

Lass uns gemeinsam herausfinden, wie du dich am besten vorbereiten kannst!

Ich schaffe das MRT

MEIN LOG BUCH

SO BEREITE ICH MICH VOR

☐ ______________________________

☐ ______________________________

☐ ______________________________

☐ ______________________________

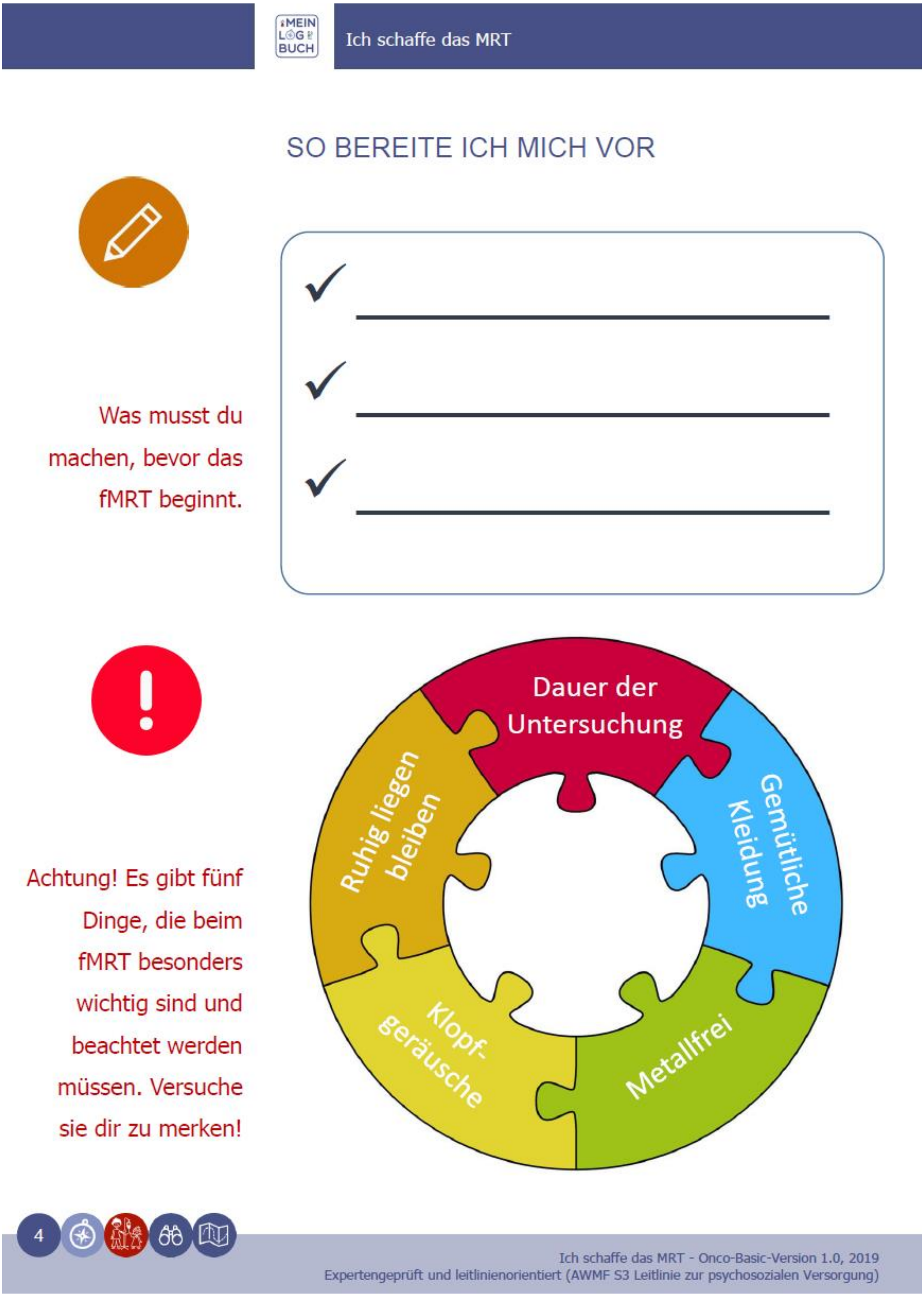
☐ ______________________________

☐ ______________________________

Ich schaffe das fMRT!!!

Weißt du eigentlich, warum du ein fMRT machen musst?

Weiler-Wichtl, L.J.[1], Fohn-Erhold, V.[1], Leiss, U.[1] & Schwarzinger, A.[1,2]
[1]Medizinische Universität Wien, [2]Österreichische Kinder-Krebshilfe



MEIN LOG BUCH

Ich schaffe das MRT

SO BEREITE ICH MICH VOR

Was musst du machen, bevor das fMRT beginnt.

✓ ____________________

✓ ____________________

✓ ____________________

Achtung! Es gibt fünf Dinge, die beim fMRT besonders wichtig sind und beachtet werden müssen. Versuche sie dir zu merken!

Dauer der Untersuchung

Gemütliche Kleidung

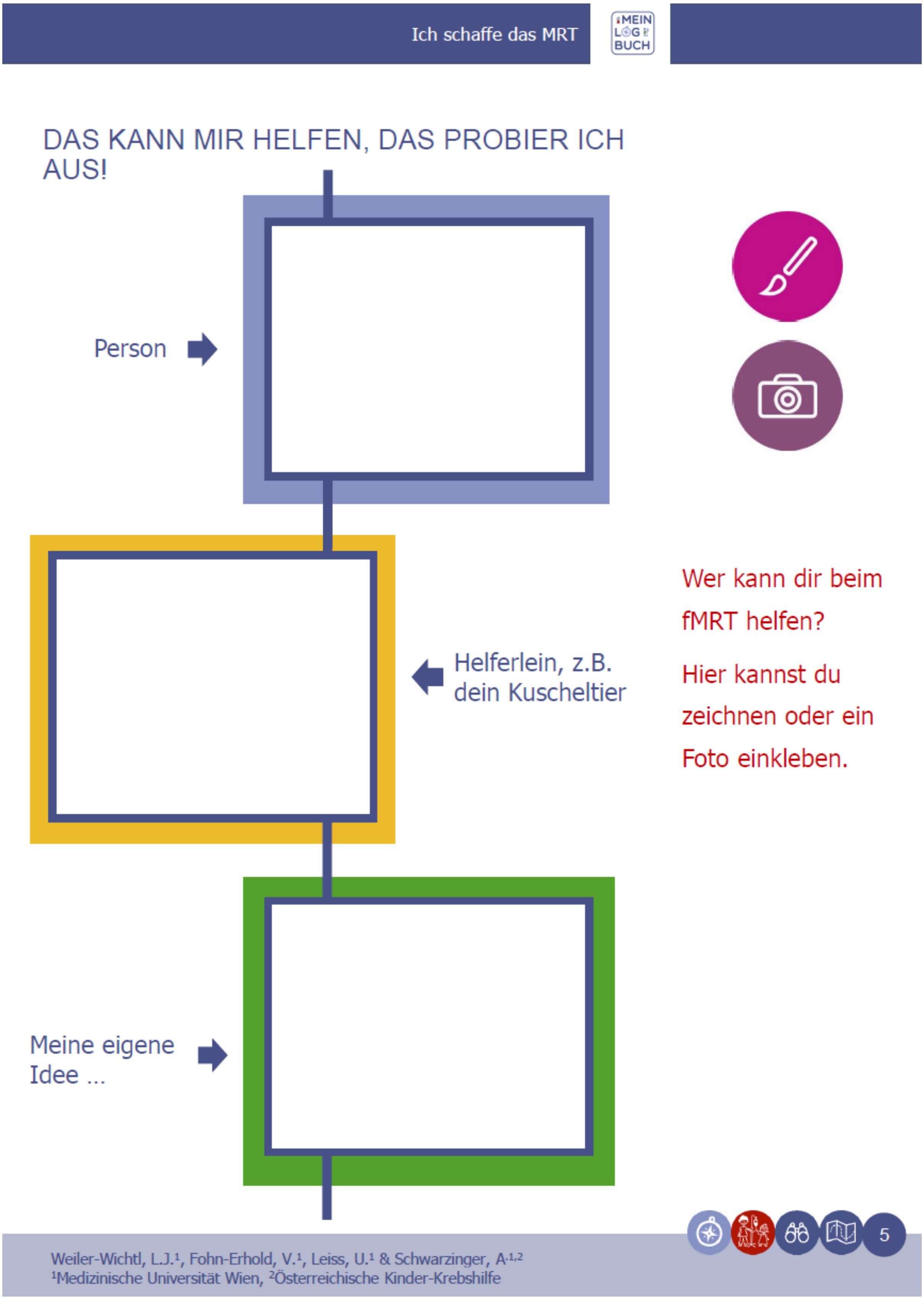
Metallfrei

Klopf-geräusche

Ruhig liegen bleiben

4

Ich schaffe das MRT - Onco-Basic-Version 1.0, 2019
Expertengeprüft und leitlinienorientiert (AWMF S3 Leitlinie zur psychosozialen Versorgung)



Ich schaffe das MRT

MEIN LOG BUCH

DAS KANN MIR HELFEN, DAS PROBIER ICH AUS!

Person

Helferlein, z.B. dein Kuscheltier

Meine eigene Idee …

Wer kann dir beim fMRT helfen?

Hier kannst du zeichnen oder ein Foto einkleben.

Weiler-Wichtl, L.J.[1], Fohn-Erhold, V.[1], Leiss, U.[1] & Schwarzinger, A.[1,2]
[1]Medizinische Universität Wien, [2]Österreichische Kinder-Krebshilfe

5

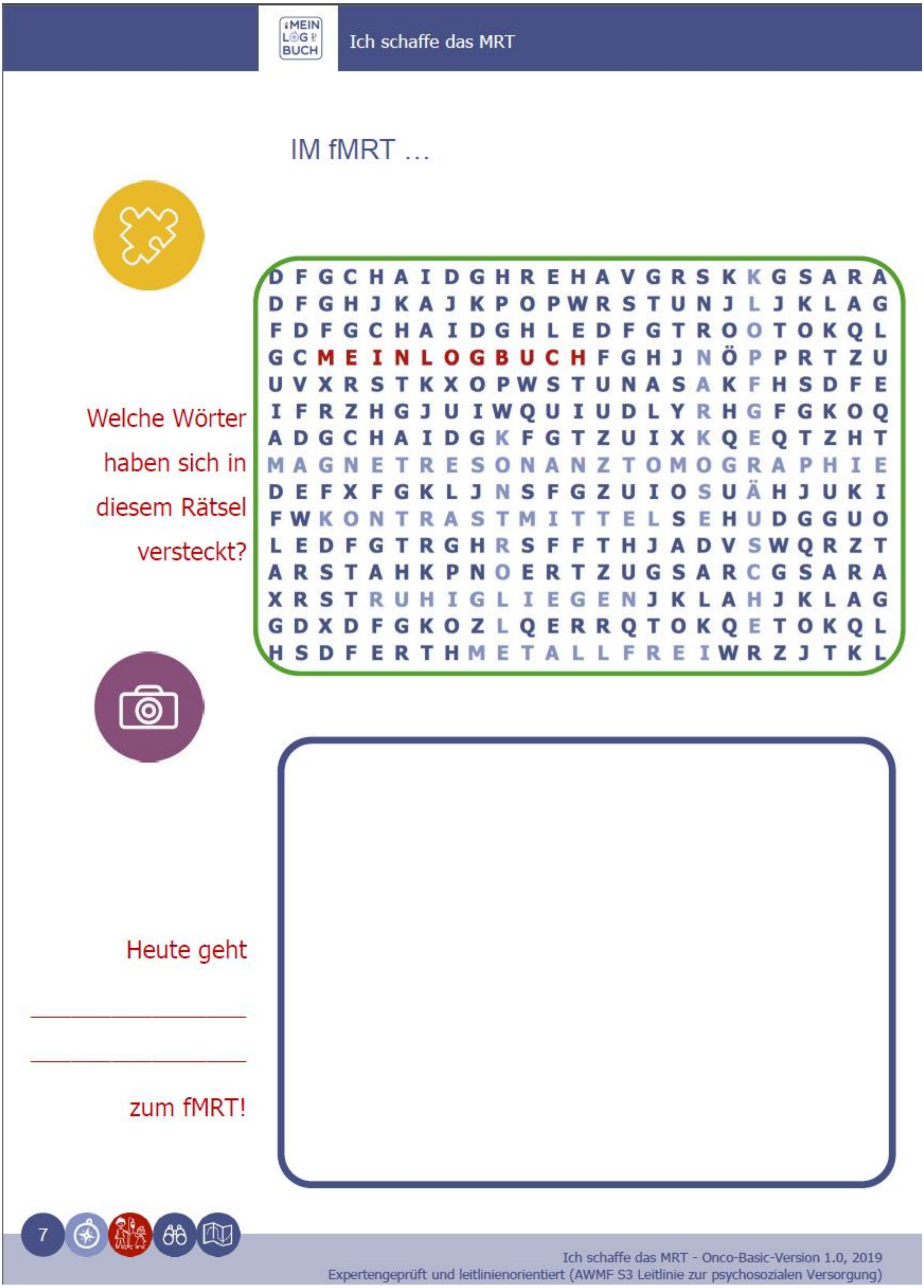
TRAINING – ICH HABE FLEISSIG GEÜBT!

Bitte übe, ruhig liegen zu bleiben, zusammen mit der Person, die dich zum fMRT begleitet. Für jede Übungseinheit kannst du dies hier kennzeichnen!

Die Geräusche vom fMRT findet man auch im Internet ... und mit ein bisschen Fantasie kann man sich ein MRT zum Üben bauen.

So lange kann ich schon ruhig liegen bleiben! Notiere deine Bestzeit!

Weiler-Wichtl, L.J.[1], Fohn-Erhold, V.[1], Leiss, U.[1] & Schwarzinger, A.[1,2]
[1]Medizinische Universität Wien, [2]Österreichische Kinder-Krebshilfe



MEIN LOG BUCH

Ich schaffe das MRT

IM fMRT …

Welche Wörter haben sich in diesem Rätsel versteckt?

D	F	G	C	H	A	I	D	G	H	R	E	H	A	V	G	R	S	K	K	G	S	A	R	A
D	F	G	H	J	K	A	J	K	P	O	P	W	R	S	T	U	N	J	L	J	K	L	A	G
F	D	F	G	C	H	A	I	D	G	H	L	E	D	F	G	T	R	O	O	T	O	K	Q	L
G	C	M	E	I	N	L	O	G	B	U	C	H	F	G	H	J	N	Ö	P	P	R	T	Z	U
U	V	X	R	S	T	K	X	O	P	W	S	T	U	N	A	S	A	K	F	H	S	D	F	E
I	F	R	Z	H	G	J	U	I	W	Q	U	I	U	D	L	Y	R	H	G	F	G	K	O	Q
A	D	G	C	H	A	I	D	G	K	F	G	T	Z	U	I	X	K	Q	E	Q	T	Z	H	T
M	A	G	N	E	T	R	E	S	O	N	A	N	Z	T	O	M	O	G	R	A	P	H	I	E
D	E	F	X	F	G	K	L	J	N	S	F	G	Z	U	I	O	S	U	Ä	H	J	U	K	I
F	W	K	O	N	T	R	A	S	T	M	I	T	T	E	L	S	E	H	U	D	G	G	U	O
L	E	D	F	G	T	R	G	H	R	S	F	F	T	H	J	A	D	V	S	W	Q	R	Z	T
A	R	S	T	A	H	K	P	N	O	E	R	T	Z	U	G	S	A	R	C	G	S	A	R	A
X	R	S	T	R	U	H	I	G	L	I	E	G	E	N	J	K	L	A	H	J	K	L	A	G
G	D	X	D	F	G	K	O	Z	L	Q	E	R	R	Q	T	O	K	Q	E	T	O	K	Q	L
H	S	D	F	E	R	T	H	M	E	T	A	L	L	F	R	E	I	W	R	Z	J	T	K	L

Heute geht

____

____

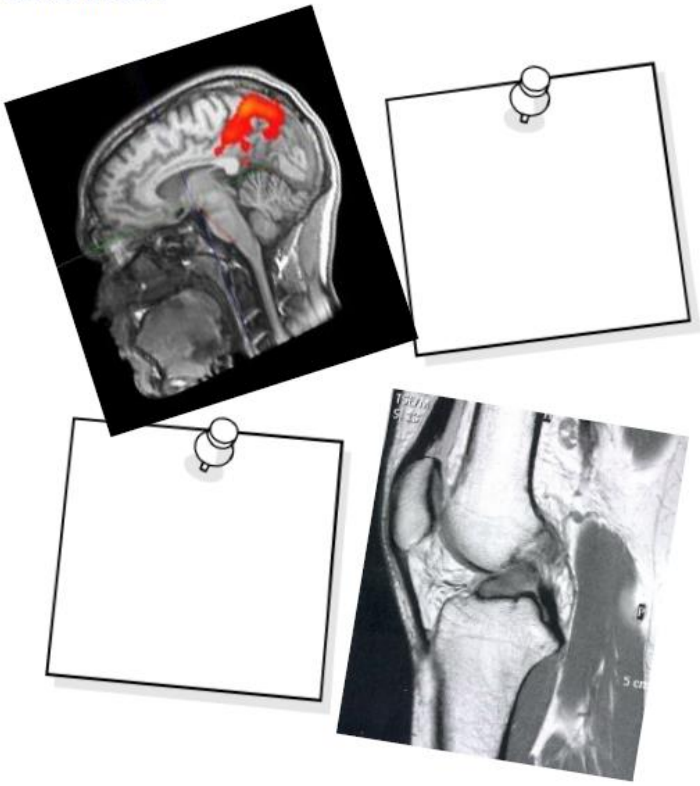
zum fMRT!

7

Ich schaffe das MRT - Onco-Basic-Version 1.0, 2019

Expertengeprüft und leitlinienorientiert (AWMF S3 Leitlinie zur psychosozialen Versorgung)

MRT Profi – was kannst du auf den Bildern erkennen?



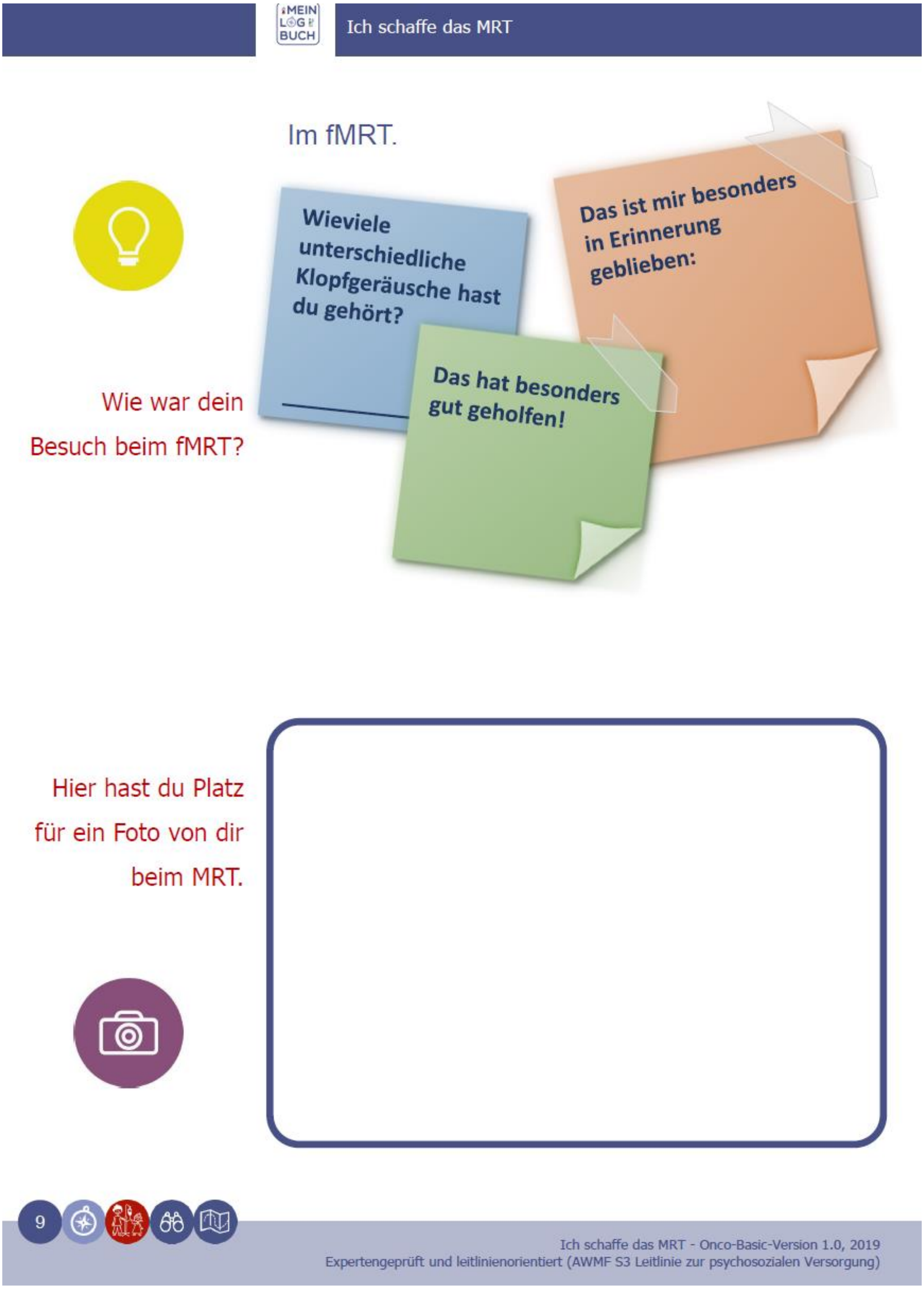
So sieht ein fMRT-Bild aus!

Was kannst du auf den Bildern erkennen?

Warum muss ich ruhig liegen?

Ahhh – jetzt sehe ich den Unterschied!

Weiler-Wichtl, L.J.[1], Fohn-Erhold, V.[1], Leiss, U.[1] & Schwarzinger, A.[1,2]
[1]Medizinische Universität Wien, [2]Österreichische Kinder-Krebshilfe



MEIN LOG BUCH

Ich schaffe das MRT

Im fMRT.

Wieviele unterschiedliche Klopfgeräusche hast du gehört?

Das ist mir besonders in Erinnerung geblieben:

Das hat besonders gut geholfen!

Wie war dein Besuch beim fMRT?

Hier hast du Platz für ein Foto von dir beim MRT.

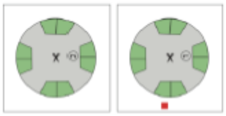
9

Ich schaffe das MRT - Onco-Basic-Version 1.0, 2019
Expertengeprüft und leitlinienorientiert (AWMF S3 Leitlinie zur psychosozialen Versorgung)

Bastelanleitung für dein eigenes MRT

Wir beginnen mit der Röhre:

Gestalte zuerst die Oberfläche des MRTs wie du gerne möchtest.



- Schneide Nr.1 und Nr.2 des Vorlagebogens aus und die graue Fläche in der Mitte. Die Klebeflächen mit den Punkten bleiben erhalten und werden entlang des Kreises nach innen gebogen.

- Schneide nun Nr.3 aus und und falte die Flächen an der gekennzeichneten Linie. Nun kannst du diesen Teil so um die beiden ersten Teile kleben, dass eine Röhre entsteht.

- Nr.4 wird die Hülle des MRTs. Schneide sie aus, falte sie an den gekennzeichneten Stellen und klebe sie um die Röhre.

Du brauchst

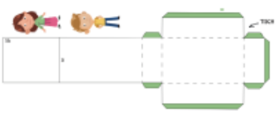
1 Schere, 1 Kleber

& bunte Stifte ...

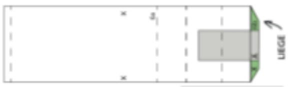
Überlege wer dir

dabei helfen kann!

Nun gestalten wir die Liege:



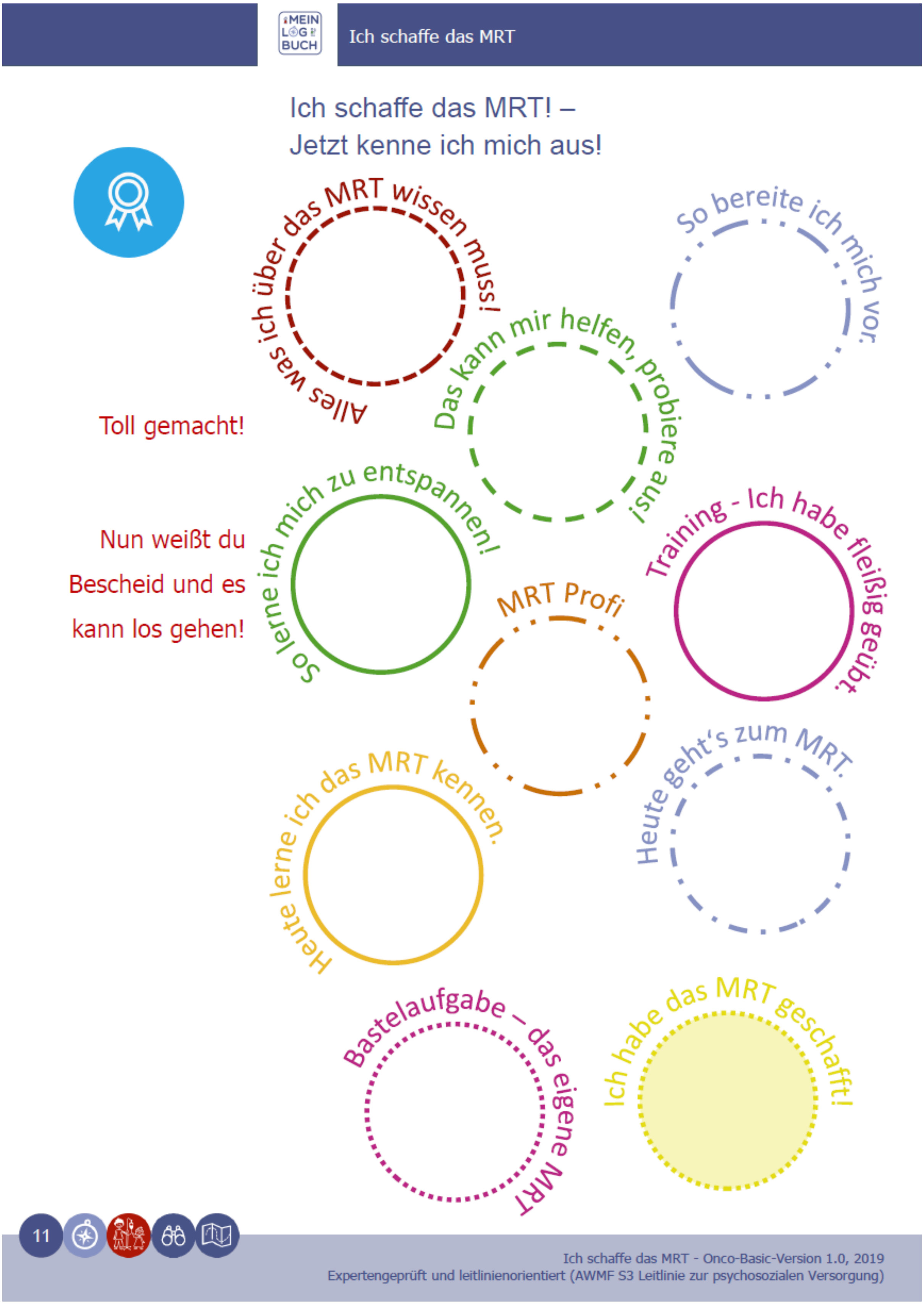
- Schneide Nr.5 aus und falte die gekennzeichneten Linien. Klebe die Kreuzchen zusammen, sodass eine kleine Box mit Verlängerung entsteht. Du kannst nun den Tisch mit der Verlängerung in die Röhre legen.



- Die verschiebbare Liege (Nr.6) wird nun ebenfalls ausgeschnitten, gefaltet und an den Kreuzchen zusammengeklebt. Sie ist nun bereit, dass du sie in das MRT hineinlegst.

Jetzt musst du dir nur noch eine Figur suchen, die darin Platz hat und dein MRT ausprobieren kann.

Weiler-Wichtl, L.J.[1], Fohn-Erhold, V.[1], Leiss, U.[1] & Schwarzinger, A.[1,2]
[1]Medizinische Universität Wien, [2]Österreichische Kinder-Krebshilfe


MEIN LOG BUCH

Ich schaffe das MRT

Ich schaffe das MRT! –
Jetzt kenne ich mich aus!

Alles was ich über das MRT wissen muss!

So bereite ich mich vor.

Das kann mir helfen, probiere es aus!

Toll gemacht!

So lerne ich mich zu entspannen!

Training - Ich habe fleißig geübt.

Nun weißt du
Bescheid und es
kann los gehen!

MRT Profi

Heute lerne ich das MRT kennen.

Heute geht's zum MRT.

Bastelaufgabe – das eigene MRT

Ich habe das MRT geschafft!

11

Ich schaffe das MRT - Onco-Basic-Version 1.0, 2019
Expertengeprüft und leitlinienorientiert (AWMF S3 Leitlinie zur psychosozialen Versorgung)