Neurophysiological indicators of emotional and cognitive maturation of the human brain in the mirror of emerging and developing dreams in children

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final report

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GENERAL INTRODUCTION AND AIMS OF THE PROJECT

Most developmental studies have a narrow focus of investigation and examine the behavioral, cognitive, emotional or neural aspects of children's functioning separately. The main aim of our study is to break with this approach and move towards a more holistic one: to investigate maturation by evaluating together and comparing directly indices of sleeping, dreaming and awake behavior. We examine and interpret the traditionally well-measured and discussed awake cognitive and emotional aspects of behavior – such as IQ, attention, executive functioning, working memory, emotional processing and coping, temperament, etc. – in a broader framework: relating them to measures of dreaming and dream quality (an unconscious mirror of cognitive -emotional development) and to the indices of brain maturation and neural functioning.

We chose to investigate the neural background in the sleeping state. This approach seems an optimal choice as children spend more than half of their first 10 years asleep (Iglowstein, Jenni, Molinari, & Largo, 2003), the intertwined nature of sleep and wakefulness is now widely accepted, moreover sleep represents an ideal state to study the developing brain because it minimizes possible confounding factors related to waking activities such as level of attention and distractibility, motivation or cognitive capacity (Jenni & Dahl, 2008).

REM sleep is associated with vivid oneiric experiences in adults and in verbal aged children. Since REM sleep has a defined developmental pattern from fetal age to adulthood, some authors assume that the case is similar with dreaming as well (Staunton, 2001). Others assume that dreaming is a cognitive achievement dependent on the maturation of the visuospatial fields of the brain, and thus the formation of dreams is impossible for children with underdeveloped visuospatial skills, that is approximately until the age of 2 years (Foulkes, 1982, 1999). In fact the formation and development of human dreaming is still unknown in spite of the inspiring results from adult dream research that associates dreaming with emotional and cognitive development as well as neural connectivity (Ross Levin & Nielsen, 2009; Maquet et al., 1996, 2005; Nielsen & Levin, 2007).

Current literature on brain maturation and on dreaming show that various measures of both phenomena are associated or even dependent on cognitive and/or emotional achievements. The aim of this study is to test these associations in order to form a more inclusive and comprehensive picture of development in conscious and unconscious territories of human functioning. We examine children between 4 and 8 years of age, in a relatively narrow age range which is associated with important developmental changes in dreaming, cognitive and emotional functioning.

STRUCTURE OF THE PROJECT: STUDIES AND HYPOTHESES

Study 1. Formal and content related characteristics of children’s dreams

Given the controversies of developmental dream research we needed to provide a general description about the state and changes of formal and content related dream characteristics between 4 and 8 years of age. Thus, we critically reconsidered the field, systematically compared the findings based on different methodologies, and highlighted the advantages and disadvantages of methods, arguing in favor of methodological pluralism.

Study 2. The development of children’s dreaming, brain, cognitive and emotional functioning

Our hypothesis were:

1. HT: The frequency, length and complexity of dream reports are positively associated with
    a. intelligence (memory, verbal and visuospatial abilities, visual pattern recognition with analogy finding) and executive functioning (measured by neuropsychological tests)
    b. emotional regulation (as measured by neuropsychological tests)
    c. antero-posterior ratio of NREM sleep slow wave activity (a recently proposed index of brain maturation)
    d. *inter- and intrahemispheric EEG synchronization during REM sleep*

2. HT: The emotional quality of children's dreams as well as the developmentally relevant features of the dream plot (self-representation, self induced activities, human characters, interactions and cognitive activities) are positively correlated with
    a. emotional regulation (measured by neuropsychological tests, frontal asymmetry of the sleep EEG and *EEG coherence*).
    b. intelligence and executive functioning (measured by intelligence and neuropsychological tests.)

Study 3. Cognitive development and brain maturation: associations with fronto-parietal brain connectivity and measures of NREM sleep EEG sigma activity

Our hypothesis was:

3. HT: Measures of intelligence and neuropsychology are positively associated with individual values of centro-parietally measured NREM sleep EEG sigma power, fast sleep spindling and fronto-parietal brain connectivity.

Study 4. Sleep Quality, Emotional Behavior and Dreaming in Childhood

We hypothesized that the markers of enhanced arousal during the night (such as difficulties falling asleep, waking after sleep onset, sleep duration or parasomnias) are connected to emotional symptoms and dream characteristics such as recall frequency and bizarreness. Moreover emotional symptoms are also connected to indicators of arousal and therefore are important factors in shaping dream characteristics and recall.

METHODOLOGY AND STEPS OF THE PROJECT

Step 1. Assessment of dreaming and behavioural variables

40 healthy children and their parents were recruited for this study (age: 4 to 8.5 years, mean: 6.3 years, SD: 1.6). *Dreams* were obtained from the children upon morning awakenings over a 6 week period of time in form of a structured dream interview conducted by the pre-trained parents. Tests of *intelligence, executive functioning and of emotional maturation* were carried out in a laboratory environment. For measure details see our submitted research proposal.

Step 2. Assessment of cortical functioning

A subsample of 36 children (age range: 3.8-8.4 years, find more details on participants below) underwent 10/20 polysomnographic monitorings (EEG, EOG, EMG, ECG; see Image 1.) of nighttime sleep on two consecutive nights in our sleep laboratory accompanied by their parents or close relatives. Gold-coated Ag/AgCl EEG cup electrodes were fixed with EC2 Grass Electrode Cream (Grass Technologies, USA). Impedances were kept below 15 kΩ. Signals were collected, prefiltered (.33–1,500 Hz, 40 dB/decade anti-aliasing hardware input filter), amplified, and digitized with 4,096 Hz/channel sampling rate (synchronous) with 12 bit resolution by using the 32 channel EEG/polysystem (Brain-Quick BQ 132S, Micromed, Italy). A further 40-dB/decade anti-aliasing digital filter was applied by digital signal processing which low-pass filtered the data at 450 Hz. The digitized and filtered EEG was undersampled at 1,024 Hz. Recordings were referenced to the mathematically linked mastoids (A1+A2) and also to the average of all derivations (AVG).

Image 1. 6.25 years old girl prepared for polysomnographic recording of nighttime sleep (photo: S. Sz.)

Only the recording of the second night was analyzed. Visual macrostructural analysis of the sleep recordings was carried out by an experienced sleep researcher based on the latest criteria in the literature (Rechtschaffen stb; Iber et al, 2007) in 20 sec epochs using a self-developed software, FerciosEEG (© 2009-2014. Ferenc Gombos). 9 recordings were excluded from further analysis: 6 were part of the pilot research and could not be used in the correlational studies, 3 could not be analyzed due to technical reasons (electronical noise in the laboratory). In the final sample there were 27 subjects (3.8-8.4 years, 6.17±1.5

years; 18 females, 3 age groups: 1. age group (4.64±0.45 years), 2. age group (5.94±0.29 years), 3. age group (8.14±043 years)).
Artifact rejection was carried out manually with FerciosEEG as well in 4 sec epochs before further automatic analyses. Poor quality electrodes were excluded from further analysis. Average power spectral densities (1 Hz to 50 Hz) were calculated by a mixed-radix Fast Fourier Transformation (FFT) algorithm applied to the 50% overlapping, Hanning-tapered 4 sec windows of the EEG signal of the electrodes. Relative spectral power values were obtained for each frequency bin (width: 0.25 Hz) by dividing the absolute power of the given frequency bin with the total spectral power (the sum of the absolute power of the whole range of analysis between 1–30 Hz). Spectral analysis was carried out on the first 8.5 hours of NREM (stage 2, 3) and REM sleep and also on the first 1 hour of NREM sleep. Further, more specific data analysis is always described at the specific studies' methodology section.

STUDIES

Study 1. Formal and content related characteristics of children's dreams

Background of Study 1.

Looking at the available data emerging from different sampling procedures it seems obvious that different methods suit different research objectives, but they also seem to have an effect on the outcomes. It is not accidental that the most passionate debate of dream research has long been the question of setting. Although Foulkes, who systematically compared children's dreams under home and laboratory conditions found no significant difference between dreams from the two settings (Foulkes 1979), other studies of young children's dreams conducted in different settings found dream reports to be richer in motion, self-representation, human characters and interactions (Honig and Nealis 2012; Resnick et al. 1994).

Now aiming to find a compromise between the two sharply differing approaches of neutrality and familiar environment we propose a home based study with well-established methodological details.

Results of Study 1.

1. *Report rate and length*

Children recalled dreams at 21% of the morning interviews, which is a recall rate similar to Foulkes' reports (1982, 1999) on 3-5-year-olds, however we found no significant age-dependent change in dream report rate in our study. Regarding report length children improved from 38 words (Group 1: 3,8-5 years) to 58 words (Group 2 and 3: 6-6,5 and 6,5-8 years, respectively) on average. The most prominent difference from Foulkes' results here is yielded by the youngest age group, but if we compare the average report length to a home study by Colace (2010), we see rather similar results (35 words for the 3 to 5-year-olds, and 41 for the 5 to 7-year-olds).

2. Dream characters and active self representation

Active self-representation was relatively high in the dream reports of all age groups of our study appearing in 78% of the dreams. Although values showed an increasing trend across the age groups, differences did not reach statistical significance. Thus, we did not confirm Foulkes' results (Foulkes 1982), who only found 17% of preschoolers' dreams depicting an active self. In contrast, other non-laboratory studies reported values as high as 59% (Honig and Nealis 2012) or 85% (Resnick et al. 1994) in preschoolers' dreams.

In addition to the self-portrayal of the dreamer there were several other characters clearly and unambiguously mentioned in the dream reports of the 4-8 years old children (3.13 characters/dream report on average).

3. Kinematic imagery and actions

The present results are in coherence with Honig and Nealis' study (2012) as we found that children reported motion in the majority of their dreams (86% on average, 80% amongst preschoolers). The above results on self-reported movements were further confirmed by counting explicit self-initiated actions in the dream reports. We found 4.7 actions per dream on average (3.8 for the youngest age group) and 90% of the dreams contained at least one action.

4. Social interactions

We found that social interactions are present in almost every dream report (0.92 interactions per dream). Although the number of interactions is equally distributed among the age groups, the relative ratio of aggressive interactions does show a significant increase and the relative ratio of friendly interactions a decrease across the age groups.

5. Cognition and emotion in the dreams

Although only 15% of the dream reports of the youngest age group contained verbs reflecting cognitive effort and metacognitive activity, this value gradually grew to 39% amongst the 7-8.5-year-olds (see Fig.1)). Thus proving that high-order cognition is present in children's dreams and it gets more prominent with increasing age.

We found an average of 0.85 emotions per dream report which ranges from 0.72 in the youngest age group and reaches almost one emotion per dream (0.99) in the oldest (see Fig 1). In line with the adult findings (Hall and Van de Castle, 1966) the number of dreams containing at least one emotion ranges between 61% (Group 1) and 66% (Group 3), which is divergent from Foulkes' 8% in the preschoolers' group (Foulkes 1982).

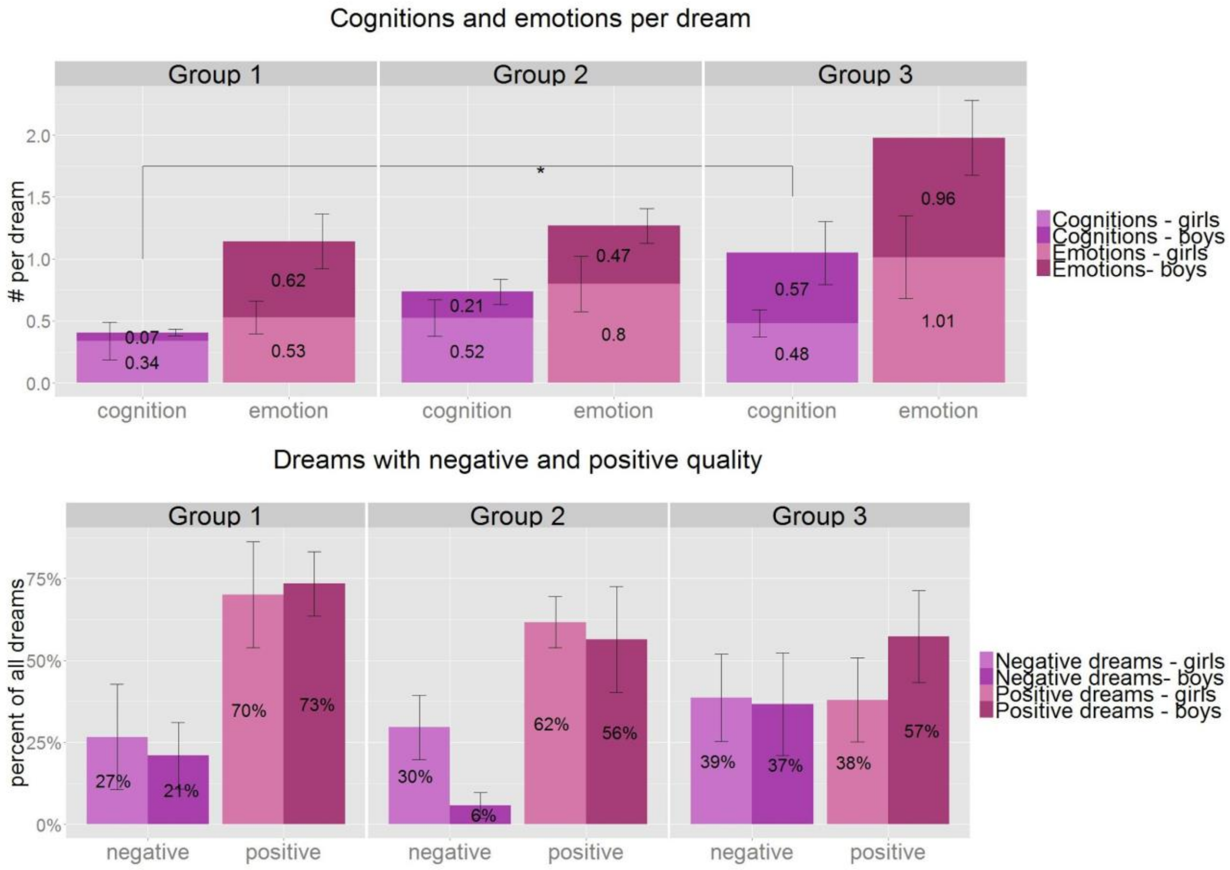

Figure 1. Above: the average number of cognitive verbs and emotions per dream by gender and age group. Below: The ratio of dreams with negative (purple) and positive (pink) dream quality by gender and age group.

Discussion of Study 1.

Our results support the basic concept of Foulkes' claiming that children's dream narratives follow a developmental pattern of some kind. The age-related increase in the lengths, self-initiated actions, and cognitions in the dream reports are the subject of maturation and growth during ontogenesis. At the same time, the results also suggest that even at a preschool age the level of most measures of dreams are significantly closer to adult standards than the laboratory based approach had concluded. Foulkes hypothesized that immature symbolization skills of preschool aged children have a direct effect on the dream experience itself. Consistently with other home and school based studies we found a high level of active participation of the dreamer's self in preschoolers dream narratives together with a relatively high level of self-initiated actions and kinematic imagery. Recent studies of children's waking spatial imagery indicate that preschool aged children have the ability to mentally represent movements and rotation (Newcombe & Frick 2010). Moreover, Fonagy and his coworkers (Fonagy et al. 2004) have shown that children as young as 3 years old are able to understand and engage in pretense play, which requires the simultaneous symbolic representation of the outer and inner reality. Based on these studies, as well as on our current findings we assume that even preschoolers are able to represent mental imagery such as vivid and eventful dream scenarios.

Furthermore, our results suggest that emotions are significant and relevant components of even young children's dreams. This finding helps us to bring together the results of developmental and adult dream research and to evaluate them in a common theoretical framework.

Study 2. The development of children's dreaming, cortical, cognitive and emotional functioning

General background of Study 2.

Isolated pieces of evidence show a possible parallel development between characteristics of *dream* reports and cognitive maturation. In a series of studies of children's dreams, they found the Block Design test from the Wechsler Intelligence Scale for Children to be a stable correlate of dream report frequency (Foulkes, 1982; 1999; Foulkes, Hollifield, Sullivan, Bradley, & Terry, 1990). Surprisingly, neither working memory tests nor verbal skills predicted reliably the rate of dream recall in the above study. Another study (Colace, 2010) showed a correlation between dream bizarreness and various cognitive abilities, like linguistic skills, long term memory capacity, attention span, symbolization, visuo-spatial skills and superego development.

Overlapping neuro-anatomical structures also show a close relationship between cognitive -emotional prefrontal functioning and REM sleep, thus supporting psychological models of dreaming that connects dreaming with the dreamer's affective experiences and supposes an emotion regulation function of dreams (Cartwright, Luten, Young, Mercer, & Bears, 1998; Cartwright, 2011; Nielsen & Levin, 2007). Special dream contents and characteristics has also been associated with the functioning of the above mentioned brain areas. For instance according to Nielsen and Levin's neurocognitive theory, emotionally loaded dreams especially nightmares can be a consequence of a disruption in the cooperation of the emotionally loaded subcortical areas and prefrontal-cortical areas (including the anterior cingulate cortex), which are unable to down-regulate those emotions, resulting in ineffective emotional regulation (Nielsen & Levin, 2007). Nightmare sufferers were also found to exhibit impaired measures of waking frontal executive functions in neuropsychological tests compared to healthy subjects (Simor, Pajkossy, Horváth, & Bódizs, 2012).

Thus it is plausible to assume that specific characteristics of dreaming such as dream recall frequency, bizarreness or emotional tone could be associated with intelligence and frontal-neuropsychological measures. The ongoing maturation of the prefrontal cortex and executive, emotional processing functions in childhood are supposed to be directly associated with the development of dreaming in children.

Sleep spindling is a result of thalamocortical resonance. It emerges from the synchronized hyperpolarization-rebound sequences of the thalamocortical neurons, the inhibition of which is caused by the NREM-dependent activation of GABAergic neurons in the reticular thalamic nucleus (Huguenard and McCormick, 2007; Steriade, 2000). Sleep spindles are tigthly related with neuroplasticity, cortical development and cognitive functioning (Cirelli and Tononi, 2014; Bódizs et al., 2014; Ujma et al., 2014). Given these findings, we aimed to unravel the hypothesized associations between individual measures of sleep spindling and cognitive functioning.

Deep (slow wave) sleep is characterized by extensive maturational changes across the developmental trajectory of humans in parallel to a massive synaptic remodeling in the brain and cortical maturation both structurally and behaviorally (Buchmann et al., 2011). *NREM slow wave activity* (SWA, EEG spectral power between 1-4.5 Hz) decreases during childhood in parallel with a recently reported back-to-front shift in its topographical distribution (Kurth et al, 2010). Moreover, this shift was hypothesized to reflect the development of specific functions and skills over the age range of 2-26 years, cohering with the concept of caudo-rostral pattern of cortical maturation (Kurth et al, 2012) meaning roughly that electrophysiological, structural and behavioral maturation processes work early at the posterior cortical areas of vision and with time move gradually towards the frontal areas responsible for executive functioning. We aimed to test the associations of the maturational level of SWA with cognitive performance and the indices of dreaming in a narrower age range by investigating the relationships between the topographical distribution of SWA, executive functions.

Methodology of Study 2.

Dreaming As indicated in the hypotheses section we expected significant correlations in the areas of dream content that proved to be developmentally most relevant according to previous findings (Foulkes, 1982; Sándor et al, 2014) and our own content analysis results (see Study 1).

1. Dream recall frequency measured by the number of dreams recalled during the 6 weeks of data collection period upon morning awakenings.
2. Dream report length and complexity measured by the number of words and the number of verbs in the reports respectively.
3. Active self -representation.

4. Actions and interactions in the dreams (especially dreamer initiated activities including gross-motor verbal and exploratory activities as well as success of the dreamer).
5. Cognition measured by verby reflecting cognitive activity and self reflective thoughts.
6. Emotional quality of the dreams (including the number of emotions experienced, the emotional quality and the dream's emotional impact on the next morning's mood).

Sleep spindling was assessed by applying the Individual Adjustment Method (IAM) of sleep spindle analysis to the NREM phases of sleep in the first 8,5 hours of polysomnographic recordings of the second night.

In order to measure the *topographical distribution of delta waves* subgroup-specific delta power (1-4,5 Hz) maps (see Figure 3.) were created. In addition we calculated the delta power ratios of the electrodes on the antero-posterior midline as follows: Fpz/Fz, Fz/Cz, Cz/Pz, Pz/Oz, Fpz/Cz, Cz/Oz, Fpz/Oz.

We also calculated the antero-posterior center of gravity of delta power by weighted averages of all electrodes (weights were derivation-specific delta power values, while the locations were specified according to the 10-20 system of the standard EEG in %).

Moreover we calculated the SWA Maturation Index (SWAMI) based on the method of (Kurth et al, 2012). Delta power (1-4,5 Hz) of the electrodes was normalized (delta power for each subject and each electrode was divided the mean delta power across all subjects for the specific electrode) in order to account for regional delta power differences with age and to identify the age which is associated with the highest delta power in every cortical region. The 6 brain regions associated with specific skills (Kurth et al, 2012) were defined in the 10-20 electrode placement system as the following: (1) vision: O1, O2 (2) visuomotor: P3, Pz, P4 (3) simple motor: C3, Cz, P4 (4) complex motor: F3, Fz, F4 (5) language: F7, F8, T3, T4, T5, T6 (6) cognitive control: Fp1, Fp2. For each region we calculated the average of delta power of these derivations. SWAMI was calculated for each subject and each skill based on the location of the maximum delta power. If the delta power maximum was in the region of a specific skill, the SWAMI was scored 0 for that skill, for the rest of the regions the index was calculated based on the hypothesized direction of brain maturation (from region (1) to region (6)): areas supposed to mature earlier received a positive, areas supposed to mature later received a negative number, the value of the number was determined by the distance of the 0 scored region.

Skill variables associated with the investigated regions were z-transformed.

EEG synchronization was assessed by the weighted phase lag index (WPLI) on groups of predefined electrode pairs in both NREM and REM sleep phases. The electrode pairs were grouped as follows: seed region (frontal, centro-temporal, posterior) × hemisphere (left, right) × cross-hemispheric coupling (intra- and interhemispheric).

Results of Study 2.

1. *Intelligence and executive functions*

a. Correlations with measures of intelligence

The number of verbal actions per dreams correlated positively with the vocabulary subtest of the WISC IV. (tau= .24, p= .03).

Interestingly, we found no significant correlations with other measures of intelligence and either of the dream variables. Thus, our findings diverge from the results of laboratory studies concluding that dream recall frequency is dependent on visuo-spatial skills measured by the Block Design subtest of the Wechsler intelligence scale.

b. Correlations with neuropsychological tests

Fruit Stroop Test: Incongruency Index, which indicates executive effectiveness measured by reaction times, was correlated with dreamer initiated actions (tau= -.31, p= .006) (gross-motor activities, exploratory activities) and interactions (tau= -.22, p= .04) as well as with success per dreams (tau= -.31, p= .006). The ratio of correct answers (Accuracy) in the Stroop test was correlated with active self-representation in the dreams correlated positively with the level of accuracy of incongruent stimuli in the fruit stroop test (tau= .24, p= .028).

The number of dreamer initiated gross-motor activities per dreams (tau= .26, p= .02) was also associated with the accuracy measures in the Stroop test in case of incongruent stimuli.

Attention Network Test (ANT):

Alerting Network: Alerting is defined as achieving and maintaining an alert state is measured by reaction times and proved to be associated with emotional quality of the dreams. Dreams with negative quality (bad dreams) were negatively correlated with the Alerting Network (tau= -.24, p= .04) as opposed to neutral quality of the dreams with had a positive correlation with it (tau= .23, p= .04).

Orienting Network: Orienting is the selection of information from sensory input, is measured by reaction times and was associated with the number of positive emotions per dreams (tau=- .26, p= .02).

Conflict Network: Executive control is defined as resolving conflict amongst responses is measured by reaction times and was correlated with the ratio of dreams that had an effect on the children's daytime mood self rated right after the morning dream reports (tau= -.27, p= .02).

Accuracy: The ratio of correct answers in the ANT was correlated with the number of dreamer initiated gross-motor activities per dreams (tau= .22, p= .04) in case of incongruent stimuli.

2. Emotional regulation

Emotional Stroop for children:

Emotional Interference Index: As a measure of the effectiveness of emotional processing by reaction times, Emotional Interference Index was correlated with activities resulting in success (tau= -.26, p= .02) and friendly interactions in the dreams (tau= -.24, p= .03). Emotional processing was also associated with the ratio of dreams that had an affect on the children's daytime mood (tau= - .33, p= .004, see Fig 2.).

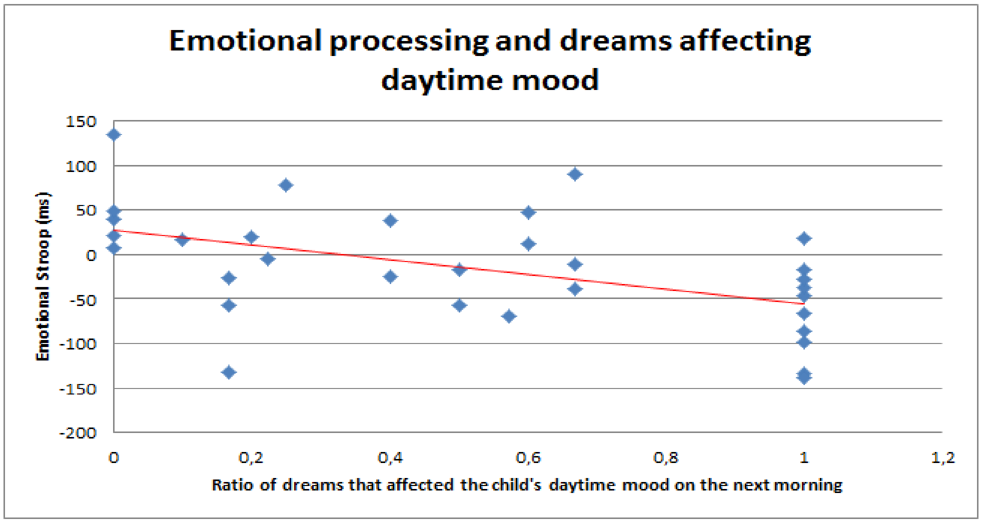

Figure 2. The correlation between Emotional Interference Index and the ratio of dreams that had an effect on the children's daytime mood

Frontal asymmetry of sleep spindling

According to previous studies right frontal EEG asymmetry is correlated with negative affect expression in adults (Fox, 1994) and in children (Forbes et al., 2008). The activation of the left frontal cortex is associated with positive emotions, as it is shown in studies mainly investigating in the alpha range of EEG power (Coan & Allen, 2003). Evidence from our studies on adult subjects strongly suggest a left hemispheric dominance in sleep spindling in the vast majority of the right-handed participants. Moreover, growing dominance of the left hemisphere is known to be a developmental feature of the maturing brain, thus is expected to be correlated with more frequent dream recall and more complex dream reports, indicated by more activities, interactions, active-self representation and cognitive verbs in the dreams.

Left-lateralized frontal sleep spindling:

As we predicted, dream recall frequency correlated with the relative left-to-right hemispheric [(left-right)/(left+right)] frontopolar dominance of fast sleep spindle density (tau= 0.38, p= 0.01).

In parallel with the above finding, activities in the dreams with successful outcomes were also associated with the relative left frontal dominance in slow sleep spindle density (tau= 0.44, p= 0.005).

Interestingly, and in contrast with our predictions, the ratio of fearful emotions per all emotions in the dreams also were correlated with a left dominance of frontal activation in both slow (tau= 0.45, p= 0.006) and fast spindle density (tau= 0.35, p= 0.03).

Right-lateralized frontal sleep spindling:

Active self-representation in the dreams were associated with right frontal activation measured by fast spindle amplitude (tau= -0.38, p= 0.01). Both of the latter two findings contradict our hypotheses.

3. Antero-posterior ratio of NREM sleep slow wave activity

Cognitive measures were positively associated with age. There were few and not systematic significant correlations between the various variables of the topographical distribution of delta power and age. Multivariate ANOVA did not reveal differences in the three age groups in the delta power measures: nor in the delta power ratios of the electrodes on the antero-posterior midline neither in the location of the antero-posterior center of gravity of delta power.

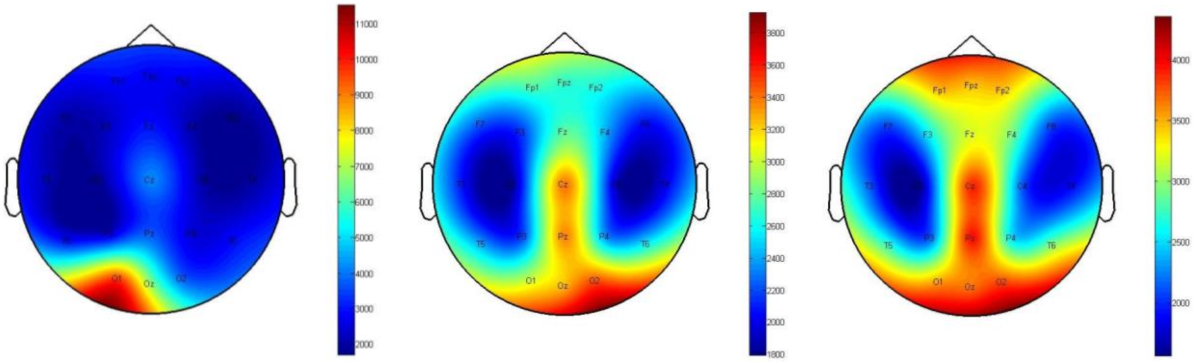

Figure 3. Delta (1-4.5 Hz) power maps of the 3 age groups (from left to right: 1. age group (4.64±0.45 years), 2. age group (5.94±0.29 years), 3. age group (8.14±043 years)) based on the spectrum analysis of the first 60 min of NREM sleep referenced to AVG.

The significant correlations with the skill variables were also scarce and not straightforward.

The SWA Maturational Indices were in line with previous findings: the maturation of the regions were following the known caudo-rostral pattern, except for the visuomotor region (see Table 1.).

	vision	visuomotor	simple motor	complex motor	language	cognitive control
no of subjects	4	2	8	5	3	5
age: mean±SD (years)	5.5±1.7	6.1±2.3	5.7±1.3	6.2±1.2	6.2±0.1	7.2±1.3

Table 1. Maturation of SWA topography as reflected in mean ages for maximum delta power at the investigated brain regions

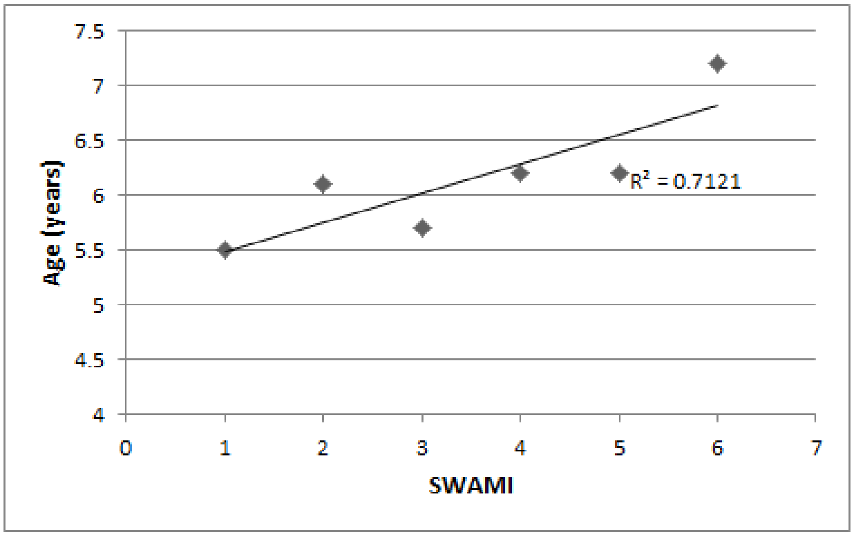

Figure 4. Mean age associated with the highest delta power in specific brain regions involved in: (1) vision (2) visuomotor (3) simple motor (4) complex motor (5) language (6) cognitive control. SWAMI - Slow wave activity maturational index

Relationship between the SWA Maturational Indices and skills (see Figure 5.) were tested with Spearman correlation. We found a significant correlation (R=0.4; p=0.03, n=27) between the SWAMI for cognitive control and z-scored RAVEN results, which became insignificant if controlled for age.

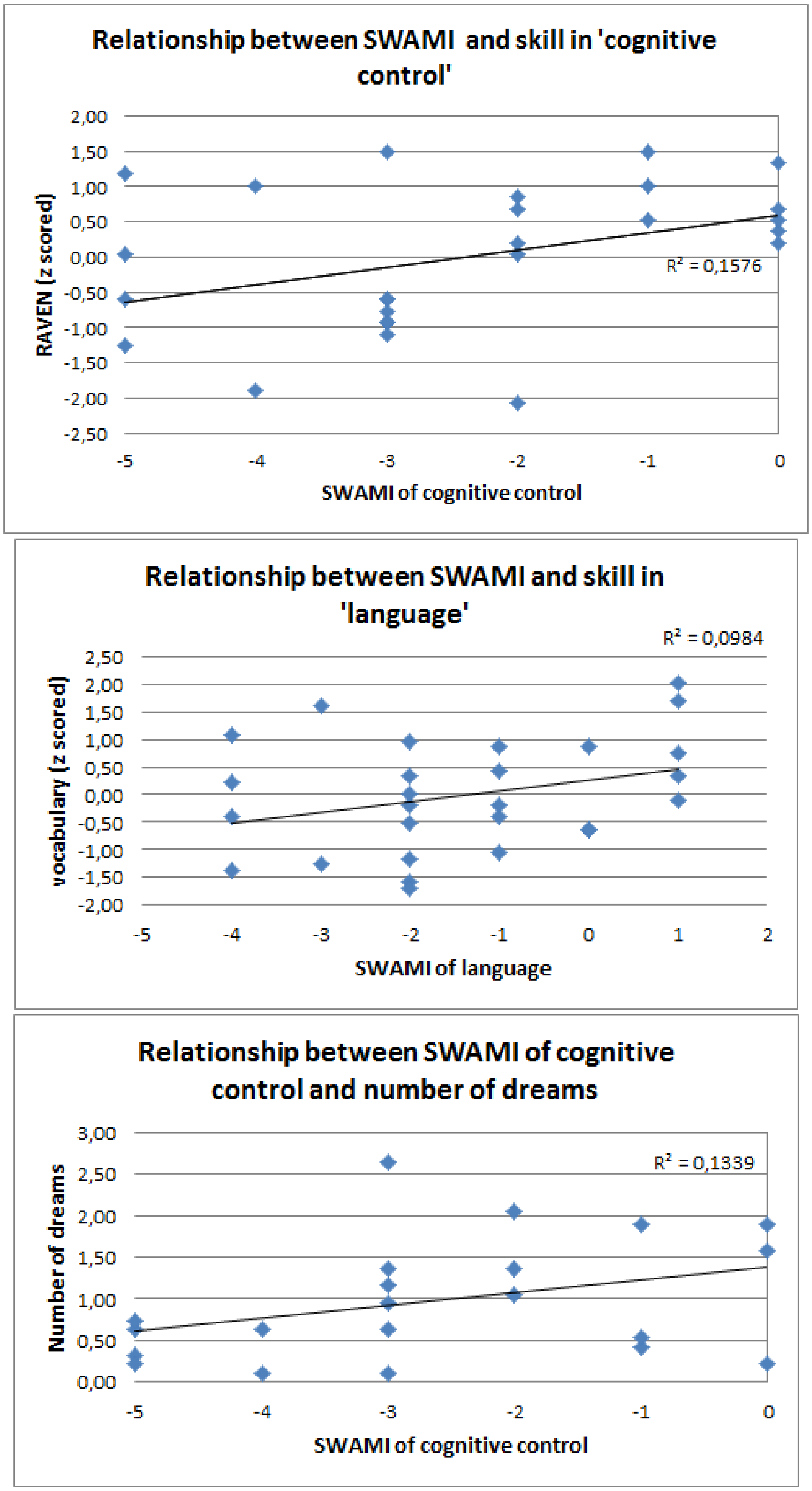

Figure 5. Relationship between the SWA Maturational Index for specific regions and skills hypothesised to be associated with these brain regions. The associations were found to be non-significant.

4. *Inter- and intrahemispheric EEG synchronization during REM sleep*

We revealed a series of correlations highlighting the importance of NREM sigma, REM sleep high alpha-low beta power in dreaming. The participation of the active self, the successful outcomes of dreamed actions, as well as neutral and positive dream qualities (affective tone) correlated negatively with inter and intrahemispheric synchronization in the 11-15 Hz. On the other hand, negative emotions in dreams were positively correlated with this measure. The dominant involvement of REM sleep in the above effect was clearly evident, however NREM sleep showed a similar pattern of relationships with dream features.

Discussion of Study 2

Active self-representation correlated positively with accuracy measures of the Stroop test. The presence of an active self of the dreamer in the dreams might be a signal of elevated self-awareness during REM sleep, which hypothesis is supported by Blagrove, Bell, & Wilkinson (2010) who found that self awareness in lucid dreams correlates with better performance in the standard Stroop test as measured by reaction times.

The activity of the dreamer and other characters in the dreams also turned out to be correlates of executive skills: the number of activities per dream and the successful outcome of activities in the dreams were positively correlated with the ability to process and select incongruent information in the Stroop test.

The ability to achieve and maintain an alert state, to select relevant information from sensory input and to resolve conflict amongst responses required for cognitive tasks, were all associated with emotional aspects of dreams and dreaming. This association indicated the close interplay between cognitive and emotional neural networks in the brain as predicted by the Nielsen-Levin model (2007).

Emotional processing measured by emotional Stroop was correlated with activities in the dreams and the dream’s effect on the daytime mood.

Left frontal EEG asymmetry was associated, as hypothesized, with elevated dream recall and richer dream reports in terms of successful activities.

Interestingly fearful emotions were also associated with left frontal asymmetry in the present sample which diverges from the literature data in connection with negative emotions. Although previous results were calculated with differences in the spectral power of the alpha band (8-12 Hz) of the EEG (Davidson, 2004), which might behave in a slightly different way than spindles (11-16 Hz) during NREM sleep.

Regarding the caudo-rostral cortical maturation the few significant correlations we found could not confirm the robust positive associations of delta power topography with age and cognitive functions. The posterior-anterior maturational pattern could only be caught by the SWA Maturational Index of (Kurth et al, 2012), but associations with behavioural data were non-significant in this case as well. In sum we could say that the caudo-rostral shift of delta power distribution may be a global cortical developmental pattern, but the examination of a narrower age range at higher resolution suggests that a more subtle approach and/or higher subject number is needed to map the relationships between the topography of sleep-related cortical functioning and maturational level of cognitive skills in children.

Our findings on EEG synchronization contradicts our previous hypothesis suggesting that network connectivity is a maturational index reflecting the advancements in the ontogenesis of dream production. Instead of this general finding, our results suggest that the REM sleep high alpha-low beta power (11-15 Hz) is an index of negative emotionality in dreams of children. This coheres with our already published findings on adult subjects showing that REM sleep high alpha activity is an index of frequent nightmare sufferance.

In study two we aimed to make a first step towards a general characterization of the associations in the development patterns of children's abilities on a behavioural (intelligence and neuropsychological tests), on a subconscious (characteristics of dream reports) and on a directly neural (through sleep EEG) level between the ages of 4 and 8 years. As regarding the associations of dreaming and neuropsychological tests, results seem to support the general idea of an interplay between the subcortical emotional and prefrontal-cortical regulatory brain areas during REM sleep and dreaming. This interplay maturates during the preschool ages. However, the picture becomes less clear as we test the direct neural data from the polysomnographic measures. It seems like that the measures of developmental EEG patterns used in the literature today are still not fine and specific enough to highlight differences in this narrow age range of 4 to 8 years.

Study 3. Cognitive development and brain maturation: associations with fronto-parietal brain connectivity and measures of NREM sleep EEG sigma activity

Background of Study 3

Increasing evidence supports the bidirectional relationship between sleep spindle oscillations and higher order cognitive abilities. Former studies focused mostly on adult subjects but a few reports on adolescents as well as preadolescent children are available in the literature. Several studies support the positive association between individual measures of sleep spindle intensity and cognitive ability (intelligence). However, a significant sexual dimorphism of the effect is also evident. No study analysed the relationship between sleep spindle features and cognitive performances (intelligence) in preschoolers. Here we aim to extend fill this gap by a deliberate investigation of the hypothesized relationship between sleep spindling and cognition/intelligence in 4-8 years old children. Although we do not originally planned to investigate the differences between girls and boys, the recent findings lead us to test the presumed sexual dimorphism of these relationships.

Methods of Study 3

NREM sleep EEG was analysed by FFT and binwise (0,25 Hz) spectral power was correlated with IQ (Coloured Raven Progressive Matrices), Block Design, as well as Digit span measures. In addition, outcomes from the formerly mentioned Individual Adjustment Method (IAM) of sleep spindle analysis of NREM sleep were correlated with the above mentioned measures of cognitive performances. Multiple testing was corrected by using the Descriptive Data Analysis technique delimiting so called Rüger areas.

Results and Discussion of Study 3

No significant correlation between sigma power and the cognitive variables were revealed in our study. In contrast to our hypothesis delta (bins between 0,5 and 5 Hz) correlated positively with IQ and other cognitive measures. Moreover, our findings reveal a positive association between fast sleep spindle density (spindles/minutes of NREM sleep) and the Block Design score (rmax = .47; p = .01 at Fp1). No other correlations survived the correction for multiple testing. As regarding the sexual dimorphism of the effect the following findings were revealed: fast sleep spindle density correlates with IQ in boys (rmax = .63; N = 14; p = .01 at derivation Fz), but not in girls. The effect is due to an age-related increase in fast sleep spindle density in boys. In conclusion there is weak evidence for the relationship between sleep spindling and mental abilities in children as young as 4-8 years of age. Specific cognitive measures like the visuo-spatial ones might be predictable on the basis of fast sleep spindle density, while individual differences in general mental ability are only reflected in age-mediated differences in fast spindle density of boys. Given the low number of subjects in these latter analyses, as well as the opposite results in adolescents and adults (the IQ of women, but not men is reflected in spindling) these results should be treated with precaution.

Study 4. Sleep Quality, Emotional Behavior and Dreaming in Childhood

Background of Study 4.

Evidence from developmental dream research shows a strong correlation between age and dream recall frequency as well as the amount of bizarre contents in dreams (Colace, 2010; Foulkes, 1982; Resnick et al., 1994). Hypotheses based on adult studies show the possibility that dream recall and report characteristics are dependent on arousal levels, circa/ultradian modulations during sleep (Chellappa & Cajochen, 2013; Rosenlicht, Maloney, & Feinberg, 1994). Bizarreness is one of the core features of dreaming that has been associated with social and cognitive development (Colace, 2010; Foulkes, 1982; Resnick et al., 1994) and also arousal and activation levels during sleep (Colace, 2003). Emotional difficulties and trauma were also associated with elevated arousal levels and both enhanced dream recall and bizarreness in dreams (Foulkes, Larson, Swanson, & Rardin, 1969; Punamäki, Ali, Ismahil, & Nuutinen, 2005).

Methods of Study 4

Dream Bizarreness was coded according to the guidelines of Revonsuo and Salmivalli (1995).

Sleep quality was described by the macrostructural data (measuring the time in sec for sleep duration, slow wave sleep duration, REM and NREM duration, waking after sleep onset duration and wake duration altogether and calculating sleep efficiency) and by the indices of the Child Sleep Habits Questionnaire (CSHQ, Owens, Spirito, & McGuinn, 2000).

To access emotional symptoms and profile we used the Strength and Difficulties Questionnaire (SDQ) (Goodman, 2001).

Results of Study 4

In this sample of healthy children subjective measure of sleep quality was associated with the objective PSG measures in some basic features, thus showing the validity of the used methods (for example CSHQ bedtime resistance correlated positively with PSG wake duration (p=0.02, tau=0.42) and negatively with sleep efficiency (p=0.01, tau=-0.44)). The number of bizarre elements in the dreams showed significant correlation with total sleep problem scores in the CSHQ (p=0.03, tau=0.25) and PSG Waking After Sleep Onset (WASO) measures (p=0.008, tau=0.45). Dream report frequency was not correlated to any of the sleep quality measures but showed a connection with the emotional difficulties indicated by SDQ (p=0.001, tau=0.36). Dream report rate was not significantly increasing with age but the number of dreams with at least one bizarre element showed a significant increase (p=0.046, tau=0.22) with age from 4 to 8 years.

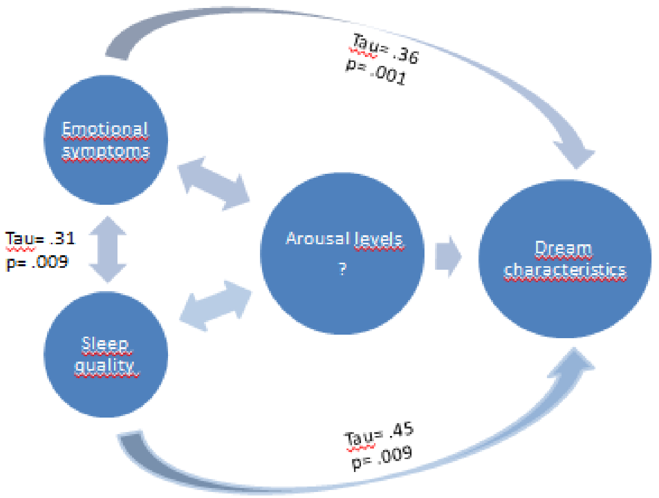

Figure 6. The hypothesized model of the relationship between sleep quality, emotional symptoms and dream characteristics mediated by arousal levels.

Discussion of Study 4

As previously shown in adults, sleep quality and emotional regulation are both related to each other and aspects of dreaming. Dream recall frequency is related to emotional symptoms but not sleep quality and bizarreness is related to sleep quality but not emotional symptoms. Thus it is likely that both sleep problems and emotional symptoms would be mediated by a common factor such as arousal. To test an independent measure of arousal or anxiety would be useful for further research, thus as a next step we plan to include alpha and beta power during REM and NREM sleep in the study as measure of arousal level during sleep.

Surprisingly preschoolers in this study reported the same amount of dreams as the 7-8-year-olds, showing that dream report frequency might not be so strongly dependent on cognitive abilities as previously thought, but may be more connected to the children's emotional coping mechanisms. Emotional difficulties may modulate arousal levels both in waking life and in sleep which in turn might affect sleep quality and dream characteristics, such as recall frequency and bizarreness. Recent neuro-cognitive theories in adult dream research, based on evidence provided by neuroimaging techniques, appreciate the crucial role of REM sleep and dreaming in emotional regulation. These findings show children's development in sleep and dreaming relative to emotional regulation to be continuous and extendable to adult research.

GENERAL DISCUSSION OF THE PROJECT

As formal and content-related aspects of dreaming, as well as objective measures of sleep, including sleep architecture, EEG power and connectivity measures are subjects of dramatic developmental changes in children we aimed to find support for our thesis through the implicit assumptions based on it. We found support for the involvement of executive functions and attentional control in the development of dreaming in preschoolers. That is, the claims of the Nielsen and Levin (2007) model on the involvement of anterior cingular/prefrontal cortices in the overall elaboration of dreaming and control of subcortical-limbic structures gets indirect support from our data. We consider this an important step in the long needed convergence of the models of dreaming in adults and children. The desperate need for this convergence is further supported by our findings on the comparability of children's dream reports with the adult standards in many respects. In order to obtain such kind of introspective data from children of 4-8 years of age a deliberate dream sampling method characterized by both familiarity and objectivity is needed. We developed such dream sampling method and suggests its implementation in future studies on dreaming in children.

Many of the parallel changes in objective neural measures of sleep and subjective or behavioural measures during both sleep and wakefulness were tested in the present work. Only a few parallel changes revealed reliable, inherent interrelationships, however. Hemispheric laterality (left hemispheric dominance) in sleep spindling was shown to index the developmentally acquired complexity in dreaming, while the deliberate analysis of the caudo-rostral developmental pattern of the brain as revealed by topographic distribution of delta power over the scalp resulted in marginal effects only. Although the majority of the hypotheses on brain-mind relationships were not supported in our study a set of new predictions were initiated by the unpredicted findings, such as the relationship between nighttime arousal, dreaming and wakefulness-related emotional problems in children or the specific neural synchronization processes related to negative dream emotionality. The solution of the hard problem of finding the convergence between neural and behavioural developmental processes needs further scientific investigations.

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