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Auditory-Visual Matching and Language-Based Learning Disorders: Two Studies of Specific Language Impairment and Developmental Dyslexia

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Abstract

This is a binary study about auditory-visual matching in language-based learning disorders (N=212). Much controversy ensures about the extent to which auditory processing deficits are important in the genesis of language-based learning disorders, particularly specific language impairment and developmental dyslexia. Explorative study 1 focused on children between the ages of 6 and 13, with SLI (N=84), dyslexia (N=52) and typical language development (N=28). The results showed that children with SLI experience very similar difficulties to those of children with dyslexia in auditory-visual matching. Comorbidity was evident, as 63% of children had additional diagnoses. Encouraged by interesting results, an intervention study was conducted. Study 2 involved 48 children, [pre-schoolers (N=23), first-graders (N=25)] who participated in the auditory-visual matching training period. After the training, an improvement in the auditory-visual matching test was found. The positive effect was also evident based on the Assessment Inventories, which evaluate the development of overall cognitive performances.

Keywords: Auditory-visual Matching, Language-based learning disabilities, Specific language impairment, Developmental dyslexia, Comorbidity, Computer program, Intervention

1. Introduction

Language may be viewed as a necessary tool for successful academic, social, and behavioral achievement. This notion would predict that young children with poor language skills would be at risk for later learning and social problems. It is also reasonable to propose that academic, social, and behavioral experiences influence language skills.

The failure of some children to master language at a normal rate, despite normal intelligence and adequate instruction, has puzzled researchers for decades (Tallal & Piercy, 1973; Bishop, 1992; Tallal, Miller, & Fitch, 1993; Snowling, 1998). There is a long history and much controversy about the extent to which auditory processing deficits are important factors in the genesis of a variety of language-based learning disorders. One theoretical account proposes that auditory perceptual problems cause specific language impairment (SLI) in children (Tallal, 2000; Tallal & Piercy 1973). Most children with SLI have literacy problems, and the theory has also been extended to account for developmental dyslexia.

This paper discusses the role of auditory-visual matching in language-based learning disorders, such as specific language impairment (SLI) and developmental dyslexia. Apart from the fact that both of these disorders involve deficits in some part of the language system, they also represent specific deficits occurring in the context of other cognitive abilities that are more or less normal. Also possible comorbidity is discussed.

1.1 Specific Language Impairment (SLI)

Specific language impairment, also known as developmental a- or dys-phasia, is regarded as a neurobiological disorder that seriously influences on a child's educational and psychosocial outcome. Children with SLI often being spontaneous speech late and lag behind normally developing children in acquiring sophisticated language and grammar despite having adequate hearing, at least average nonverbal intelligence, no known hearing, physical, or emotional problems, and an adequate learning environment (Asikainen, 2005; Bishop, 1992, Bishop et al., 2006; Tomblin et al., 1997). Children with SLI have deficits in receptive and expressive language, and often poor phonology and semantic skills; short-term memory problems may also occur. Because of this broad span of both language and literacy deficits, some theorists have considered SLI a more extreme form of other language disorders than dyslexia, where oral language abilities remain intact (Bishop & Snowling, 2004). Some have proposed that SLI may result from cognitive and linguistic difficulties (van der Lely & Stollwerck, 1997). Other theorists, however, have hypothesized that the primary deficit in SLI is in auditory processing (Tallal, 2000; Tallal & Piercy, 1973). This is not a hearing loss in the same way as deafness is, but rather an inability to perceive, categorize, and process sounds properly, which may lead to higher-level problems. Such a perceptual processing view emphasizes the importance of the detection and discrimination of low-level, basic acoustic components, suggesting that these bottom-up problems interfere with higher linguistic processing.

Findings in SLI studies are contradictory, however, and the core problem of the disorder is still under debate. Thus far, differential diagnostics between SLI and other disorders in the

spectrum of developmental disorders, socio-emotional disorders and learning difficulties also remain undetermined (Bishop & Snowling, 2004; Asikainen, 2005).

1.2 Dyslexia

A commonly accepted definition of dyslexia is that it is a specific learning difficulty primarily affecting the acquisition of reading and spelling such that these skills remain below the level expected of a given age and general cognitive ability.

When learning to read, we develop an explicit understanding that words can be broken down into constituent phonemes, which map to visually presented letter strings, known as graphemes. *Phonological-deficit theories* of dyslexia, which have dominated the field for several years, view dyslexia as a cognitive difficulty in processing phonemes (Snowling 2001). Indeed, *robust evidence* suggests that the phonological skills of individuals with dyslexia are compromised, but this does not fit with the complexity of the phenotype, which includes an array of subtle sensory impairments and motor difficulties (Ramus, 2003).

Rapid-processing hypotheses propose that dyslexia arises from a basic deficit in rapidly processing successive and transient stimuli that enter the nervous system, thus affecting all modalities (Hari & Renvall, 2001; Eden, Stein, Wood & Wood, 1995). In such models, the phonological impairments responsible for reading difficulties stem from a lower-level inability to discriminate acoustic cues involved in distinguishing phonemes (Temple et al., 2000). *The magnocellular deficit theory* is based on data from anatomical, psychophysical, and imaging studies indicating that many people with dyslexia have mild anomalies in the magnocellular visual subsystem (Eden, 1996). Magnocells are neurons concerned with motion perception and temporal resolution, and are important for the control of eye movements. Magnocellular pathways may exist in other sensory modalities, so a multi-modal magnocell deficit could account for the full range of symptoms associated with dyslexia, with reading difficulties resulting from a combination of visual and phonological impairment (Stein & Walsh, 1997). More recently, researchers have suggested that dyslexia represents a general impairment in skill automatization resulting from *cerebellar dysfunction* (Nicolson, Fawcett, & Dean, 2001).

1.3 Language-Based Learning Disorders and Auditory Processing

Much controversy ensures about the extent to which auditory processing deficits are important in the genesis of language-based learning disorders, particularly in specific language impairment (Rosen, 2003). A review of the literature reveals that, on average some, but not all, auditory skills are impaired in groups of SLI listeners (Rosen, 2003). A matter of controversy is whether difficulties in segmenting, discriminating, and identifying speech sounds have their basis in a more fundamental auditory perceptual deficit affecting the processing of all sounds, not just speech (Bishop et al., 1999b).

Many children with SLI experience auditory processing difficulties, but for most children, these are not specific to brief, rapidly successive acoustic cues. Rather, sensitivity to durational and amplitude envelope cues appears to predict language and literacy outcomes more strongly. The potential role of auditory processing difficulties in explaining SLI has

been explored in depth by Tallal and colleagues (Benasich & Tallal, 2002; Spitz, Tallal, Flax & Benasich, 1997; Tallal & Piercy, 1973, 1974, 1975). They have proposed a rapid temporal processing deficit account of SLI. Difficulties in rapid temporal processing are thought to explain language problems "as speech occurs at roughly 80 ms per phoneme" (Tallal & Piercy, 1973a, p. 397).

Although some studies of children with SLI have subsequently reported difficulties in rapid auditory processing (Alexander & Frost, 1982), they have found no such difficulties in others (Bishop, Carlyon, Deeks & Bishop, 1999; Norrelgen, Lacerda & Forssberg, 2002). Some argue that although children with SLI may show auditory processing deficits, the rapidity of the stimuli do not characterized these deficits (see McArthur & Bishop, 2001; Rosen, 2003). Others have argued that when children with SLI show difficulties in perceptual tasks, these difficulties may arise from auditory immaturity (Bishop, Adams, Nation & Rosen, 2005) or from task artifacts (Coady, Kluender & Evans, 2005). The role of auditory perceptual deficits in explaining the etiology of SLI is thus strongly debated.

Dyslexia, in this view, arises from deficits in phonological processing, which is to say a process specific to speech sounds (Snowling, 1998). Similarly, some claim SLI results from deficits in neural systems that process grammar and, more specifically, syntax (van der Lely et al., 1998). On the other hand, others have claimed that deficits in underlying nonlinguistic sensory mechanisms are the core deficit in these disorders (Ramus, 2003). Still others have made far stronger claims about the role of impaired auditory processing in the genesis of SLI and dyslexia, especially with regard to the perception of rapidly changing or transient sounds (e.g. Hari & Renvall, 2001).

1.4 Auditory-Visual Matching and Interventions

The concept of *auditory structuring ability* (Karma, 1984, 1989, 1999, 2002b) is defined as a sub-skill of auditory processing and represents a general ability to relate tones with each other. This ability is considered clearly distinct from sensory acuity (i.e., the ability to hear small differences in the different parameters of sounds). Auditory structuring ability is very similar to spatial ability in that both consist of perceiving patterns or relationships; the role of single elements is simply to form these structures through certain relationships to each other. The difference between auditory structuring and spatial ability is that in the former, the relationships are mainly temporal and auditory, whereas in the latter, they are mainly static and visual (Karma, 1989, 1999, 2002b). Auditory structuring is represented in the segmentation and synthesis of the heard word (e.g. *CAR*; it consists of letters /k/, /a:/, and /r/ but in a specific order. Without auditory structuring it could be e.g. *ACR* or *CRA*.) Although reading is also a visual process it could be that the concept of auditory structuring is insufficient. A more useful concept could be auditory-visual matching.

Several studies have explored auditory-visual matching in children with learning disabilities, such as developmental dyslexia or ADD (Karma, 1989, 1999; Kujala et al., 2001; Törmänen & Takala, 2009; Törmänen, Takala & Sajaniemi, 2008) using auditory-visual matching computer training. A study by Kujala et al. (2001) aimed to determine whether audiovisual training without linguistic material has a remedial effect on reading skills and central auditory

processing in children with dyslexia. The study found that this training resulted in plastic changes in the auditory cortex, indexed by enhanced electrophysiological mismatch negativity and faster reaction times to sound changes. Importantly, these changes were accompanied by improvements in reading skills. The results indicate not only that special training programs can improve reading difficulties but further, that brain activity can reflect the effects of training. Moreover, the fact that the effects of training were obtained by using a program that included no linguistic material indicates that dyslexia is at least partly based on a general auditory perceptual deficit (Kujala et al., 2001).

The data found in research by Corriveau et al. (2007) indicate that the auditory processing difficulties that are most strongly predictive of language and phonology in children with SLI are found in tasks requiring the integration of temporal information over relatively long temporal windows. Studies by Richardson et al. (2004) and Corriveau et al. (2007) found that the relationships among auditory processing, phonological awareness, and literacy were very similar in both samples of children with a developmental language disorder. However, the relationships appear stronger in terms of the absolute variance accounted for in the sample of children with SLI.

Could deficits in auditory processing lead to SLI in some cases and dyslexia in others? This study will focus on the empirical evidence relevant to auditory-visual matching, which posits deficiencies in auditory processing as the deficit in SLI and dyslexia. Further, children with language-based learning disorders training auditory-visual matching training underwent.

1.5 Comorbidity

Specific language impairment is characterized by a broad spectrum of developmental impairments **(**Webster et al., 2006). Approximately 7% of children are believed to have speech and language difficulties, although this will vary with both the diagnostic criteria and the children's age (Bishop & Adams, 1990, Tomblin et al., 1997). Because children with SLI can develop slowly in a range of domains (Haynes & Naidoo, 1991) and experience problems with auditory, visual, tactile, phonetic, and dihaptic perception, as well as with motor tasks (Bishop & Adams, 1990; Powell & Bishop, 1992), researchers theorize that such problems stem from a generalized neuromaturational delay (Locke, 1994). Other proposals emphasize the role of timing in neural processing and posit that a cross-modal inability to process rapidly changing stimuli also termed pansensory (Tallal et al., 1993), may characterize developmental-language disorders (Anderson, Brown & Tallal, 1993). This later characterization is in contrast to earlier work by Tallal and Piercy (1973a, 1974), which suggested that a modality-specific auditory-perceptual dysfunction was the underlying cause of dysphasia in children. The view implicating a pansensory deficit apparently stemmed from the failure of Tallal and colleagues to replicate modality-specific effects.

While most children's difficulties resolve, children whose difficulties persist into elementary school may have long-term problems concerning literacy, socialization, and behavior as well as school achievement. Studies have shown that students with language learning disabilities differ from their normally achieving peers not only in the development of linguistic skills, but also in the motivational and emotional profiles they display as early as in the first grade

(Poskiparta et al., 2003). In particular, the child's ability to maintain focused attention both on the learning task and on instructional discourse benefits reading acquisition (Lepola et al., 2005; Onatsu-Arvilommi & Nurmi, 2000; Rowe & Rowe, 1999). One motivational component associated with teacher–student and parent–child interaction is the child's social dependence, that is, the lack of responsibility the child assumes over his or her own learning activity. The kind of other-focusing motivational tendency is especially found to be associated with surface-level cognitive processing (Graham & Golan, 1991), as well as with learning difficulties in reading and mathematics (Vauras et al., 1999).

Language is an eminently integrative function and none of its components operate in isolation from the others. In addition, language development is functionally dependent on emotional regulation (Fujiki et al., 2002). Taking this into account, it is unsurprising that children with SLI commonly exhibit comorbidity in other developmental areas, such as psychiatric and behavioral disorders (Glogowska et al., 2006; McCabe, 2005; Westby & Blalock, 2005; Toppelberg & Shapiro, 2000; Beitchman et al.,1996). A study by Estrem (2005) confirmed connection between problem behavior and language development, documenting that observed aggression increased as expressive and receptive language scores decreased in 100 preschoolers. Other studies (Bruce, 2006; Beitchman et al., 2001; Cohen et al., 2000) have also revealed a significant interrelationship between language disorders, attention deficit disorders and autism spectrum disorders.

The development of language is also intertwined with the development of motor skills (Bishop, 2002). According Webster et al. (2005), children identified on the basis of language impairment show significant motor comorbidity. The common association between language and phonologic impairment identified in children with SLI (Leonard, 1998) raises the possibility that factors contributing to motor planning and sequencing may also be important in other phases of language processing. Motor deficits observed in SLI are usually described similarly to those identified in other neurodevelopment disorders such as developmental coordination disorder (Hill, 2001). The fact that various disorders overlap in SLI seems to indicate a shared underlying etiology and that behavioral expressions of disorders differ due to various factors such as the timing and severity of disruption to brain development (Gilger & Kaplan, 2001).

2. Purpose of the Study

The purpose of this binary study was to investigate the role of auditory-visual matching and overall cognitive performances of children with language-based learning disorders, such as specific language impairment and developmental dyslexia.

3. Study Design and Methods

The study design consists of two different studies. Study 1 (N=164) was explorative focusing on auditory-visual matching and overall cognitive performances of children with SLI (n=84). Results of auditory-visual matching of children with developmental dyslexia (n=52) and typical language development, TLD (n=28) were used as background information.

Encouraged by interesting results of study 1, a study 2, an intervention study was conducted with children with language-based learning disorders, like SLI and dyslexia (N=48).

STUDY 1:

SLI (N=84), Dyslexia (N=52), TLD (N=28)

1. Auditory-visual matching test (N=164)
2. Standardized Elementary School Reading Test Battery *(n=84; children with SLI)*
3. Assessment Inventory *(n=84; children with SLI)*

STUDY 2:

Language-Based Learning Disorders (N=48)

1. Auditory-visual matching test (N=48)
2. Standardized Elementary School Reading Test Battery (n=25)
3. *or* School-readiness Assessment (n=23)

Training period, 16 sessions, twice a week, 15min./session

1. Auditory-visual matching test (N=48)
2. Assessment Inventory (N=48)

Figure 1. The Study Design

The main research method of both studies was the Auditory-Visual Matching Test, also an Assessment Inventory of overall cognitive performance and reading-skill tests (see chapters 4.2.1 and 5.2.1) were used. Study 2 involved nonverbal audio-visual computer training, called *Audilex* (see chapter 5.2.2).

3.1 The Auditory-Visual Matching Test

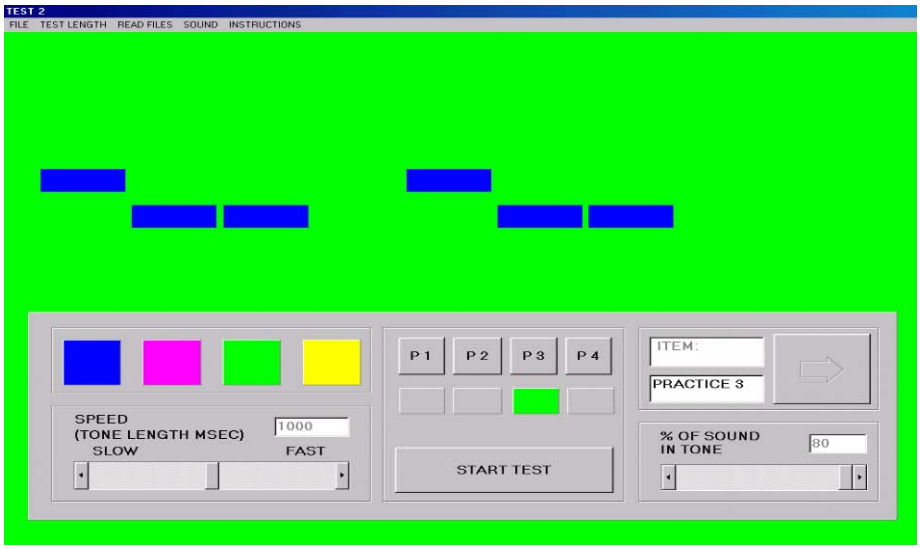

Figure 2. The Auditory-Visual Matching Test

Each child in studies 1 and 2 participated in the Auditory-Visual Matching Test (Karma, 1998). Test version 2 of the computer program devised by Karma (1998) was used (Figure 2), which consisted of abstract, nonverbal tasks requiring auditory-visual matching. The auditory-visual matching test included a set of 30 tasks. In the test, a pattern was displayed on a computer screen, after which a sound pattern was played; the pattern remained on the screen throughout the entire task. Various sound patterns featuring 3 to 15 elements were graphically represented on the screen as horizontal sequences of rectangles. The sound elements varied in pitch, duration, and intensity (see Figure 3), and were visually represented on the screen by the respective vertical position, length, and thickness of the rectangles. Participants pressed the space bar on a computer keyboard when the sound pattern matched the rectangle on the screen. The time window for doing this was when the last sound of the pattern was being played. When a participant responded correctly, the computer registered a hit. Stimulus elements were presented with a 1,000-ms stimulus (element)-onset asynchrony (SOA) and a 550-ms sound duration throughout the test, following the same regulation as those used in the studies of Karma (1999) and Kujala et al. (2001). A computer screen presented four different choices of colors: blue, purple, green, yellow. A researcher conducted the auditory-visual matching test, which included a practice session, at a school in a quiet classroom suitable for special education.

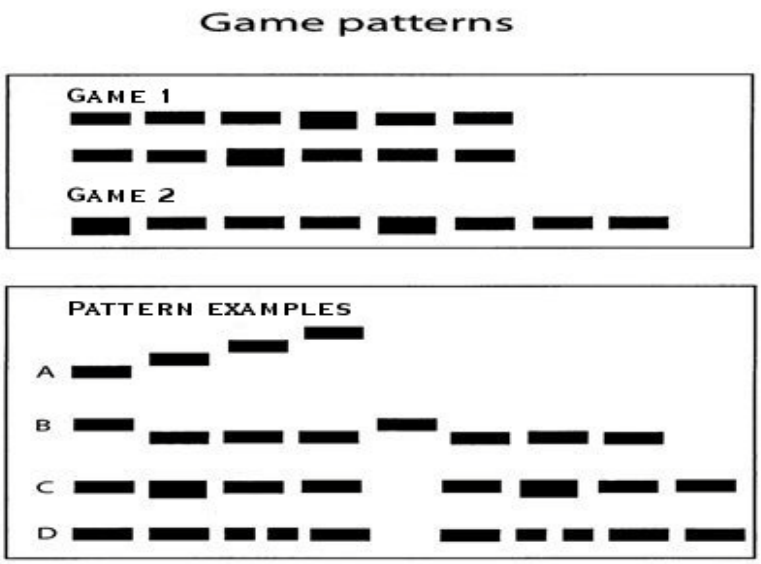

Figure 3. Task Examples of the Patterns Used in The Auditory-Visual Matching Test

3.2 Assessment Inventory

To explore different skills, possible deficits and comorbid problems in the overall cognitive development of children with language-based learning disorders such as SLI and developmental dyslexia, a researcher-developed Assessment Inventory was used (see Appendix). The special education teachers evaluated students. The inventory consisted of four different categories of children's development: sensory, cognitive, socio-emotional and motor. Attention focused largely on evaluating maturational aspects: 1) Auditory, visual and tactile discrimination in sensory abilities; 2) Children's use of cognitive skills and strategies, such as linguistic skills (like semantics and dysnomia), memory (like auditory memory), and logical thinking; 3) Socio-emotional skills through motivation, task orientation, social dependence, and ego-defensive orientation, as well as interaction skills and the ability to concentrate; 4) Students' somatic knowledge, fine, gross-motor and sensor-motor functions in motor development.

4. Study 1

4.1 Participants in Study 1

In study 1, 164 children ranging in age from 6 years (78 months) to 13 years (158 months) (M=110, SD=20) were involved (Table 1). 84 children with diagnosis of SLI served as participants in all three measurements. The test results of auditory-visual matching of children with a diagnosis of dyslexia (n=52), and typical language development, (TLD) (n=28) served as background information. The children with typical language development were first-graders (6 to 8 yrs), because based on earlier research (Karma 2002b) and test results children with TLD had no difficulties in auditory-visual matching.

Table 1. Number of Subjects and Average Ages in Study 1

	Girls			Boys			
	6–8 yrs	**9–10 yrs**	**11 -13yrs**	**6–8 yrs**	**9–10 yrs**	**11-13yrs**	**N**
SLI	9 (93)*	8 (116)	8 (140)	23 (95)	22 (115)	14 (142)	84 (114)
Dyslexia	4 (104)	6 (125)	1 (139)	19 (100)	16 (119)	6 (141)	52 (115)
TLD**	18 (87)			10 (84)			28 (86)
N	31 (91)	14 (120)	9 (140)	52 (95)	38 (117)	20 (142)	164 (110)

Note. * Age in months.

Note. ** TLD = Children with Typical Language Development

Note. Age in months varies between 78 and 158 months.

The participants with a diagnosis of SLI (n=84) came from the same special elementary school in Finland. A certified speech-language clinician had previously been diagnosed these children by with SLI [(F 80 Specific developmental disorders of speech and language) ICD-10**].** Children with SLI had an Individualized Education Plan (IEP) and they received speech therapy in their schools. 63% of children had additional diagnosis according to the International Statistical Classification of Diseases and Related Health Problems (see Table 2).

Table 2. Study 1: Additional diagnoses in the SLI group according to the International Statistical Classification of Diseases and Related Health Problems (N=53)

SLI + one other diagnosis	**40**
F81 Specific developmental disorders of scholastic skills	18
F82 Specific developmental disorder of motor function	13
F84.5 Asperger's syndrome	2
F90 Hyperkinetic disorders	4
G40 Epilepsy	2
E10 Diabetes	1
SLI + two other diagnoses	**13**
F81 Specific developmental disorders of scholastic skills + F90 Hyperkinetic disorders	3
F81 Specific developmental disorders of scholastic skills + F82 Specific developmental disorder of motor function	1
F81 Specific developmental disorders of scholastic skills + F98 Other behavioral and emotional disorders with onset usually occurring in childhood	1
F90 Hyperkinetic disorders + F82 Specific developmental disorder of motor function	5
F90 Hyperkinetic disorders + F95.2 Combined vocal and multiple motor tic disorder (Tourette´s syndrome)	1
F90 Hyperkinetic disorders + Premature Infant	1
Paresis nervi + Expansio medulla oblongata + Mild mental retardation	1

A qualified educational psychologist or special education teacher, followed the general curriculum, had formally diagnosed the children with dyslexia (n=52) whose test results of auditory-visual matching served as background information. These children were diagnosed with developmental dyslexia only (i.e. no other diagnosed disabilities). Due to their dyslexia, they had received remediation from special education teachers since the first grade (age seven), which took place once or twice a week with a special education teacher in a resource room. The participants came from three different mainstream elementary schools in the same Swedish town.

Based on school records and background information supplied by their teachers, the children with typical language development (n=28) had no history of speech, language, or hearing problems or of any other exceptional educational needs and came from same elementary school from Finland.

4.2 Methods in Study 1

Every child in this study participated in *the Auditory-Visual Matching Test* (Karma, 1998). In study 1, two additional measures were used to classify the children with SLI: 1) *the Reading Test for Elementary School* (Lindeman, 1998) and 2) *the Assessment Inventory*.

4.2.1 Reading-skill tests

Two sub-tests of the Standardized Elementary School Reading Test Battery, called *ALLU* (Lindeman, 2000), develop to evaluate the reading status of 7- to 13-year-old Finnish-speaking children served to assess decoding and reading comprehension through the use of test battery that included age-matched tasks.

The decoding test (max. 9) consisted of word and sentence recognition, which included, for example, letter cluster identification, picture-word matching, and picture-sentence matching, silent word decoding, and word recognition. Every task had four alternative answers. The reading comprehension test (max. 9) included a narrative story and an expository text together with questions, each of which had four alternative answers. The questions assessed literal (e.g., fact finding, information ordering) and inferential text comprehension skills (e.g., deriving word meaning and making inferences beyond the sentence level). Each correct answer earned one point. The children's speech therapists or special education teachers carried out the individual testing in two 30-45-min sessions. Each child could refer to the text for the entire duration of the test.

4.3 Results of Study 1

The data were analyzed using the statistical package SPSS for Windows (version 15.0, SPSS). Table 3 presents group means and standard deviations from the Auditory-Visual Matching Test. The results of the children diagnosed with SLI were below average (see Table 3.) as were those of the children diagnosed with dyslexia. Children with Typical Language Development showed no difficulties in the Auditory-Visual Matching Test Cronbach's Alpha coefficients were over .85.

Table 3. Descriptive Information of The Auditory-Visual Matching Test (max. 30) in Study 1

	M	**(SD)**
SLI*	23.42	(4.94)
6-8 yrs	21.69	(5.62)
9-10 yrs	24.47	(4.39)
11-13yrs	24.55	(3.99)
Dyslexia	21.56	(6.34)
6-8 yrs	18.00	(7.37)
9-10 yrs	24.14	(2.98)
11-13yrs	25.14	(4.85)
TLD**		
6-8 yrs	28.86	(1.65)

Note. * SLI = Specific Language Impairment

Note. ** TLD = Children with Typical Language Development

The Standardized Elementary School Reading Test Battery showed that the overall reading level of children with SLI was below the age-normal range. Mean scores of word and sentence recognition and sentence comprehension appear in Table 4.

Table 4. Descriptive Information from Used Tests with Children with SLI in Study 1

			6-8 yrs		9-10 yrs		11-13yrs	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Standardized Elementary School Reading Test Battery (max. 9)								
Reading Comp.*	3.04**	(1.70)	2.75	(1.65)	3.10	(1.75)	3.36	(1.71)
Decoding	2.79**	(1.76)	2.63	(1.79)	2.97	(1.69)	2.77	(1.88)
Assessment Inventory (max. 3)								
Sensory	1.87	(0.41)	1.92	(0.31)	2.19	(0.30)	1.41	(0.20)
Cognitive	1.79	(0.36)	1.80	(0.31)	2.04	(0.35)	1.46	(0.15)
Socio-Emotional	2.05	(0.48)	2.11	(0.42)	2.41	(0.29)	1.50	(0.19)
Motor	2.08	(0.49)	2.07	(0.55)	2.43	(0.26)	1.67	(0.16)

Note. SLI = Specific Language Impairment (N=84)

Note. * = Reading Comp. = Reading Comprehension

Note. ** = The overall reading level

In the Assessment Inventory (max. 3p/category, four categories) special education teachers evaluated the children's sensory, cognitive, socio-emotional, and motor development. Surprisingly, there were no significant differences between these four categories (see Table 4).

For further analysis, the participants were divided into three *age* groups, of which had difficulties (scored below 1.6 of a possible 3.0) with *auditory discrimination* (M=1.38,

SD=0.44) in the category of sensory development and in *auditory memory* (M= 1.44, SD= 0.53) from category of cognitive development. Difficulties also occurred with linguistic skills such as *semantics* (M=1.59, SD=0.53) and with *dysnomia* (M=1.43, SD=0.51) in the category of cognitive development.

Surprisingly, the oldest participants performed worse in all overall cognitive development categories (see Table 4).

4.3.1 Summary of the Results of Study 1

The results of the Auditory-Visual Matching Test for the children diagnosed with dyslexia (n=52) were very *similar* to those of earlier studies (Karma, 1989, 2002b; Kujala et al., 2001; Törmänen & Takala, 2008). The results for the children diagnosed with SLI support the view of auditory deficits (Tallal, 2000). The Assessment Inventory showed no significant differences between the four categories, which supports the view of previous studies (Bishop, 1990; Johnson, 1992) that children with SLI have problems with auditory, visual, tactile, and phonetic perception, as well as with motor tasks. Difficulties in auditory discrimination in the category of sensory development, as well as difficulties in auditory memory and in linguistic skills such as semantics and dysnomia in the category of cognitive development, were expected based on common theories about core deficits in SLI (Tallal, 2000). Surprisingly, the *oldest* participants performed worse overall in all cognitive development categories, which supports the view of comorbidity in developmental disorders (e.g., Botting & Conti-Ramsden, 2000)

5. Study 2

Encouraged by the interesting results of the first study, nonverbal auditory-visual matching computer training was carried out among the children with language-based learning disorders (N=48). Study 2 applied a pre-test–intervention–post-test design (see Figure 1).

5.1 Participants in Study 2

Altogether 48 children (26 girls and 22 boys) diagnosed with language-based learning disorders such as specific language disorder or developmental dyslexia participated in auditory-visual matching training, called *Audilex* intervention (Chapter 5.2.2). These children differed from those who participated in study 1. Participants had no additional diagnoses and were in mainstream schools; 23 children were in pre-school (from 6 to 7 yrs; *M*=80.09, *SD*=3.16) and 25 were at the first-grade (from 7 to 8 yrs; *M*=95.28, *SD*=3.76).

5.2 Methods in Study 2

In study 2, the *Auditory-Visual Matching Test* was used before and after the intervention. In the pre-test, a rigorous practice procedure was applied before the presentation of the experimental tasks to ensure that all children understood the directions for the computer tasks. Special teachers trained to use the Auditory-Visual Matching Games and Test conducted the intervention. *An Assessment Inventory* was then used after the intervention (see description on page 12).

5.2.1 Reading skill tests

Scores from two reading skill tests served as criteria for participation in the intervention. The Standardized Elementary School Reading Test Battery (children at first-grade) showed that

the overall reading level (max. 9) was below the age-normal range: in reading comprehension (*M*=4.46, *SD*=2.06) and in decoding (*M*=4.00, *SD*=1.79). The School-Readiness Assessment (Vauras et al., 1994), commonly used in Finnish schools, was used with children at pre-school (n=23). This test measured knowledge of the alphabet among the 19 most frequently appearing letters in the Finnish language, which the special education teacher presented visually one at a time; the children were then asked to name the letter shown. Spelling of the alphabet was measured with 19 letters in the Finnish language, which the experimenter this time presented orally one at a time; the children were then asked to write the requested letter. In addition, a pre-school word recognition measure, consisting of 18 familiar, mainly two-syllable words accompanied by 4 alternative pictures, was administered to assess "pre-reading" skill levels; the maximum score was 39. This measure showed that pre-reading skill levels (n=23) were below the age-normal range (*M*=27.09; *SD*=9.58).

5.2.2 Audilex Intervention in Study 2

A total of 16 sessions with the computer game took place twice a week over a period of two months, with each training session lasting for about 15 minutes. The teacher or assistant was present at every training session with each pupil in a resource room. This intervention used the pullout system; one pupil left the class to participate in the *Audilex* session while the others remained. The training sessions were carried out during the school day during regular lessons or breaks, but not when a pupil was in special education.

Both the auditory-visual matching test and games consisted of similar but not identical tasks. The tasks in the games used in the intervention, were also the much more varied. A central feature of the games and the test is that they were completely nonverbal; they attempted to train cognitive operations necessary for learning to read and write successfully, rather than reading and writing themselves. In addition, the computer program aimed to strengthen the student's ability to integrate visual and auditory codes (Karma, 2002b). The aim of the games was to train the participants` perception of sound structures and their skill in combining a visual and an auditory signal. Another aim was to train the participants` sense of direction. The tasks were always read from left to right, which corresponds to moving ahead in time. The games contain no text or semantic meanings, but are aimed at those perceptions and thinking processes, considered preconditions for reading and writing.

Two versions of the game (Karma, 1998) were used during the training period (see Figure 3). In game 1, two patterns appeared on the screen. After a couple of seconds, a sound sequence was played that corresponded to one of the patterns. The player's task was to indicate which of the patterns was played. In game 2, only one pattern was drawn on the screen, followed by a corresponding sound sequence. The player's task was to follow the pattern (from left to right) as it was being played. The player had to press the space bar upon hearing the sound corresponding to the last element of the visual pattern. After a correct response, the participant was rewarded, whereas after an incorrect response, the same pattern was repeated, but the color of the rectangle changed at the moment when the sound corresponding to it was played.

Both easy and difficult patterns were randomly presented throughout the training period. Each training session began with a stimulus block with a 1,000-ms stimulus (element) onset asynchrony (SOA) and a 550-ms sound duration. During the sessions, subjects could change the SOA within a window of 200 to 1800 ms, and the sound duration within a window of 30% to 80% of the SOA (60-1440 ms). After a couple of training sessions, the pupils would usually change the duration, making it faster or slower, to make the games more difficult. The tempo used in the games had different meanings for different pupils.

5.3 Results of Study 2

Statistical analysis were performed using the statistical package SPSS for Windows (version 15.0, SPSS) and were examined with a general linear model repeated-measures ANOVA. The effect size, which measures the magnitude of the treatment effect, was measured with Cohen´s *d* (Cohen, 1988).

Table 5. Descriptive Information of the Training Effect (Repeated Measures ANOVA) in Study 2

The Auditory-Visual Matching Test							
	Pre-Test		Post-Test				
	M	*(SD)*	*M*	*(SD)*	*d*	*F*	*Sig.*
LBLD	18.71	(6.80)	24.23	(4.52)	0.98	33.1	**<.001**
Pre-School	17.91	(7.15)	23.48	(4.63)	0.95	19.5	**<.001**
First-Grade	19.44	(6.50)	24.92	(4.40)	1.0	14.2	**<.001**

Note. LBLD = Children with Language-Based Learning Disabilities

Note. Children at pre-school = from 6 to 7 years, and at first-grader_ = from 7 to 8 years

Note. Significant results ($p<0.05$) in bold.

Following the audio-visual training period, differences between pre- and post-tests were found in the Auditory-Visual Matching Tests (Table 5). Children diagnosed with language-based learning disorders performed significantly better [$F(1,47)= 33.1$; $p<.001$; $d=.98$] in the auditory and visual matching test after the training period. Dividing the participants into age groups yielded no differences in the training effect: Children at pre-school performed significantly better [$F(1,22)= 19.5$; $p<.001$; $d=.95$] and as well as did the children at first-grade [$F(1,24)= 14.2$; $p<.001$; $d=1.0$] after the training period. Cronbach´s Alpha coefficients were over .68. The training effects appear in Figure 4.

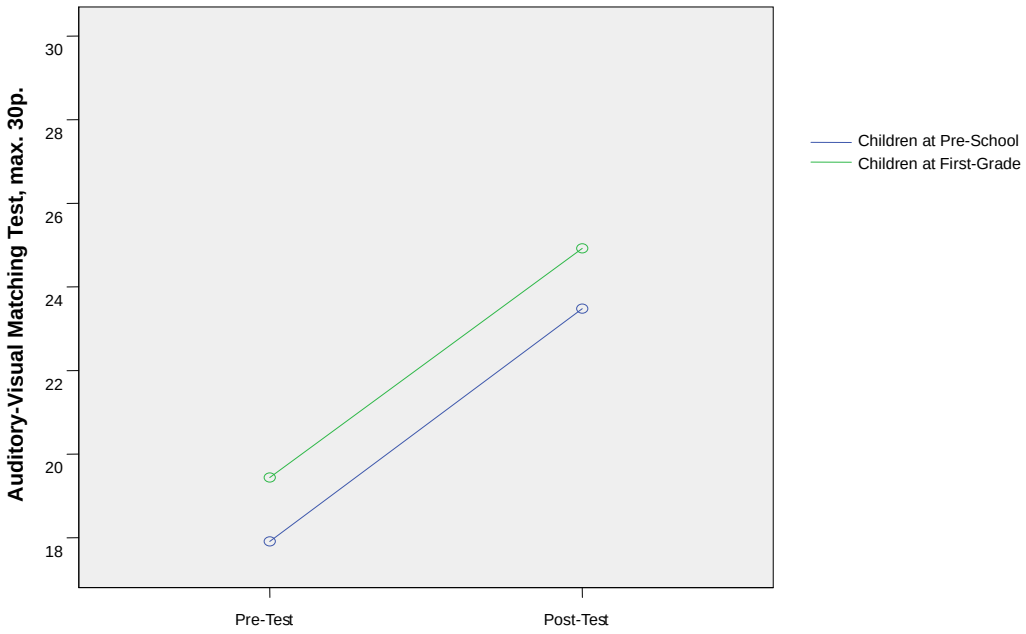

Figure 4. The Training Effect in the Auditory-Visual Matching Intervention in Study 2

After the *Audilex* training, special education teachers used the Assessment Inventory (max. 3p/category, four categories) to evaluate the children's sensory (*M*=2.55, *SD*=0.51), cognitive (*M*= 2.46, *SD*=0.50), socio-emotional (*M*=2.43, *SD*=0.50), and motor development (*M*=2.67, *SD*=0.37)

5.3.1 Summary of the Results of Study 2

This intervention study showed that auditory-visual matching improved after nonverbal computer training in children with language-based learning disorders. According to the Assessment Inventory, after the intervention, children with language-based learning disorders performed well in all four categories of children's development. Thus, the intervention appears to have slightly improved the children's sensory development as well as their overall cognitive performance.

6. Discussion

The purpose of this binary study was to investigate auditory-visual matching among children with language-based learning disorders such as SLI or developmental dyslexia. Study 1, which was explorative, showed that children diagnosed with SLI have difficulties in auditory-visual matching *similar* to those of children with dyslexia.

Despite the wide variety of theories, that attempt to account for SLI, two general approaches have received the most attention. The first posits that SLI arises from deficits in specifically linguistic systems. Such linguistic and sensory deficits are not necessarily exclusive, moreover auditory and visual processing deficits may be linked, as Stein (2001) expressed most elegantly in the form of his magnocellular hypothesis. More importantly, auditory processing theories make explicit claims that phonological deficits arise from auditory

deficits, which in turn lead to the language disorder. Insofar as literacy requires explicit meta-phonological awareness related to the auditory structure of speech, it is easy to see how an impaired phonological system could lead to dyslexia. For SLI, grammatical difficulties have frequently been tied to imperfect perception of the relevant morphological inflections (Rosen, 2003). Some researchers have hypothesized that limitations in (verbal) working memory arising from a phonological coding deficit can impede the learning of various grammatical structures (Joanisse & Seidenberg, 1998).

Other investigators (Bailey & Snowling, 2002) have assumed a common substrate for dyslexia and SLI, suggesting in effect that dyslexia is a mild form of SLI. But this assumption is likely justified only for children whose SLI is characterized by expressive language difficulties and phonological processing problems, rather than for those who exhibit pragmatic language abnormalities involving difficulties with the use of language in interaction. These distinctions between different forms of language difficulty have sometimes been obscured by the use of the term 'language learning impaired', but it is important to note that SLI children have more extensive language problems than do dyslexic children, encompassing poor vocabulary, grammatical deficits and problems with the comprehension and production of sentence structure.

An important result of study 1 was *comorbidity* in SLI. According to formal diagnoses, 63 % of participants also had additional diagnosis. The Assessment Inventory, which explored different skills and possible deficits in the children's development of overall cognitive performance, also reflected similar results. Presumably, language-based learning disorders are characterized by a broad spectrum of developmental impairments, as many studies have also reported, comorbidity in SLI. According to Tomblin et al. (2000), children with language impairments are at significantly greater risk for both reading disability and behavioral disorders. Children with SLI have been reported to experience concurrent difficulties in the area of social and behavioral development (Botting & Conti-Ramsden, 2000; Redmond & Rice, 1998), which many believe arise from such factors as frustration, peer rejection, and lack of confidence in the face of poor linguistic skills. However, there is now increasing concern that problems with social relationships and other behavioral difficulties may be characteristic of children with SLI well after language difficulties have supposedly been resolved (Clegg, Hollis & Rutter, 1999). This supports the results of this study in which younger participants performed better than did older ones in the assessment of overall performance. Offering individual and qualified education to children with specific language impairments requires comprehensive assessment of their cognitive strengths and difficulties in order to specify more accurately the nature of their difficulties. Assessment should form part of the evaluation and follow-up of children with language-based learning disorders. The Assessment Inventory used in this binary study can served as practical tool to investigate and evaluate children with language-based learning disorders.

Study 2 showed that nonverbal computer training significantly *improved* auditory-visual matching in children with language-based learning disorders. This result was expected based on earlier studies (e.g., Karma, 1989, 2002b; Kujala et al., 2001), and also supports the view that phonological deficits arise from auditory deficits, which may in turn lead to the

language-based learning disorder. Focusing the training on a combination of auditory and visual processing revealed significant improvements in reading skills and comprehension (Kujala et al., 2001). Because auditory-visual matching training is nonverbal, explanations can be directed towards perception and processing. The effects of this intervention could also be connected to motivational factors; the engagement between the student and the researcher yields positive interaction and further change in overall cognitive performance.

The results of this binary study cannot be generalized due to the unavoidable limitations of the research design. Study 2 had no delayed test after intervention. In this study reading skill tests served to select participants; in future studies, however, it would be interesting to observe possible effects in reading skill tests as well. Additional research is necessary to determine (a) whether these children would, despite comorbidity, benefit from long-lasting intervention and (b) whether impaired auditory-visual matching is associated with lasting language-related difficulties.

6.1 Implications for Practice

Training in auditory-visual matching could be an opportunity for some children at risk for language-based learning disabilities, as well as for older students. Success in training emboldens confidence, which can motivate students to practice, focus and concentrate on reading, which, in turn, could prevent the otherwise cumulative disadvantages of learning disabilities. Despite various intervention programs, studies show accelerating numbers of learning disabilities (Vaughn & Fuchs, 2003); the need for practical methods for children at risk is evidently growing. Hopefully the intervention used in this study can be easily applied in pre-school or school settings, and the teachers or school-assistants could carry it out. Such a plan would also be cost-effective.

In addition, the auditory-visual matching training could also serve as an opportunity for older students at risk for comorbidity. The ease and playfulness of the auditory-visual matching computer program seems to motivate students, thus encouraging them to practice otherwise difficult tasks. Further, the auditory-visual matching training might have international implications because of the promising results of this study as well as of earlier studies (Kujala et al., 2001; Törmänen & Takala, 2009), and could be considered a universal instrument due to its nonverbal character.

In conclusion, language development is a dynamic process involving various aspects of social, cognitive and emotional behaviors. To acquire a sound base for linguistic development, a child must become aware of how to use language as a means of communication, learning and transmission of emotions. Children with language-based learning disorders cannot use language and related skills optimally, and meet many obstacles in tapping everyday learning opportunities. Thus preventing cumulative disadvantages and providing interventions that take into account the multidimensional nature of language development is of crucial importance.

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Appendix

Appendix 1. Assessment Inventory: Children's Overall Cognitive Development (max. 3p.)

I Sensory development:

1. Auditory discrimination
2. Visual discrimination
3. Tactile discrimination
4. Combining sensory and motor functions

II Cognitive development

5. Linguistic skills
   - 5a. Articulation
   - 5b. Semantics
   - 5c. Grammatical development (syntacs and morphology)
   - 5d. Dysnomia
6. Memory skills
   - 6a. Visual memory
   - 6b. Auditory memory
7. Cognitive thinking
   - 7a. Categorization and observation skills
   - 7b. Logical argumentation
   - 7c. Problem solving skills
8. Reading and writing skills (over 8 yrs)
9. Mathematical skills
   - 9a. Mathematical vs. linguistic skills
   - 9b. Understanding spatial concepts

III Social-Emotional development

10. Independent initiative
    - 10a. Independence
    - 10b. Responsible
    - 10c. Ability to start and finish tasks
11. Interactions skills
    - 11a. Being a member of a group

11b. Pay attention to others

11c. Own opinions

12. Ability to concentrate

12a. In group

12b. Alone

IV Motor development

13. Knowledge of own body

13a. Pointing

13b. Naming

13c. Awareness

14. Gross Motor Skills

15. Fine Motor Skills

16. Spatial and temporal skills

16a. Orientation

16b. Motor possession of spatial concepts

16c. To orient oneself in a time concept