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Khalifa Award for Education

Winner of the 2024 Khalifa International Award for Early Learning: Best Research and Studies

Horowitz-Kraus Neuroeducation Executive-Functions-based Early Learners Training Program (HOKNELP)

Abstract

Neuroeducation is an emerging field that combines biological principles of brain structure and function with child learning and education to provide crucial knowledge for educators and learners. The use of this technology allowed Dr Horowitz-Kraus, a world leader in educational neuroscience, to **innovatively** reveal that Executive Functions (EF), a set of cognitive abilities, play a critical role in reading acquisition in early learners. The **importance** of this finding is that due to this identification, Dr. Horowitz-Kraus developed, designed and tested several interventions and training programs for early learners that train EF combined with additional linguistic and cognitive abilities early in life to acquire reading skills better. Among these interventions and training programs Dr. Horowitz-Kraus developed, are EF-based Dialogic reading training, EF-based Mindfulness training, and EF-based reading and math fluency. The effects of the **Horowitz-Kraus' Neuroeducation EF-based Early Learners Training Program** (aka **HOKNELP**) were measured using neuroimaging tools as well as behavioral/cognitive measures. Using neurobiological tools to develop mechanistic-based training for early learners and then testing the effectiveness of these EF-based training programs is **rigorous** and adds important support for the need for precision education, similar to the need to be precise in providing treatments in the medical field. All the materials are available for use in English, Hebrew, and Arabic, and the protocols are freely shared. As Dr. Horowitz-Kraus has vast international scientific, outreach and educational activities and connections, the **impact** of the neuroeducation-inspired intervention for early learners is via scientific research designs published in more than 100 peer-reviewed journals, grants and foundations support and an intensive activity shared with education and the public during international meetings, podcasts and, interviews and developed materials. In ongoing and future research, we propose to expand our program and translate it into additional languages to extend its promising results.

Horowitz-Kraus Neuroeducation Executive-Functions-based Early Learners Training Program (HOKNELP)

Tzipi Horowitz-Kraus, Ph.D.
Technion, and Kennedy Krieger Institute and Johns Hopkins School of Medicine

Background

<u>What is neuroeducation, and why is it important?</u>

More than fifteen percent of children worldwide suffer from language and reading difficulties that might be attributed to biological (e.g., dyslexia, attention difficulties, epilepsy, autism, and others) or environmental factors (e.g., illiteracy, screen exposure, bilingualism, maternal depression, or other stress factors). Untreated reading difficulties have long-term social, emotional, and academic consequences: 70% of prisoners suffer from reading difficulties, 90% of whom dropped out of school. In many others, the long-term effects of reading difficulties include avoidance of reading materials with a greater dependency and heavy reliance on family and friends, higher rates of unemployment, low self-esteem, and increased risk for emotional, behavioral, and anti-social problems.

> <u>This unique neuroeducation approach, from the classroom to the MRI scanner and back to class,</u> facilitates breakthroughs in prevention, treatment, and translation into educational programs for typically developing children and children who are at risk of developing language and reading difficulties even prior to reading age. Neuroimaging data provide the "hidden reasons" for the difficulties by pinpointing the affected neural circuits underlying the language/reading challenges (Figure 1). This neurobiological mechanistic information is combined with data acquired from other behavioral/cognitive modalities to provide a model for reading acquisition, which allows the development of tailored academic interventions (Figure 2).

Early detection of the mechanisms underly future reading acquisition and challenges is critical for designing the most appropriate interventions and training programs even before reading is acquired, before the age of 8 years. Efficient and precise tools to identify future reading abilities/difficulties during early childhood may provide these children with a better starting point and a more positive and functional future. Since most reading and language difficulties exhibit similar challenges on the surface (slow and inaccurate reading), *only neurobiological data, such as the data generated from neuroimaging tools (MRI and EEG), can provide objective and accurate mechanistic information regarding the reasons for a future occurrence of reading challenges.*

The **Horowitz-Kraus' Neuroeducation Executive-Functions (EF)-based Early Learners Training Program** (aka **HOKNELP**) training programs are developed based on insights generated from neuroimaging tools. This data allows the identification of basic mechanisms for future reading acquisition, with a special emphasis on EF. These insights stimulated the development of several EF-based interventions to improve future reading acquisition in typically and atypically developing children. These tools also allowed testing the effectiveness of the interventions on brain plasticity in specific brain regions related to future reading acquisition.

Horowitz-Kraus' early learners' intervention program of integrating EF principles in pre-literacy and learning skills has focused on two main perspectives both rely on neurobiological, rigor data: 1) The role of EF in the formation of future reading network, and 2) Early learners training integrating EF principles to improve future reading outcomes. These two perspectives are detailed below.

1)The role of EF in the formation of the future reading network

Executive-Functions (EF; or cognitive control) is an umbrella term for several cognitive abilities aiming to improve learning [12]. These EF are part of the attention network and include three main parts: inhibition, switching and working memory[13]. Traditionally, behavioral studies suggested that EF develop later in life and reaches full maturation at age 26 years [14]. However, HOKNELP continuously provided neurobiological scientific evidence that these EF are part of language and reading acquisition, even during the first years of life, and are the foundation for reading acquisition in children.

HOKNELP showed that pre-readers listening to stories who are able to engage brain regions related to EF, also show better reading abilities when growing up [15]. HOKNELP then demonstrated how these EF-related brain networks (e.g., the cingulo-opercular and fronto-parietal networks) exist in children as young as 18 months while listening to stories [16]. Importantly, functional connectivity within these EF networks is related to verbal ability and increases until reading age (nine years), creating a scaffold for future reading [16].

These findings initiated a series of neurobiological studies by Horowitz-Kraus, demonstrating the role of nurturing environments such as home literacy exposure, maternal reading ability, and interactions between parents and children during storytelling in improving EF and learning in young children. HOKNELP found that exposure to these nurturing factors at young ages (3–6 years) is related to more solid structure and function of brain regions related to EF, the same ones that support the formation of the future reading

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Mechanistically, and in relations to the developed interventions, HOKNELP suggests that a stimulation of basic EF, especially working memory and inhibition, allows faster information processing (i.e., faster processing speed) [1]. This faster processing speed allows the processing of more units (i.e., letters) in a given time and hence lowers the cognitive load in children [1].

network [17,18,19]. HOKNELP also showed that stimulated storytelling by the parent engages brain regions related to EF and imagination in 3-5-year-old children [20,21]. On the other hand, HOKNELP demonstrated how the lack of stimulation due to maternal depression [22] or screen exposure [23-27], lowers the engagement of brain regions related to EF in these early learners. To strengthen the involvement of EF in future reading development, HOKNELP has recently demonstrated the increased involvement of brain networks related to EF as part of the establishment of the reading network in the brain from age 5 to 18 years in the same children who received an MRI scan every year for 12 years [28].

These findings were the first published investigations associating factors positively and negatively affecting EF as part of the development of the future reading network from a neurobiological perspective in preschoolers. This line of research led to an in-depth investigation of the appropriate approaches to expose children to literacy materials while engaging EF during a parent-child interaction [29,30]. Using the uniqueness of neuroeducation,

These findings generated from HOKNELP studies, provided a strong neurobiological support for the critical role that EF play in the facilitation of the future reading network even before reading is acquired (before the age of 8 years). Hence, this line of research led to the development of the EF-based intervention program for early learners to improve future academic outcomes, specifically reading by HOKNELP.

we were able to determine the level of engagement of attention and EF abilities of the child while the parent was telling stories in real time. This could be achieved by measuring the brain-to-brain synchronization of the parent and child dyads while interactively telling stories to their 2-3-year-old children. During interactive storytelling, these studies demonstrated that increased parent-child brain synchronization in brain regions related to EF and language processing was evident in very young children vs a condition with decreased interactions (2-3 years old).

2)Early learners training integrating EF principles to improve future reading outcomes

Results from Horowitz-Kraus' several carefully designed experiments outlined above led to the development of three EF-based interventions for improving future reading abilities. The programs were developed in English, Hebrew and Arabic and were validated using the neuroeducation tools, i.e., using data generated from neuroimaging tools:

1) An EF-based Dialogic reading[2];
2) An EF-based Mindfulness[3];
3) An EF-based reading and math fluency software (Braincraft)[4-11].

All three interventions, which will be elaborated on in this proposal, are part of HOKNELP and are focused around a similar principle: stimulating EF while training additional abilities (i.e., language processing during dialogic reading; attention during mindfulness and reading fluency during Braincraft) to enhance the outcomes of training. The effect of these interventions was tested using neuroimaging tools.

Sharing of the effect of training with this rigor HOKNELP, is made possible by Dr. Horowitz-Kraus' development of three world-class reading and literacy research programs, which focused on the role of EF in future reading and literacy skills and the response to intervention in young children, which was made possible by utilizing neuroimaging. These three programs include the Educational Neuroimaging Group at the Technion, Israel; the Reading and Literacy Discovery Center at Cincinnati Children's Hospital, Ohio, USA; the Reading and Remediation Research Program; READ at Kennedy Krieger Institute, Johns Hopkins University, Maryland, USA.

Dr. Horowitz-Kraus' extensive outreach activity includes her role as the communication/education chair in the executive committee of the Developmental Cognitive Neuroscience Society (Flux), her membership at the board of the International Mind Brain and Education Society (IMBES), her advising activities to early child development groups, her policymaking activity in Israel as well as abroad (membership at the FABBS group for enhancing policymaking based on scientific neuroimaging findings), her talks in the Israeli Parliament, outreach talks, podcasts and numerous interviews on her research outcomes based on HOKNELP, and activities for children in several languages (via *Frontiers for Young Minds* editorial board, and outreach activities via the support from Dana Foundation).

The HOKNELP was supported nationally and internationally with more than 4 million dollars in donations, supported by US federal grants (from the National Institute of Health), international foundations (Waterloo, Greenspoon, Mind and Life, Joy, and more), international competitive grants (DFG; German-middle east collaboration), Ministry of

The state-of-the-art neuroeducation insights combined with the unique perspective of EF stimulation during interventions and the above leadership roles make HOKNELP a leading program for early learners worldwide.

Education in Israel, and many more. Horowitz-Kraus published more than 100 peer-reviewed research papers and shared her findings with the scientific committee via scientific presentations, membership in editorial boards, grants and ad-hoc reviews, and membership in scientific societies.

Scientific Rigor

From neurobiology to class and back

The advancement of technology in the past 30 years has allowed the utilization of tools previously used for medical purposes only, such as education. This "fusion" between the two fields (medical imaging and education) allows a better understanding of learning processes and development.

Neuroimaging tools, such as Magnetic Resonance Imaging (MRI), traditionally used to detect tumors or brain abnormalities, now also allows researchers to measure brain function. This is possible due to a special development called "functional MRI," which allows the tracking of blood flow to active brain regions. Other tools, such as electroencephalogram (EEG), medically used for assessing the quality of sleep or for epilepsy diagnosis, allow the characteristics of brain activation in an excellent temporal resolution. This tracking of blood flow or characterizing electrical activity over the scalp enables the understanding of how different cognitive abilities are acquired (such as language processing, EF and even reading), and how learning a new skill modifies brain function (aka plasticity). It also allows pinpointing specific cognitive skills and underly complex cognitive abilities, such as the involvement of EF in the reading process. Finally, it can provide objective support for the structural and functional changes (i.e. plasticity) following learning or training of a specific skill). HOKNELP relies on these valuable tools to gain more accurate and objective information on the role of EF in future reading acquisition, the development of EF-based interventions, and the changes in brain plasticity following these interventions.

These tools allowed a rigorous definition of the role of EF in the development of the reading network in the brain to better understand the underlying mechanism it is composed of so tailored interventions can be designed.

How reading is acquired: recycling basic sensory brain regions and engaging EF

Reading is a source of knowledge and is the key to academic success. For 15% of children worldwide, translating letters to their corresponding sounds (phonological processing) and automatically recognizing word templates (orthography) and their meaning (semantics) is not an intuitive process [31]. In the classroom, reading is usually performed in a context that demands synchronization between these basic mechanisms, which results in fluent reading [1,32]. The critical role of fluent reading is that it "releases" attention resources for comprehending the written material [33].

Oral language is a very intuitive human ability, starting from the ability of the fetus to recognize a human voice in utero [34]. However, reading is a relatively phylogenetically new skill (roughly 5000 years old) that demands the utilization of existing neural circuits for language, visual processing, and other cognitive abilities. In its earliest incarnations, reading was an elite skill, reserved and taught to only select highly educated members of society. Now, the expectation in the education system is that every 3rd grader should read proficiently [35]. Reading demands the translation of abstract graphemes (letters) into their corresponding spoken language sounds (phonemes) that format meaningful words (semantics). It, therefore, engages visual [36], auditory/phonological [34] and semantic brain regions [37], mainly in the left hemisphere [38].

Per Horowitz-Kraus' findings, efficient synchronization of these processes is needed for fluent reading, which demands the engagement of the EF [28]. This study demonstrated how changes in brain networks related to EF and their correspondence with visual and auditory networks from age 5 to 18 years predict reading efficiency at the age of 18 years [28].

Only the use of rigorous neuroimaging tools used in HOKNELP allow pinpointing at the critical role of EF in future reading development, leading to the development of training programs which rely on stimulating EF in young children (which will be detailed below). See Figure 3 for the brain networks composing the reading network, including EF networks.

Dr. Horowitz-Kraus founded and currently leads the Educational Neuroimaging Group in the Faculty of Education in Sciences and Technology and the Faculty of Biomedical Engineering at the Technion in Israel. She also leads the Reading Remediation Research Program (R3P) at Kennedy Krieger Institute, Johns Hopkins School of Medicine, Baltimore, Maryland, USA. Dr. Horowitz-Kraus also developed and was the Program and Scientific Director of the Reading and Literacy Discovery Center at Cincinnati Children's Hospital Medical Center in Ohio for almost ten years (2013-2021), which she raised almost $4M to establish.

Trained in biology, neurobiology, and education, Dr. Horowitz-Kraus received her Ph.D. in Brain Sciences of Learning Disabilities from the Faculty of Education, University of Haifa in 2008. She has received several professional awards (e.g., Jacobs Foundation, Fulbright Foundation, Trustee award, Alon Foundation, Greenspoon Foundation, Waterloo Foundation, and others) and has authored over 100 peer-reviewed scientific publications, for most of which she is the first or senior author. Dr. Horowitz-Kraus has been awarded a $3.2M NIH grant to investigate the underlying neural circuits related to cognitive control in reading as well as additional competitive international (DFG, Germany) and National (Ministry of Education) grants.

Her career has been fully devoted to studying the neural circuits underlying typical and atypical development in children, developing interventions, and testing their effects on behavioral and neurobiological correlates for these abilities in young children. Dr. Horowitz-Kraus is invested in sharing the research findings via public talks, outreach activities (workshops for families, educators and professionals), sharing the interventions in an open access manner (with publicly sharing the protocols for all interventions she developed (see Figure 4 as an example for a manual for the EF-based dialogic reading intervention and Figure 5 for the EF-based reading and math fluency Braincraft training software).

In the past years, Dr. Horowitz-Kraus has also been active in the policymaking field, with talks given at the Israeli Parliament to the leadership of the Israeli Ministry of Education, as well as an international involvement as a member of FABBS (Federation of Associations in Behavioral & Brain Sciences) and a recently accepted paper published in a journal that advocates for research informing policy (*Policy Insights from the Behavioral and Brain Sciences*), supporting the implementation of dialogic reading intervention (one of the interventions outlined in the current proposal) by parents and teachers [39].

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Innovativeness

HOKNELP innovativeness is manifested by the 1) use of neuroimaging tools in educational settings; and 2) focusing on EF as a way of training future reading outcomes:

1)The utilization of neurobiological tools allows the definition of basic mechanisms underly reading development in a way that no other tool can determine. This is attributed to the unique ability to image brain activity while children are attempting to read, which allows for determining which brain areas are active (or less active) during this process. The use of neuroimaging tools in HOKNELP allowed the definition of one of the most fundamental underlying factors in reading acquisition (i.e. EF), designing the EF-based programs in the lab, and testing the programs in the kindergarten and school settings and then bringing it back to the lab to test the effectiveness of these training using neuroimaging tools.

By that, Dr Horowitz-Kraus' research moved from the education system ("the need") to the lab (neuroimaging assessment of EF and designing the interventions), back to school (implementing the interventions) and back to the lab (while testing their effect using neuroimaging tools), which is a **highly innovative** approach.

2) Stimulating EF while training language, attention, or reading: The **Horowitz-Kraus' Neuroeducation EF-based Early Learners Training Program** (aka **HOKNELP**). Pointing at EF as a critical component in future reading acquisition is an innovative approach, as most reading-related studies focus on phonological processing [40-42]. Also, innovatively, HOKNELP does not support a focused training of EF to improve future reading abilities, but the *integration of EF principles* as part of training additional skills, as explained below, which is a highly innovative concept based on neurobiological

Results from Horowitz-Kraus' several carefully designed experiments outlined above, led to the development of three EF-based interventions for improving future reading abilities, all were validated using the neuroeducation tools, i.e., using data generated from neuroimaging tools:
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b) An EF-based Mindfulness[3]
c) An EF-based reading and math fluency software (Braincraft)[4-11].

mechanisms[1] .

a) An EF-based Dialogic reading: Hebrew and Arabic

Reading stories to children is considered one of the most significant linguistic experiences in the preschool period [19]. This activity allows the child to participate in a linguistically rich, meaningful and motivating dialogue [43], which is also socially and emotionally beneficial [44]. Dialogic Reading (DR) is a method of shared storytelling reading in which the adult reader leads the process by asking questions while reading and guides the child to follow the story by pointing at the written letters and words while reading [45]. This reading method was found to positively engage the child by creating a dialogue [45]. The DR method includes a number of guidelines while reading the story, such as allowing the child to complete the sentence, reconstruct the story, and link the events heard to the child's personal experiences [46]. In addition, the adult is encouraged to prompt the child to point to objects in the book and talk about them (**P**rompt), to expand the child's verbal expressions by repeating the child's words and adding information (**E**valuate and **E**xpand) and at the same time encourage the child to repeat the extended expression (**R**epeat) – in short- '**PEER**' [46]. The main goal of DR is to enhance the child's discourse skills and, specifically, to expand vocabulary and enrich grammatical abilities [47].

There is ample evidence that reading stories to young children by their parents contributes to the child's vocabulary. Four weeks of DR for young children led by their mothers showed a significant increase in the number of words produced by their children (i.e., their spoken vocabulary) compared to age-matched children in the non-DR group [48]. These children showed further improvement in their literacy abilities [48]. This improvement can be explained by the interest that children show in words and letters when their parents read them a story: in a study conducted in at HOKNELP using an eye-tracking device, 4-5 year old children showed longer and more eyes-fixations on the letters (vs the pictures) when their parents read them stories (compared to a story condition read by a stranger) [29]. This finding emphasizes the important role the parent plays in increasing the child confidence during storytelling time in exploring new features in the book, such as letters, even in pre-reading stages.

In **HOKNELP**, a special emphasis on EF was added to the DR to create the EF-based DR training protocol: eye contact (joint attention with the reader), tracking the letters with the fingers while reading (visual attention), shifting between pointing at the pictures vs pointing at the letters, and practicing inhibition while asking the child to try and inhibit comments [49]. Dr. Horowitz-Kraus' research team researched this EF-based DR among 4-6-year-old children in their kindergarten [49]. Training took place for six weeks, three times per week for 30 minutes for each session, with an active control group of age-matched children who were exposed to the same stories recorded on a computer screen but without the interaction and stimulation involved in the EF-based DR approach explained earlier. Results suggest that children in the EF-based DR improved their cognitive abilities (especially visual attention and inhibition) and vocabulary (number of words produced) vs. the active control group [49]. This behavioral/cognitive improvement was accompanied by changes in brain activity related to EF as measured using the EEG tool [49].

This EF-based DR intervention was then translated into Arabic. Similarly to Hebrew, Arabic is also a Semitic language with special characteristics; the oral and written languages are different (a phenomenon called diglossia). Arabic-speaking children formally acquire Literary Arabic when reaching school. However, they are exposed to literary Arabic in its auditory form even before reaching formal education through the media (i.e., television programs) [50]. As the use of language depends on the socio-functional context in the case of diglossia, as well as the difference in the acquisition method between the two variations (the written and the spoken)- the proficiency level of Arabic-speaking children in the written (literary) language is lower than that of the spoken one[51].

HOKNELP has adapted and implemented this EF-based DR program in Arabic as well. Uniquely to Arabic, the DR training was conducted in literary Arabic and not in spoken Arabic to engage children's attention towards the literary form of Arabic these young children are not yet well familiar with (as they are less exposed to written language prior to entering school). This study in Arabic has not yet been completed; however, preliminary results from 23 Arabic-speaking mothers and their 4-6-year-old children showed reduced joint attention measured by the EEG tool when mothers were telling stories to their children in literary vs spoken Arabic [52]. These results emphasized the EF load these children share when they listen to stories in literary Arabic. At this point of data collection, ten pairs of mothers and native Arabic-speaking children ages 4-6 years showed significant improvements in the children's language (vocabulary, phonological awareness) and cognitive abilities (working memory, visual attention, i.e. EF) following training. Throughout the intervention, an increase in the number of syllables that the mother and child produced during the storytelling sessions was observed. HOKNELP is eager to continue digging deeper into implementing the EF-based

Taken together, this specific **EF-based DR** developed by HOKNELP both in Hebrew and Arabic (and hopefully soon in English as well) showed a positive effect not only on EF but also on literacy and language abilities in children ages 4-6 years (in Hebrew and Arabic). These improvements were supported both behaviorally and neurobiologically.

DR training in Arabic in kindergartens and schools around the world, translating it to English, and investigating this training's effect on reading abilities in all three languages and others.

b) An EF-based Mindfulness training

Mindfulness is a psychological construct drawn from the Buddhist tradition, which refers to a self-regulated attentional stance oriented toward present-moment experiences, characterized by curiosity, openness, and acceptance [53]. Scientific inquiry into various mindfulness-based practices in adults suggested beneficial effects on various cognitive and socio-emotional processes (e.g., [54]). These findings have sparked a growing interest in mindfulness-based interventions for children in a school setting. A HOKNELP basic assumption is that it is especially important to apply Mindfulness interventions during early childhood, as this is a period marked by substantial development in self-regulatory and EF skills, considered central in supporting socioemotional competence, theory of mind, school readiness, language and reading acquisition and future academic success [15,55-59].

As part of the EF-based Mindfulness intervention for young learners, HOKNELP implemented EF principles as part of the Mindfulness training [3].

In this curriculum, we embedded EF principles such as shifting the attention from the children's breath to their thoughts and imaginations, inhibiting their responses, and stimulating their memory by retrieving information given at the beginning of a session during a short story told by the instructor. This intervention was conducted for eight weeks, three times per week for 30 min for each session in 4-6-year-old Hebrew-speaking children vs. an active control group. Improved inhibition abilities were found among children in the EF-based mindfulness group, accompanied by EEG changes related to improved EF [3]. Full protocols are available [3].

Overall, these results demonstrated the benefit of **EF-based Mindfulness** training among children at kindergarten while training in a group setting (in their kindergarten) with neurobiological markers related to changes in EF following this intervention.

c) An EF-based fluency intervention

Current interventions for reading acquisition focus on the different components of reading, such as phonology (Graphogame [60], Fast-forward [61,62]) or reading comprehension [63], but do not target EF directly or stimulate them while training academic abilities. Crucially, the findings on the role of EF in reading in general and reading fluency led to the development of a software package that aims to train reading fluency in children using embedded EF principles as part of HOKNELP. This EF-based fluency intervention (aka "Read") training is a reading fluency program with embedded EF principles tailored to each child's reading speed and comprehension.

It begins with a computerized assessment of the child's reading speed by presenting simple, short sentences on the screen that the child reads silently, followed by a comprehension question. After the evaluation phase, sentences are shown on the screen, with the letters being deleted from the screen (from left to right in English and right to left in Hebrew and Arabic) based on the child's reading rate; subsequently, the software speeds up or slows down the deletion rate based on the accuracy of responses to comprehension questions in a personalized manner [10].This manipulation is thought to reinforce the processing of more letters at a given time, which lowers the bottleneck in working memory of slow, non-automatic letter decoding, pushing towards word recognition rather than decoding and increasing the number of words read orthographically in the mental lexicon, thereby improving fluency and is appropriate for children at the age of 6 years and older.

HOKNELP demonstrated how this training improves oral and silent contextual reading fluency in English and Hebrew-speaking children with and without reading difficulties [4,7,64-72]. This training manipulation was associated with improvements in both short-term reading fluency as well as a number of EF subcomponents (visual attention[73], inhibition[71] and working memory[74], switching[7], and processing speed [64]). HOKNELP is currently assessing the effect this EF-based training on children in 1st and 2nd grades.

At the brain level, increased engagement of brain regions and networks related to EF was found in children with reading difficulties but also in typical readers [73,67,75] (Figure 6). Further, the program demonstrated how this EF-based stimulation, while children are reading sentences, results in a greater synchronization between visual and auditory regions while reading words [8,9], and sentences [70,75]. It was claimed that this increased visual-auditory synchronization results in "holistic" reading (using the orthographic processor) by leveraging enhanced error monitoring[4,7,64,65] and switching.

These findings highlight the critical importance of stimulating EF while exposing children to written language to enhance reading fluency in Hebrew and English. This intervention also exists in Arabic, with future plans to test the effect of this training in additional languages. The software also has an EF-based math fluency module in all three languages, which HOKNELP would also like to research in the future.

Importance

The importance of the neuroeducation-inspired EF-based interventions led by HOKNELP is twofold:

1) Revealing neurobiological mechanisms for future academic abilities early in life:

Horowitz-Kraus' research characterizes the brain connections between EF regions and oral and written language-related regions in different stages of development. Revealing the mechanisms for academic abilities and, especially, reading using neuroimaging tools and determining the neurobiological relations between these sub-components early in life will enable the prevention of academic difficulties as well as developing interventions such as EF in HOKNELP. **Identifying these neural circuits associated with language and reading development allows pinpointing the reasons for reading or language difficulties** and distinguishing them from one another (see Figure 1 for some of the conditions suffering from reading difficulties).

2) Designing interventions based on EF abilities and testing them objectively using neuroimaging tools:

The use of neuroimaging data allows examining the response to intervention not only behaviorally but also by determining the pathways leading to a specific response among different children. For example, the response to the EF-based reading fluency intervention was different for typical readers and for children with reading difficulties vs. those with attention difficulties [76]. These differences in response (i.e. different effects on EF and reading abilities) were attributed to a different effect on brain regions related to attention, EF, and visual-related brain regions in these three groups. Hence, designing specific interventions and then testing them using neurobiological tools, allows taking a “precision education" approach (similar to precision medicine)- providing each child the most appropriate intervention for their needs and verifying the interventions work and how.

Impact

The long-term goal of HOKNELP is to establish a framework for understanding the role of EF in typical and atypical oral and written language development in children to continue developing interventions tailored to each child's abilities. As the manuals of the interventions and the software developed in HOKNELP are available to the public and exist in several languages (and are in the process of translation to additional ones), *the impact of the findings reaches beyond a specific language or geographical location*. The following activities of Dr. Horowitz-Kraus allow the dissemination of the HOKNELP results to the scientific community, the educational system, and the public at large.

Service and Leadership

Dr. Horowitz-Kraus is very active in advocacy and education for preschool and school-age children and activities in science education nationally and internationally using a suite of platforms:

1. Advocacy and education for preschool children: Since 2020, she has been a consultant to several non-profit organizations founded by Israeli pediatricians to significantly change the landscape of early childhood development in Israel (e.g., TAUB, Goshen, PJ Library, Israel- etc.). She is also an editor of the International Frontiers for Young Minds journal (the American and Israeli branches), producing widely available and popular podcasts and writing papers on the topic of neuroscience and education in English, Hebrew and Arabic. She has also delivered open-access meetings for children called "Ask The Neuroscientist", focusing on language, reading, and attention abilities. She was also supported by the Data Foundation to organize Brain awareness activities in Hebrew and Arabic in Israel.

1) International activities in science education: For the past six years, Horowitz-Kraus has been a member of the Communication Committee of the Organization of Human Brain Mapping, communicating scientific findings to the layperson and publishing articles/interviews in the field of neuroscience. She is also on the executive board of the Society of Developmental Cognitive Neuroscience society, where she shares scientific findings related to brain and education to educators. She is engaged in a similar activity at the International Mind Brain and Education Society, where she is also on the board.

1) Policymaking: In the past two years, Dr. Horowitz-Kraus has been heavily invested in making sure that policymakers comprehend her research findings, to ensure they are implemented in the field. She gave talks in the Israeli Parliament, served as the executive chair of education and communication of the Society of Developmental Cognitive Neuroscience Society, and was the head of the communication committee at the Department of Education in Science and Technology at the Technion. She is also part of the Federation of Associations in Behavioral & Brain Sciences (FABBS), seeking to translate neuroscience and education into policy.

1) Media and public communication: Horowitz-Kraus has extensive media and public communication experience and has written and published material for a range of Israeli and US media: print, online, podcasting, and TV/radio.

Publications(selected from over 100)

Horowitz-Kraus has published over 100 peer-reviewed articles (per Google Scholar), inc. 90% in journals with an impact factor > 2 and Q1. Her work has received 3,329 citations, and her H-index is 31 (December 2023, Google Scholar).

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Appendix

Figure 1. Children with different genetic or environmental conditions show various brain alterations in relation to their reading challenges. These images show the complexity of the reading network in the brain and the challenge in designing interventions for future reading acquisitions without a precise understanding of the reading network and its more basic mechanisms.

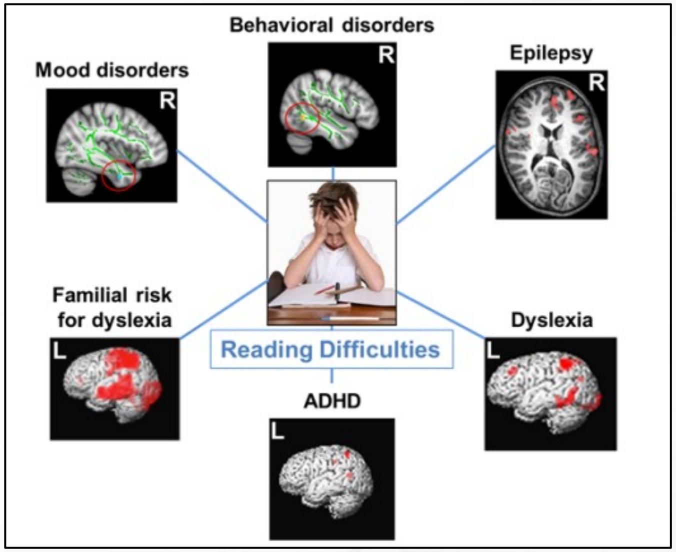
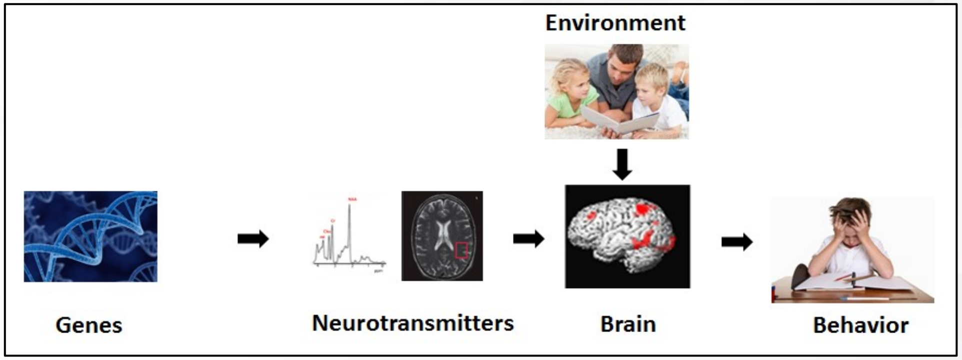


Figure 2. Data generated from neuroimaging tools allow the objective and accurate identification of mechanisms supporting reading acquisition.



Appendix

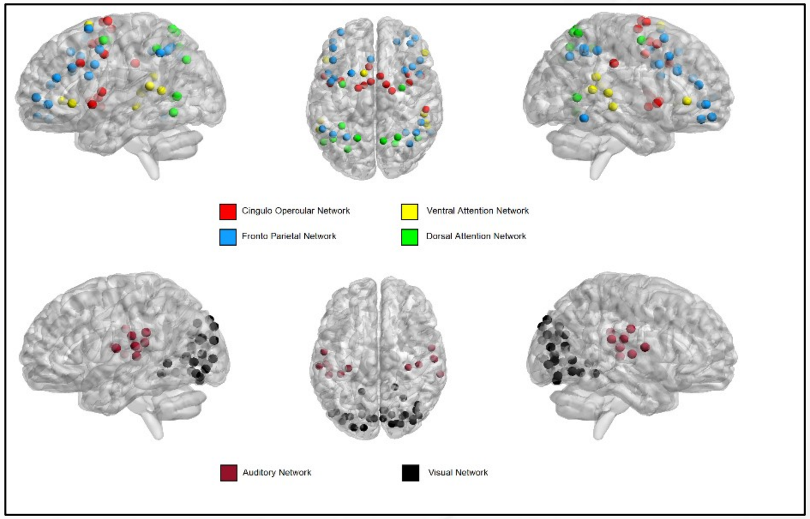
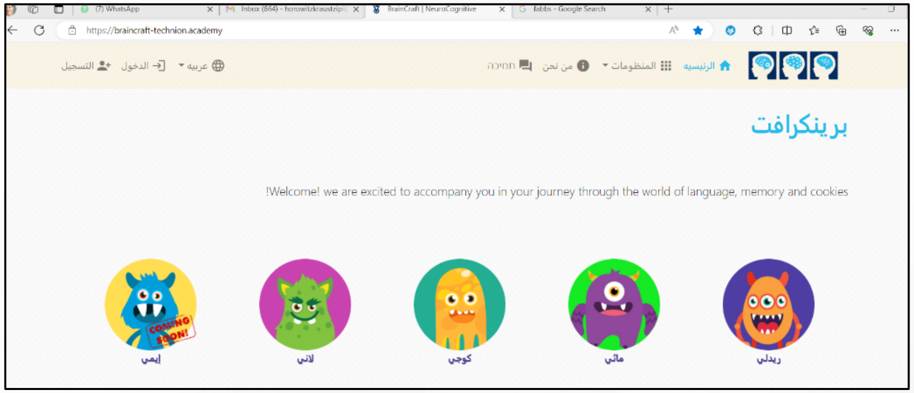


Figure 3. The reading network in the human brain. To be able to read, the brain had to "recycle" brain networks related to language processing (i.e. auditory, brown), visual processing (black), as well as cognitive control (EF, red, blue) and attention networks (yellow, green) (taken from Taran et al., 2022).

Figure 4. A Manual for the EF-based dialogic reading program was created by Horowitz-Kraus' program, published by the Israeli Ministry of Education and shared with all daycares, kindergarten and elementary school teams in the country.

Appendix

Figure 5. The EF-based reading fluency program (Braincraft: [BrainCraft | NeuroCognitive (braincraft-technion.academy)](https://braincraft-technion.academy))



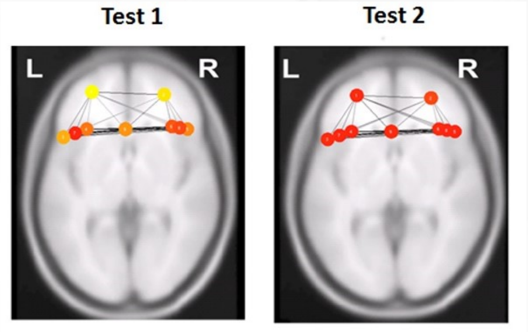


Figure 6. Changes in brain networks related to EF following training in the Braincraft EF-based reading fluency program, before training (left) and after 8 weeks of training (right). The hot color (red) represents greater network synchronization (taken from Horowitz-Kraus et al., 2015).

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