Session A

Watching the brain during the acquisition on new words with rich and poor meaning: an ERP study

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Behavioural studies have consistently shown that semantic richness (the amount of meaning a word contains) can affect performance across a wide variety of tasks, with rich semantics associated with faster word processing. Despite the importance of semantic richness, very little is known about its effects during word learning. The current study investigated the acquisition of novel words associated with many semantic features (rich) and few semantic features (poor) in English as a second language. Twenty-three bilingual Dutch-English speakers fluent in their second language participated in the study. They were presented with novel words (e.g., hoaf, luspy) followed by a sentence that described their meaning and contained few semantic features (e.g., has leaves and branches) or many (e.g., is black, brown or white, and is domestic). Each novel word was presented seven times throughout the study. EEG recording took place during each of the presentations of the words. We found that the number of semantic features (with which the novel words were presented) modulates word learning as reflected in N400 and LPC amplitudes. N400 amplitude was higher for novel words associated with many semantic features, which might reflect more effortful processing, harder (automatic) access to meaning, or increased difficulty during semantic integration. We also observed LPC reductions for words learned with many features, which seems to indicate difficulty in conscious semantic access and evaluation of new words during learning. These findings suggest that semantic richness does not facilitate word processing during learning, but only after new representations have been established.

Neuronal plasticity during foreign language learning in adulthood

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Verbal communication displays one of the most essential cognitive functions in everyday social life. As globalization grows, being proficient in several languages gains more and more importance even in later stages of life. Hence, it seems crucial to investigate neuronal processes of foreign language learning in adulthood. In the present project, at first an implicit semantic training was conducted with healthy adults who were raised with German as their only native language. In this 20-minutes-long training, pseudowords were acoustically presented via loudspeakers, each combined with a simultaneous visual presentation of a real object on the computer screen. Afterwards, just learned picture-pseudoword-pairings were presented again alongside with new, unknown pairings. Subjects had to decide whether they recognized the respective combination.

Electrophysiological and vascular responses were assessed simultaneously by means of electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS). Both neuroscientific methods are soundless and easily combinable in a relatively natural setting, thus being ideal for the investigation of acoustic stimuli. The EEG excellently tracks online processing mechanisms with an exquisite temporal resolution whereas the fNIRS provides a good spatial resolution of the recruited brain areas.

EEG results showed larger amplitudes for unknown picture-pseudoword-pairings compared to learned pairings. This suggests a greater effort to access the mental lexicon when processing unknown and therefore unlearned picture-word-pairings. fNIRS results confirm these findings by revealing greater activations in temporal brain areas. Results of the present project underline the fascinating plasticity of the adult brain during foreign language learning, even after such a short semantic training.

How the brain attunes to complex sentence processing: The tripartite relationship between cognitive, brain structural, and brain functional maturation

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The observation that brain-related changes and the decrease of neural plasticity occur parallel to changes in language learning suggest a certain causality between these processes. However, concrete evidence for the tripartite relation between brain development, language processing, and language performance is rare. In order to address the complex interplay of different maturational factors, participants' ability to process complex sentences was related to cognitive abilities (verbal working memory), brain structure (gray matter probability), and brain functional activation in different age-groups (5–6 years, 7–8 years, and adults). In total, 59 children and 21 adults were tested. Our functional analysis revealed the activation of a qualitatively similar neural network in children and adults during sentence processing including the left pars opercularis, the left inferior parietal lobe together with the posterior superior temporal gyrus, the supplementary motor area, and the cerebellum. Furthermore, correlational analyses indicate that complex sentence processing is not only related to cognitive and brain structural maturation of these areas but that verbal working memory expansion and structural maturation are strongly associated with the development of brain functional activation in language-relevant brain areas. Moreover, resulting functional selectivity of these regions is associated with more efficient sentence processing. Our finding of differences in sentence processing between 5- to 8-year old children and adults on the basis of immature cognitive abilities and immature brain structure has important implications for early language intervention programs.

Working memory moderates the relationship between domain-specific skills and mathematics achievment

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Large individual differences in children's mathematics achievement are observed from the start of schooling. Previous research has identified three cognitive skills that are independent predictors of mathematics achievement: procedural skill, conceptual understanding and working memory. However, most studies have only tested independent effects of these factors and failed to consider moderating effects. We explored the procedural skill, conceptual understanding and working memory capacity of 75 children aged 5 to 6 years as well as their overall mathematical achievement. We found that, not only were all three skills independently associated with mathematics achievement, but there was also a significant interaction between them. We found that levels of conceptual understanding and working memory moderated the relationship between procedural skill and mathematics achievement such that there was a greater benefit of good procedural skill when associated with good conceptual understanding and working memory. Cluster analysis also revealed that children with equivalent levels of overall mathematical achievement had differing strengths and weaknesses across these skills. This highlights the importance of considering children's skill profile, rather than simply their overall achievement.

Using artificial orthographies and fMRI to investigate abstraction along the ventral visual stream

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Learning to read involves abstracting from surface form to recognise letters independent of case, font, size, and position (e.g., b is the same in BAD and cab). This is because the goal of reading acquisition is to understand how written words correspond to spoken language. Neuroimaging research suggests that such abstraction is achieved by ventral occipitotemporal cortex (vOT; e.g., Dehaene et al., 2005). We used Representational Similarity Analysis (RSA; Kriegeskorte et al., 2008) of fMRI data to examine the nature of this abstraction for newly learned artificial orthographies. Specifically, we asked which regions a) represent letters as opposed to basic visual form, b) abstract across position, and c) abstract from visual form to capture sound or meaning. 24 adults learned to read two sets of 24 pseudowords written in different artificial orthographies. Following two weeks of training, neural activity was measured with fMRI whilst participants read the learned words. Analysing neural patterns for items from the same orthography revealed that posterior vOT represented letters not basic visual form and did not show position abstraction. In contrast, mid-to-anterior vOT did show position abstraction – neural patterns were similar for words containing the same letters in different positions. Comparing neural patterns for items from different orthographies revealed that left anterior vOT abstracted from orthography entirely – neural patterns were similar for items with overlapping sounds or meaning, despite distinct visual forms. Our findings show that mid-to-anterior vOT abstracts across letter-position and that the representations in left anterior vOT are phonologically and semantically structured.

Domain-general predictors of mathematics skills in 4-year-olds: The role of executive functions and language skills

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Having proficient mathematics skills provides a strong foundation for success in various areas of life. In recent years it has been found that general cognitive abilities such as executive functions and language skills play an important role. However, little is currently known about the specific contribution of working memory, inhibitory control, and language skills to early mathematics skills in 4-year-olds. The preschool years are particularly important for mathematics' development research, since they provide an appropriate window to investigate how individual differences in domain-general abilities relate to mathematics skills. A sample of 72 children (39 female) between 48 and 55 months (M=50.08, SD=1.52) completed 2 mathematics measures [Mathematical Reasoning from the WIAT-II and the Mathematics sub-test from the Reception Baseline Assessment of the National Foundation for Educational Research (NFER)], one working memory measure (Self-ordered pointing task), one inhibitory control (Flanker task) measure, and 2 language skills measures (BPVS-II and NFER Language). Preliminary results suggest that inhibitory control and language skills are significant unique predictors of 4-year-old's mathematics skills. Additionally, the β values indicated that in predicting mathematics, language skills (β=.46) were slightly more important than inhibitory control (β =.29). These results are in line with previous findings that have suggested that language skills are significant predictors of calculation skills and knowledge of the number system (LeFevre et al., 2010; Sowinski et al., 2015) in preschool children. Theoretical implications will be further discussed.

The teenage brain: Public perceptions of neurocognitive development during adolescence

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Over the past decade, important insights about neurocognitive development during adolescence have been acquired. As these insights have raised much interest among the public and at schools, we investigated how communication of these scientific insights has shaped public perceptions of the 'teenage brain'. When asking free associations with the word 'teenage brain', adolescents (n = 363, Mage = 14.47 years) and parents (n = 164, Mage = 47.16 years) more often mention undesirable behaviors (e.g. "irresponsible") than desirable behaviors (e.g. "creative"). Despite these dominantly negative associations, priming adolescents with positively versus negatively framed statements about adolescent brain development did not influence their subsequently performed risk-taking, impulsivity and response-to-failure tasks. However, we did find a more nuanced effect of the priming statements: Adolescents' negative beliefs about adolescent brain development reinforces negative behavior by increased risk-taking behavior, and adolescents' positive beliefs reinforces positive behavior by using positive strategies to cope with academic setbacks. The current findings underline the impact of pre-existing worldviews which build up over time, and that these are not easily influenced by a one-time instance of information, but rather reinforce the impact of new information. To prevent negative perceptions of the 'teenage brain' from becoming self-fulfilling prophecies, it is important that communication about adolescent neurocognitive development is framed in a more balanced way. Teachers can play an important role in communicating such balanced information to their students and help adolescents appreciate their unique and flexible qualities rather than focusing on stereotyped undesirable behaviors that are assumed to be unchangeable.

Relationship between resting-state connectivity and social network structure in school-aged girls

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Social interactions and the negotiation of friendships are ongoing processes within the classroom and may impact an individual's ability to engage in academic activities. The current study is investigating whether students exhibiting high degrees of centrality in a social network exhibit greater functional connectivity in brain networks associated with reward and memory. Data were gathered from year 8 and 9 (12- to 14-year-old) girls attending a local boarding school. Resting-state functional magnetic resonance imaging (rs-fMRI) data from 51 girls were accompanied by social network information from all girls in each year. Participants were asked to rate the amount of time they voluntarily spent with each person in their year group on a Likert scale, and directed social network matrices were derived from these responses. Using the social network matrices, several centrality measures (degree, betweeness and Eigenvector centrality) were determined for each participant. The preliminary results showed that social network structures differed between cohorts, with the year-8 network exhibiting greater segregation and less integration than the year-7 network. Rs-fMRI data are currently being analyzed using independent component analysis, with the aim to identify spatial maps of temporal correlations (resting-state networks; RSNs), and we are planning to examine the associations between RSNs and centrality measures using dual regression. We anticipate that individuals exhibiting high centrality scores will exhibit greater connectivity in RSNs comprising social and reward-related regions.

Neurophysiological and cognitive mechanisms of enhancing intelligent behaviour

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Throughout evolution humans have strived to change their environment. However, in the Information Age the pursuit and opportunities to augment human abilities, physical as well as mental, is growing. A particular effort has been focused on improving fluid intelligence (Gf), a predictive of important life outcomes including academic success. Gf represents the ability to cope with novelty, to think rapidly and flexibly, and to see relations amongst items. Despite repeated efforts to enhance fluid intelligence (Gf), there is a lack of understanding of the involved mechanisms, and a controversy whether such improvement is achievable. We trained 392 participants in executive function (EF) training, combined with brain stimulation or sham stimulation, or active control training with sham stimulation in a randomized, controlled, double-blind, multicenter design. We show that enhancing Gf depends on progress in EF training, and is mediated via improvement in working memory performance but not improvement in other EFs. The efficacy of brain stimulation to enhance EF training and Gf depended on baseline frontal midline theta power. The current mechanistic understanding including the mediators and moderators roles of specific neurocognitive components paves the way toward effective interventions to enhance human cognition.

Associations between executive functions and maths and science misconceptions in primary school children

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Children's ability to understand science and mathematics concepts is limited by their ability to inhibit direct perceptual evidence or pre-existing beliefs. For example, the concept that a large negative number is smaller than a small negative number is initially counterintuitive. Many concepts in mathematics and science are counterintuitive, and are thus difficult for children to understand. Executive functions, such as working memory, inhibitory control and cognitive flexibility, may play an important role in an individual's ability to learn and understand counterintuitive concepts. In phase 1 of the UnLocke project (www.unlocke.org), we examined the association between executive functions and children's ability to answer mathematics and science misconception problems in 168 pupils from Year 3 and Year 5 (aged 7-10 years old) from 16 primary schools in the UK. The pupils completed a cognitive task battery in school in a one-on-one session, which included IQ tests and four executive functions tasks assessing inhibitory control and verbal and visuospatial working memory. In addition, pupils completed a novel curriculum-tailored maths and science misconception quiz, consisting of multiple-choice questions on maths and science concepts that school-aged children find difficult to understand. Preliminary analyses suggest differential relationships between misconceptions performance in science and maths and executive function measures, and between Years 3 and 5. In addition, these analyses provide some evidence that individual differences in working memory and inhibitory control associate with the ability to solve counterintuitive mathematical problems, independently of IQ.

Reading-induced shifts of cortical speech representations in dyslexic and typically reading children

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Developmental dyslexia is a common learning difficulty characterised by impaired reading fluency and spelling despite adequate intelligence, motivation, and schooling. One of the proposed underlying mechanisms is impaired letter-speech sound integration. We pursue the hypothesis that this impairment stems from reduced auditory cortical plasticity which affects the mapping of visual to auditory speech representations. Here we investigate these mappings in 8-10 year-old typically reading and dyslexic children using fMRI and text-based recalibration, a short-term audio-visual learning paradigm (Keetels et al., 2016; Bertelson et al., 2003). In this paradigm, an ambiguous speech sound between /aba/ and /ada/ is combined with disambiguating text to bias the perception of the speech sound in subsequent auditory-only post-test trials. Previous research in adults reveals that typical readers show a shift in the perceptual boundary of the ambiguous sound towards the text thus showing a recalibration effect whereas this shift is not observed in dyslexic readers. Our current findings intriguingly show that both typical and dyslexic children show a behavioural recalibration effect. However, preliminary fMRI results do point to differences in cortical activation patterns mediating this effect. Whereas dyslexic readers appear to exhibit more activation in parietal and frontal areas, typical readers show more activation within the auditory cortex and occipito-temporal/fusiform areas. These results not only suggest different mechanisms of reading-related audiovisual learning in developmental dyslexia but also highlight the importance of considering the dynamic nature of reading development when investigating group differences between typical and dyslexic readers.

Look math anxiety in the eyes: A physiological study

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There is a shared understanding that learning mathematics involves a complex interplay of cognitive, motivational and (negative) emotional processes. In particular, these emotional impairments, mainly defined in the literature with the term math anxiety (MA), have been highly investigated over the last decades.
Regarding MA measures, self-reported data (collected through questionnaires) seems to be the primary measure and, to date, only a few studies tried to find more objective MA measures. Similarly to general anxiety, MA is supposed to involve changes in behavioural as well as in physiological systems. It is not clear however, just how tightly coupled these changes are. Thus, to examine this issue, this study investigates physiological parameters related to characteristics of the eye and eye-movements that could describe maths anxiety indirectly.
Eye movements were gathered from 90 participants while they solved complex addition problems in two different time-pressure conditions (high vs. low). The level of MA and general anxiety were measured by questionnaires, together with standardized measures of math performance and working memory. Analyses of the eye-data have shown that specific physiological parameters are more likely to be associated with emotional aspects, whereas other parameters are more likely related to mathematics performance. In particular, an increase in stress due to time pressure conditions and task difficulties was associated to an increase in changing in pupil sizes.
Due to novelty of this research, educational and clinical implications are discussed.

Reading ability modulates the brain network of children with mathematical difficulties

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Math disabilities are a well characterized learning disability at both the behavioral and brain level, with a deficits in numeracy (Butterworth, 2010) accompanied by aberrations in a network of brain regions known to support quantity and symbolic representations, memory, as well as higher order executive functioning (Menon, 2014). However, the vast majority brain studies of children with MD are either entirely restricted to samples with in tact reading skills, or fail to take language ability in account. While the incidence of co-morbidity across learning disabilities in mathematics and reading is well documented (Lewis et al., 1994), the mechanism driving this heterogeneity in skill level across academic disciplines remains unclear. Here we characterize the neural signature of children with MD with a range of reading abilities. We find reduced cortical thickness in the left anterior temporal lobe for all children with MD, and demonstrate that MD status modulates the relationship between ATL intrinsic connectivity and reading ability. There is some evidence for a plausible hybrid model of both domain-general and domain-specific deficits (Ashkenazi et al., 2013), which our study provides support for at the brain level. Our results suggest that the ATL may be a locus of co-morbid learning disability, and aberrations to a domain-general hub supporting semantic processing may cascade into both reading and math impairments in childhood.

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Task preparation and emotion regulation in numerical cognition

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The ability to prepare efficiently for an upcoming task is an important cognitive control mechanism in everyday life. Various studies on task preparation used numbers as cues, but so far studies systematically investigating specific effects of numerical cues on task preparation are missing.
In the present study, we investigated brain activation of 24 non-math anxious participants following the presentation of a numerical stimulus cueing an upcoming proportion magnitude comparison task with four different presentation notations (i.e., fractions, decimals, pie charts, dot patterns). We orthogonally manipulated notation (symbolic vs. non-symbolic) and difficulty (easy vs. difficult) of the upcoming proportion magnitude comparison task.
We replicated typical patterns of brain activation associated with the processing of cues and task preparation. Furthermore, we observed number-specific activation in the visual number form area associated with recognizing symbolic Arabic digits. However, we found that also a neural network associated with the processing of negative emotions was activated when a numerical stimulus cued a difficult upcoming magnitude comparison task. Interestingly, these numerical cues also led to activation in anterior cingulate cortex, which plays a key role in emotion regulation. This suggests that whether or not an initial negative emotional response impairs math performance (as observed in math-anxious individuals) may depend on the ability to regulate those emotions sufficiently.
Taken together, these results indicate that the use of numerical cues comes with specific effects on brain activation that should be considered when investigating neural correlates of task preparation.

Interference and problem size effect in multiplication fact solving: Individual differences in brain activations and arithmetic performance

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A large variability of performance in simple multiplication is observed and has not found a compelling explanation yet. One robust effect in simple multiplication is the problem size effect (better performance for small problems compared to large ones). Recently, studies brought to light another effect, the interference effect, indicating that high interfering problems (receiving more proactive interference from previously learned problems) are more difficult to retrieve than low interfering problems. The behavioral sensitivity-to-the interference effect is shown to explain individual differences in multiplication, in children and adults. This study aimed at investigating the individual differences in multiplication in relation to the neural interference effect and the neural problem size effect.
In a multiplication verification task, we orthogonally contrasted the level of interference and of problem size. Forty-two healthy adults, who showed high variability in an arithmetic fluency test, undertook the task during fMRI acquisition. The general reasoning level (IQ) was taken into account in the analyses.
Our findings revealed a neural interference effect linked to individual differences in multiplication in the left inferior frontal gyrus, indicating a higher interference effect for low performers compared to high performers. This region is suggested to be involved in resolution of proactive interference. No correlation between the neural problem size effect and multiplication performance was found. This study supports the idea that the interference due to similarities/overlap of physical traits (the digits) is crucial in memorizing multiplications and in determining individual differences in arithmetic.

Context dependent memory effects as measured in virtual reality: effects of age and working memory capacity

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The environmental context is oftentimes encoded alongside learnt information and presence of the same contextual information during recall has been shown to facilitate remembering. At present, it is not clear whether context-dependent memory effects are stable across development but it has been suggested that in adults the effect may be largest in individuals with high working memory (WM) capacity. A problem with utilizing the context dependent memory effect in educational settings is that it is often difficult to recreate the environment in which learning occurred during recall. However, recent developments in Virtual Reality (VR) technology allow for creating immersive pseudo-environments. Here, we investigated context dependent memory effects in a group of 4-5-year-olds, a group of 10-12- year-olds, and an adult control group. Participants were fitted with a HTC VIVE VR headset and explored a forest or playground environment while a list of words was presented to them through headphones. After a 25-minute retention interval during which participants performed an executive task battery, they were randomly placed back into the same or a different VR environment and were asked to recall the words heard earlier. Preliminary analyses (N=60) suggest that age and WM capacity influenced recall performance. High WM capacity led to improved recall when VR context was identical between encoding and recall in the 4-5-year-olds only. The results suggest that VR could be useful in helping young children to more efficiently learn and remember information and may be relevant for children with learning disabilities.

The effect of acute physical activity on children's memory for language learning

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Recent studies showing a high prevalence of paediatric mental health issues (10-20% worldwide; Kieling et al., 2011; Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015) and raising numbers of children falling in the overweight or obese categories (Ng et al., 2014) emphasise the importance of promoting activities that improve children's mental and health outcomes, such as physical activity (PA). But, while schools provide an excellent space to implement these types of intervention, limited resources and the need to prioritise pre-established academic goals may complicate their inclusion in the curriculum. Understanding how increased amounts of exposure to PA affects cognition and, in turn, academic achievement, could provide more evidence of their value in schools.

In this study, we explored the relationship between exercise and long-term memory in children, focusing on whether the general-domain effects observed in previous studies could translate to a school-based learning activity. In particular, we looked at the possible effects of a bout of moderate, aerobic PA on the immediate and delayed recall of newly acquired word forms and form-meaning connections of children in a school setting. In line with previous research, the results show a positive effect of exercise, but only for word form recall. Furthermore, our results highlight the selectivity of the effects, as we found that both gender and testing time affected the outcomes. Overall, this study expands our understanding of the differential effects of exercise on memory, while raising questions regarding the possible moderating influence of individual differences and memory consolidation.

Moving towards spaced learning in medical education: time to start an instructional revolution?

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The longevity of knowledge learned during medical training remains a serious concern. The preclinical years of medical school focus on the basic science of human health and disease mechanisms, however, most of this information is often not retained by students. Since basic science knowledge plays an important role in clinical reasoning and diagnostic accuracy, its retention is considered critical for healthcare. The spacing effect is a reliable finding in psychology, showing that knowledge retention can be increased through retrieval practice. Studies investigating spaced education mainly focus on the implementation of multiple examinations or low stakes quizzes spaced in time to enhance retention. Interestingly, neurobiology provides a new point of view, shifting the focus from spaced testing to spaced instruction. Research on molecular mechanisms of learning delineates the dynamic properties of synapses and cellular signalling pathways underlying the effectiveness of spacing on various temporal domains. Using this mechanistic information, spaced education may already show its benefits during the instructional phase. In this scoping review, we explore the implementation of spaced education during medical training. We demonstrate that beneficial effects of spaced testing are reported frequently, but that research on spaced instruction is scarce. Additionally, we provide suggestions for developing and testing spaced instructional designs based on neuroscientific findings. Moreover, we aim to conduct a spaced instruction study with medical students, translating the optimised spacing protocols from neuroscience to the educational setting.

A brain-inspired method for second language vocabulary learning

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Acquiring vocabulary is an essential component of second language (L2) learning. While many methods have been developed to support this process, we suggest that what is currently known in cognitive neuroscience about the structure of the mental lexicon may help improve these methods.

According to current theories in cognitive neuroscience and psycholinguistics, words in the mental lexicon are organized along orthography, phonology, and semantics. Similarities along these dimensions determine where words are stored, forming a complex network. The structure of this network plays an essential role in how words are learned. For example, words that look alike but have a very different meaning may be easily confused during learning. A critical question is how educational methods for L2 word learning relate to this similarity-based structure of the mental lexicon.

To answer this question, we consider a framework of word learning consisting of two continua, the first one form and meaning, and the second one focusing on a single word versus integrating it into its semantic and formal neighbourhood. We review the most commonly used educational methods for L2 learning, placing them within the aforementioned framework. Our findings reveal that, at present, there is no fully integrative method that accounts for the similarities between words on both the form and meaning dimension. To bridge this gap, we propose a brain-inspired serious game to acquire vocabulary. By doing so, we hope to further both neurocognitive L2 acquisition research and classroom practices.

Domain-general skills in early learning? Cross-sectional and longitudinal data on emerging mathematics, the preschool and the home educational environment point beyond attention maturation

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The cognitive neuroscience of attentional and executive control describes very strong evidence for their striking changes over early childhood, and how these are supported by the development of increasing co-ordination within fronto-parietal cortices, as well as across their subcortical and cortical partners. These domain-general skills play a role as predictors of young children's ability to demonstrate their proficiency with newly learnt skills, as well as in new learning itself. However, the current Early Years Foundation Stage curriculum focuses more on factual knowledge milestones (e.g., counting to 20) than on attention and self-regulation skills while learning. Furthermore, studies on domain-general learning skills most often studies them in isolation, without considering how they may be malleable and influenced by the learning environment itself (e.g., the child's home and preschool learning environment). A combined cross-sectional and longitudinal study of pre-schoolers aged between 3:00 years and 4:11 collected data on relationships between attentional and executive control skills and emerging mathematics to test the dynamic interactions between these developing cognitive skills and the characteristics of the learning environment. Ongoing analyses support robust relationships between domain-general skills and emerging numeracy. Of note, these relationships seem to be moderated by age and by characteristics of the home and preschool environment. Initial conclusions raised by bidirectional relationships between domain-general skills, domain-specific skills and the learning environment will also be presented, to ask how preschool learning environments could be optimised to facilitate attention development.