A report on the Literacy Network and Numeracy Network Deliberations

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Prefatory Remarks

The agenda for the Boston Numeracy and Literacy Network meetings is provided in Appendix A. It is not the goal of this review to repeat in detail what was said by each of speakers. Where preparatory notes were made available by the speakers, these are reproduced in the appendices.

The reader of this report might find it helpful to refer to a number of other reference reports/publications. The first publication is by Dehaene, (1997) "The number sense," Oxford, UK: Oxford University Press. The second publication is "Understanding the Brain" by the OECD (2002), which summarized the findings from the first three workshops conducted in phase one of this project. Of particular interest in this report is the section entitled, "Learning seen from a neuroscientific approach," which deals with research tools and methodologies of brain imaging and that also reviews pertinent literature on the relationship between the brain and mathematics learning and the brain and literacy. This OCED report reiterates Koizumi's contention that progress in cognitive neuroscience and education will necessitate the creation of a transdisciplinary effort. The third report is a review of educational research in mathematics learning from grades K – 8 by the National Research Council (2001). "Adding It Up: Helping Children Learn Mathematics", Washington, DC: National Academy Press. The fourth report describes the deliberations of the US National Reading Panel (2000), see Appendix B.

General Goals for the Meeting

The three-fold goal of Boston brain network meeting was set forth by Michael Posner of the Sackler Institute in New York. The first goal was to determine what the consensus knowledge was in each of literacy and mathematics education research as they related to cognitive neuroscience. Part of this effort includes the development of working papers on areas in which there is yet no scientific consensus, and to develop a website to communicate areas of scientific agreement. The second goal was to innovate research in both of these areas. The third goal was to think about how to make this knowledge or accessible to a global audience of educators and policymakers. The work proposed in these networks differs from former work in its attempt to develop interconnected activities that would link intervention training techniques to specific cognitive and brain imaging research.

The report will now describe first the presentations from the Literacy Network, and then those from the Numeracy Network. It will then compare progress in each as reflected in the talks in Boston.

READING RESEARCH

The reader of this section might wish to refer to the recent review of reading research drawn from the National Reading Panel (US), some highlights of which are presented in Appendix B. During the meeting, Ehri reviewed and extended these findings (see Appendix C) and provided a set of questions for research in reading, reproduced here. In later sections, the intersection of this work with the work of other researchers at the meeting will be examined. Before we discuss the reading (primarily decoding) discussions, we should note that phonemic awareness (which was discussed almost exclusively as text-related) relates also to language acquisition, generally, a process complexified by second language learning.

<u>Language Acquisition and Phonemic Awareness</u>

Early linguistic exposure plays a crucial role in the process of becoming a competent native speaker

In her presentation, Sebastian Galles pointed out that reading is a specific cultural task that arises in the context of mastery of a mother or second language. She directed the participants' attention to the development of processes of phonemic awareness among language learners before they learn to read and for those that are not exposed to reading. She noted that, "Research in cognitive neuroscience, both in monolingual and bilingual individuals, has shown that early linguistic exposure plays a crucial role in the process of becoming a competent native speaker. To acquire a specific language, infant brains must develop a structure that emphasizes some relevant distinctions existing in the language of the environment, while ignoring others." A similar point has been made to explain some of the difficulties that adult Japanese exhibit in learning certain sounds in English (see the reports from Phase I or the OCED publication on the brain (OCED, 2002).

In other words, Sebastian Galles' presentation pointed out that the mastery of a writing system, which converts speech into a visual code, depends upon acquiring an adequate phonological knowledge of the language. Researchers and teachers must face the complexity that some readers (or potential readers) may have language acquisition problems in both the mother tongue and in second-language learning.

Reading Research Review

At the Boston meeting Ehri presented the participants with a set of questions. Four of which derived from the perspective of psychology and had potential links to cognitive neuroscience, the fifth question involved implications for instruction:

What Questions And Issues Are Controversial Or Need More Research

1. What is the role of strategic, conscious, analytic processes in building a lexicon of sight words? Are connections formed to retain sight words in memory spontaneously without the reader's devoting special attention or effort when words are being read, or is more conscious analytic processing required? Are conscious, strategic processes important at the outset of development but lose importance subsequently as these processes become automatic?

2. Do graphophonemic and graphosyllabic connection-forming processes account fully for the retention of word spellings in memory or is there a "visual memory" component as well? If so, what are the processes involved and what factors are influential? Connectionist theory requires letters to be connected to sounds in order to be remembered. What about letters that are not perceived as representing sounds? How does visual memory for word spellings work? To what extent is it independent of graphophonemic processes?

3. Is it more useful to distinguish phases of development in learning to read words or to view development as a continuous process? (Source of controversy).

4. What factors explain the close relationship between word reading and word spelling? To what extent are the brain mechanisms activated during word reading and spelling tasks identical or distinct?

5. To what extent do bad habits inhibit the impact of phonics instruction in older poor readers? One potential bad habit is the strategy of guessing words using partial letter cues plus context. If this strategy is activated rapidly, it may preclude execution of the slower process of forming complete connections to bond spellings to pronunciations of words in memory.

The first four questions set the stage for an examination of the contributions from cognitive neuroscience, the genetic bases for dyslexia, the contributions of orthography to dyslexia, and computational models of reading processes. All of these topics were discussed at the meeting. The fifth question on instruction raised an issue that also permeated the conference and one that provides an important impetus to the work of both the Literacy Network and the Numeracy

Network. We will first comment on the cognitive neuroscience issues that emerged in the Literacy Network.

Cognitive Neuroscience Research: Solving the Brain's Problem in Reading

The brain, it may be said, "faces a problem" in learning to read. According to Carr, it lies in establishing an interface between vision and language. From a cognitive neuroscience perspective, the problem presents itself thus: Reading is a rather recent cultural invention. How does the brain establish cooperation among a number of brain subsystems that have not been selected by evolutionary processes (for reading) in order to combine visual word recognition, phonology, articulation and semantics and combine them into the act of reading for comprehension?

A growing consensus

What is remarkable about the brain research related to reading is the amount of detailed knowledge available related to fine operational distinctions in reading processes. We will find that this richness of detail is not yet available for mathematics learning processes.

There is growing evidence of "hot spots" in the brain from a reading perspective

McCandliss pointed to the emerging consensus from the imaging research (citing the presentation of the Shaywitzs) that there is growing evidence of "hot spots" in the brain from a reading perspective. The role of the peri-sylvian regions of the superior temporal gyrus, angular gyrus and supermarginal gyrus are clear when normal and dyslexics are faced with phonologically demanding tasks. Equally, the superior frontal gyrus region is implicated, perhaps, in control or articulation. Finally, the ventral occipital temporal region may be associated with skilled reading or the emergence of rapid skilled word recognition.

The contributions of neuroscience were spelled out in more detail by S. and B. Shaywitz, and are reported here in their entirety. The first section deals with current points of consensus, which are followed by more tentative conclusions. A more detailed treatment of much of this work may be found by Carr in Appendix D, and prepared by Pugh in Appendix E.

Shaywitz Section I. Research-based insights for which broad consensus might be reached

1. Brain activation differences between good and poor readers are most consistently observed with tasks that engage phonology.

The central difficulty in dyslexia reflects a deficit within the language system

There is now a strong consensus that the central difficulty in dyslexia reflects a deficit within the language system, and more particularly, in a lower level component, phonology, which has to do with the ability to access the underlying sound structure of words (S. Shaywitz, 1998; Wagner & Torgesen, 1987). In young school-age children a deficit in phonology represents the most reliable and specific correlate of dyslexia (Fletcher et al., 1994; Morris et al., 1998).

2. An emerging consensus indicates that there are at least three neural systems serving reading, one in the anterior brain region around the inferior frontal gyrus, and two posterior systems, one situated in the parieto-temporal region encompassing parts of the posterior superior temporal gyrus, supramarginal gyrus and angular gyrus; the second posterior system is in the occipito-temporal region, involving inferior occipital and temporal gyri and the fusiform gyrus.

Converging evidence from a number of lines of investigation indicates that a portion of the posterior reading systems, the occipito-temporal area, is critical for the development of skilled reading and functions as an automatic, instant word recognition system, the visual word form area (Cohen et al., 2000; Cohen et al., 2002; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002; McCandliss, Cohen, & Dehaene, in press). In this region brain activation increases as reading skill increases (B A Shaywitz et al., 2002); this region responds preferentially to rapidly presented stimuli (Price, Moore, & Frackowiak, 1996), responds within 150 msec after presentation of a stimulus (Salmelin, Service, Kiesila, Uutela, & Salonen, 1996), and is engaged even when the word has not been consciously perceived (Dehaene et al., 2001).

3. Evidence from investigators around the world converges to indicate a disruption of posterior neural systems for reading in dyslexic children, adults and adults with a history of dyslexia as children.

In dyslexic readers, a range of neurobiological investigations shows a failure of left hemisphere posterior brain systems to function properly during reading

A range of neurobiological investigations using postmortem brain specimens (Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985), brain morphometry (Filipek, 1996) , diffusion tensor MRI imaging (Klingberg et al., 2000) and functional brain imaging in dyslexic readers (Brunswick, McCrory, Price, Frith, & Frith, 1999; Helenius, Tarkiainen, Cornelissen, Hansen, & Salmelin, 1999; Horwitz, Rumsey, & Donohue, 1998; Paulesu et al., 2001; Rumsey et al., 1992; Rumsey et al., 1997; Salmelin et al., 1996; S. E. Shaywitz et al., In Press; S. E. Shaywitz et al., 1998) shows a failure of left hemisphere posterior brain systems to function properly during reading.

Dyslexia does not reflect a developmental lag but remains with the child for his lifetime

This neurobiological evidence of dysfunction in left hemisphere posterior reading circuits is already present in dyslexic children and cannot be ascribed simply to a lifetime of poor reading (Seki et al., 2001; B A Shaywitz et al., 2002; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000; Temple et al., 2000). More importantly, with the caveat that the studies were not longitudinal but reflect cross-sectional studies in children and in adults, the consistency of findings support the notion that dyslexia is not outgrown but rather reflects a persistent chronic condition. This indicates an urgent need for intervention at an early age. These data converge with our and other data demonstrating that dyslexia does not reflect a developmental lag but remains with the child for his lifetime (Bruck, 1998; Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; B.A. Shaywitz et al., 1995; S. E. Shaywitz et al., 1999; S. E. Shaywitz et al., In Press).

4. Evidence of a disruption in the normal reading pathways provides a neurobiological target for reading interventions.

Evidence from studies using fMRI (Temple et al., in press; Temple et al., 2000), magnetic source imaging (Simos et al., 2002) and magnetic resonance spectroscopy (Richards et al., 2000) demonstrate changes in the brain in dyslexic readers (both children and adults) using linguistically based reading programs (Berninger et al., in press; McCandliss, Beck, Sandak, & Perfetti, 2003). These changes involve both anterior and posterior brain systems. Importantly, the effects of the experimental intervention on the activation of the occipito-temporal word form area shown to be critical for skilled reading in children (B A Shaywitz et al., 2002) are similar to the cooccurrence of visuospatial proficiency and cortical specialization reported in adults (Gauthier, 2000; Gauthier et al., 2000).

5. It is reasonable to believe that interventions designed to improve reading fluency positively influence the visual word form area if such interventions are provided at an early age.

According to recent findings (Torgesen et al., 1999), provision of an evidence-based intervention at an early stage of reading instruction leads to the development of fluent reading ["the ability to read a text quickly, accurately and with proper expression" (Report, 2000)], the hallmark of skilled reading.

Intervention at an early stage of reading instruction leads to the development of fluent reading

Shaywitz Section II. Points that might be considered more controversial, for which additional research is needed

1. In addition to individuals with dyslexia as a result of a disruption in phonological systems, do other subtypes of reading disability exist?

Theories of dyslexia have been proposed that are based on the visual system (Demb, Boynton, & Heeger, 1998; Eden et al., 1996; Stein & Walsh, 1997), and other factors, such as temporal processing of stimuli within these systems (Talcott et al., 2000; Tallal, 2000). While children and adults with a phonologic deficit represent the majority of cases of dyslexia, other subtypes may account for some cases of dyslexia, for example, surface dyslexia (Coltheart, Curtis, Atkins, & Haller, 1993), D- and L- type dyslexia (Bakker, 1992; Bakker, Licht, & van Strien, 1991) and dyslexia resulting from deficits in naming-speed in addition to phonological deficits, [double-deficit hypothesis, (Wolf & Bowers, 1999)].

Are there differences depending on etiology, that is, whether the reading disability occurs primarily on a genetic basis or whether dyslexia results from environmental disadvantage?

In a recent study of young adults who were dyslexic as children, functional brain imaging studies distinguished two potential types of reading disability (S. E. Shaywitz et al., in press). These are consistent with Olson's suggestion of two possible etiologies for childhood reading disability: a primarily genetic type with IQ scores over 100 and a more environmentally influenced type with IQs below 100 (Olson, 1999; Olson, Forsberg, Gayan, & DeFries, 1999; Wadsworth, Olson, Pennington, & DeFries, 2000).

3. What are the influences on the development of the visual word form area?

Studies in progress are following children longitudinally with fMRI and comprehensive behavioral testing to determine the influences on the development of this region.

The complexity of the problem faced in reading extends to the semantic aspects of the task. Semantic processing is also widely distributed in the brain. According to Carr, "Lexical semantics rely on frontal and temporal cortex. Propositional semantics and referential interpretation rely on additional contributions from the right hemisphere." Further, detailed comments by Carr are available in Appendix D.

The Role and Value of Computational Models in Understanding Reading

There is clearly much complexity within the cognitive neuroscience research that appears to have implications for reading. How can these data be brought to bear on reading, an activity takes place at the psychological level? How can scenarios suggested by one level of analysis be examined efficiently at the other level? One possible solution to this problem is to simulate hypothesis testing using a computational model.

In his presentation, Seidenberg described a connectionist model that attempts to simulate the reading processes from the psychological perspective. In this computational model, performance on "reading" tasks emerges from the model dynamically – parameters are not fitted to the model post hoc. For example, aspects of the performance of dyslexics (impaired representation at the phoneme level, impaired ability to generalize) are seen to emerge naturally from a model that has an intrinsic deficit in the capacity to represent and process phonology.

The model can also represent the simulated effects on reading acquisition of different orthographies, it can test hypotheses regarding the division of labor between visual and phonologically-mediated reading processes, and so on.

In other words, this computational model allows researchers to pose and examine a variety of questions and compare the performance of the model with data from human subjects.

Seidenberg listed a number of questions that are appropriate for this model:

There might be significant differences in how reading occurs in different writing systems

1. Which is more effective: promoting knowledge of the relationship between the spoken and written forms of language or promoting a direct, visual processing strategy that obviates phonology entirely?

2. What are the sources of individual differences among children and adults with respect to reading achievement?

3. Do different types of constitutional deficits give rise to different patterns of impaired reading? That is, does dyslexia have a single cause or are there different subtypes associated with different etiologies?

4. If there are a small number of distinct etiologies (as we believe), how can they be identified psychometrically and what methods for remediating these deficits will be effective?

5. How is the process of learning to read affected by other aspects of instructional practice, e.g., the order in which words are introduced, the feedback provided to the child, the type of reading activity they engage in, and so on?

6. How are reading acquisition and skilled reading affected by the nature of the orthography? Although more research has been conducted on English than on any other writing system, this situation is rapidly changing. On the one hand, English has some atypical properties and so problems that arise in learning to reading this orthography do not necessarily arise in other writing systems (e.g., Italian or Finnish). This suggests there might be significant differences in how reading occurs in different writing systems. On the other hand, ignoring pathology and minor individual differences, we all have the same brains and there are many commonalities among writing systems, and so there should be universal aspects of the reading process as well.

7. How is reading accomplished by the brain? Our models serve two functions in this regard. First, they provide a way of interpreting the kinds of data that are emerging from neuroimaging studies of reading. For example, we can go beyond identifying brain circuits involved in reading to understanding what kinds of computational functions they serve. Thus we can begin to answer why questions about the involvement of different brain structures, not merely where questions. Second, our models suggest directions for neuroimaging studies. Though it is limited in some obvious respects, we have a basic theory of simple aspects of word reading that suggests nonobvious directions for neuroimaging research. These are directions that would not be considered without a computational model in hand.

The Role of Orthography in Diagnosis of Reading Difficulties

Differences among dyslexics in reading performance in different countries are due in part to different orthographies

In Seidenberg's set of questions, we see the posing of the role of orthography on reading, particularly in the diagnosis of dyslexia. What is the role of orthography on learning to read?

On the general question of orthography and dyslexia, Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith and Frith (2001), claimed that there is a universal neurocognitive basis for dyslexia. They further claimed that differences among dyslexics in reading performance in different countries are due at least in part to different orthographies. This topic was discussed by a number of participants at the meeting.

According to the presentation by van der Leij:

> It is clear that most European orthographies are quite transparent. Combined with emphasis on grapho-phoneme correspondencies in the instruction methods, this results in high accuracy scores (> 80 %) at the end of grade 1. In contrast, 'deep' orthographies, in particular English, indicate lower scores (< 40 %). Specific reading disability ('dyslexia') in a shallow orthography appears to be a matter of speed more than of accuracy, while accuracy problems are abundant in English (German/English: Wimmer, Landerl, Frith, et al; Italian/French/English: Paulesu et al.; Dutch: De Jong et al.).

van der Leij made two other observations that will impact research methods for dyslexia:

> All orthographies include phonemic, graphemic and orthographic complexities; therefore, depending on the amount of them, dyslexics may show accuracy problems to accompany their dominant speed problems, even in shallow orthographies; to detect them, items to be read and spell should be selected and developed carefully;
>
> Shallow orthographies seem to miss a large amount of exception words; as a consequence, it is impossible to base subtypes on nonwords/exception words contrasts (as was done for English by Harm & Seidenberg, 1999).

<u>Early markers of dyslexia appear even for readers of shallow orthographies</u>

Even for children who read within a fairly shallow orthography (e.g., Finnish), problems of reading performance still occur, and they can be predicted by a variety of indicators from an early age. According to Lyytinen, "Earliest significant differences between groups were found from brain responses (event-related potentials, ERP) and behavioural data to quantity (duration) variation in (or categorical perception of) speech elements characteristic to Finnish soon after birth and also at a later date. ERPs to speech stimuli immediately after birth, as well as those recorded at 6 months of age, reveal significant correlations to later language development and reading acquisition."

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<u>Learning to read and the orthography of Chinese characters</u>

When the orthography question is extended to learning Chinese, a reading system that uses characters instead of letters, strikingly similar results were found to the case of learning a deep orthography such as English. In Chinese, there is the added complexity of the morphology of the characters. In the presentation by Shu (the abstract of which is available in Appendix F), she noted:

Recent studies have provided the strong evidence that phonological processing is crucial in learning to read Chinese (Ho & Bryant, 1997; Shu, Anderson & Wu, 2000; Tzeng, Lin, et al., 1995; Yang & Peng, 1997), and phonological impairment is highly related with Chinese dyslexic children (Ho, 1997, 1999; So & Siegel, 1997; Tzeng, 1993). Also studies have reported the importance of morphological awareness in learning to read Chinese (Chan & Nunes, 1998; Shu & Anderson, 1997, 1998). A study with first and fourth grade children showed that both morphological and phonological awareness contribute to reading proficiency, in which the role of morphological awareness was relatively larger than that of phonological awareness (Li, Anderson, et al, 2002). McBride-Chang, Shu, et al. (in press) found that, when the role of visual, phonological, speed and oral vocabulary were partialed out, morphological factor still significantly contributed to character recognition in 5 years old kindergarten and second grade children.

Prevalence rates for dyslexia vary by language group

It was clear from these discussions that diagnoses of dyslexia (and related reading problems) is not simple. As noted in Phase I of this OCED project. The effects of the depth of the orthography and its morphology on reading difficulties opens an important line of research into understanding how the brain struggles with the cultural task of learning to read with comprehension.

Intervention, Heritability and the Hard Task Ahead

One of the major themes that arose from Phase I of this project (see OCED, 2002) was that, while we are only in the early stages of research, a number of companies are marketing “brain-based interventions” with claims that they can remediate learning deficits or enhance learning experiences. In fact, part of the impetus for this project was the paper by Bruer (1999), which pointed to the gulf between cognitive neuroscience research and direct implications for education. This caution is strengthened by the presentation by Olson on behavioral genetic studies and the impact of instruction or training. Olson’s entire abstract may be found in Appendix G. Olson noted:

> Recent analyses by Gayan and Olson (2001) of data from 8-18 year old twins in Colorado indicated that 50-60% of the group deficit in word reading was due to genetic influences. For individual differences across the normal range, genetic factors accounted for 69-92% (.05 confidence interval) of the broad variability in word reading (Gayan & Olson, 2003). Similar estimates of genetic influence on word-reading deficits and

individual differences have recently been reported from a large (4,737 pairs) representative sample of 7-year-old twins in the U.K. (Harlaar et al., submitted).

Gayan and Olson (2001) demonstrated that 60-70% of the group deficits in phoneme awareness and nonword reading were largely due to the same genes, and there were substantial genetic correlations between subjects' deficits in these two skills and their deficits in word reading, even after controlling for subjects' Wechsler full-scale IQ scores.

There are significant genetic influences on preschoolers' ability to learn about phonemes prior to formal reading instruction, and preliminary indications are that this early learning ability is linked to subsequent individual differences in early reading. Surprisingly, individual differences in letter name knowledge, a traditionally powerful predictor of later reading skill, were almost entirely due to environmental differences between families.

Surprisingly, individual differences in letter name knowledge, a traditionally powerful predictor of later reading skill, were almost entirely due to environmental differences between families.

The important questions for those interested in educational interventions include, how amenable to instruction or training are the deficits? On this point, Olson pointed out that the heritability of some reading difficulties should have value in early detection and early intervention, though the impact of such intervention has not been extensively studied. Further, the research into identifying particular genes and intervening on this basis is immature. There is, however, some hope for targeted instruction. Olson continued:

In spite of the high heritability for phonological deficits in school age children, it is clear from a number of training studies that poor readers' deficits in phoneme awareness and phonological decoding, as they are typically measured, can be substantially improved even into the normal range (McCandliss et al., 2003, Torgesen et al., 2001, Wise, Ring, & Olson, 2000). Unfortunately, these studies did not observe significantly greater gains in fluent word reading when their phonologically based interventions were compared to equally intense but non-phonologically based interventions (Torgesen et al.; Wise et al.), or surprisingly, to a no treatment control (McCandliss et al.), at the end of training. Moreover, Torgesen et al. and Wise et al. found that while phonologically remediated groups maintained their phonological advantage one or two years after their training had ended, there was still no transfer to significantly better word reading skills when compared to the non-phonologically trained groups.

The above results seem paradoxical: If phonological deficits are highly correlated both phenotypically and genetically with word reading deficits, why does the presumed repair of phonological deficits have little or no unique benefit for fluent word reading in older children with reading disabilities? One answer may be that the improved explicit knowledge that is trained and tapped in our traditional measures of phoneme awareness and phonological decoding does not represent the status of underlying phonological processes that influence rates of growth in word reading, even though the status of those underlying processes contributed to the commonly observed correlations between our measures of phonological skills and reading.

Perhaps we have not gone <u>deep</u> enough in our training of phonological skills. Wise et al. (2000) suggested that further intensive training of phonological processes to achieve greater "automaticity" in their application during reading might facilitate higher growth rates in word reading, but this hypothesis remains untested. Alternately, maybe the intervention did not start <u>early</u> enough, but the evidence for the unique <u>long-term</u> efficacy of early phonological intervention is mixed (Olson, 2002). A possible resolution to the paradoxical genetic correlations and training results in older children is that there is some yet deeper third factor that accounts for variance in both phonological and fluent word reading skills, and thus their correlation. In this view, remediating phonological deficits might not significantly improve fluent word reading because the causal third factor had not been remediated. Some theorists have suggested that processing speed, as measured in the rapid naming of letters and numbers, is an important core deficit in children with reading disabilities (Wolf, 2001). Other researchers have pointed to more basic sensory temporal processing deficits (c.f., Tallal, 1980). However, sensory processing deficits may not be specific to reading deficits, since all or nearly all of their relation to reading is mediated by subjects IQ scores, and sensory processing deficits are not specific to tasks demanding rapid processing (Hulslander et al., submitted; Olson & Datta, 2002). Further research is needed to clarify the underlying reasons for genetically influenced reading disabilities and their implications for remediation.

The Role of Instruction

As noted by the National Reading Panel and in Ehri's report, instruction in reading is critical. Carr noted that:

A. Classroom instruction matters.
   1. When reading instruction focuses on rule-governed word recognition, higher skill at spoken language helps.
   2. When reading instruction focuses on "whole language" and sight-word recognition, higher skill at spoken language can actually *hurt*.

B. Remedial instruction matters.
   1. When classroom reading instruction fails to establish structure sensitive or "rule-governed" knowledge and processing, more intensive specialized instruction helps.
   2. Such instruction, done right, makes the *brain* look like a reader.

On this point, Morrison reported on natural experiment to assess the effects of schooling on early mathematics and literacy development. The methodology uses the school entry cut-off date, which is based on birth date, to select groups of children who are effectively equated on age. Analyses have shown that these two groups are also equated on critical control variables (e.g., IQ, SES, and preschool experience). Morrison found parallel findings, in some respects, to those found by Olson. Citing from the abstract provided by Morrison (and reported in Appendix H):

> **Schooling influences on growth of literacy skills appeared to be confined to a relatively delimited subset of elementary reading and math skills with little evidence for early schooling effects on or transfer to other important skills such as vocabulary, general knowledge, narrative skills, and conservation**

> In a series of studies over the past five years, the patterns of change across a broad range of domains and skills appeared to be highly domain and even sub-domain specific. For example, changes in phonological segmentation differed greatly depending on the level of segmentation involved (phonemic, sub-syllabic, or syllabic; Christian, Morrison, Frazier, & Massetti, in press). Second, surprisingly little transfer was observed across skills that, on the surface, appear to share cognitive

or experiential components (e.g., conservation of number and number addition skills; Bisanz, Morrison, & Dunn, 1995). Finally, schooling influences on growth of literacy skills appeared to be confined to a relatively delimited subset of elementary reading and math skills with little evidence for early schooling effects on or transfer to other important skills such as vocabulary, general knowledge, narrative skills, and conservation (Christian, Morrison, et al.). Overall, results from these studies reveal a relatively high degree of specificity in the nature and timing of changes in cognitive skills (Christian, Morrison, et al.).

When Morrison and his colleagues looked at the effects of instruction, they found important interactions between teaching methods and IQ and found significant differences in how teachers allocated instructional time and its expected effects on learning:

Greater amounts of teacher-directed activity (e.g., letter-sound instruction) predicted greater growth for low IQ but not high IQ children. In stark contrast, greater amounts of child-directed activity (e.g., sustained silent reading) predicted better growth for high IQ but not low IQ children.

Regression equations demonstrated that, controlling for several background factors, greater amounts of teacher-directed activity (e.g., letter-sound instruction) predicted greater growth for low IQ but not high IQ children. In stark contrast, greater amounts of child-directed activity (e.g., sustained silent reading) predicted better growth for high IQ but not low IQ children. Hence, both amount and type of activity surfaced as crucial elements of instruction but the benefits of each of these activities differed dramatically for children of differing IQ's.

Most striking were differences across teachers. Some children received as much as 180 more hours instruction on language arts compared to other children.

Third, findings from the [Classroom Observation Narrative, CON (Griffin, 2000a)] CON have revealed substantial variability across teachers and subject areas in amount of instructional time in both kindergarten and first grade (Frese et al., 2000). Kindergarten teachers spent most time in non-instructional activities (like transition and management) followed by language arts, with much less time spent on mathematics and very little time on science or social studies. First-grade teachers increased the time devoted to language arts but non-instructional time was still high and comparatively little time was spent on math. Most striking were differences across teachers. In first grade, some teachers spent

> as little as 43 minutes on language arts while others devoted over 104 minutes per day. Extrapolating to a whole academic year, some children received as much as 180 more hours instruction on language arts compared to other children. Similarly, large discrepancies were noted for math instruction and in kindergarten (Frese et al.).
>
> Finally, the general pattern of instructional emphases across more specific literacy skills strongly suggested that in those subject areas where most instructional time is placed (e.g., word decoding, phonemic awareness), schooling effects are most pronounced in kindergarten and first-grade, and individual differences (e.g., across IQ) decrease over time. In contrast, in subject areas with less instructional time, IQ differences are maintained or magnified over the course of kindergarten and first grade (Williams et al., 2000).

As we can see, the instructional picture is neither simple nor clear from the perspective of cognitive neuroscience. One of the hopes of this project is that the combined expertise from the many research domains represented in the OCED networks can accelerate progress for education and intervention. These gains may come from what the behavioral analyses provide to inform brain imaging and what brain imaging studies provide in terms of suggesting and testing new hypotheses about learning. A promising direction may be the use of computer-based activities that can be provided via the Net to large numbers of learners across the world. Please see Appendix I for a description of related work by McCandliss.

Dissemination of Findings and Diffusion of Interventions

The meeting of each of the Literacy Network and Numeracy Networks concluded with a discussion of a potential web site that could provide information and other resources to parents, teachers, and policymakers. The vision for this site was provided by McCandliss:

Thus, one important research innovation activity involves the development of interactive computer activities that link intervention/training techniques to specific cognitive and brain imaging research, and at the same time making those resources widely available via a non-profit, globally accessible, interactive platform. Such activities will ideally:

A. Provide laboratory researchers with a unique forum and set of resources to create and revise new intervention procedures that address research-based insights and questions concerning brain mechanisms of literacy acquisition and the potential of influencing these mechanisms through focused intervention activities.

B. Provide users (i.e. children, educators) with direct access to the diagnostic, intervention, brain activation tasks that appear within brain imaging/intervention studies.

C. Provide researchers with access to performance and outcome data on a large diverse population of learners interacting with experimental versions of these activities.

D. Provide "translational researchers" with a host of observations concerning commonly recurring challenges facing the process of integrating research insights into classroom practice and school cultures.

Both Networks discussed plans for such sites and progress in this regard is ongoing. One possibility is to draw upon "lessons-learned" from the design of effective video games. A review of that literature was presented by Rosas Diaz (see Appendix J).

MATHEMATICS RESEARCH

Numeracy Network Sessions

The National Research Council (2001), Adding it up, reiterated the point made by Dehaene that mathematics is a creation of the human mind.

Mathematics is a creation of the human mind

It then reviewed the literature in the learning of mathematics pre-kindergarten to grade eight. The review claims that mathematical proficiency is composed of five separate strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. The literature cited on the pre-kindergarten and kindergarten learning of mathematics (the focus of the Boston workshop) is primarily drawn from developmental psychology or classroom studies.

The Numeracy Network held separate sessions during the time that the Literacy Network was holding its sessions (see Appendix A). In the first session, the emphasis was on infancy. Spelke described the findings related to the development of models of numerical competence in infancy, including both small and large numbers. Xu described number perception in infancy. And, Wynn described the arithmetic ability of infants.

In the second session, the Network focused on learning from infancy to early childhood. Brannon described findings related to the development of serial ordering in infants. Barth described non-symbolic arithmetic in young children. And, Gelman described preverbal knowledge and the transition induced by counting.

Following the joint sessions described under the Literacy Network, the Numeracy Network then held a separate session on the transition to school learning and also pathologies associated with mathematics learning. Griffin underscored the importance of early experience for number learning. Bevan provided findings from the London dyscalculia study and emphasized the emotional burdens of dyscalculia. The session ended with Battro providing unique insights into number and geometry from rare research on the hemispherectomized child. The Numeracy Network ended with a session on a synthesis of the meeting’s insights and directions for new research.

Synthesis

Unlike the direction followed by the Literacy Network, the goal of the mathematics sessions was not to exhaustively review the literature on mathematics learning to the depth and scope of the reading literature. Rather, the Numeracy Network in this meeting chose to review and to attempt to achieve consensus around normal child development in the learning of number. The presentations, therefore, focused on simple task learning by young children. There was less emphasis on brain-based research compared to the presentations in the Literacy Network and no papers were presented on the genetic basis for mathematics learning. Further, there were no direct comparisons, internationally, on the role of the development of reading competence on the learning of mathematics [comparisons that would appear to be fruitful for future meetings since Dehaene's Triple Code Theory of mathematics learning (see Appendix K) provides an important role for language].

Further, while there exists in mathematics learning research work on an analog to dyslexia in reading ("dyscalculia"), the Numeracy Network in this meeting did not focus on this aspect of nonnormal mathematics learning and also did not focus on problems of rehabilitation.

Learning Sequences for Mathematics

Recognizing that the studies presented are works in progress and that much more research is needed before suggesting that we understand the development of mathematics learning among children, a rough "timeline" of mathematics learning for young children began to emerge across the papers.

The first point made was that those working with children tend not to speak of stages of development; rather, they prefer to speak of looser arrangements of sequences of appearance of mathematical competencies. The notion of stages suggests some maturational landmarks of cognition are known, and that these are firmly fixed chronologically. Not only does the research literature not support a stage formulation, but the extent of the ameliorative effects of educational interventions on learning sequences is only beginning to be understood. Further, many links from mathematics learning to cognitive neuroscience have yet to be established, the number of behavioral studies is relatively small, the number of subjects in these studies is not large, and replication studies would (as in the case of science, generally) be desirable.

Nevertheless, there is some convergence towards a more precise model of numerical development in the first years. The consensus now is that there are at least two systems that are underlying number development in the early years and are already available to the infant (see the presentation by Spelke, for example). The first system is a system for estimation of numerocity

The consensus now is that there are at least two systems that are underlying number development in the early years and are already available to the infant

(subitizing), but there is no consensus as to whether the system is limited exclusively to large numerocities or not. This system approximates number and extracts it from either visual or auditory stimuli. The other system, which is also available at the very young age, tracks very small numbers of objects (maybe up to 3). According to the presentation by Carey, these two types of competence are employed differently in different types of tasks.

Griffin described a series of performance landmarks that are tied to rough age ranges. These landmarks are based on Central Conceptual Structure (CCS) theory and propose the following:

1. At ***3-4 years: Global Quantity and Counting Schema.*** Children by age 4 typically demonstrate the ability to make global quantity determinations (judging "a lot" vs "a little"; and have a schema for counting small sets of objects by saying the counting words as they touch each object. These systems do not yet appear to be interacting coherently at this age, however.
2. At ***5-6 years: Mental Counting Line Schema (Central Conceptual Structure for Number*****).** By this age, many children have begun to integrate the quantity and counting schemas, so that they can use counting words and know that small numerals signify "a little" and larger numerals signify "a lot." They also come to understand that each increase in a counting number represents an increase or one unit. There is a growing understanding of magnitude (9 is bigger than 7) and that addition and subtraction can be accomplished by counting forward or backward along a counting string.
3. At ***7-8 years: Double Mental Counting Line Schema.*** By age 8, many children have learned to use the two systems in a coordinated fashion so that they handle two variables simultaneously: e.g., figuring dollars and cents or hours and minutes. They learn to solve double-digit problems and to tell which of two double-digit numbers is larger or smaller.
4. At ***9-10 years: Integrated Double Counting Line Schema.*** The prior schemas are now more fully integrated allowing children to perform two-digit borrowing and carrying, translate from one dimension (e.g., hours) to another (e.g., minutes) and to tell which complex representation of time is later or earlier than another. Further, many children, by age 10, can work with balance beam problems to determine compensation of quantities on either side of a fulcrum.

According to Griffin, Central Conceptual Structure (CCS) theory assumes that "that four factors contribute to the development of these structures: (i) maturation; (ii) exploration (e.g., opportunities to actively interact with numbers and quantities and to construct relationships among them); (iii) social interaction (e.g., opportunities to learn the terms used to describe number and quantity in the culture); and (iv) equilibration (e.g., opportunities to extend current knowledge and to build upon it). Because of these core assumptions, an adequate, "good enough", preschool experience (one rich in the above-mentioned opportunities) is essential for the timely development of the precursor knowledge structures that will be required for school learning and, ultimately, for success in school."

Of particular interest to the Numeracy Network, therefore, is that we appear to be able to characterize learning behaviors to tell if the performance is coming from one level of representation or the other.

Maturation alone does not account for mathematics learning, but that appropriate educational intervention is key

In other words, we may be able to identify what Mike Posner refers to as signatures that can link behavioral and cognitive neuroscientific analyses. On this point, Griffin has available concrete interventions (i.e., *Number Words*) that can function as educational inputs to help extend our understanding of mathematics both in the classroom and from the point of view of cognitive neuroscience. Griffin's data shows that maturation alone does not account for mathematics learning, but that appropriate educational intervention is key.

It should be noted that normal adults have available to them (due to language development) a third system that can operate on mathematics using verbal symbols. Such data cannot be (easily) collected from infants or primates. On the other hand, the data presented in this meeting suggest that between ages 4 – 6 years, children have begun to form a mental counting line structure that by its integration of sub schemas allows for the later ability to solve verbal mathematics problems.

The work of Wynn suggests that when we look at infants (around 5 months) that it is possible to replicate simple addition and subtraction effects (e.g., 1 + 1 = 2; and 2 – 1 = 1), but when the variable effects may be obtained when physical parameters of the display are changed. How much of the understanding of simple arithmetic is due to an innate mathematical sense and how much is a function of physical parameters (e.g., involving a tracking competence) is the focus of ongoing work.

In her presentation, Brannon described a number of studies that suggest a sharp landmark between infants at 9 months and those at 11 months in being able to appreciate the ordinal relationship among numbers (e.g., 2, 4, 8). Whether this effect appears because of maturation or as function of maturation and experience, it occurs well before the acquisition of number words. Continuing the theme of some form of nonsymbolic understanding of mathematics, Barth's presentation showed that adults can add, subtract, multiply, and divide large arrays of dots, even when the paradigm prevented the use of counting or continuous quantity information.

A number of studies suggest a sharp landmark between infants at 9 months and those at 11 months in being able to appreciate the ordinal relationship among numbers (e.g., 2, 4, 8)

Other studies that attempt to control for the years of mathematics learning by adults has begun to show similar nonsymbolic processing by five- to six-year olds, pointing to a rudimentary “rough sense of number” that may serve as a foundation for later mathematics learning. These studies show that children’s primitive sense of numerosity does not rely on continuous quantity cues such as summed area, density, or contour length.

Gelman’s presentation showed that children of age 4 or even 3 years of age have a sense of the direction and result of a transformation even when the understanding is not precise, numerically. Thus, taking 2 away from a quantity suggests that the remaining amount would be smaller and roughly by how much. [The conference notes by Gelman are available in Appendix M.] Thus, [researchers] are beginning to learn how to design tasks that map numerals into quantities.

Important Research Questions for the Numeracy Network include:

1. In the learning of number by infants, what are the invariances, if any? Must some type of learning (related to numerocity or object tracking) precede the other? How should these competencies develop to better support later learning in mathematics that also uses the verbal system?
2. Are there really two systems as suggested by these data? Or are we seeing, rather, differential responses to the tasks provided? More definitive tasks must be designed to settle this question, behaviorally, and to support direct cognitive neuroscience corroborative studies.

It may be that children can handle mathematics that are more sophisticated than we had imagined

3. Deciding these questions is important (according to Griffin) since education in mathematics inevitably makes assumptions about the skills and competencies of children that may not be borne out by cognitive or cognitive neuroscience studies. Where there is a development mismatch, the child may be substantially disadvantaged both cognitively and emotionally (on this point, see the presentation by Devan on the deleterious affective effects of dyscalculia on children, particularly stigmatization). On the other hand, we may find that children can handle mathematics that are more sophisticated than we had imagined, particularly if the educational intervention (perhaps using technology) is guided by scientific studies. The work by Barth and others on primitive number understanding suggests the importance of well-designed educational interventions.
4. There should be effort expended to come up with better and more precise tasks that allow the type of multilevel signature studies that were described in this meeting. For example, Griffin’s board game

ideas allow for task design that can be exploited both instructionally and in brain-imaging studies. For example, we could learn: are the sequences of number acquisition serial but independent? Or are they nested so that the more primitive is crucial to the mastery of the more advanced? Is the first step to map numbers to quantities?

5. Teachers, parents, and policymakers must begin to realize how much mathematics even young children bring to school. Since we are coming to understand that these systems are unconscious, the child will have difficulty articulating where the inhibitors to learning are. [On this point, see the review of literature on implicit learning by Tudela from Granada.] We must extend the behavioral and cognitive neuroscience studies to provide teachers and others with more articulated models to guide instruction and policy.

6. We must also get clarity for young children on how the emerging quantity system can give meaning not only to small numbers, but also to larger exact numbers, and as Wynn showed, to the child's understanding of "absence" of objects (i.e., a concept of zero). Additionally, fundamental work is needed to understand how the quantity system deals with complex uses of numerals in mastery of fractions. How do the systems of the two numbers in a fraction map to one another? How might we design tasks that allow for a testing of this problem at the cognitive neuroscience level?

7. From a cognitive neuroscience point of view, it will be highly desirable to build upon the existing foundations to provide a precise numerical model of numerical development similar to the connectionist and simulation models described by the Literacy Network. One question that arises in this regard is whether or not a simulation model can account for times when young children's counting is due to visual and auditory processing with external objects and times when the brain is actually processing the data using a quantity subsystem.

8. The concept of the brain being central to the study of mathematics learning was seen as foreign by some of the researchers who prefer a behavioral and developmental perspective. By contrast, both Frith and Dehaene argued for extending brain-based work on adults' impairments in learning mathematics (e.g., dyscalculia) to studies of children (as is the case in London with Bevan).

9. Note that studies are required to extend the work described in this meeting to other fundamental concepts such as negative numbers, measurement, the concept of zero, and variable thus extending to algebra.

10. There appeared to be general consensus that educational interventions should not emphasize rote forms of symbolic manipulation; it is important to give meaning to mathematical symbols. What this observation shows is that educational

interventions can proceed from psychological studies of mathematics learning (a point argued persuasively by Bruer). On the other hand, cognitive neuroscience studies can provide crucial data to disambiguate hypotheses from the cognitive and behavioral levels of analysis. These advances may depend on methodological advances in technology including (near infrared spectroscopy) NIRS, fMRI on babies and improved procedures for the use of ERPs. Further, because mathematics learning involves nonverbal aspects it can also be studied in animals and even in single-cell studies.

11. Additionally, techniques now being developed in adults suffering from genetic illnesses may be exploited to study numerical competence in young children suffering from William's or Turner's syndrome, fetal-alcohol syndrome, prematurity at birth; and even gifted children.

Looking ahead, work needs to be put into the development of a website that helps parents and others to learn what is known about cognitive neuroscience and mathematics learning. It is important that technical terms be clearly explained (with at least a good glossary), and that if any instruments from research are presented that all possible safeguards against invalid use are in place. Such concerns include human subjects issues.

Integrating the Literacy and Numeracy Sessions

It is possible to compare the two sessions (one on literacy and one on mathematics learning) in order to draw some tentative observations.

Reading research has tended to focus on more componential analyses such as phonemic awareness and decoding skills. This attention to operationalizable knowledge has led to the collection of empirical data across many fronts including behavioral, computational, and genetic studies. Further, the research into reading difficulties, particularly the case of dyslexia, has matured considerably in diagnostic tests, behavioral, and classroom and developmental studies in many countries across different orthographies.

This componential and pathology-centric focus appears to have produced data and hypotheses that are amenable to study by a variety of brain-imaging technologies. We saw the emerging fruits of this connection in these meetings.

Moreover, the fact that so many researchers share a common platform (e.g., phonemic awareness or dyslexia-related studies) appeared to allow researchers with quite different backgrounds (e.g., geneticists and psychologists) to have fruitful conversations.

On the other hand, the relative amount of research on reading comprehension as opposed to decoding, and the character of this research makes it less likely that we will have as much progress as soon linking brain-imaging research to semantic processes. Comprehension processes are more complex and introduce cultural, social, affective and cognitive features that are difficult to model or to render as testable hypotheses suitable for brain-imaging.

This case can be compared to related activity in mathematics learning. It is noteworthy that in the NRC report, *Adding it up* (NRC, 2001), which reviewed mathematics learning literature from grades K – 8, there is not a single reference in the index to the brain or to cognitive neuroscience. For this reason, the links from the behavioral and social research in reading is much closer to the brain imaging work than is the research that might tie mathematics learning to brain imaging studies of mathematics learning.

On the other hand, cognitive neuroscience has only begun to explore the five components of mathematical expertise that are described in the behavioral and psychological literature: viz., conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition.

Moreover, mathematics education research also studies complex mathematics such as geometry, statistical understanding, and proportional reasoning. In the schooling context, these mathematical formalisms are in turn applied to practical problems (e.g., design of architectural space, inferential reasoning from samples to populations) that involve other issues both social and cultural. This complexity is compounded by the fact that mathematics problem solving in the higher grades is necessarily expressed in language and requires reading comprehension.

Mathematics problem solving in the higher grades is necessarily expressed in language and requires reading comprehension

This final observation returns us to the original observation about literacy research and brain science – the paucity of work related to reading comprehension.

In the shorter term, it may make sense in the Numeracy Network to continue to focus on simple counting and arithmetic studies since these appear to be amenable to being recast as brain-imaging studies. We may also be able to continue to include the data from primate studies since parts of mathematics understanding are pre- or nonverbal.

As for studies of mathematics beyond simple counting, it may be possible to link Dehaene's work on the verbal aspects of the Triple Code theory to some of the comprehension-related areas of mathematics learning. Perhaps it may be possible to extend the visualization research described in OCED (2002) to geometry learning studies.

General Processes

Some processes general enough to encompass both reading and mathematics learning and might form the basis for integrated work: the study of affect and emotion, pathological conditions that might have implications for learning such as autism or other syndromes, or studies from cognitive science research such as the solving of closed problems (such as the Towers of Hanoi puzzle). There may also be fruitful work in discovering more about the research in Japan on the use of near-infra red techniques to study working memory. In fact, the research and activities of the Literacy and Numeracy Networks may need to be more coordinated with those of the Life-Long Learning Network.

On the other hand, the Numeracy Network is able to draw on animal studies more readily than reading researchers since mathematical quantity subsystems can function without verbal competence and across primates and other animals.

Appendix A

OECD-CERI - 23.01.2003

Boston Literacy Network Meeting

Venue: Best Western Carlton House, 1005 Belmont Street, Brockton, MA 02301 - Tel/Fax: +1 508 588 3333

AGENDA

WEDNESDAY, JANUARY 29

Session 1 - Opening - 9:00-10:00 (JOINT)
Chair: Liz Spelke

9:00: OECD work on Education and the CERI "Brain project" (Bernard Hugonnier / Bruno della Chiesa)
9:30: Goal setting (Michael Posner)

Session 2 - Consensus building on brain mechanisms of skilled reading - 10:00-13:00 (SEPARATE)
Chair: Bruce McCandliss

Speakers: Tom Carr, Mark Seidenberg, Ken Pugh, Nuria Sebastian *(order to be confirmed)*
(each talk 10' + discussion)

Lunch Break 13:00-14:00

Session 3 - Biological basis of dyslexia - 14:00-17:00 (SEPARATE)
Chair: Eamonn Kelly

Speakers: Dick Olson, Elena Grigorenko, Bennett Shaywitz, Aryan van der Leij *(order to be confirmed)*
(each talk 10' + discussion)

Session 4 - 17:30-18:30 (JOINT)
Chair: Emile Servan-Schreiber

Number and language (Susan Carey)

THURSDAY, JANUARY 30

Session 5 - 9:00-10:00 (JOINT)
Chair: Dan Berch

9:00: Behavioral and brain abnormalities associated with dyscalculia in Turner's syndrome (Stan Dehaene)
9:30: Early markers of dyslexia (Heikki Lyytinen)

Session 6 - Literacy development - 10:00-13:00 (SEPARATE)
Chair: Penny Milton

Speakers: Linnea Ehri, Shu Hua, Fred Morrison, Catherine Snow *(order to be confirmed)*
(each talk 10' + discussion)

Lunch Break 13:00-14:00

Session 7 - Website, network discussion and synthesis, 14:00-17:00 (SEPARATE)
Chair: Michael Posner

14:00 - Website research projects
Speakers: Bruce McCandliss, Ricardo Rosas, Dan Schwartz *(order to be confirmed)*
(each talk 10' + discussion)
15:30 - Discussion and synthesis: design of new research projects; relevance to dyslexia; preparation of the next two meetings.

Session 8 - 17:30-18:30 (JOINT)
Chair: Hideaki Koizumi

17:30: Large-scale imaging and rehabilitation studies of dyslexia (Sally Shaywitz)

FRIDAY, JANUARY 31

Session 9 - Plenary synthesis - 9:00-11:00 (JOINT)
Chair: Kenneth Whang

9:00 - 10:00: Synthesis of Literacy work (B. McCandliss, with M. Posner) + plenary discussion
10:00 - 11:00: Synthesis of Numeracy work (S. Dehaene, with Ch. Ball) + plenary discussion

Session 10 - Conclusions - 11:00-12:15 (JOINT)
Chair: Jarl Bengtsson

Speakers: Eamonn Kelly, Richard Bartholomew, Barry Sloane, Penny Milton, Bruno della Chiesa
(each talk 10' maximum + 5' discussion)

Boston Numeracy Network Meeting

Venue: Best Western Carlton House, 1005 Belmont Street, Brockton, MA 02301 - Tel/Fax: +1 508 588 3333

DRAFT AGENDA

WEDNESDAY, JANUARY 29

Session 1 - Opening - 9:00-10:00 (JOINT)
Chair: Liz Spelke

9:00: OECD work on Education and the CERI "Brain project" (Bernard Hugonnier / Bruno della Chiesa)
9:30: Goal setting (Michael Posner)

Session 2 - Numerical development in infancy - 10:00-13:00 (SEPARATE)
Chair: Stanislas Dehaene

10:00: Small and large numbers: models of numerical competence in infancy (Liz Spelke)
11:00: Infants' arithmetic ability (Karen Wynn)
12:00: Number perception in infancy (Fei Xu)
(each talk 20', followed by a 40' discussion)

Lunch Break: 13:00-14:00

Session 3 - Numeracy from infancy to childhood - 14:00-17:00 (SEPARATE)
Chair: Barry Sloane

14:00: Non-symbolic arithmetic in young children (Hilary Barth)
15:00: Development of serial ordering in infants (Liz Brannon)
16:00: Preverbal knowledge and the transition induced by counting (Rochel Gelman)
(each talk 20', followed by a 40' discussion)

Session 4 - 17:30-18:30 (JOINT)
Chair: Emile Servan-Schreiber

17:30: Number and language (Susan Carey)

THURSDAY, JANUARY 30

Session 5 - 9:00-10:00 (JOINT)
Chair: Dan Berch

9:00: Behavioral and brain abnormalities associated with dyscalculia in Turner's syndrome (Stan Dehaene)
9:30: Early markers of dyslexia (Heikki Lyytinen)

Session 6 - Numeracy at school and in pathology - 10:00-13:00 (SEPARATE)
Chair: Richard Bartholomew

10:00: Importance of early experience for number learning (Sharon Griffin)
11:00: The London dyscalculia study (Anna Bevan)
12:00: Number and geometry in the hemispherectomized child (Antonio Battro)
(each talk 20', followed by a 40' discussion)

Lunch Break: 13:00-14:00

Session 7 - Network discussion and synthesis, 14:00-17:00 (SEPARATE)
Chair: Christopher Ball

Writing up of summary "time line"
Design of new research projects
Relevance to dyscalculia
Preparation of the next two meetings

Session 8 - 17:30-18:30 (JOINT)
Chair: Hideaki Koizumi

Large-scale imaging and rehabilitation studies of dyslexia (Sally Shaywitz)

FRIDAY, JANUARY 31

Session 9 - Plenary synthesis - 9:00-11:00 (JOINT)
Chair: Kenneth Whang

09:00: Synthesis of Literacy work (B. McCandliss, with M. Posner) + plenary discussion
10:00: Synthesis of Numeracy work (S. Dehaene, with Ch. Ball) + plenary discussion

Session 10 - Conclusions - 11:00-12:15 (JOINT)
Chair: Jarl Bengtsson

Speakers: Eamonn Kelly, Richard Bartholomew, Barry Sloane, Penny Milton, Bruno della Chiesa
(each talk 10' maximum + 5' discussion)

Appendix B

National Reading Panel.

The National Reading Panel reviewed a large number of studies devoted to reading. It should be noted that the Panel used strict criteria for selecting studies. The studies were: (a) published in English in a refereed journal; (b) Focused on children's reading development in the age/grade range from preschool to grade 12; and (c) Used an experimental or quasi-experimental design with a control group or a multiple-baseline method. For this reason, many qualitative and classroom-based studies were not considered in the report. Further, the definition and treatment of dyslexia were limited by a consideration of the English orthography, only.

Importance of phonemic awareness. A central finding of National Reading Panel review was that instruction in phonemic awareness is crucial to the learning of reading. The following block quotation from the National Reading Panel clarifies the distinction between phonemic awareness and contrasts it with phonics instruction:

> Phonemes are the smallest units composing spoken language. For example, the words "go" and "she" each consist of two sounds or phonemes. Phonemes are different from letters that represent phonemes in the spellings of words. Instruction in phonemic awareness (PA) involves teaching children to focus on and manipulate phonemes in spoken syllables and words. PA instruction is frequently confused with phonics instruction, which entails teaching students how to use letter-sound relations to read or spell words. PA instruction qualifies as phonics instruction when it involves teaching children to blend or segment the sounds in words using letters. However, children may be taught to manipulate sounds in speech without any letters as well; this does not qualify as phonics instruction. PA is also frequently confused with auditory discrimination, which refers to the ability to recognize whether two spoken words are the same or different.

The National Reading Panel review concluded:

> The results of the meta-analysis were impressive. Overall, the findings showed that teaching children to manipulate phonemes in words was highly effective under a variety of teaching conditions with a variety of learners across a range of grade and age levels and that teaching phonemic awareness to children significantly improves their reading more than instruction that lacks any attention to PA.
>
> Specifically, the results of the experimental studies led the Panel to conclude that PA training was the cause of improvement in students' phonemic awareness, reading, and spelling following training. The findings

were replicated repeatedly across multiple experiments and thus provide converging evidence for causal claims. While PA training exerted strong and significant effects on reading and spelling development, it did not have an impact on children's performance on math tests.

Instruction. A related and pertinent finding of the National Reading Panel was the importance of instructional strategies; the panel noted:

> PA instruction is ready for implementation in the classroom, but teachers should keep in mind several cautions. First, PA training does not constitute a complete reading program. Rather, it provides children with essential foundational knowledge in the alphabetic system. It is one necessary instructional component within a complete and integrated reading program. Several additional competencies must be acquired as well to ensure that children will learn to read and write. Second, there are many ways to teach PA effectively. In implementing PA instruction, teachers need to evaluate the methods they use against measured success in their own students. Third, the motivation of both students and their teachers is a critical ingredient of success.

Regarding phonics instruction:

> The meta-analysis revealed that systematic phonics instruction produces significant benefits for students in kindergarten through 6th grade and for children having difficulty learning to read. The ability to read and spell words was enhanced in kindergartners who received systematic beginning phonics instruction. First graders who were taught phonics systematically were better able to decode and spell, and they showed significant improvement in their ability to comprehend text. Older children receiving phonics instruction were better able to decode and spell words and to read text orally, but their comprehension of text was not significantly improved.
>
> Systematic synthetic phonics instruction (see sidebar for definition) had a positive and significant effect on disabled readers' reading skills. These children improved substantially in their ability to read words and showed significant, albeit small, gains in their ability to process text as a result of systematic synthetic phonics instruction. This type of phonics instruction benefits both students with learning disabilities and low-achieving students who are not disabled. Moreover, systematic synthetic phonics instruction was significantly more effective in improving low socioeconomic status (SES) children's alphabetic knowledge and word reading skills than instructional approaches that were less focused on these initial reading skills . . . The effects of systematic early phonics instruction were significant and substantial in kindergarten and the 1st grade, indicating that systematic phonics programs should be implemented at those age and grade levels.

The National Reading Panel viewed phonics instruction as a means to an end, not an end in itself:

> It is important to recognize that the goals of phonics instruction are to provide children with key knowledge and skills and to ensure that they know how to apply that knowledge in their reading and writing. In other words, phonics teaching is a means to an end. To be able to make use of letter-sound information, children need phonemic awareness. That is, they need to be able to blend sounds together to decode words, and they need to break spoken words into their constituent sounds to write words. Programs that focus too much on the teaching of letter-sound relations and not enough on putting them to use are unlikely to be very effective. In implementing systematic phonics instruction, educators must keep the end in mind and ensure that children understand the purpose of learning letter sounds and that they are able to apply these skills accurately and fluently in their daily reading and writing activities.

Most importantly, the National Reading Panel (NRP) stressed the complexity of reading comprehension and provided some insight into the future challenges of the Literacy Network:

> In carrying out its analysis of the extant research in reading comprehension, the NRP noted three predominant themes in the research on the development of reading comprehension skills. First, reading comprehension is a complex cognitive process that cannot be understood without a clear description of the role that vocabulary development and vocabulary instruction play in the understanding of what has been read. Second, comprehension is an active process that requires an intentional and thoughtful interaction between the reader and the text. Third, the preparation of teachers to better equip students to develop and apply reading comprehension strategies to enhance understanding is intimately linked to students' achievement in this area.

Appendix C

What Is Known About The Development of Word Reading Skills?

Linnea C. Ehri, CUNY Graduate Center, New York

Ways to Read Words. Beginners learn to read words in several ways. Words they have not read before may be read in one of three ways: by decoding (i.e., transforming graphemes into phonemes or spelling patterns into syllabic units and blending them to form recognizable words), by analogy to known words (e.g., "beak" to read "peak"), or by predicting words using partial letters or context. Words that readers have read before and stored in memory are read by accessing the words in memory, also called sight word reading.

Alphabetic Knowledge. All of these forms of word reading require or benefit from knowledge of the alphabetic system when they develop. This knowledge includes phonemic awareness (i.e., the ability to distinguish and manipulate phonemes in spoken words), letter shapes and names, grapheme-phoneme correspondences, graphosyllabic correspondences, left-to-right directional processing, and how to match letter to sounds in words. The best kindergarten-entry predictors of how well pre-readers will learn to read during the first two years of school are letter name knowledge and phonemic segmentation skill.

Reading Words From Memory. In English, learning to read words from memory is essential for becoming a skilled reader because the writing system is too variable to rely on decoding or analogizing. The process of reading words from memory involves recruiting alphabetic knowledge to form connections between letters seen in spellings and sounds detected in pronunciations of specific words. This bonds spellings to pronunciations and meanings of the words in memory so that when these words are subsequently seen, their identities are activated in memory and the words are recognized. This way of reading words is especially important in English because grapheme-phoneme correspondences are variable rendering decoding efforts problematic.

Children's ability to remember how to read words is governed by their alphabetic knowledge and decoding skill. Several points or phases in the course of development can be distinguished:

(1) Non-use of letter-sound information to form connections. Because children have not learned how to use the sound values of letters to connect spellings to pronunciations in memory, they resort to other features for remembering how to read words. They may select visually salient features, for example, two eyes in the middle of look, or the tail on dog. Or they may memorize individual letters in words. Because these connections are arbitrary or ideosyncratic, they are hard to remember and hence word reading is poorly developed or non-existent.

(2) Partial use of letter-sound information to form connections. Once letter shapes and names or sounds plus some phonemic awareness are known, children can use this knowledge to remember how to read words. When they first move into word reading, their phonemic awareness and letter-sound knowledge may be limited, so they can form only partial connections, for example, initial and final letters in words. This results in confusions among similiarly spelled words and use of a word guessing strategy based on partial cues.

(3) Full use of grapheme-phoneme relations to form connections. When children acquire more complete phonemic awareness and knowledge of the alphabetic system, they can fully connect spellings to pronunciations of words in memory to read them. Their ability to decode unfamiliar words emerges during this phase and operates as a self-teaching mechanism enabling them to read words independently, to bond words fully in memory, and thus to build a store of sight words. As the store of sight words grows, children's ability to read new words by analogy to these known words is enhanced, particularly if they are taught to use this strategy for reading words.

(4) Use of graphosyllabic units to form connections. As children's memory for sight words grows, they acquire knowledge of spelling patterns that recur in different words. These larger graphosyllabic units become available for use in forming connections to store words in memory. This eases the task of remembering how to read multisyllabic words.

Rapid Automatic Word Reading. Another dimension of development involves learning to read words rapidly and automatically. When readers store written words in memory and practice reading them, they can read the words automatically with little attention or effort, even when they try to ignore the words. Automatic word recognition skill as revealed by performance in a Stroop task is evident by the end of first grade in normally developing readers.

Contribution of Learning to Spell. Word reading and word spelling abilities are very strongly related, with correlations in a range indicating that word reading and spelling tasks are measuring almost the same thing even though reading words accurately is an easier process than spelling words accurately.

Teaching beginners to spell words contributes to their ability to read words, perhaps because it enhances phonemic segmentation and grapho-phonemic connection forming capabilities.

What Is Known About Word Level Difficulties In Poor Readers

- Children who get off to a poor start in learning to read rarely catch up. The poor first grade reader continues to be a poor reader.

- Two areas of deficiency have commonly been detected in poor readers: phonologically processing impairments, and speed impairments. Both are thought to contribute to their word reading difficulties.

- Skilled readers can read words accurately and rapidly in or out of context because they have good decoding skill and because familiar words are fully secured in memory. In contrast, poor readers read words slowly and less accurately because their decoding skill is weak and because sight words are less securely connected in memory. As a result, poor readers are more apt to rely on context and to apply a guessing strategy to identify words than skilled readers. Also poor readers require more practice reading words before they are read from memory.

- Poor readers typically possess not only limited decoding skill but also weak phonemic awareness spelling skills. Because their knowledge of the alphabetic system is not as well developed, they are unable to form complete connections when they retain words in memory for reading and spelling.

What Is Known About Effective Instruction To Teach Word Reading Skill

Phonemic Awareness Instruction. Phonemic awareness (PA) instruction is designed to teach students how to manipulate phoneme-size units in spoken words. PA is hard because phonemes are folded into each other and co-articulated in words. However, it is essential because it enables students to unlock the sounds that letters symbolize in words. Meta-analyses of experiments comparing instruction with and without PA reveal moderate effect sizes favoring PA instruction. The most important forms of PA instruction for learning to read and spell are segmenting words into phonemes and blending phonemes to form words. PA instruction is more effective when it is taught with letters serving as concrete markers for the phonemes.

Systematic Phonics Instruction. Systematic phonics instruction is designed to provide students with the alphabetic knowledge they need to read and spell words. Meta-analyses of experiments comparing systematic phonics instruction to non-phonics instruction reveal moderate effect sizes favoring phonics instruction. Effect sizes are larger for students in kindergarten and first grade who learn to read with this method. Effect sizes are smaller for struggling readers in 2nd grade and above who receive this method after they have received instruction and moved into reading presumably with some other method. Effect sizes are similar for different types of systematic phonics programs, including synthetic phonics and larger-unit phonics programs. Effect sizes on decoding words and pseudowords are large and on reading miscellaneous words and spelling words are moderate.

Accomplishments to Target. In order to maximize the likelihood that children become skilled at learning to read and spell words, instruction should be provided on several fronts:

1. Knowledge of the alphabetic system (see constituents above)

2. Foundation and reading practice to build a well-secured lexicon of sight words: Although beginners may exhibit word reading behaviors characteristic of the first two phases when they begin reading, instruction is needed to move them to the third phase so they can fully bond spellings to pronunciations of specific words in memory. Words need to be practiced in text so that meanings are bonded to spellings.

3. Skill decoding unfamiliar words

4. Strategy of reading new words by analogy to known words

5. Learning to spell words: Learning to read words is aided by spelling instruction that follows a course from teaching children to write plausible sound spellings to teaching them to remember correct conventional spellings.

Vocabulary learning: Knowledge of the meanings of new words need to be acquired through exposure in speech as well as text.

Appendix D

Consensus building on brain mechanisms of skilled reading

Tom Carr
Michigan State University

In his presentation, Carr viewed the visual word form center (VFCW) as an important "biological gateway from visual encoding to language processing." The VWFC prepares *orthographic* codes, but is not involved in phonology, articulation, and semantics. Specialized roles in computing phonological and articulatory codes from visually presented words are played by the:

a. Posterior peri-Sylvian regions [Angular Gyrus, Supramarginal Gyrus, and posterior Superior Temporal Gyrus/Wernicke's Area]
b. Inferior Frontal Gyrus/Broca's Area, Superior frontal motor regions [Primary Motor Cortex and Supplementary Motor Cortex].

Some of the neurophysical complexity for phonological and articulatory processes can be seen in this summary by Carr:

a. Results suggest a very general (perhaps supervisory) role for IFG/Broca's Area, a generalized role as a "phonics engine" for AG/SMG, and a trade-off in roles as a function of word frequency between posterior STG/Wernicke's Area and superior frontal motor regions.

b. IFG/Broca's Area is active during the deployment of phonological and articulatory codes for all words, regardless of regularity, frequency, or priming from a recent reading. Broca's Area is more widely activated than its right-hemisphere homologue during these activities, consistent with left-hemisphere dominance of phonological and articulatory processing.

c. AG/SMG is sensitive to regularity for high and low frequency words alike, but is not sensitive to priming.

d. For high frequency words, Wernicke's Area and its right-hemisphere homologue are sensitive to regularity, but not to priming. Anterior motor cortex (Primary Motor Cortex plus Supplementary Motor Area) is sensitive to regularity and also to priming. For low frequency words, these regions trade sensitivities. Wernicke's Area and its right-hemisphere homologue are sensitive both to regularity and to priming, whereas anterior motor cortex is sensitive only to regularity.

e. The role of middle temporal cortex is not clear. Wise et al. found left posterior Middle Temporal Gyrus to be more active for written words than for auditory words and concluded that posterior MTG is a "visual lexicon" -- an associative memory system for specific written words. Huang et al. found posterior MTG to be active for all words, but activity was equally distributed between left and right hemispheres and there was no sensitivity to priming.

Appendix E

Neurobiological Studies of Reading Development

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<u>The posterior (dorsal and ventral) and anterior reading systems and their roles in skilled reading.</u>

There is substantial converging evidence that visual word identification involves a posterior cortical reading system with both ventral and dorsal components (see Pugh et al., 2000 for a review and relevant citations). The ventral system includes lateral extrastriate areas and the left occipito-temporal area extending into the middle/inferior temporal gyri; these areas show robust activation in functional imaging studies of word reading. In skilled readers, this system tends to respond with higher activation to familiar words than to pseudowords and higher activation to pronounceable pseudowords than to illegal nonwords at some sites. That the ventral system shows higher activation for familiar (i.e., well-learned) stimuli suggests that it is involved in memory-based processing. Moreover, the ventral system is fast acting; evoked responses to words and pseudowords differ from those to nonlinguistic stimuli early in the ventral system (between 150-180 ms), whereas responses arise later in time in the dorsal system (at approximately 250 ms).

Note that both of these responses are absent or delayed in reading disabled (RD) readers. Developmentally, subsequent to the initial period of reading instruction, nonimpaired readers develop an increased ventral response associated with increased proficiency at word-recognition latency and accuracy (Shaywitz et al., 2002). Taken together, these findings suggest that the ventral system may constitute a linguistically structured, memory-based word identification system (i.e., a template-like word-form recognition device).

The more dorsal temporoparietal system includes the angular gyrus and supramarginal gyrus in the inferior parietal lobule, and the posterior aspect of the superior temporal gyrus (Wernicke's Area). Sites within this region seems to be involved in mapping visual percepts of print onto the phonological structures of language. In skilled readers, the LH [Left Hemisphere] temporoparietal system (particularly the supramarginal gyrus) responds with greater activity to pseudowords and low frequency words than to familiar words. The fact that the dorsal system responds more strongly to unfamiliar stimuli suggests that it engages in the kinds of phonological and semantic analyses that are relevant to learning new material.

Indeed, in beginning readers who will eventually become skilled readers, the dorsal system predominates as it first learns to decode print. This is consistent with behavioral studies that implicate skill in the phonological analysis of speech (measured by phonological awareness tasks and pseudoword reading) as critical predictors of success in early reading acquisition). Together, these findings suggest that the dorsal system is necessary for rule-based, algorithmic, learning; we suggest that this system is associated with slow decoding and is critical for extracting and learning the relationships between orthography and its phonological forms (O→P), and connecting these to morphological and semantic information.

An anterior system centered in and around Broca's Area in the inferior frontal gyrus (IFG) appears to be associated with fine-grained, speech-gestural, phonological recoding. This system has been found to function in silent reading and naming and like the dorsal system, is more strongly engaged by low frequency words and pseudowords than by high frequency words. Functional imaging studies implicate this inferior frontal region in reading disability: the anterior system appears to be more heavily used by RD than normal readers, perhaps in compensation for their failure to develop the posterior systems adequately. We suggest that this anterior system operates in close conjunction with the temporoparietal system to master word learning during normal reading development.

Developmental Changes in the three LH systems

As noted above, we have examined developmental changes in the LH response to print stimuli in non-impaired and RD cohorts ranging in age from 7 through 17 (Shaywitz et al., 2002). The primary finding was that as normally developing readers mature, there is a shift in functional neuroanatomy from multiple temporoparietal, frontal, and [Right Hemisphere] RH sites towards a more consolidated response in LH occipitotemporal region. Indeed, when multiple regression analyses examined both age and reading skill (measured by performance on standard reading tests) the critical predictor was reading skill level: the higher the reading skill the stronger the response in LH ventral cortex (with several other areas showing age- and skill-related reductions). Thus a beginning reader on a successful trajectory, employs a widely distributed cortical system for print processing including, temporoparietal, frontal and RH posterior areas.

As reading skill increases, these regions play a diminished role while LH ventral sites becomes more critical in the recognition of printed (word) stimuli. In contrast, for children who are reading disabled (RD), this pattern of dorsal-ventral consolidation is disrupted. This disruption is characterized neurobiologically by 1) poorly developed LH dorsal and ventral circuit function, 2) increased reliance on the inferior frontal gyrus (IFG), and 3) an increased tendency to engage the right hemisphere (RH) homologues to the deficient LH posterior circuits. These frontal and RH developments are likely to be compensatory and may reflect an inability to use the phonological and morphological aspects of spoken language appropriately in their relationship to writing.

Our findings suggest that the reason RD children shift disproportionately to inferior frontal sites is their increased reliance on articulatory recoding (covert pronunciation) in an attempt to cope with their deficient phonological analysis of the printed word. In addition, their greater activation of RH suggests a process of word recognition that uses nonlinguistic visual pattern recognition circuits (visuo-semantic processing). From all of this we speculate that the neurobiological target in any reading instruction program, particularly those aimed at remediating reading difficulties for poor readers, is the development of a highly structured LH posterior word form system that can carry fluent and automated word identification.

New directions

Recent studies conducted in my lab have been focused on two broad research topics using a combined behavioral and functional neuroimaging approach. First, we have used a variety of paradigms to gain a more fine-grained understanding of the computational properties (and interactions) of the major LH reading-related systems in skilled readers. Another line of studies examines the cognitive processes and neurobiological changes associated with adaptive learning for print (both novel word learning and repetition effects have been examined) in skilled and less skilled readers.

With regard to the first topic, we examined phonological priming effects word recognition. Results indicate that facilitatory vs. inhibitory phonological primes modulate activation both in the supramarginal gyrus and at IFG (thus both dorsal and anterior systems are effected by prime type). This confirms the role of these regions in decoding and assembly. We have also examined the interaction between orthographic-to-phonological consistency, imagability, and frequency in word identification in order to better understand semantic and phonological interactions in word identification. Consistency had maximal affects at IFG, while imagability and frequency modulated posterior regions. Critically, behavioral data show that consistency effects are attenuated on high imagability tokens; the neural signature is increased posterior and decreased anterior brain responses. This allows us to better characterize at a neurobiological level the relative trade-off between phonological and semantic features; the results provide a more refined account of computational roles and cross talk at each of the LH regions of interest.

With regard to adaptive leaning one line of studies have examined repetition effects in both word naming and silent reading tasks. The major finding is that increased familiarity with a given token is associated with diminished roles both of dorsal and anterior systems, and a heightened role for ventral sites. In this respect, it appears that localized learning in skilled readers mirrors general development in younger readers (an increased reliance on LH ventral word form system). In another set of experiments we have examined learning of novel tokens as a function of whether the training reinforces orthographic, phonological, and/or semantic features. Behavioral results suggest that combined phonological and semantic training optimize learning rates; the neurobiological correlates appear, thus far, to be increased ventral responses associated with more efficient learning. As all of this work progresses we focus on explicating critical brain/behavior relationships that can provide us with a neurobiologically grounded model of reading acquisition.

Appendix F

Reading acquisition in Chinese: Behavior and brain imaging approach

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Learning to read is fundamentally metalinguistic (Nagy & Anderson, 1999). To learn to read successfully, a child has to understand whether and how the print words represent phonemes, syllables, morphemes and words. In the past two decades, one of the most important discoveries is the role of phonological awareness in learning to read alphabetic languages. Recent research has also supported that an understanding of the nature of the correspondence between print and sound, print and meaning is crucial in learning to read Chinese.

Acquisition of characters and words

The vocabulary of Chinese is represented with a vast number of visually complex characters. What visual information children extract when they read and write characters? Research reported that children of all grades made false response for non-characters (components in impossible positions) less than for pseudo-characters (components in possible positions). The rate of false response for ill-formed component pseudo-characters decreased over the school years (Cheng and Huang, 1995; Shu & Anderson, 1998). Children were able to be aware of the component position information at early stage, and the internal structure of components, positional frequency relatively later (Li, Fu & Lin, 2000; Peng & Li, 1995). The findings suggested that children decomposed characters into sublexical units. The insight of inter-structure knowledge of characters is important in children reading and writing.

How children map print to sound in Chinese? Research suggested that phonetic awareness, or the insight into the structure and function of the phonetic of compound characters, develops. School children in Beijing, Hong Kong and Taiwan were found to read more accurately for regular characters than irregular characters (Ho & Bryant, 1997; Shu, Anderson & Wu, 2000; Tzeng, Zhang, et al., 1995). The fact that regularity effect was shown in both familiar and unfamiliar characters suggests that the phonetic awareness is important for encoding and remembering the pronunciations of characters already learned as well as for anticipating the possible pronunciations of unknown characters. Children have a period of overgeneralization at middle grades, and their awareness of phonetic consistency develops at relatively later stage (Anderson, Li, et al., in press, Yang & Peng, 1997; Shu & Wu, in press). The priming-naming experiment revealed that phonetic components embedded in compound characters were decomposed from visual input at early stage of recognition (Wu, Zhou & Shu, 1999). The fact that the phonetic was activated even in irregular characters indicates that it is an automatic process.

The corpus analysis showed that about 72% of the characters children learn in primary school contain internal cues to pronunciation, in which 23% of the compound characters are fully regular and 42% are semi-regular. The proportion of regular and semi-regular characters children learn through the textbooks steady increases as the frequency of characters decreases (Shu, Chen, Anderson, et al., 2003). Children presumably acquire the phonetic principle gradually as they learn to read increasing numbers of characters. Children who are aware of the phonetic principle are able to organize the lexicon efficiently and able to learn and remember characters in a systematic fashion. Children who are unaware have to encode characters as a whole and memorize their pronunciations one by one. Even there are many semi-regular characters in which the phonetic of a character provides only partial information, the research has revealed that children can make use of partial information in learning and memorizing new characters (Anderson, Li, et al., in press; Shu, Bi & Wu, 2003).

Reading development in normal and dyslexic children

Recent studies have provided the strong evidence that phonological processing is crucial in learning to read Chinese (Ho & Bryant, 1997; Shu, Anderson & Wu, 2000; Tzeng, Lin, et al., 1995; Yang & Peng, 1997), and phonological impairment is highly related with Chinese dyslexic children (Ho, 1997, 1999; So & Siegel, 1997; Tzeng, 1993). Also studies have reported the importance of morphological awareness in learning to read Chinese (Chan & Nunes, 1998; Shu & Anderson, 1997, 1998). A study with first and fourth grade children showed that both morphological and phonological awareness contribute to reading proficiency, in which the role of morphological awareness was relatively larger than that of phonological awareness (Li, Anderson, et al, 2002). McBride-Chang, Shu, et al. (in press) found that, when the role of visual, phonological, speed and oral vocabulary were partialed out, morphological factor still significantly contributed to character recognition in 5 years old kindergarten and second grade children.

Comparing with in alphabetic languages, researchers know much less about dyslexic children in Chinese. Zhang, et al. (1996) investigated the proportion of dyslexic children in Mainland China. It was found that the proportion of dyslexic children is about 4.55% - 7.96%. The reading difficulty for poor readers is mainly in character and word levels (Shu & Meng, 2000). Poor readers were found to process much slower in accessing to phonology and semantics than good readers in on-line tasks (Xu, Peng, et al. 2002). Their poor performance might reflect the poor quality and organization of their orthographic and phonological representations and access. Group and case studies showed that there are different subtypes of Chinese developmental dyslexia. The deficits of phonological and morphological awareness may affect differently lexical representation and processing, and cause different problems in reading (Luan, Shu et al, 2002; Meng, 2000). Specific hearing and visual deficits were also reported to be related with poor performance in reading (Meng & Zhou, 2002; Sai & Zhou, 2001).

Brain imaging research in Chinese processing

In recent years, the neural mechanism of language processing by using fMRI or ERP techniques have attracted more and more research attention in China. In a study investigating the neural basis of the automatic activation of words by using a mask paradigm, Peng, Xu, et al. (in press) found that bilateral fusiform gyri, cerebellum, right inferior parietal lobe, medial frontal gyrus, and the right temporal-occipital junction are sensitive to word frequency, and are related to both the attentional and non-attentional access of lexical representations. The study also reported the possibility that phonology is automatically generated when reading, even when attention is not directed to the words (Peng, Ding, et al., in press). The study on the language representation in Chinese-English bilinguals's brain found that in the orthographic task, besides the overlapped brain areas induced by both Chinese and English, the left posterior middle temporal gyrus and the anterior cingulate gyrus was activate by Chinese stimuli only, while the bilateral parietal inferior lobe and supramarginal gyrus by English stimuli only. In the semantic task, the left middle and posterior temporal lobe and the fusiform gyrus are activated by both Chinese and English stimuli.

The results suggested that semantic storage was shared by the two languages in Chinese-English bilinguals. Compared with the process of L1, the right hemisphere was more involved in the process of L2 (Ding, 2001). The brain mechanisms underlying emotional word representation and processing indicated that more activation was induced by negative versus positive words; the cingulate and the right prefrontal cortex play an important role in processing negative words; in addition, medial prefrontal cortex is important for processing emotional words. The patterns of brain activation produced by emotional words were different across extrovert subjects, introvert subjects and depression patients in both subliminal and supraliminal conditions. The findings suggested that the different valence of the emotional words, such as positive and negative, has different neural mechanisms of representation and processing, furthermore, the personality is an important factor that influenced these mechanisms (Xu, 2002).

Appendix G

What do behavioral genetic and training studies tell us about the causes and cures of reading disabilities?

Richard Olson, University of Colorado

Causes

There is now substantial evidence from studies of identical and fraternal twins in the U.S. and the U.K. that both reading disabilities (performance in the low tail) and individual differences across the normal range are substantially heritable in populations with near universal access to "adequate" instruction and print in their environment. Recent analyses by Gayan and Olson (2001) of data from 8-18 year old twins in Colorado indicated that 50-60% of the group deficit in word reading was due to genetic influences. For individual differences across the normal range, genetic factors accounted for 69-92% (.05 confidence interval) of the broad variability in word reading (Gayan & Olson, 2003). Similar estimates of genetic influence on word-reading deficits and individual differences have recently been reported from a large (4,737 pairs) representative sample of 7-year-old twins in the U.K. (Harlaar et al., submitted).

The mechanisms of genetic influence on deficits and individual differences in word reading are not fully understood. It is likely that part of the genetic influence is mediated by individual differences in reading practice: Poor readers generally read much less than good readers, suggesting a possible genotype-environment correlation. Proximal causes of less reading practice in poor readers may include slower word learning rates (Ehri & Saltmarsh, 1995; Reitsma, 1983), resulting in lower accuracy and fluency levels that make reading more difficult and less enjoyable.

Slower learning rates for word reading may in turn be tied to deficits in phonological language and reading processes. The ability to isolate and manipulate abstract phonemes in language (phoneme awareness) and represent their correspondence with letters and letter patterns (assessed by nonword reading) are highly correlated core deficits in most poor readers. Gayan and Olson (2001) demonstrated that 60-70% of the group deficits in phoneme awareness and nonword reading were largely due to the same genes, and there were substantial genetic correlations between subjects' deficits in these two skills and their deficits in word reading, even after controlling for subjects' Wechsler full-scale IQ scores.

The above results with school-age children have led us to explore genetic and environmental influences on possible reading related cognitive learning skills in preschool twins from Australia, the U.S., and Norway (Byrne et al., 2002).

These twins are currently being followed up through kindergarten, first, and second grade. The preschool sample is now large enough to show that there are significant genetic influences on preschoolers' ability to learn about phonemes prior to formal reading instruction, and preliminary indications are that this early learning ability is linked to subsequent individual differences in early reading. Surprisingly, individual differences in letter name knowledge, a traditionally powerful predictor of later reading skill, were almost entirely due to environmental differences between families.

Cures

In spite of the high heritability for phonological deficits in school age children, it is clear from a number of training studies that poor readers' deficits in phoneme awareness and phonological decoding, as they are typically measured, can be substantially improved even into the normal range (McCandliss et al., 2003, Torgesen et al., 2001, Wise, Ring, & Olson, 2000). Unfortunately, these studies did not observe significantly greater gains in fluent word reading when their phonologically based interventions were compared to equally intense but non-phonologically based interventions (Torgesen et al.; Wise et al.), or surprisingly, to a no treatment control (McCandliss et al.), at the end of training. Moreover, Torgesen et al. and Wise et al. found that while phonologically remediated groups maintained their phonological advantage one or two years after their training had ended, there was still no transfer to significantly better word reading skills when compared to the non-phonologically trained groups.

The above results seem paradoxical: If phonological deficits are highly correlated both phenotypically and genetically with word reading deficits, why does the presumed repair of phonological deficits have little or no unique benefit for fluent word reading in older children with reading disabilities? One answer may be that the improved explicit knowledge that is trained and tapped in our traditional measures of phoneme awareness and phonological decoding does not represent the status of underlying phonological processes that influence rates of growth in word reading, even though the status of those underlying processes contributed to the commonly observed correlations between our measures of phonological skills and reading.

Perhaps we have not gone <u>deep</u> enough in our training of phonological skills. Wise et al. (2000) suggested that further intensive training of phonological processes to achieve greater "automaticity" in their application during reading might facilitate higher growth rates in word reading, but this hypothesis remains untested. Alternately, maybe the intervention did not start <u>early</u> enough, but the evidence for the unique <u>long-term</u> efficacy of early phonological intervention is mixed (Olson, 2002). A possible resolution to the paradoxical genetic correlations and training results in older children is that there is some yet deeper third factor that accounts for variance in both phonological and fluent word reading skills, and thus their correlation. In this view, remediating phonological deficits might not significantly improve fluent word reading because the causal third factor had not been remediated. Some theorists have suggested that processing speed, as measured in the rapid naming of letters and numbers, is an important core deficit in children with reading disabilities (Wolf, 2001). Other researchers have pointed to more basic sensory temporal processing deficits (c.f., Tallal, 1980). However, sensory processing deficits may not be specific to reading deficits, since all or nearly all of their relation to reading is mediated by subjects IQ scores, and sensory processing deficits are not specific to tasks demanding rapid processing (Hulslander et al., submitted; Olson & Datta, 2002). Further research is needed to clarify the underlying reasons for genetically influenced reading disabilities and their implications for remediation.

Tallal and colleagues (Scientific Learning Corporation) have attempted to claim the high ground for brain-based interventions in dyslexia. Their patented stretched-speech intervention is claimed to remediate a core brain-based deficit in the temporal processing of language, and they claim this will ultimately remediate poor readers' deficits in phoneme awareness, phonological decoding, and word reading. That would be a wonderful result, but independent studies have not supported this claim (Hook et al., 2001). The Scientific Learning Corporation example should caution us not to claim too much regarding the relevance of current findings in neuroscience and genetics to practical problems in remediation. Unfortunately, desperate parents may uncritically accept and pay for expensive unproven treatments that make brain-based claims.
Of course all remediation is "brain based" in the general sense that the brain is where remediation or any experience must have its impact. I understand that we can currently see brain activity changes in response to intervention that seem to reflect a more normal pattern, but the efficacy of any intervention is far more sensitively measured by external reading measures. I will be all ears if anyone at this meeting can prove otherwise, and if not, I hope to hear how more effective brain based interventions will emerge from future brain research.

The same modesty should be maintained in claims for the immediate relevance of genetic results for intervention. We know genes matter and family history is a predictor of poor reading for both genetic and environmental reasons. Using that knowledge might improve the odds for successful early prediction and early environmental intervention for dyslexia, but that is all we can offer for now. Perhaps there is an additional benefit in recognizing that there are inherent genetic constraints on many children's reading development, and that we should honor those children, parents, and teachers who expend the extraordinary effort needed to overcome these constraints.

Removing these constraints is the highest goal of genetic and brain based research. We are not there yet, and I believe we are now coming to the hardest part of our work toward this goal. On the genetic side, we face the daunting difficulty of identifying multiple genes of small effect on reading. (We have evidence for several approximate locations through linkage studies, but no specific genes have been identified yet. See Fisher & DeFries (2002) for an excellent review.) These genes may interact in complex ways with each other and with the broader environment. Following the identification of relevant gene variants, we face the task of understanding how their coded proteins influence brain development, and ultimately how we might directly intervene with gene therapy or related biochemical treatments that would result in normalized or even superior learning rates for important things like reading. It will take lots of brilliant young gene hunters like Cathy Barr, Simon Fisher, Clyde Franks, Javier Gayan, Elena Grigorenko, Jeff Gruen, and Shelley Smith to begin to achieve these lofty goals. I hope our funding agencies will support them in their efforts. The payoff could be huge.

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Appendix H

Schooling and Cognitive Development: A Natural Experiment

Frederick J. Morrison, University of Michigan

Historically, psychology's concern about the sources of developmental change has been focused on the classic "nature-nurture" controversy. Unfortunately, progress in understanding the genetic versus experiential sources of change has been hampered by lack of methodologies designed to adequately separate nature from nurture.

For the past few years, we have been utilizing a natural experiment (designated "school cutoff") that permits assessment of the influence of a culturally valued learning experience (schooling) and circumvents some, if not all, of the serious biases found in other research. Each year, North American school boards proclaim that those children whose birth dates precede some specific date will be allowed to go to kindergarten or first grade while other children who just miss the cutoff date will be denied entry. Such an arbitrary selection criterion has itself given rise to a voluminous technical and popular literature on the role of entrance age in school readiness (Shepard & Smith, 1985), a topic that is the focus of a separate research investigation (Bachman, Bagdade, Massetti, Morrison, & Frazier, 2000; Morrison et al., 1997).

In essence, the methodology involves selecting groups of children whose birth dates cluster closely on either side of the cutoff date, thereby effectively equating two groups of children on age. Background information gathered from parent questionnaires and direct assessments have routinely found that the two groups are equated on critical control variables (e.g., IQ, SES, and preschool experience). With the groups matched on control variables, the children's progress may be compared using a pre-post design (with testing in the early fall and late spring of the school year). In other words, comparing the degree of change in the target skill from pre- to post-test (Fall to Spring) in children who just made versus just missed the cutoff allowed us to assess the impact of a relatively specific schooling experience on the growth of that skill.

In a series of studies over the past five years, the patterns of change across a broad range of domains and skills appeared to be highly domain and even sub-domain specific. For example, changes in phonological segmentation differed greatly depending on the level of segmentation involved (phonemic, sub-syllabic, or syllabic; Christian, Morrison, Frazier, & Massetti, in press). Second, surprisingly little transfer was observed across skills that, on the surface, appear to share cognitive or experiential components (e.g., conservation of number and number addition skills; Bisanz, Morrison, & Dunn, 1995). Finally, schooling influences on growth of literacy skills appeared to be confined to a relatively delimited subset of elementary reading and math skills with little evidence for early schooling effects on or transfer to other important skills such as vocabulary, general knowledge, narrative skills, and conservation (Christian, Morrison, et al.). Overall, results from these studies reveal a relatively high degree of specificity in the nature and timing of changes in cognitive skills (Christian, Morrison, et al.).

Ongoing work highlights the unique role of instructional activities in producing the pattern of specificity in cognitive change observed in the cutoff studies. In our current study, a total of 13 different literacy skills are being assessed and followed longitudinally in young first graders and old kindergartners up to Spring of third grade (the end of the grant period). Simultaneously, we have undertaken an extensive series of observations of classroom activities for all participating teachers (Griffin, 2000a). Each classroom is observed for a full day three times a year (Fall, Winter and Spring) and time-tagged observations of classroom activities, sub-activities and participants are recorded. Transcription, coding and analysis of the classroom observations yield indices of the absolute and relative amounts of instructional time devoted to different activities (e.g. language arts, math, social studies, discipline, transition). Analyses of type of instructional activity are also being conducted (Frese, Morrison, Griffin, & Williams, 2000).

To date, four major sets of findings have emerged from this ongoing project. First, the Classroom Observation Narrative, CON (Griffin, 2000a) has proven to be a reliable instrument for observing and coding instructional activities in kindergarten and first-grade classrooms. Inter-observer reliability for observation averaged .95 and for coding .86. Second, classroom activity codes for reading instruction have successfully predicted unique variance in growth in word decoding skill in first grade (Griffin, 2000b). In addition, separate codes for amount of teacher-directed and child-directed reading activity have discriminatively predicted growth for low versus high IQ children (Griffin, 2000b). Regression equations demonstrated that, controlling for several background factors, greater amounts of teacher-directed activity (e.g., letter-sound instruction) predicted greater growth for low IQ but not high IQ children. In stark contrast, greater amounts of child-directed activity (e.g., sustained silent reading) predicted better growth for high IQ but not low IQ children. Hence, both amount and type of activity surfaced as crucial elements of instruction but the benefits of each of these activities differed dramatically for children of differing IQ's. Third, findings from the CON have revealed substantial variability across teachers and subject areas in amount of instructional time in both kindergarten and first grade (Frese et al., 2000). Kindergarten teachers spent most time in non-instructional activities (like transition and management) followed by language arts, with much less time spent on mathematics and very little time on science or social studies. First-grade teachers increased the time devoted to language arts but non-instructional time was still high and comparatively little time was spent on math. Most striking were differences across teachers. In first grade, some teachers spent as little as 43 minutes on language arts while others devoted over 104 minutes per day. Extrapolating to a whole academic year, some children received as much as 180 more hours instruction on language arts compared to other children. Similarly, large discrepancies were noted for math instruction and in kindergarten (Frese et al.).

Finally, the general pattern of instructional emphases across more specific literacy skills strongly suggested that in those subject areas where most instructional time is placed (e.g., word decoding, phonemic awareness), schooling effects are most pronounced in kindergarten and first-grade, and individual differences (e.g., across IQ) decrease over time. In contrast, in subject areas with less instructional time, IQ differences are maintained or magnified over the course of kindergarten and first grade (Williams et al., 2000).

Taken together, these findings document clearly that domain specificity in growth of cognitive, language, and literacy skills is produced in part by the pattern of instructional activities provided in early elementary school classrooms. Moreover, the stability of individual difference in important background characteristics such as IQ on later academic achievement depends fundamentally on the amount of a particular type of instruction experienced by students in early elementary classrooms. Specifically, more teacher-directed instructional time on fundamental reading skills like word decoding and phonemic awareness will greatly enhance growth of reading in lower IQ children and reduce the gap between them and higher IQ children by the end of first grade. In contrast, less instructional time on a given subject area like vocabulary or mathematics will yield weaker schooling effects and maintain or actually magnify the size of individual differences produced earlier by background characteristics like IQ. These findings have direct implications for the research proposed here.

To examine the early roots of individual variation as well as its sources, ongoing work focuses on preschoolers who will just make or miss the school cutoff two years later in the school district. A comprehensive battery of assessments of child, family, preschool, schooling and sociocultural variables as well as of literacy and numeracy outcomes will permit us to examine the interplay of factors that shape the child’s pathways as they negotiate the critical transition to school and into the early grades.

Appendix I

Computer Interventions, Brain Imaging, and Broad Scale Accessibility

Bruce McCandliss

Sackler Institute
Weill Medical College of Cornell University

I am involved in interdisciplinary work that may help to illustrate the benefits of such an infrastructure. I am currently working with a decoding intervention program known as Word Building (based on prototype by Beck & Hamilton, 2000), which was designed to draw a child's attention to letter-sound combinations at all positions within written words. This intervention was adapted into a fully scripted algorithm that served as the basis of a computer tutorial which incorporated adaptive training techniques to continually adjust to the decoding abilities of a child. The first empirical study of this technique (McCandliss, Beck, Sandak, & Perfetti, 2003) examined the reading skills of children who had deficient decoding skills in the years following the first grade, and traced their progress across 20 sessions of the intervention. Initially, the children demonstrated deficits in decoding, reading comprehension, and phonemic awareness skills. Further examination of decoding attempts revealed a pattern of accurate decoding of the first grapheme in a novel word, followed by relatively worse performance on subsequent vowels and consonants, suggesting that these children were not engaging in full alphabetic decoding. The intervention directed attention to each grapheme position within a word through a procedure of progressive minimal pairing of words that differed by one grapheme. Relative to children randomly assigned to a control group, children assigned to the intervention condition demonstrated significantly greater improvements in decoding attempts at all grapheme positions, and also demonstrated significantly greater improvements in standardized measures of decoding (equivalent to 1.2 grade levels of improvement), and also demonstrated transfer to standardized measures of reading comprehension, and phonological awareness. The progressive minimal pairing technique may help children to engage in more fully alphabetic decoding by focusing attention on a single grapheme-phoneme mapping within each new word. It is possible that by reducing the load on phonological analysis, and using attentional cueing techniques to focus attention on particular grapheme-phoneme mapping within a typically ignored section of a word form, that this intervention process helps scaffold the decoding process in a way that is highly approachable for these children. Additional "critical ingredients" studies are required to directly address such claims, although such work is highly resources intensive and slow in nature.

The same intervention was administered to a connectionist model of developmental phonological dyslexia (adapted from Harm and Seidenberg, Psych Review, 1999) to examine potential insights into how progressive minimal pairing might influence reading processes marked by poor phonological abilities and poor ability to transfer reading knowledge to novel words. The same materials and progression rules that were used with children were used with the model. The simulation allowed us to examine several issues within a single study, such as a contrast between this intervention and other phonological awareness interventions, examination of intervening at different ages, and also ‘single cell recordings’ within the hidden layer of the model to examine the impact of the intervention on the organization of connections that carried out the mapping from print to phonology. The simulations broadly replicate the patterns of success and failure found in the developmental literature, and provide explicit computational insights into exactly why the interventions that include training on spelling-sound regularities are more effective than those targeting phonological development alone for impaired-readers with several years of experience. (Harm, McCandliss, and Seidenberg, in press, SSR).

The same intervention was incorporated into a neuroimaging study (McCandliss, et al., 2001) of children with reading impairments (7 to 10 years of age) to examine the potential impact of the progressive minimal pairing procedure on the pattern of brain activity associated with deficits in decoding ability. Before and after participating in Word Building, children with reading impairments engaged in a decoding activation task during an fMRI scan (one-back repetition detection with pseudwords vs. consonant strings). This study provided preliminary evidence that, unlike non-impaired readers, these reading impaired children failed to increase activation levels in left superior temporal gyrus in response to pseudowords. This reading-impaired pattern was largely normalized after 20 sessions of intervention, suggesting a potential relationship between the intervention-based gains in decoding ability and the changes in brain activity patterns. Such studies provide a basis for examining the conditions under which patterns of brain activity can be influenced by training procedures, and open up new lines of research that might help explicate models of the cognitive and neural mechanisms underlying such forms of change.

Finally, this same intervention is currently being tested in realistic educational settings—inner city public elementary schools in Harlem and the Upper East Side of New York City—to examine whether the same magnitude of gains can be achieved outside the laboratory, and whether such research-based approaches to addressing decoding difficulties might produce gains when compared to common practices of guided-reading with tutors. Preliminary results suggest that this computer intervention can be successfully extended beyond the context of the laboratory and into more realistic educational settings, while maintaining its original efficacy. Furthermore, the opportunity to work with the larger sample sizes afforded by work with schools, combined with the increased fidelity to program afforded by the computer, may provide a realistic testing base for hypothesis testing.

Appendix J

Video games as an instructional tool: An Educational Opportunity

Ricardo Rosas, Escuela de Psicología
Universidad Católica de Chile

Videogames and incidental learning: capturing attention and learning without conscious effort are key issues for promoting literacy in disadvantaged children

With sales of approximately $4 billion in 1990 and $8 billion in the year 2000, video games are clearly a preferred game for children who reach game-playing age. They dominate much of the toy industry and have become a cultural and social force that shape children and adolescents' lifestyles (Provenzo, 1991). In this sense, incorporating educational computer games as instructional tools and offering it as an educational resource to a generation already labelled the video generation (Provenzo, 1992), is certainly a hurdle that should be taken.

What makes video games effective? The most highlighted features are: (a) a clear goal: almost all video games are goal-oriented; that is, they have a clear and specific goal that children must try to reach (e.g. capturing the princess, reaching a destination), (b) adequate level of complexity, not too low but not too high; well-designed games are highly challenging and are rarely totally mastered, (c) high speed: most video games have a much faster speed than traditional mechanical games, (d) incorporated instructions: in most video games, children understand instructions while playing the game and do not need to read instructions, (e) independence from physical laws: video games normally do not follow the physical laws of the universe; objects can fly, spin, change shape or color as they please, and (f) holding power: they capture players' attention and continue to do so as the game builds a microworld with its own rules and regulations (Malone, 1980; Turkle, 1984; Provenzo, 1991).

Why then use video games as an instructional tool? Because they also posses the positive elements found in computer games in general, and add value in that they create a microworld of their own, which players act on based on their natural tendencies towards learning (Rieber, 1996). Therefore, learning occurs while playing video games (Baird & Silvern, 1990). Video games model not only the principles, but also the dynamics of cognitive processes, particularly the dynamics of complex systems. Even the programming of video games is considered a highly valuable tool for the development of higher order skills (Kafai, 1997).

The learning process that occurs while playing video games has to do with the immersion effect created (Hubbard, 1991), that is, an environment into which the players submerge themselves, progressively increasing their levels of attention and concentration on the goal to obtain. This immersion effect can be related to

Csikszentmihalyi`s flow theory (1990), defined as a state in which satisfaction occurs while one is “absorbed” by a certain activity. This effect has commonly been interpreted as alienating; however, it can be understood as a genuine opportunity to take advantage of children’s concentration introducing educational contents (Lepper & Malone, 1987).

What elements must a video game have in order to become an instructional tool? Enjoyable educational programs must include elements of (a) challenge: clear, meaningful and multiple goals, uncertain outcomes, variable difficulty levels, randomness, and constant feedback, (b) fantasy: a character with whom players can identify, use of an emotionally appealing fantasy directly linked tot the activity, and use of metaphors, and (c) two types of curiosity: sensory curiosity (audio and visual effects) and cognitive curiosity (surprises and constructive feedback) (Malone; 1980; Baltra, 1990; Lepper & Malone, 1987; Kafai, 1997).

Higher motivation, attention and concentration are related to the perception that an activity is “fun”; that is, visually and cognitively attractive to children. According to Hubbard (1991), the criteria of attractiveness must prevail when designing educational software.

In this sense, the challenge of video games as an educational tool is to transform the perception of video games from “unproductive” to a resource that takes advantage of the effects on attention, concentration and entertainment, without neglecting instructional aspects. If instructional elements could be combined with the intrinsic interest that children and students have in video games, we could dispose of an important tool for learning and motivation within the classroom (Baltra, 1990). That is, of a mediating tool to assist learning and improve achievement, while having fun.

What learning mechanism lies beneath using video games as instructional tools? The concept of incidental learning suggests various lines of research that may contribute knowledge in order to diminish the gap between learning and playing.

Incidental learning is understood as the acquisition of structures of knowledge in absence of explicit presentation of knowledge, with a semi-conscious intention to learn, applying the underlining rules of such knowledge (Whittlesea & Wright, 1997). It refers to unintentional or unplanned learning that results from activities not overtly educational and occurs through observation, repetition, social interaction and problem solving during activities that involve implicit meanings (Kerka, 2000). Incidental learning involves elements considered highly effective in formal learning situations (Kerka, 2000). Therefore, the simultaneous presence of both incidental and intentional learning is considered ideal (Cohen, 1967).

Even though the concept of incidental learning is currently related to labor force situations (Kerka, 2000), its extension to the school classroom seems relevant. In this context, studies have found that incidental acquisition of meanings of words from children's reading experience (Shu & Hua, 1994), was positively related to the strength of contextual support (Konopak, 1987; Shu & Hua, 1994) and the presence of animated presentations (Rieber, 1990).

The field of incidental learning is closely related to the study of implicit knowledge, memory and learning. Underlying these, is the issue of awareness, attention and the cognitive unconscious. Implicit learning has been proven in artificial grammar and complex cognitive structures (Reber, 1993). Questions still remain, however, as to whether the (un)intentional learning that occurs during formal instruction –semantic-based knowledge of simple cognitive structures during early school years- may be considered a form of incidental learning (Saffran, Elissa, Newport, Aslin, Tunick & Barrueco, 1997), and if so, what its relation is to implicit knowledge and how it can be used more adequately as a valuable instructional tool (e.g. through the use of video games).

Do we have any research data that supports the use of videogames and incidental learning as instructional tool in the domain of literacy?

Our research team at the U. Católica de Chile is working on these topics since 1999. In a recent paper published in Computers & Education, Rosas et. al (2003) evaluated the effects of the introduction of educational videogames into the classroom, on learning, motivation, and classroom dynamics. These effects were studied using a sample of 1274 children from economically disadvantaged schools. The videogames were specifically designed to address the educational goals of the first and second years of school, for basic mathematics and reading comprehension. The sample was divided into experimental groups (EG), internal control groups (IC) and external control groups (EC). Students in the EG groups, used the experimental video games during an average of 30 hours over a three month period. They were evaluated on their acquisition of reading comprehension, spelling, and mathematical skills, and on their motivation to use video games. Teachers' expectations of change due to the use of videogames, their technological transfer, and handling of classroom dynamics, were assessed through ad hoc tests and classroom observations.

The results show significant differences between the EG and IC groups in relation to the EC group in Math, Reading Comprehension and Spelling, but no significant differences in these aspects were found between the EG and the IC groups. Teacher reports and classroom observations confirm an improvement in motivation to learn, and a positive technological transfer of the experimental tool. Although further studies regarding the effects of learning through videogame use are imperative, positive effects on motivation and classroom dynamics, indicate that the introduction of educational video games can be a useful tool in promoting learning within the classroom.

Rosas & Grau (2002) addressed the question of the relationship between implicit learning (IL) and working memory (WM). From Reber´s pioneer studies on implicit learning through artificial grammars, it is supposed that WM is to play an important role in the acquisition of implicit regularities, even though these are not acquired through metacognitive processes, but because of the effects of mere recursive (and unconscious) exposition and elaboration in the WM. The authors evaluated the role of WM in IL, comparing the performance of three different IL tasks (one of them an artificial grammar paradigm presented in a videogame) in two infant groups: children with normal IQ and average performance on WM tests, and children with intellectual deficit and poor performance on WM tests. The results support the occurrence of IL in both groups and enable to conclude that WM does not play an important role in IL. These results expose interesting perspectives for educating and rehabilitating children with intellectual or attentional deficits, since they could explain their difficulties for learning.

Questions that need more experimental research are: Which are the attentional and working memory demands of initial reading learning? Is it possible to bypass these demands with attention-enhanced tasks (video games) and/or with working memory- reduced tasks (implicit learning)? Which are the neural basis of implicit learning and working memory and what are their interactions with learning?

Appendix K

Prior Numeracy Review from the OCED Workshops

Elementary numerical skills

Just as we learned in the case of language learning, learning of mathematics complexly involves the brain. There is a region situated in the back of both human brain hemispheres[1] that is specialized for representing numbers as a quantity. Although the evidence is indirect, converging factors show that it is this region of the brain that enables us to answer questions such as, "Which is bigger, 34 or 45?" or "Which integer is found between 6 and 8?" or "Is 17 closer to 20 or to 10?" In fact, this region provides us with the ability to represent numbers on a "number line"[2].

Associating a quantity to a number like 3 or 5 is a learned process, that later becomes automatic. However, for children (or adults) that have incurred a brain injury in this precise region, they become unable to understand the quantity meaning of numbers. This condition is called "acalculia", which means inability to calculate, but can be extended to describe an inability to understand the quantity meaning of numbers. People with acalculia may be unable to perform calculations as simple as 3 minus 1 or say what lies between 2 and 4. These patients seem to have lost this spatial concept of quantity.

The capacity to associate a quantity meaning to a number automatically appears to be an example of an innate skill. For instance, some experiments show that children as young as four and a half months old are able to understand the difference between 1, 2, and 3, and can combine them.

These elementary numerical expectations can be observed in experiments where 2 objects are shown to an infant of 4 to 5 months and then hidden behind cardboard. Then, one of the objects is taken away from behind the cardboard without the infant noticing it. When the cardboard is removed, the infant manifests surprise behaviors such as staring for a longer time at the sole remaining object[3] or other facial display of surprise (e.g., raising eye brows or eyes going wide). This experience is a visual analog to the operation "2 minus 1". The expression of surprise shows, at least, that children this young are capable of numerical expectations with respect to simple operations.

In line with the prevailing view of children as active learners, these elementary numerical abilities constitute an "elementary number theory," which allows us to describe even very young children as *everyday mathematicians*. What is important and noteworthy for infants here are quantity and the differences between "a lot" and "a few". For instance, infants (as adults) will probably succeed at distinguishing between 28 and 56 objects whereas they will likely fail to discriminate between 55 and 56 objects. This is referred to as the *distance effect,* which states that the ability to discriminate between two quantities increases with their numerical difference. Another feature of this theory

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[1] The intraparietal sulci situated in the parietal lobes.

[2] Dehaene

[3] Longer time than when, in a control experiment, the two objects remain behind the cardboard.

is that it is easier for infants to distinguish between 2 and 3 objects than between 5 and 6 and it is very probably impossible for them to distinguish between 15 and 16 objects. This is referred to as the *size effect*: The higher the number of objects, the lower is infants' performance at discriminating between the two numbers (keeping equal the numerical distance between the two quantities to compare).

Learning arithmetic

As with any innate skill, elementary numerical abilities evolve with infants' development and education. Learning mathematics pushes children to exceed their innate approximation skills. That is, they become able to discriminate between 56 and 57, whether presented as visual symbols (i.e., Arabic numbers) or written words (fifty-six and fifty-seven), they learn to perform arithmetic operations and manipulations.

The *triple code model* describes a system of brain areas that are active when children are learning or performing arithmetical operations: addition, subtraction, multiplication or division[4]. The basic idea is that when manipulating a number, a child does one of three actions:

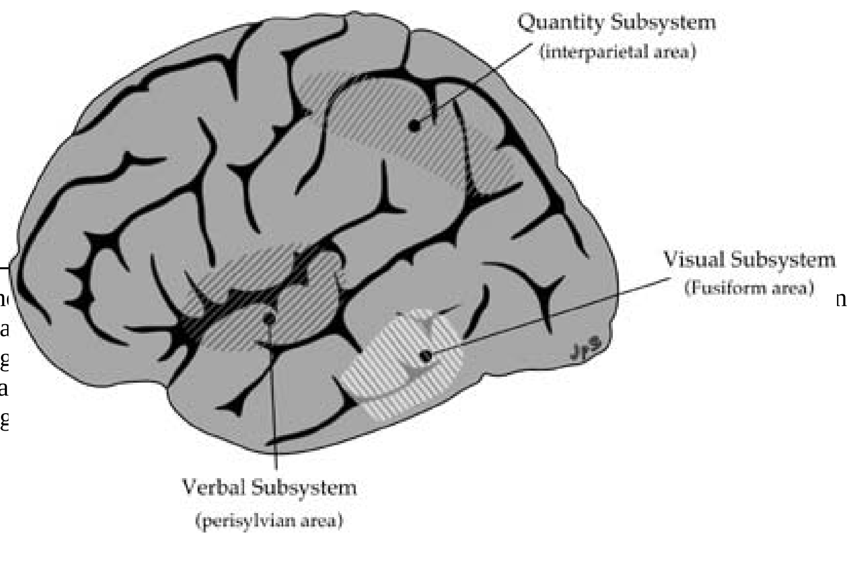
- Performs some visual manipulation (like seeing the number as a visual digit, i.e., "3");
- Performs some linguistic manipulation (like hearing or reading the number as a word, i.e., "three");
- Represents it as a quantity (e.g., "3 is bigger than 1").

Each of these processes involves a different region of the brain (see Figure xxxx):

- A visual subsystem localized on both sides of the brain behind the ear and under the brain[5];
- A verbal subsystem situated in distributed regions of the left hemisphere[6];
- The quantity subsystem situated on both sides of the brain diagonal to the ear[7].

The regions of the triple code model

This model attempts to show that depending on which arithmetic



[4] As Dehaene explain n
progress, of what's ha
[5] Areas corresponding
[6] The perisylvian area
[7] Areas corresponding

processes are undertaken, information moves back and forth within these subsystems and recruits one, two, or all of them.

For example, two seemingly similar calculations can recruit different subsystems of the triple code model, one relying on the verbal system and another relying on the quantity system. Consider the same addition problem (4 + 5) but in two different contexts. In one case subjects had to find the exact result, choosing between two results that were both close to the correct result (they were obliged to do the exact calculation). In the other, they were given two false results, one grossly false and the other approximately correct. The evidence showed that despite the superficial similarity between these two tasks, different brain regions were recruited in each case. The region most active for the approximation task was the quantity subsystem whereas the region most active when performing the exact calculation task was the verbal subsystem[8].

Why math is difficult for some

As this research unfolds, there may be important educational consequence of this model in that it may help explain difficulties that some children may with school mathematics. Mathematical difficulties might be traced to the quantity subsystem, or it might be traced to a poor connection between a quantity representation with both verbal and visual symbols. This connection takes time to be established, and it is difficult because it involves symbolic transformations that come with experience, both educational and cultural. The process of quickly and flexibly moving from one representation system to another appears to be a source of difficulty for many children.

This model goes beyond simply indicating the probable origin of mathematical difficulty because it validates two very general properties of mathematical reasoning that support mathematical pedagogy research:

1. The possibility of thought without language.

The existence of unconscious processing in mathematics.

[8] Dehaene

Appendix L

Notes from Brannon

Elizabeth M. Brannon OECD January 2003 2-page summary

A growing body of data suggests that non-human animals and humans share a primitive non-verbal numerical system (see Dehaene et al., 1998; Gallistel and Gelman, 2000). For example, the distance and magnitude effects are ubiquitous in both non-human animal and human number discriminations (e.g., Brannon and Terrace, 2002). Although a great deal of research documents that human infants also have quantitative capacities, it remains unclear whether these numerical abilities are the developmental precursors of the non-verbal numerical system displayed by adult humans and animals. One avenue towards addressing this question is to look for common features of numerical representations in non-human animals, adult humans and human infants. For example, Xu and Spelke (2000) recently showed that 6-month-old infants discriminate 8 from 16 elements but fail to discriminate 8 from 12 elements. This pattern of data might mean that the ratio of the numerosities being compared controls discrimination, however, such an account does not explain why similar age infants can discriminate 2 vs. 3 yet fail to discriminate 4 vs. 6 (Starkey and Cooper, 1980). Another prediction of the continuity hypothesis is that infants, like adults and non-human animals, should appreciate the ordinal relationships between numerical magnitudes. The experiments described here address this second question.

In Experiment 1, 9 and 11-month-old infants were habituated to three-item sequences of numerical stimuli presented in an ascending or descending numerical order. The sequences were dynamic in that they repeated continuously and infants' looking time was measured to the whole sequence. A given trial began with a black screen followed by each of three numerical stimuli (e.g., 2-4-8) and repeated (e.g., black screen- 2-4-8- black screen etc.) until infants looked away for a continuous 2 seconds after having looked for a minimum duration of 2 seconds. The absolute numerical values were varied between trials. In the habituation phase surface area increased with number on some trials, decreased with number on some trials, and was held constant on other trials. Infants were then tested with new numerical values where the ordinal relations were maintained or were reversed from that of habituation. Surface area was held constant across the three numerical values in test. If infants are able to represent ordinal numerical relations they should have looked longer when the ordinal direction was reversed from that of habituation compared to when it was maintained. Results indicate that 11-month-old infants succeeded at detecting the reversal in ordinal direction but 9-month-old infants did not.

In Experiment 2, 9 and 11-month-old infants were again tested in the same general experimental design however in the habituation phase, density and surface area were confounded with number and were then held constant in the test phase. Thus infants could not have used density or surface as a basis for a differential response to the novel and familiar test sequences. Results were similar to Experiment 1; 11-month-old infants and 9-month-old infants looked longer at test sequences with a reversed ordinal direction compared to a maintained ordinal direction.

In Experiments 3, 9-month-old infants were tested on their ability to detect reversals in the ordinal direction of non-numerical sequences. Infants viewed a single square increasing or decreasing in size in habituation. Parallel to Experiments 1 and 2, the absolute sizes of the squares varied between trials. Nine-month-old infants succeeded at detecting ordinal reversals in non-numerical sequences. In addition an unpublished experiment will be reported that tested 9-month-old infants' ability to detect a reversal in ordinal direction when number, element size, cumulative area, and density were all confounded. When all of these additional cues were available and confounded with numerical cues 9 month-old infants succeeded.

Another unpublished set of experiments tested 10-month-old infants' ability to detect the reversal in ordinal direction of an arbitrary sequence of three clip-art pictures (e.g., key, turtle, rose). In the first experiment the habituation sequence was reversed in test (rose, turtle, key). Ten-month-old infants showed a robust effect with 14/16 infants looking longer at the reversed ordinal direction. However in a second experiment, the second and third item in the habituation sequence were transposed in test. Ten-month-old infants failed to detect this change. These results suggest that the infants in the first experiment may have merely noticed the change in the first item from habituation to test. Such results are worrisome with regard to interpreting the first series of studies purportedly demonstrating ordinal numerical knowledge in 11-month-old infants because in those studies the average value of the first numerosity in the habituation sequence differed more from the first value in the novel test sequence than from the first the value in the familiar test sequence.

However, to address this concern, a final unpublished experiment tested 11-month-old infants' with the density controlled ordinal numerical task described above as Experiment 2 with an important modification: the third item in all habituation and test sequences was removed. Thus if infants merely detected the larger change in the first number when the ordinal direction was reversed they should succeed in this task. However, 11-month-old infants failed here suggesting that they require a three-item sequence to appreciate ordinality and casting doubt on the hypothesis that they were attending only to the first item in the sequence.

Collectively, these results suggest that by 11 months of age infants have a preverbal appreciation of number that includes their ordinal relations. This age is much younger than that suggested by

previous researchers using different methods and is especially surprising given the large values tested (range 1-16). A second finding is that 9-month-old infants fail to use number when it is decoupled from other stimulus dimensions but succeed in the task when continuous dimensions are available as cues. This suggests that sometime between 9 and 11 months infants become able to compare stimuli based solely on number. Before this age they may notice numerical differences but do not appreciate their ordinal relations.

Characterizing quantitative capacities of infants in the first year of life should contribute towards an understanding of the relationship between nonverbal mathematical abilities and later mastery of the verbal counting system. This enterprise should also pave the way for identifying atypical patterns of development.

Appendix M

Notes by Barth

"Nonsymbolic Arithmetic in Young Children" presented by Hilary Barth
OECD/CERI Numeracy/Literacy meeting, Boston, January 29-31 2003

A large body of research demonstrates that there is a rough "sense of number," a primitive nonsymbolic understanding of numerical quantity, that is common to nonhuman animals and humans of all developmental stages. The capabilities that accompany this primitive number concept may underlie more sophisticated mathematical systems unique to humans, but as yet we do not know much about the connections between the two. If it is true that this rough nonsymbolic numerical ability may serve as one of the building blocks of learned mathematics, then we would expect that the representations underlying this ability should be available to play a functional role in simple mathematical operations like elementary arithmetic. This possibility was recently explored through the testing of adults' ability to calculate using nonsymbolic quantity information. **Participants were able to add, subtract, multiply, and divide large arrays of dots, even when the paradigm prevented the use of counting or continuous quantity information.** Control studies suggest that subjects were indeed using approximate representations to carry out the task, rather than labeling each set of dots with an exact number and computing based on those numbers **(Barth, Dehaene, Kanwisher, & Spelke, in preparation). Also, accuracy tended to increase with larger ratio differences between the quantities to be compared, showing that these operations display the typical signature of approximate numerosity representations. However, studies in adults cannot rule out the effects of years of mathematical training; in order to gain a pure assessment of the natural arithmetic capabilities of the number sense, parallel questions must be addressed earlier in development.**

Recent work from Elizabeth Spelke's lab has extended these studies to five-year-old children. We adapted the paradigm from our adult studies to produce a nonsymbolic addition procedure suitable for presentation to five-year-olds. Participants viewed animated sequences in which sets of dots "acted out" the addition operation while the experimenter narrated with an engaging cover story. For example, in an addition experiment adapted for 5-year-olds, the first addend array, a set of blue dots, suddenly appears on the screen (and the experimenter announces, "Look, there are some blue guys!"). The blue dots are then covered by a rectangular occluder which moves onto the screen from the edge ("Now they're all covered up!"). Then the second addend array, consisting of more blue dots, moves into view from off-screen, travels across the screen, and disappears behind the occluder ("Look, here come some more blue guys, and they're going behind that wall too - now they're *all* back there!"). Finally, an array of red dots moves onto the screen. At this point, the experimenter says, "Here come some red guys! Are there more blue guys, or more red guys?"

The first three studies with 5-year-olds demonstrate that they can clearly perform addition on these nonsymbolic sets, and that they spontaneously rely on number rather than continuous quantity cues such as summed area, density, or contour length (Barth, La Mont, & Spelke, in preparation). Children's accuracy tended to decrease with larger ratio differences between the quantities to be compared; this is the same pattern of results we observed in the adults' data. Further, the children were questioned about their knowledge of comparable symbolic quantities, and their successes at nonsymbolic addition do not seem dependent upon symbolic experience at all**. These studies provide strong support for the idea that primitive approximate representations of numerosity may enter into arithmetic operations without any influence from learned mathematics. The data suggest that this rough sense of number, with its attendant computational abilities, may well play a key role in the development of later mathematical competencies.**

Advances in our understanding of nonsymbolic numerical abilities have broad implications for education. Deeper knowledge of the conceptual roots of mathematics will lead to a better understanding of how early math learning works, and may lead to the development of educational improvements based on the brain's natural modes of number processing. Such techniques may be able to use the primitive number sense as a tool for enhancing early symbolic math learning, in turn producing a deeper understanding of the underlying concepts that will act as a strong foundation for later learning. Educational approaches based in universal nonsymbolic abilities have the further advantage of applicability to all human cultures, as they are thought to be nonlinguistic capabilities arising quite early in development.

Appendix M

Rochel Gelman's Summary of Previous Research on Numerical Knowledge.

I have, and will continue to work on empirical and theoretical topics related to nature of numerical competence –be it nonverbal or otherwise. I have come to the view that is called "Street Arithmetic" benefits from a nonverbal counting-arithmetic system that we share with non-verbal species. The "arithmetic" involves the operations of addition, subtraction and ordering (and the implied principles); the entities are the positive natural numbers, without zero and very limited understanding of very large numbers. Importantly, procedures for counting to generate cardinal representations or estimating "countable" quantities, do not stand alone. They serve to generate the entities that can be manipulated and combined by addition and subtraction --- with the restriction that the permissible results must be a positive natural number. The latter is so, even though we find that the conditions for inducing the successor principle, i.e., that there is always another positive integer, are readily assimilated once an individual has come to see that their language has a way to generate new count words (Hartnett & Gelman, 1998).

My research on early number has covered a number of themes. One has been to understand the conditions that facilitate or interfere with successful counting performance, in children ranging in age from 2-1/2 to about 12 or 13 years. Early on I did a series of studies to explore counting and arithmetic. The goal of counting studies was to get a handle on the effect of different tasks and variables. These included studies of attention hierarchies of length, number and density as a function set size and age (Gelman, 1972), time, set size, item type and age (e.g., Gelman & Tucker; Gelman & Gallistel, 1978), instructions (Gelman & Greeno, 1989); task variables (e.g., Gelman & Meck, 1986); retardation (Gelman & Cohen, 1989); giftedness (Hartnett, 1991); and intermodality (e.g., Starkey, Spelke & Gelman, 1990) and dyscalculia (Weinstein, 1977). These studies were joined with ones that related the ability to reason arithmetically, even with small numbers. I used a variant of a magic show to demonstrate that children as young as 2- 1/2 treated addition and subtraction, but not displacement, as number-relevant operations and could relate the number pairs of 1 and 2 to 2 and 4 (Gelman, 1992a, b,1977; Bullock & Gelman, 1979; Gelman & Gallistel, 1978).

Together these findings led me to propose that the domain of natural number addition and subtraction is universal. An preverbal system is related to the learning of the language of number, properly speaking, that is the language that refers to uniquely (mathematically speaking) to pecifiable numbers, e.g.,the count numbers. As regards the count numbers, people (including children) who learn this language have a prelinguistic arithmetic structure that is used to identify count list and work with to engender them with meaning, that is the fact that the terms refer to ordered, successive values which when combined with addition and subtraction increase and decrease systematically. I do not, and never have held, that the mapping between the constraint on the non-verbal model of counting and the constraints on the verbal use rules implies one trial learning. The word learning that is required here, as opposed to say that for objects, involves the mastery of a long list that, on its own, has no meaning. We know that this requirement places special information processing demands on the learner. Therefore, the question is not whether mapping is instantaneous but whether the learner treats the words as stably ordered vis a vis increasing set sizes. This they do (Gelman & Gallistel, 1978).

Given that counting requires the ability to use a unique verbal or symbolic tag for each item tagged in conjunction with the fact that set sizes can be extremely large, it makes sense to expect that learning of the count list will be protracted and dependent on the extent to which a person's language has a transparent generative rule or not. This is the case (See Hartnett, 1991 for data on how long English speakers can take to crack the generative code).

Returning to the idea that despite these difficulties, young children map a nonverbal arithmetic system to one that this re-represented in language: We know that adults learn the mapping of the nonverbal, quantitative representation of counting (Barth; Cordes, Gelman, Gallistel, & Whalen; Dehaene; Moyer & Landau; Whalen et al). Since the data indicate that the counting process yields ordered quantities, one might ask whether the meaning of the verbal count words is first derived from the quantifier system in a language. This is a variant of the Descoudres un, deux, trois…. Hypothesis as well as the long-held Anthropological view that "primitives" cannot really count. Instead, they have something like a one, two, (three) and many system. If so, it is possible that the quantifier system of a language maps to the non-verbal quantitative values represented by the nonverbal counting system (eg., Carey, Bloom).

My opportunities to collect ethnographic examples from Pygmies in the North of the French Congo and a Falashel family in Israel – two groups I was told could not count – provided converging evidence for my views. So too do analyses of counting data presented in Gelman and Gallistel. More recently, with Felicia Hurewitz and Lila Gleitman I have begun to explore the question empirically. There also are logical issues – which I will present.

Currently I am working on several fronts. These include:

(1) a return to task analysis. Not only are we comparing and contrasting different tasks. We also are working up new tasks so as to be able to assess hypotheses about the source of variability. This effort is motivated by a need to make sense of the wide range of performance levels one sees, depending on the task. This is especially true in very young children, and therefore an important line of work regarding different theoretical accounts.
(2) Studies of how learners come to understand that the words and marks on paper that stand for count words are also ones that represent rational numbers. Here is where I think a conceptual change is required.
(3) Understandings of other mathematical numbers and the language of same, e.g., zero, negative numbers.
(4) The cross-cultural representation of number and quantity – especially in Mandarin.
(5) Studies with adults to get at the nonverbal discriminability of units and the relative salience of "amount" (perimeter, etc) vs. discrete number in non-verbal tasks.
(6) A preschool science program that embeds the tools, talk, and re-representations of arithmetic and measurement.

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Appendix N

Notes by Fayol

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My research relates to the acquisition, mobilization and management of information in memory (LTM and WM) during activities which involve the use of numbers and numeric operators.

Two models are referred to. The first of these, which relates to number, was developed by Dehaene and Cohen (2000). This model postulates the existence of a number of different representations of number - analogue, verbal and digital - together with channels permitting the transition from one mode of representation to another without necessarily requiring semantic mediation. So far, this model has primarily been employed to deal with arithmetic problems and examine adult performances. We intend to extend this developmental perspective, in particular by studying the acquisition of number learning and, consequently, the corresponding representations and procedures.

The second model is the one proposed by Anderson (1993; 1995) which provides an integrated theoretical framework which describes, on the one hand, the arithmetic algorithms (as procedures) and, on the other, the knowledge retrieved from memory (as chunks of declarative knowledge). It is also particularly well suited to addressing the question of explicit learning as it arises in response to teaching as is the case for arithmetic operations. We therefore systematically use this model in order to address problems relating to learning and the use of numerical processing.

Three types of question are addressed. Firstly, the initial phases in the learning of counting and the number system. Secondly, the question of transcoding. Thirdly, an in-depth study of the solving of simple arithmetic operations, and in particular of the respective importance of memory retrievals and the use of algorithms in both children and adults and during the development that follows learning.

<u>Initial phases of the acquisition of number and the number system</u>
During an earlier series of studies we showed that performances in perceptuo-tactile tasks make it possible to predict the results subsequently obtained by 5-year-old children in arithmetic, first at the age of 6-7 and then at 8-9 years (Fayol, Barrouillet & Marinthe,1998).

The link between performances in these two fields is thought to involve counting and the quality of the associations between quantities and naming as Gerstmann's syndrome suggests. These data once again raise the question of the relations between preverbal representations and verbal representations of quantity (Fayol, 2002). Within this perspective, we study the development of the representation of continuous and discrete quantities on the basis of the comparison paradigm and, in particular, the split effect: the closer the compared quantities are, the more frequent the errors are and the longer the response times are. We study the evolution of this effect in children aged between 3 and 5 years in comparison tasks involving physical quantities (continuous or discrete), oral naming (one, two etc.) and, in older children, the symbolic digital representation of these quantities. The comparison of the performances should make it possible to determine how the relations between the analogue and symbolic representations of quantities are established and how they change.

<u>The question of transcoding</u>

Many children aged 7-8 years, as well as certain patients, produce transcoding errors: e.g., /miltrwa/ sometimes transcribes 1007 and sometimes 10003. Two hypotheses have been advanced to account for these errors. The first holds that the mechanisms involved in transcoding are affected. The second considers that these errors are more probably caused by the processing load. The data we have collected in our earlier work indicates that this latter hypothesis is the more plausible (Seron & Fayol, 1994). We are currently studying learning and the implementation of different transcoding modes: from oral to written (from /trwa/ to "trois"), and from oral to the code (from /trwa/ to 3). The comparison of the performances and the establishment of a relation between these performances and the predictors classically associated with WM functioning (phonological length, phonological similarity etc.) should allow us, within a period of 1 or 2 years, to determine how transcoding tasks are managed and how this management develops between the ages of 5 and 10 years.

Operation solving

In another earlier series of studies, we investigate the procedures used to solve addition and multiplication problems. The distinction made by Anderson between the procedural and the declarative makes it possible to suppose that, in a problem checking task (e.g., 7 + 5 = 12? or 7 x 6 = 43?) as well as in production tasks (e.g., 7 + 5 = ?), additive procedures could be primed by the simple presentation of the sign, whereas declarative knowledge can only be primed by its constitutive components (i.e. the numbers themselves). This hypothesis leads to predict that priming by the sign (i.e., the sign + or x is presented before the figures using a variable SOA) would indicate the use of an algorithmic operation solving procedure.

We are pursuing this research in three directions.

Firstly, we are studying the effects of the explicit learning of addition and multiplication in a "natural" environment" (i.e. at school) on the development of the strategies used for solving these two operations. This will make it possible to trace the gradual transition from algorithmic processing to memory retrieval (in

the case of additions) and the effects of training subjects to memorize instances (in the case of multiplication) in individual subjects and on the basis of well defined operations.
Secondly, we are testing sign-based priming in production tasks. To do so, and to make the differences between addition and multiplication more obvious, we study the performances of children (at age 10-11) and adults when asked to solve additions, multiplications and subtractions in tasks involving a variable SOA (- 150 ms; 0; + 150 ms) in order to test the hypothesis of an Operation x SOA interaction: systematic priming by the sign (SOA - 150 ms) should appear only in the case of operations which are solved by means of an algorithm (subtraction, large additions) but not in the case of operations small (multiplication). If this research yields positive results, we intend to develop software which will allow us both to test the solving of the operations in question and to train children in their resolution. This software could be tested among children with arithmetic learning difficulties.
Thirdly, we study what becomes of the memory traces during the solving of simple operations. An algorithmic solution requires the manipulation and transformation of the representations of each of the operands. Consequently, the memory traces of these operands should be degraded following the calculation. In contrast, a comparison operation (27 > 32?) makes it necessary to conserve these representations. Consequently, the time required to retrieve the operands from memory after the calculation should be greater for additions than for comparisons. This is precisely what has been observed (Thévenot, Barrouillet & Fayol, 2001). We extend this paradigm to the solving of subtractions (for which the degradation of the memory trace should be even greater) and multiplications (in which case it should be reduced). Here, too, we are considering developing assessment and training software.

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Appendix 0

Notes by Frith

January 2003

Uta Frith
Summary of work

My main focus of research are the developmental disorders of autism and dyslexia. My aim has been to discover the underlying cognitive causes of these disorders and to link them to behaviour patterns as well as to brain systems. Another aim is to make this research relevant to the education of people with developmental disorders to contribute to a better quality of their everyday life.

To understand the links between observations at the behavioural level, such as impaired test scores, and their explanation at the neurophysiological or genetic level, an understanding at the cognitive level is vital. At this level the cognitive phenotype can be defined and tested through novel predictions of performance on specific tasks. At the same time it can be used to make novel predictions of anomalies in brain anatomy or function.

This approach is generally applicable to developmental disorders with a genetic cause, such as autism, dyslexia and dyscalculia. The challenge is to create testable theories that explain why the acquisition of particular skills such as, social communication, learning to read and doing maths can be affected.

In the case of autism my work has focused on ‘mentalising’ failure. The hypothesis is that there is a fault in the mechanism that underpins mentalising, that is the intuitive ability to attribute mental states to self and others. We have shown that this fault has a neurophysiological basis and persists into adulthood. It can be camouflaged by compensatory learning. This has implications for the diagnosis of hidden cases. It also indicates that there are limits to compensatory learning.

In collaboration with my colleagues we have recently compared different theories in dyslexia and in particular we have addressed the question whether low-level sensori-motor deficits can account for impairments in literacy and phonology. The answer from about four separate studies with adults and children was clear-cut: These studies converged in showing that sensorimotor dysfunctions have a limited prevalence in dyslexia (about one third for each of auditory, visual and motor deficits). This is consistent with many recent studies investigating each modality. The multi-modal design of our studies further allowed us to evaluate the overlap between the low-level deficits, in order to know whether all dyslexics are affected by at least one of them. We found that there is partial overlap between visual, auditory and motor dysfunctions, and that there are a significant number of dyslexics who seem entirely spared in all modalities. They almost all have, however, impaired phonological skills, which therefore seems to be a nearly-universal characterisation of dyslexia.

In autism too low-level sensori-motor impairments are frequent, but there are indications from preliminary studies that they do not explain the core features of the disorder. It would be interesting to ask similar questions about dyscalculia. Its association with dyslexia is well known but it can occur also without dyslexia, just as dyslexia does not necessarily occur with dyscalculia.

We tentatively conclude that those higher-level functions that are vulnerable to disorder, such as language in the case of dyslexia, and social insight in the case of autism, are not necessarily caused by dysfunction in lower-level processes. This conclusion may lead to reconsidering diagnostic procedures and designing educational programmes for individuals who suffer from these handicapping developmental disorders.

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Appendix P

Notes by Kaufmann

Arithmetic performance and math anxiety in primary school teachers: a pilot study

by
Liane Kaufmann & Margarete Delazer

Participants
unselected sample of primary school teachers (n=49); mean age 35.57 (min 21/max 51)

Methods
Math anxiety. ***sMARS (Alexander & Martray, 1989): consisting of 25 questions, multiple choice among 5 levels of anxiety (nil to very much)***
Arithmetic performance ***(multiplication problems of increasing difficulty, arithmetical reasoning). a) simple: multiplication facts (max 20), b) intermediate: two-digit times one-digit multiplication (max 10), c) complex: two-digit times two-digit multiplication (max 10), d) arithmetical reasoning, text problems (n=4)***

A) to c) were printed on separate pages, processing time per page (problem type) was 80 % of the time needed by subjects participating in the pilot study; recorded were number of completed problems as well as accuracy (AC). Arithmetical reasoning: only AC was recorded (as there was no time pressure in the latter task)

Preliminary results

sMARS performance was coded in two categories: 0 ➔ low math anxiety (n=22) versus 1 ➔ medium to high math anxiety (n=27); cutoff 28 (Alexander & Martray, 1989).

ANOVA revealed significant group differences (p<.05) regarding: simple (number of completed problems and AC), intermediate (number and AC), complex multiplication problems (AC)

Interestingly, upon qualitative error analysis of multiplication facts
some teachers committed errors on rule based problems (n=5), some committed operand errors (n=8), table errors (n=1), operation error (n=1), others (i.e. 6x1=; n=1)
9 of these 16 individuals had an anxiety score > 28 (medium or high)!!

Overall

almost half of the participating teachers (n=22 out of n=49) yielded sMARS scores reflecting medium or high math anxiety;

math anxiety seem to influence number fact retrieval as well as complex mental calculation, but not arithmetical reasoning

Limitations

The timing on the complex (two-digit times two-digit) problems was quite generous => many participants attempted to solve these problem types by writing down the intermediate solutions.